THE MINERALS OF GREENLAND

Mineralogical Record
volume 24, number 2 • March-April 1993 • $15

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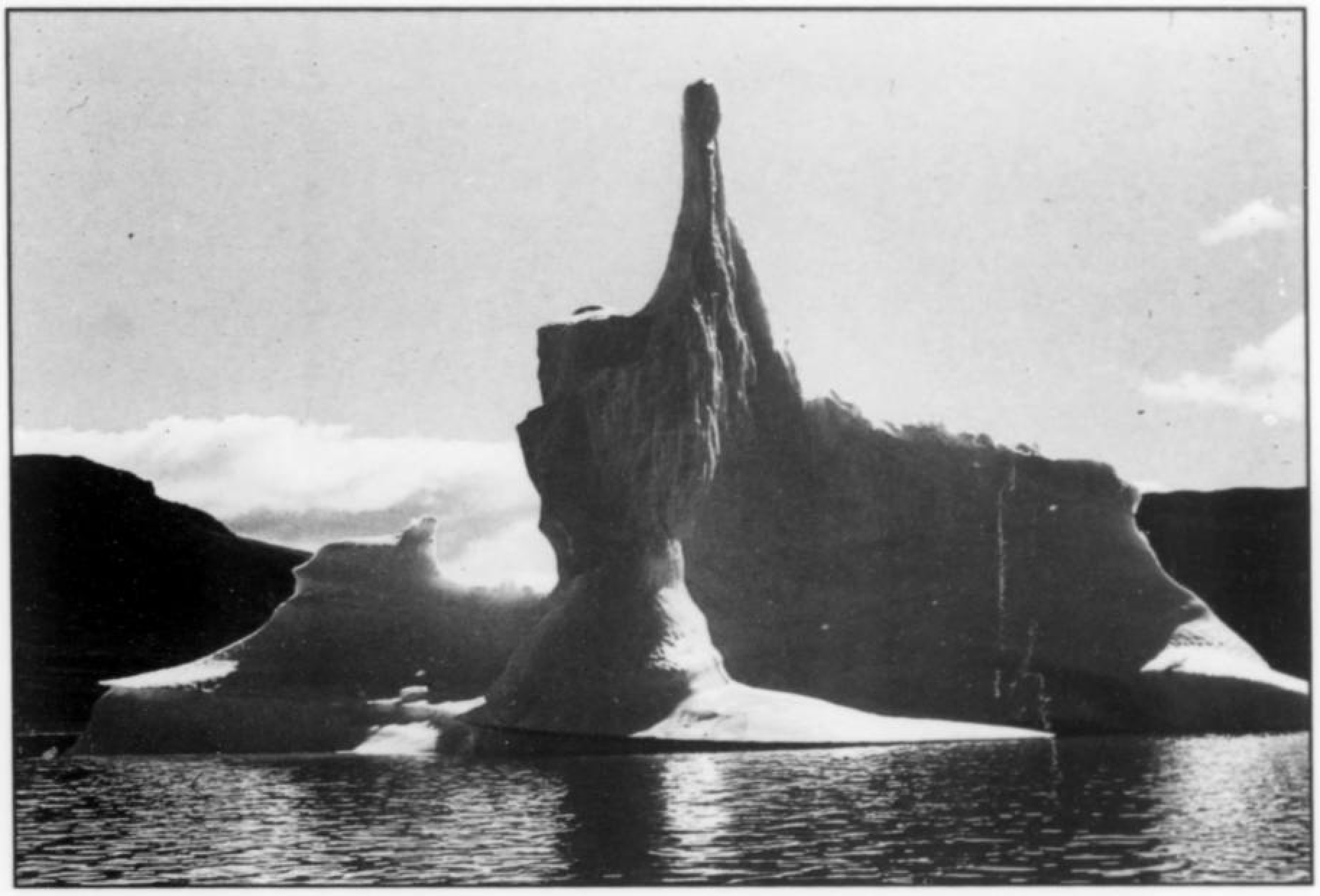

1993

THE MINERALOGICAL RECORD • TUCSON

The Mineralogical Record
March–April 1993
volume 24, number 2

Editor and Publisher: Wendell E. Wilson

The Mineralogical Record Inc.
is a non-profit organization.
Special second class postage
(USPS-887-700) paid at Tucson,
Arizona, and additional offices.
Postmaster: send address changes
to: 7413 N. Mowry Place,
Tucson, AZ 85741

Design and layout by Wendell E. Wilson
Typesetting by Capitol Communications, Crofton, MD
Color separations by Hollis Phototechnics, Tucson
Printed in Easton, Maryland, by Waverly Press

Single copies of this issue are available,
while the supply lasts, at $15 per copy
plus $1 postage and handling.

Subscription rates for one year:
Individuals (U.S.) $36
Individuals (foreign) $39
Libraries, companies and institutions (worldwide) $60
First class and airmail rates available on request

The Mineralogical Record
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P.O. Box 35565
Tucson, Arizona 85740
602-297-6709
FAX: (602) 544-0815

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4631 Paseo Tubutama
Tucson, AZ 85715
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COVER: SYNCHYSITE crystal, 1 cm,
from Narssârssuk, Greenland.
Photo by R. Bode.

TITLE PAGE: The most common mineral in Greenland:
ice—making up the typical Arctic icebergs, ubiquitous
in Greenland waters; photo by B. L. Nielsen.

This special issue was made possible in part by
grants from Randolph S. Rothschild and the
Rochester Mineralogical Symposium.

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GEOLOGICAL MAP OF GREENLAND

PREFACE

Throughout Greenland there are many interesting mineral localities, some of them world famous for their unique assemblages. Karl Ludwig Giesecke made the first systematic collection from the west coast of Greenland during the Napoleonic wars. His work drew attention to the rich variety of minerals there. Since then, numerous descriptions of minerals, including many new species, have appeared in both the Danish and the international literature. In this century, Professor O. B. Bøggild made a life-long study of the minerals in Greenland, culminating in his *The Mineralogy of Greenland,* published in 1953. This remains the authoritative work on Greenland minerals, but new data accumulated over the past 40 years have made a revision necessary.

The present account is an attempt to merge highlights of the old information with the new, concentrating on those species which are of greatest interest to mineralogists and mineral collectors. The work is compiled from the point of view that minerals are an integral part of the rock in which they are found, in its geological setting. The most famous localities are described, with historical and geological backgrounds, as well as numerous less well known localities throughout Greenland. A new and comprehensive list of the mineral species from Greenland is also included.

This work is the result of collaboration between the Geological Museum of the University of Copenhagen, the Geological Survey of Greenland, and the Danish Polar Center.

EDITORIAL NOTE ON LOCALITY NAMES

Although inconvenient, three different orthographies are in use with regard to Greenland place names: Danish, Greenlandic old spelling and Greenlandic new spelling. Many place names in Greenland were originally derived from Danish words, especially the names of many older towns. Additionally, all place names in Northeast and North Greenland are based on Danish. However, many localities, including towns in western Greenland, also have equivalent Greenlandic names. Recently an entirely new Greenlandic spelling has been officially adopted for a large number of places. Consequently, many locality names, well-known by their old Greenlandic spellings, have now changed and are not always recognizable to foreigners. Consequently the authors have adopted a double spelling according to the following principle: Original place names in Danish or Greenlandic old spelling are mentioned first, followed by the Greenlandic new spelling word in parentheses: *Example 1:* Godthåb (Nuuk)—the capital of Greenland. *Example 2:* Ivigtut (Ivittuut)—a famous mining location in West Greenland. For the sake of simplicity, only the Danish names of localities in North and Northeast Greenland are used here.

Compounding this inconvenience, it should be mentioned that the naming of many geological formations and complexes took place before Greenlandic new spelling was introduced. In these cases the Greenlandic old spelling is retained in the present use of the formation name: *Example 1:* The Nagssugtoqidian Mobile Belt. *Example 2:* The Sarfartôq Carbonatite Complex.

Figure 2. A view of the countryside around the Umanaq (Ummannaq) settlement—abandoned 1951—in the Godthåbsfjord (Nuup Kangerlua); photo by K. Secher.

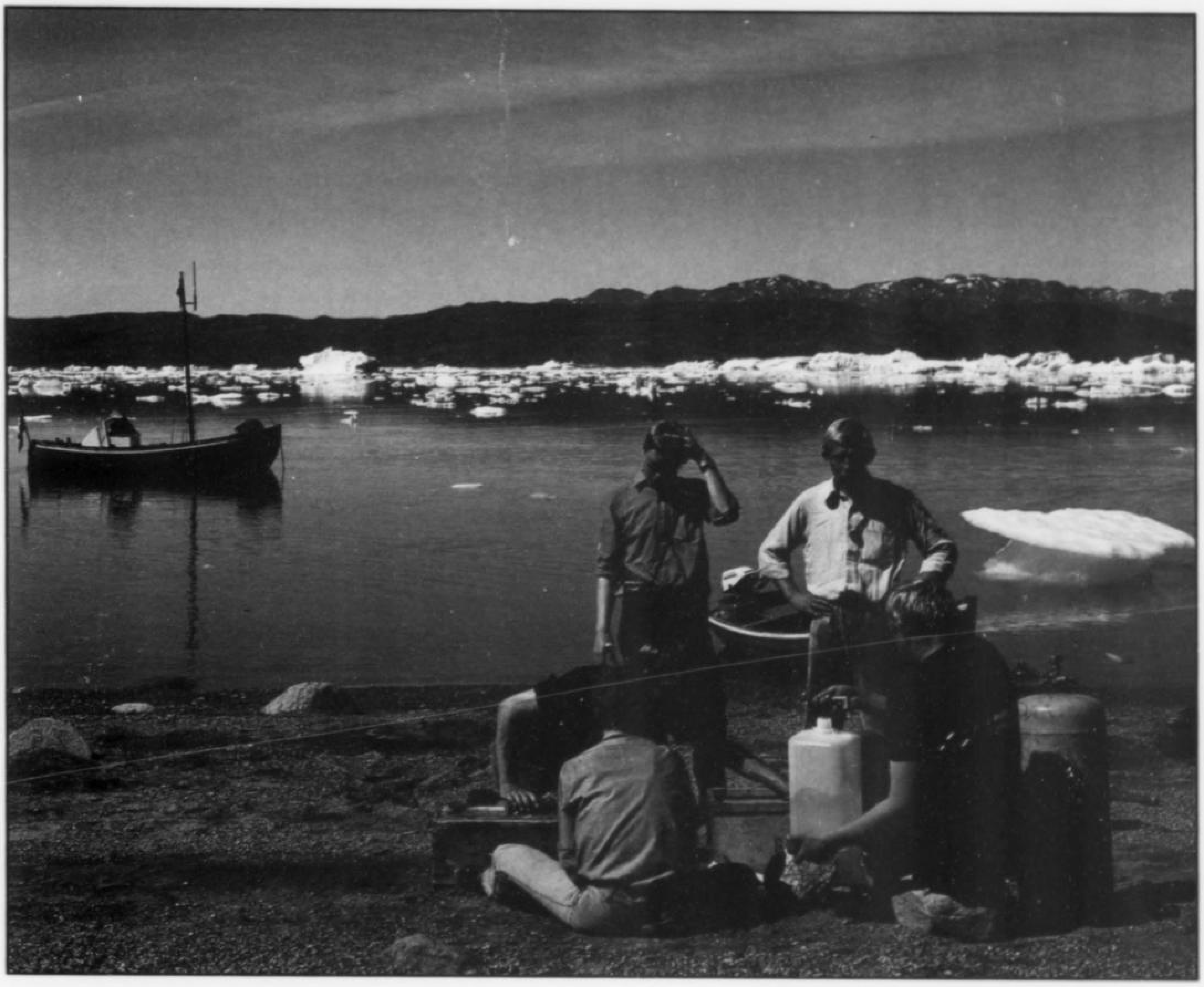

Figure 3. **During the geological field season in Greenland—June to August—there are very few days like the one illustrated here with no winds and temperatures near 20°C. The participants in the 1969 expedition to the Narssârssuk pegmatite are recuperating before carrying up the camp equipment; photo by O. V. Petersen.**

INTRODUCTION

Greenland has a surface area of 2,175,600 square kilometers of which nearly 80% is covered by a huge ice cap—the Inland ice. The ice-free marginal rim is mountainous and up to 250 km wide; the bedrock of this area is a well-exposed landscape including fjords, valleys and mountains, with the highest peak reaching 3,733 meters.

Greenland forms the eastern flank of the North American Continent, separated from Canada by only 26 km at the Nares Strait. The length from north to south is 2,670 km, and the distance from Greenland's northern coast to the geographic North Pole is only 740 km. The landscape is characterized by glacial erosion, with rugged terrain close to the Inland ice and smoother areas nearer to the coast, except for an Alpine-type terrain in some of the coastal regions. The general impression is of a country without trees and forests, with sparse grass and moss vegetation as the only green cover. In the valleys and other sheltered places, however, luxuriant vegetation is widespread.

Geologically speaking, most of the ice-free area consists of crystalline rocks of the Precambrian shield. The shield acted as a stable block on which deposits accumulated at various times throughout the Precambrian; these were later deformed and metamorphosed. In North and East Greenland sedimentary deposition continued into the Palaeozoic and Mesozoic, and some of the deposits along with the basement rock were involved in tectonic and metamorphic events during this period. Finally, in both West and East Greenland there was considerable volcanic activity in the early Tertiary.

GIESECKE

Every student of the minerals of Greenland will sooner, rather than later, meet the name K. L. Giesecke. Giesecke was the first to examine the sapphirine and kornerupine-bearing rocks at the harbor of the village Fiskenæsset (Qeqertarsuatsiaat), and realized that sapphirine was a new species; Giesecke was the first to visit the famous tourmaline occurrence at Qarusulik (Qaarusulik) in the Ameralik Fjord; at Ilímaussaq (Ilimmaasaq), Giesecke collected the material which was used for the descriptions, in 1812 and 1823 respectively, of the two new species sodalite and arfvedsonite; in September of 1806, shortly after landing in Greenland, Giesecke found on the south coast of the Arsuk Fjord (Ilorput), the most famous occurrence of the interesting and then newly described mineral cryolite, at Ivigtut (Ivittuut). But who was this man?

The man who called himself Karl Ludwig Giesecke was born on

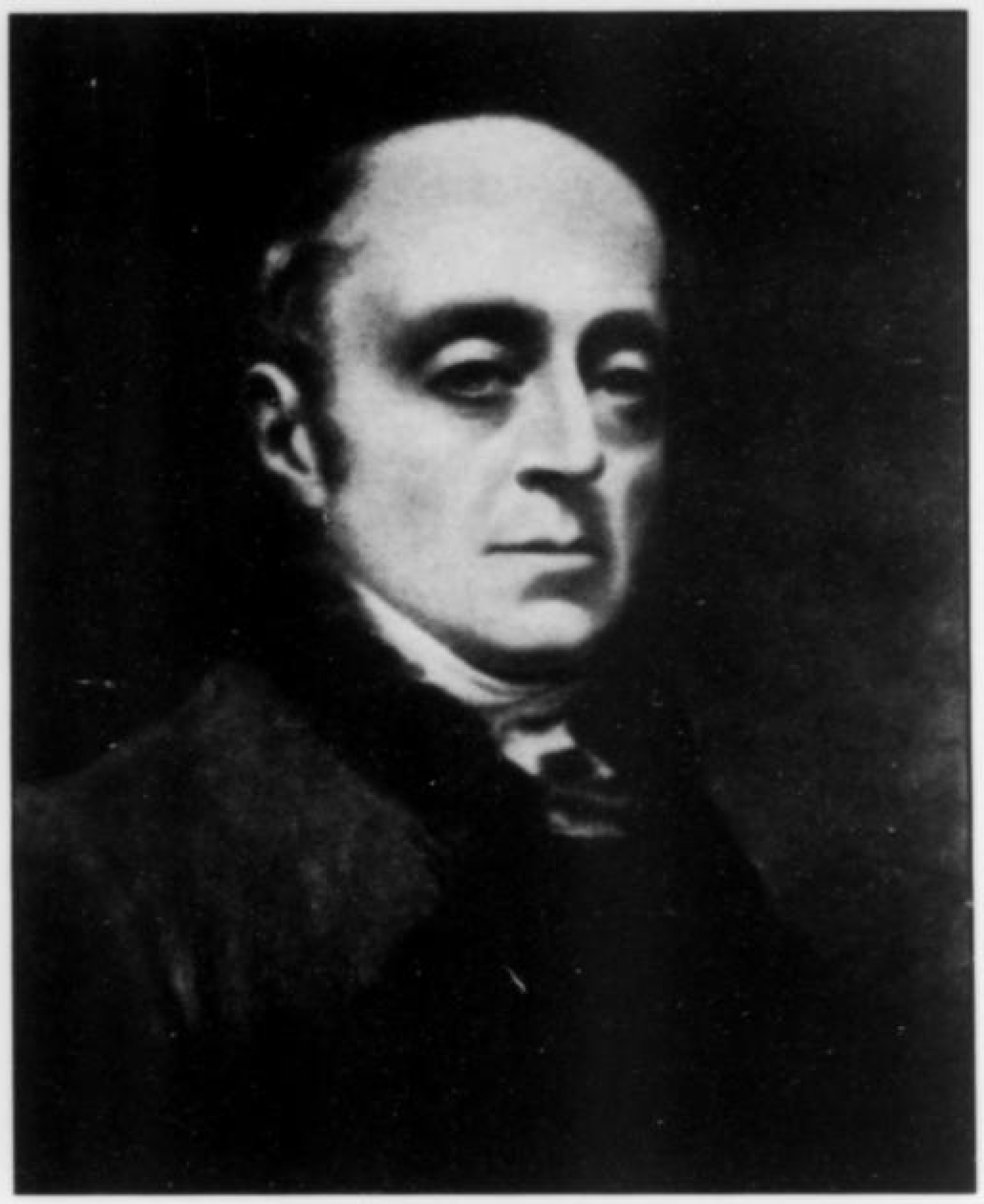

Figure 4. **Karl Ludwig Giesecke (1761–1833). A charcoal drawing, after Sir Henry Raeburn's painting in the Royal Dublin Society.**

April 6th, 1761, in Augsburg, Germany, as the second oldest son of a master tailor, Johann Georg Metzler and his wife Sibylla Magdalene Götz. He was baptized Johann Georg Metzler. It has never been satisfactorily explained why he preferred the name "Karl Ludwig Giesecke"; it appears for the first time in his own handwriting in 1781, when he was 20 years old, on the title page of his diary, where he signed himself as "Carolus Ludovicus Metzler cognomine Giesecke." Under the name of Johannes Georgius Metzlerus he allegedly studied law from 1781 to 1783 at the University of Göttingen, Germany.

For the following 10 years information concerning Giesecke is sparse; of his diary, only the volumes 3 and 5 have been preserved and, whereas these give a very good picture of the periods 1781 to 1784 and from 1800 until he finally settled in Dublin, Ireland, in 1813, and further up into the 1820's, the information concerning the period from 1784 to 1800 is very sparse. All of his biographers agree that during most of this period Giesecke lived in Vienna, Austria. From *Erneuerte vaterländische Blätter für den österreichischen Kaiserstaat* (no. 18, March, 1819) it appears that Giesecke spent altogether 13 years in Vienna, part of the time as a talented actor at E. Schikaneder's "Theater im Starhembergischen Freihause auf der Wieden." During this period he wrote several texts for the theater and co-wrote, with E. Schikaneder, the libretto to Mozart's "The magic flute"; at the first performance on September 30th, 1791 he played first slave.

His great interest in minerals can be traced back to his school years in Göttingen, Germany. In his application for the professorship in Dublin he wrote: "During the course of my academical studies in Göttingen, I first applied myself to the study of mineralogy under the auspices of the celebrated Blumenbach." This interest in mineralogy was revived in the second half of the 1790's when he went on a large number of study and collecting trips to Germany, Austria, Hungary, Italy and elsewhere.

Giesecke finally gave up his career as an actor and a playwright and in 1800 left Vienna for unknown reasons; on 16 May 1800 he was officially registered as a mineral dealer. From his diary it appears that in the same year he visited Salzburg, Austria, and Erlangen and Würzburg, Germany. In 1801 he visited Bayreuth, Bamberg, Jena, Leipzig, Berlin and Freiberg, Germany. In Berlin, where he stayed for almost 4 months, he heard D. L. G. Karsten's lectures and compiled a catalog of a complete systematic mineral collection arranged and described according to Karsten's system, entitled *Katalog einer vollständigen systematischen Mineralien-Sammlung nach Karstens Grundsätzen geordnet und beschrieben*, a large manuscript of 350 folio pages preserved in the National Library of Ireland, which accompanied him on all his later travels. In 1801 he also visited Johanngeorgenstadt, Chemnitz, Schneeberg and again Würzburg, Germany. In 1802 he was in Hamburg, Marburg, Kassel, Braunschweig, Göttingen, Hildesheim, Bonn and several other cities in the northern part of Germany; in 1803, after having visited Lübeck, Greifswald, Stralsund and Rostock, Germany, he traveled through Copenhagen, Denmark on his way to Stockholm and Uppsala, Sweden. On his return from Uppsala to Copenhagen in September of 1804 and until his departure in April, 1806 he was busy with the preparations for what was to become his greatest single achievement, his seven-year odyssey in Greenland. An application to the King of Denmark and Norway, from the Treasurer of the Crown, on behalf of the Greenland and Faeroes Trading Commission, to subsidize Giesecke's expedition to Greenland was turned down in May of 1805. But Giesecke got permission to travel, at his own expense, in Greenland and to the Faeroes and a strong hint that he should start with the Faeroes. Late in the summer of 1805 Giesecke traveled to the Faeroes where he collected on almost all the islands. After returning to Copenhagen he traveled to Norway where he visited the famous silver mines at Kongsberg and the mineral-rich areas around Arendal.

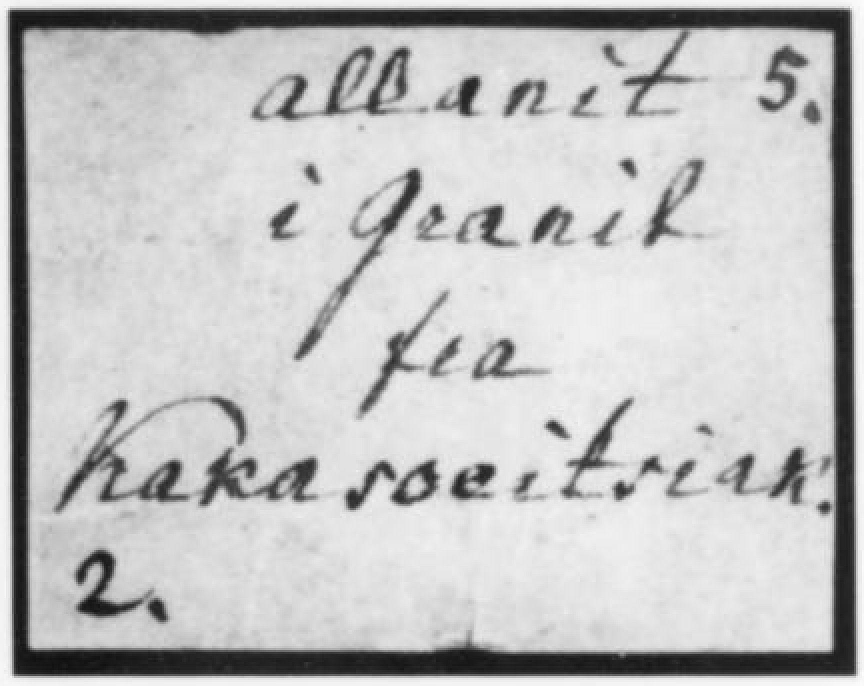

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Figure 5. **A label handwritten by Giesecke; the allanite specimen matching this label is from the historically significant Qáqarssuatsiaq locality at Aluk, the first place where this mineral was found.**

Finally on April 19, 1806 he was able to leave Copenhagen for Greenland. All he brought with him was his diary and the aforementioned catalog; everything else was left behind in the rectory of the St. Petri Church in Copenhagen. On May 31st he arrived in Frederikshåb (Paamiut). His travel accounts, a treasure chest of information for everyone occupied with the minerals of Greenland, start on June 1st and continue uninterrupted until September 19th, seven years later, when he arrived in Leith, Scotland.

Two copies of the travel account, both handwritten by Giesecke himself, are preserved, one in Dublin and one in Copenhagen. One copy Giesecke wrote for himself, and the other for the Greenland and Faeroes Trading Commission. Several corrections and additions in the Dublin copy prove that this was the original draft, and the Copenhagen copy was the transcription.

His original plan was to spend two or three years in Greenland. But, mainly due to the Napoleonic Wars, he was forced to spend no less than 6 summers and 7 long winters there. In 1806 he traveled by boat, south to Julianehåb (Qaqortoq), and from there he continued to Kap Farvel (Uummannarsuaq) by *umiak* (a women's boat of seal skin normally with 6 female rowers). On his way back he visited the now-famous fjords near Julianehåb (Qaqortoq), and on October 15th he reached Godthåb (Nuuk), where he spent the winter. In the following year he traveled in the same way to the north and reached the areas north of Upernavik. During the first half of 1808 he traveled by dog sled around Disko Island (Qeqertarsuaq).

In May of 1808 he learned that the ships carrying everything he had collected during the first years had been captured by English warships. Giesecke therefore decided to spend one more year in Greenland, collecting more specimens. A new trip to the south brought him once more to Julianehåb (Qaqortoq) and back to Godthåb (Nuuk). The following winter was unusually hard, even for Greenland, and everyone suffered from the cold. When the news reached him that everything he had left in Copenhagen had been destroyed by a fire caused by the English bombardment of the city, he decided to stay yet another year in Greenland. In the summer of 1810 the connections to Denmark and Norway were virtually severed, and no ships reached Greenland that summer. Most of the summer was spent in preparation for the winter, but Giesecke collected whenever possible. In the deepest Greenland winter, with temperatures down to minus 35° C, and into a stormy headwind, he traveled by dog sled as far north as Umanak (Ummannaq). It was his plan to leave Greenland in the summer of 1811, but the travel back from Umanak (Ummannaq) took longer than anticipated. According to Giesecke, the female rowers were more interested in eating than rowing, and when he finally reached Ritenbænk his ship had already left.

The year 1812 was even worse; supplies of bullets and gunpowder were exhausted, and famine ravaged large parts of Greenland. Finally, in the summer of 1813, he managed to find a ship that was willing to take him back to Europe, and on August 8th he left Godhavn (Qeqertarsuaq) for Leith, Scotland. Safe in Edinburgh, he finished the account of his Greenland travels with the words "Ich habe nun endlich nach einer langen Prüfungszeit von 7 Jahren dies Land des Elends verlassen . . ." (I have now, finally, after a trying period of seven years, left this land of misery . . .).

In Edinburgh, Giesecke stayed in the house of the banker Thomas Allan—the man who bought part of his collection which had been captured by British warships and sold at auction in Leith. Another part of the collection was purchased by a Lieutenant-Colonel Imrie; through the late Earl Gray and the late Brodie of Brodie, part of these specimens ended up in the Nairn Museum, Scotland. After some years of neglect they are presently being examined and (re)cataloged; several of very good quality, including cryolite, arfvedsonite and eudialyte, definitely originating from Giesecke, have been identified. After less than one month in Edinburgh he applied for the professorship at the Royal Dublin Society. In December he received his appointment, and later in 1816 he gave his first lecture on the natural history of Greenland.

In 1814 and again in 1817–1819, during extensive journeys to the continent, Giesecke visited Copenhagen and donated several large collections to various museums, including the Royal Natural History Museum; Count Moltke's Natural History Museum, belonging to the University; and the Mineral Collection of the Prince Christian Frederik (later King Christian VIII). Altogether he gave away 1,635 specimens. The handwritten catalogs of these collections are today preserved in the Geological Museum of the University of Copenhagen, where the various collections have found their final repository.

The number of museums, scientific societies and personal collections (in Berlin, Weimar, Munich, Frankfurt, Augsburg, Germany; and Graz, Austria) that received donations shows that the amount of material collected was very, very large.

The largest collection went to Vienna, shipped from Copenhagen via Kiel, Hamburg, Lüneburg and Leipzig to Regensburg, Germany, and from there by ship down the Danube River, to Vienna. The Austrian Emperor paid the freight, and the collection was temporarily put on exhibit in Hofburg. In addition to 215 ethnographic objects, 41 bones from whales and seals, 43 furs of seals, foxes and birds, a zoological collection preserved in alcohol, several shells and more than 200 dried plants, this collection also included minerals: 325 specimens from South Greenland, 145 specimens from North Greenland and 402 from various localities in Greenland, Iceland, England, Scotland, Ireland and North America. The entire collection was valued at 6,000 to 7,000 Guilders; the Emperor gave Giesecke 1,000 gold Ducats and a beautiful golden box set with gemstones and decorated with the monogram of the Emperor.

These travels were Giesecke's last major journey; the rest of his life he spent in Dublin, where he died suddenly on March 5th, 1833. His death was announced at the meeting of the Society on March 7th, 1833, and as a token of respect to his memory, the museum was closed for a fortnight.

Giesecke possessed a pleasant personality and a well-developed ability to make acquaintances. He was a gentleman, well-known and appreciated not so much as an outstanding scientist but because of his ability to identify minerals and his skill as an enthusiastic mineral collector. His devoted interest in minerals drove him from place to place for the purpose of collecting minerals, minerals that were later donated to a large number of museums and collections throughout Europe.

Johann Georg Metzler, Karl Ludwig Giesecke, Charles Lewis Giesecke, actor, mineral collector and professor of mineralogy, was an interesting person with a very interesting life, one of the most fascinating pioneers who have contributed significantly to the knowledge of the minerals of Greenland.

Figure 4. **Location map**

***Figure* . During the 1975 expedition to the Fiskenæsset area, a large amount of ruby-bearing rocks was collected, particularly at Siggartartulik, and partly by means of heavy equipment; photo by O. V. Petersen.**

PRECAMBRIAN SHIELD

In the Precambrian shield of West Greenland, four major structural provinces are recognized. An old Archaean block is flanked by the late Archaean and early Proterozoic Nagssugtoqidian mobile belt to the north and the Ketilidian mobile belt to the south. To the north of the Nagssugtoqidian mobile belt another early Proterozoic complex, the Rinkian mobile belt, occurs that contrasts strongly in character with the Nagssugtoqidian. Cratogenic conditions were established by middle Proterozoic time when sediments and volcanic rocks accumulated in the Gardar province of South Greenland and platform sediments were deposited in North Greenland.

The mineral localities described here are mainly located within the Archaean block, in the Nagssugtoqidian mobile belt, and in the Gardar complexes.

The Fiskenæsset area

GEOGRAPHY and GEOLOGY

Fiskenæsset (Qeqertarsuatsiaat) is a small community of about 400 inhabitants, located nearly 160 km south of Godthåb (Nuuk) on the southwestern coast of Greenland. The ice-free coastal belt in the Fiskenæsset area is about 100 km wide; it is characterized by deep fjords cutting far inland. The relief rises to about 1,500 meters, and the degree of rock exposure, at least in the snow-free areas, is close to 100%.

Geologically, the Fiskenæsset area includes a metamorphosed, layered magmatic complex, known as the Fiskenæsset Complex, which occurs as a concordant layer up to 2 km thick—extending for at least 200 km—in granitic gneiss bordered by amphibolites. Ultramafite and anorthosite, partially chromium-rich, are the most prominent rock types.

MINERALOGY

Most of the sapphirine, kornerupine and corundum (ruby) occurrences in the Fiskenæsset area are localized within the stratigraphy of the Fiskenæsset Complex. They are found along the contact of the intrusion with the upper marginal amphibolite, i.e. in the topmost portion of the intrusion between the garnet or chromite-bearing anorthosite and the amphibolite into which the intrusion was emplaced. The majority of the sapphirine-bearing rocks were formed by introduction of mobilized potash feldspar material during amphibolite facies metamorphism, along the zone of assimilation of the anorthosite component of supracrustal material from the amphibolites. The kornerupine-rich rocks are interpreted as originating from boron-rich evaporites in the sedimentary rocks series. There are four major types of sapphirine-bearing rocks, and four associated rocks without sapphirine. These types are characterized by the prevalence of enstatite, magnesiohornblende, gedrite or phlogopite, respectively. The sapphirine-bearing rocks occur as lenses and narrow layers of variable size from less than 1 meter to approximately 1,000 meters in length. Altogether 40 localities with sapphirine, often associated with ruby corundum, are known, of which only six localities also contain kornerupine. In all, around 50 different minerals (sulfides, oxides and

Table 1. **Minerals from Fiskenæsset.**

- Actinolite
- Allanite
- Anthophyllite
- Apatite
- Biotite
- Bravoite
- Calcite
- Chalcopyrite
- Chlorite (group)
- Chromite
- Clinochlore
- Clinozoisite (chromian)
- Clintonite
- Cordierite
- Corundum
- Corundum (variety ruby)
- Cubanite
- Cummingtonite
- Digenite
- Diopside
- Diopside (variety Salite)
- Dolomite
- Enstatite
- Enstatite (ferroan)
- Epidote
- Epidote (chromian)
- Ferrogedrite
- Garnet (group)
- Gedrite
- Godlevskite
- Goethite
- Grandidierite
- Graphite
- Heazlewoodite
- Hercynite (chromian)
- Högbomite
- Hypersthene
- Ilmenite
- Kornerupine
- Kyanite
- Mackinawite
- Magnesiohornblende
- Magnetite
- Magnetite (chromian)
- Microcline
- Millerite
- Molybdenite
- Muscovite
- Muscovite (chromian)
- Olivine
- Orthoclase
- Pentlandite
- Pentlandite (cobaltian)
- Phlogopite
- Plagioclase
- Polydymite
- Pyrite
- Pyrrhotite
- Quartz
- Rutile
- Sapphirine
- Scapolite (group)
- Serpentine (group)
- Sillimanite
- Sphalerite
- Spinel
- Spinel (chromian)
- Spinel (ferroan) (chromian)
- Talc
- Titanite
- Tourmaline (group)
- Tremolite
- Tschermakite
- Violarite
- Zircon

silicates) have been recognized within the sapphirine-bearing rocks, and only three of these, sapphirine, ruby corundum and kornerupine, will be individually described here.

Sapphirine $(Mg,Al)_8(Al,Si)_6O_{20}$

Sapphirine was found by Giesecke in 1809 in the southern harbor at Fiskenæsset (Qeqertarsuatsiaat) village. Originally he called it "cyanite," on a later occasion "emerald," but in his catalog, written in German, "blauer Diamantspath (saphirine)." Friedrich Stromeyer undertook, in 1819, the first analyses of the mineral; in the following years several investigations of the chemical, crystallographic and optical properties were carried out by various mineralogists including Johannes Theodor Lorenzen, but not until Niels Viggo Ussing's investigations in 1889 were all the various properties of the mineral made entirely clear.

Sapphirine from the Fiskenæsset area occurs in many habits: as rims on dark green magnesian spinel or red brown chromian spinel; as rims on corundum; and as individual, often irregularly shaped, rarely well-developed crystals in association with the above-mentioned enstatite, magnesiohornblende, gedrite or phlogopite. Most often sapphirine occurs in various types of aggregates of platy or bladed single and twinned crystals. The size of the crystals varies from small (a few millimeters) to several centimeters, as does the size of the aggregates. The color of the Fiskenæsset sapphirine ranges from pale blue, green, gray or pinkish gray, to dark blue or greenish blue. Even purplish varieties have been found.

Corundum Al_2O_3

Ruby corundum was first found in the mid-1960's in considerable quantities at several of the sapphirine localities. Investigations of the corundum occurrences for their gem potential were carried out in the 1970's. The ruby corundum occurs as single crystals and crystal clusters. The crystals vary in size from a few millimeters to several centimeters; clusters of crystals covering several hundred square centimeters have been reported. The small crystals most often are isometric, somewhat rounded and irregular; the larger ones are more often well-developed and are clearly tabular with {0001} faces showing characteristic growth trigons. The color of the Fiskenæsset ruby corundum varies from rose-red through pigeon-blood red and dark red to the rare purple-red. The Fiskenæsset rubies have an unusually high chromium content, up to 3.0%; they are strongly fluorescent, particularly in long-wave ultraviolet light. The overwhelming majority of the ruby corundum is opaque, but some is translucent; clear, transparent stones are very rare. Fortunately, rubies which can be cut into cabochons are somewhat more common. Although the quality of the Greenland rubies is comparable to that of rubies from Thailand, the Umba Valley (Tanzania), and the Taita Hills (Kenya), the immediate prospects for the Fiskenæsset rubies are bleak; the cost of mining would make them much too expensive. The red ruby corundum, whether in the light green to dark green amphibole-rich (tschermakite) rock or the snow-white plagioclase-rich rock, makes very nice hand specimens. It is likely that they may find some use for ornamental items.

Kornerupine $Mg_4(Al,Fe^{+3})_6(Si,B)_4O_{21}(OH)$

Kornerupine was first investigated by Lorenzen in 1884, in samples from the southern harbor of Fiskenæsset (Qeqertarsuatsiaat) village (which is also the type locality for sapphirine), collected by Knud Johannes Vogelius Steenstrup. The details of the crystallography and optical properties of the mineral were determined by Ussing in 1889. The Geological Museum in Copenhagen has no material directly connected with the investigations of Lorenzen, but does possess four specimens, collected by Steenstrup in 1877 and registered in the museum in 1883 as kornerupine, possibly by Lorenzen. As late as in 1970 these four specimens, together with the sparse material (a few measured crystals and vials with powder) from Ussing's investigations, were the only kornerupine from Greenland available. As already mentioned detailed mapping and investigation in the Fiskenæsset region began in the mid 1960's and continued through the 1970's, resulting in the identification of 40 localities with sapphirine, six of which also contain kornerupine.

In the spring of 1975 one of us (OVP) learned that a sapphirine-kornerupine occurrence had been found north of the Allumersat Fjord. In the summer of 1975 a visit was made to this and several other kornerupine localities, where a very large quantity of rich material was collected which surpasses the old material, both in quantity and quality, by a hundred-fold. Following is a short account of the four days spent at the Allumersat locality, during which the largest known crystal of kornerupine in the world was found.

On July 17 I (OVP), my assistant and all our equipment were lifted by helicopter to our base camp. Because the occurrence is situated at a relatively high elevation and even in summer is often covered by snow, we had chosen to camp near a small brook, close to the snow-free bottom of the valley, at a height of about 900 meters above sea level. The next day (which was one of the best of the best Greenland days, with sunshine from a cloudless sky, calm and about 5° C) we started work at the locality. It soon proved to be a very rich one, and in our anxiety to obtain as many good specimens as possible we "forgot" to pack the specimens. At the end of the working day we had covered all the snow-free rocks with exciting specimens. The next morning found us in the middle of a snow storm, which had covered everything with about 25 cm snow! It continued with undiminished violence all day and into the following night, and did not stop until late afternoon on July 20. Any thought of work was dismissed until the morning of the 21st, when we woke up to bright sunshine. We spent the entire day finding our specimens, digging them out of the snow and packing them. When the day was over, we had a large quantity of first-class specimens securely packed in 20 boxes.

At the occurrence, a 10 x 30-meter lenticular body entirely surrounded by anorthosite, the kornerupine shows a great variation in

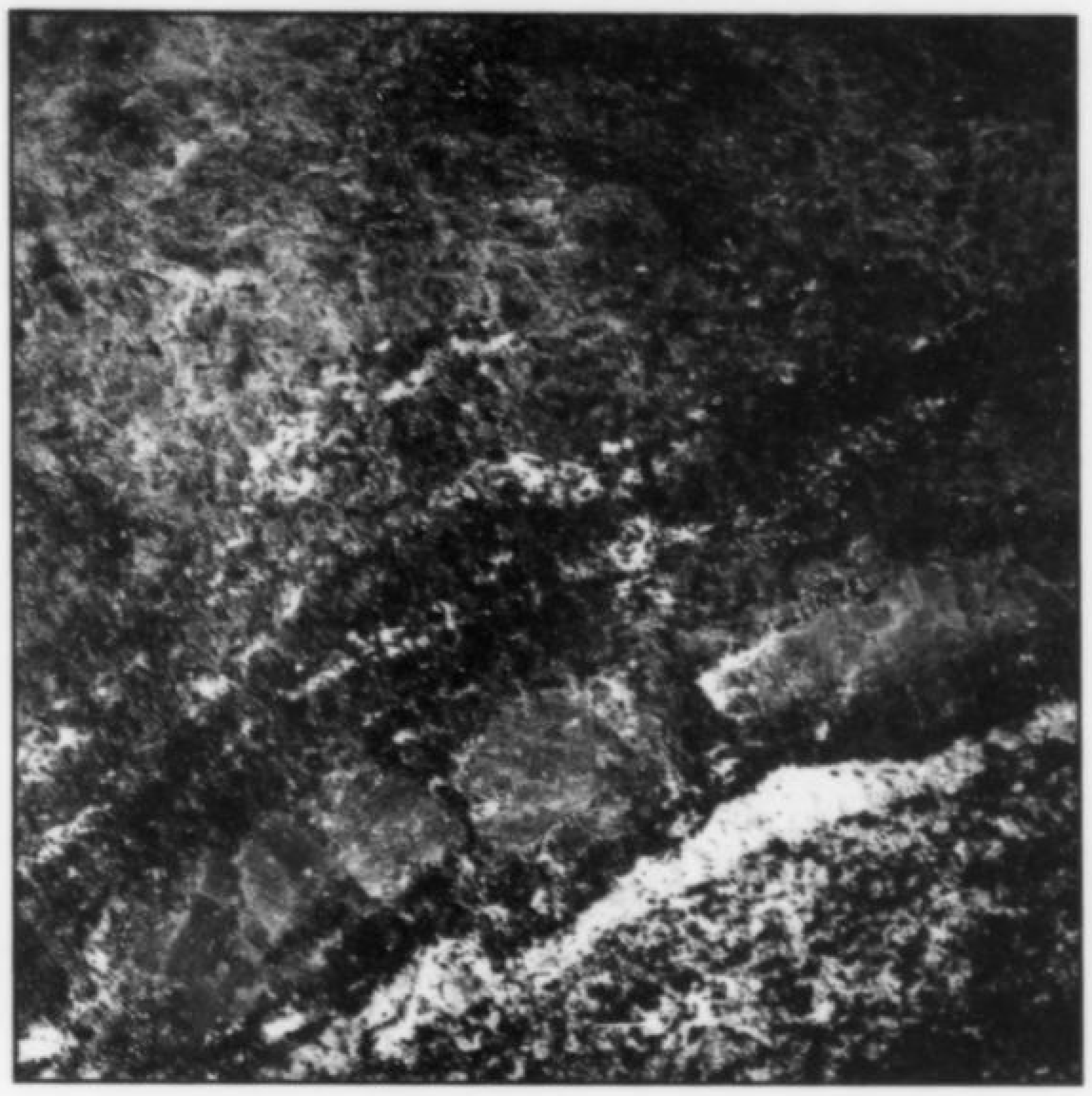


Figure 8. The greenish ruby-bearing rock from Fiskenæsset shown here is rich in tschermakitic amphibole associated with gedrite (brownish), sapphirine (blue), plagioclase and mica; actual size 8 cm across; photo by O. Medenbach.

Figure 9. The type locality of sapphirine is the south harbor at Fiskenæsset (Qeqertarsuatsiaat), where K. L. Giesecke in 1809 found the mineral for the first time. Well-developed crystals are rare in Greenland, the 1.1-cm crystal shown here, found in 1975, is among the best in the Geological Museum, Copenhagen, Denmark; photo by R. Bode.

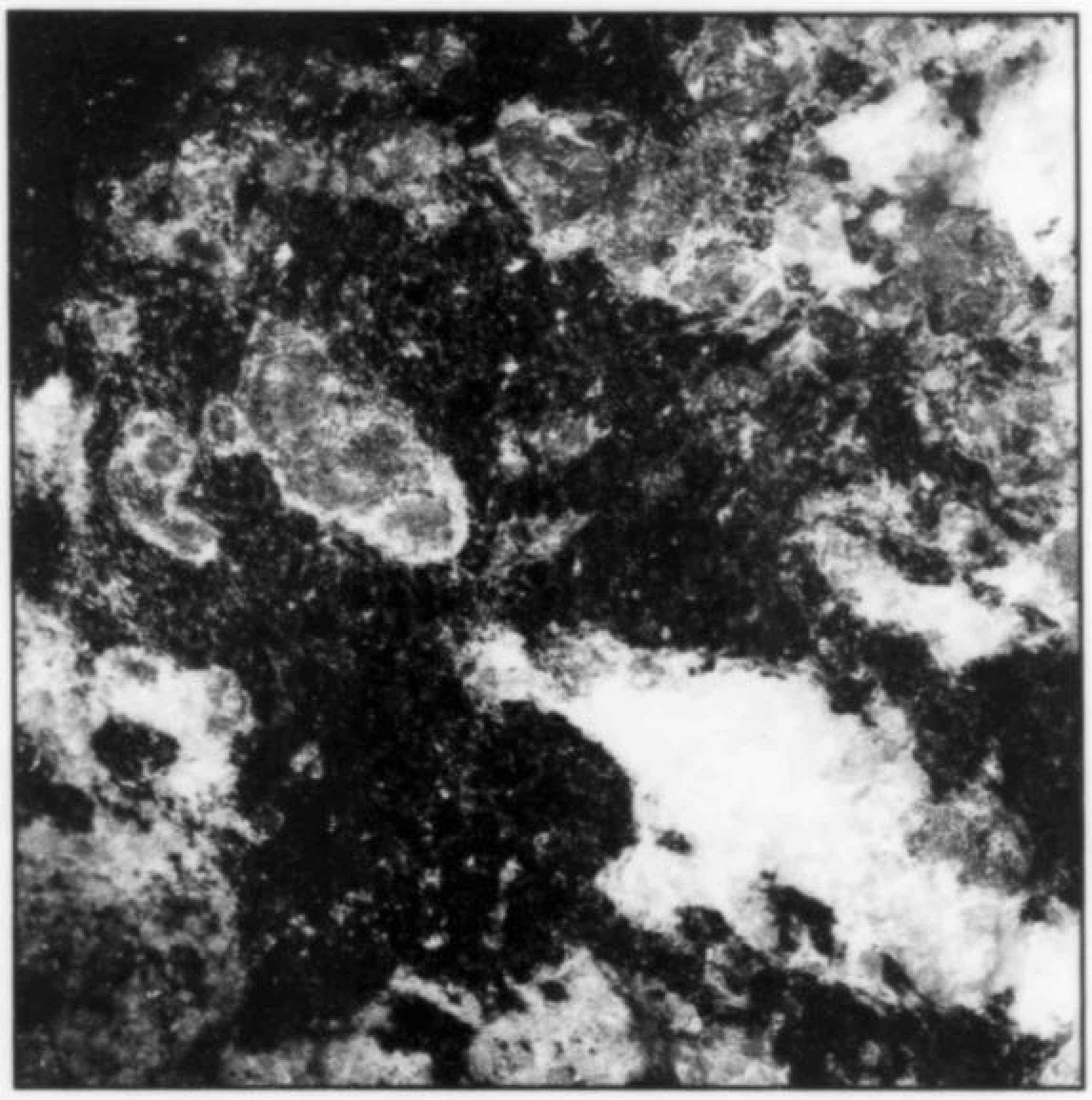


Figure 10. Rubies from Fiskenæsset in a mainly white plagioclase and mica-rich rock; actual size 8 cm across; photo by O. Medenbach.

Figure 11. This giant kornerupine crystal, fully 23 cm long (!), is one of the largest ever found anywhere. It was found in 1975 under extreme conditions at a locality near Fiskenæsset (Qeqertarsuatsiaat), not far from the inland ice in the margin of one of the sapphirine-kornerupine-bearing lenses toward the enclosing anorthosite; photo by P. Nielsen.

both habit and color. In the uppermost part of the occurrence the kornerupine forms more or less radiating aggregates of white and almost colorless crystals; downwards these are replaced by aggregates of long, prismatic blue crystals. Much lower, kornerupine forms crystal groups and singles with distinctly prismatic habit, in a matrix of cordierite, mica and plagioclase. The kornerupine of this zone is dark green and, in rare cases, translucent. The extraordinarily large single crystals of kornerupine occur further below in the surrounding anorthosite. These crystals, which without any doubt are the most impressive kornerupine crystals ever found, are dark green and in general completely non-transparent, but some areas in some of the crystals are transparent. The largest crystal found is 23 cm long and shows {110}, {100} (both strongly striated) and {021}. A further visit to this relatively inaccessible locality might well yield more such specimens. The classic occurrences of kornerupine in the Fiskenæsset (Qeqertarsuatsiaat) area have for many years been considered to be without gemological interest. This statement is no longer true; at least part of the new material is of gem quality. From a few cleavage fragments, a total of 14 faceted stones and 7 cabochons varying in size from 5.88 ct to 0.09 ct were cut. The stones are all transparent and have a beautiful dark green color without any brownish tint. They are strongly pleochroic: dark green, reddish blue, light blue. Larger inclusions seem to be absent, but the stones have tension cracks.

At yet another locality, columnar radiating aggregates with kornerupine "crystals" approximately 50 cm in length have been found in association with phlogopite. Many other minerals from the Fiskenæsset region could be mentioned. Chromite, for example, forms horizons from 50 cm to 20 meters in thickness which can be followed for several kilometers. Molybdenite has been found there in incomplete 10-cm crystals. However, the three minerals described in detail above are (and probably will remain) the most interesting minerals from this well-known mineral-rich area.

The Godthåbsfjord (Nuup Kangerlua) area

GEOGRAPHY and GEOLOGY

The Godthåbsfjord region is situated in the very center of West Greenland just east of Godthåb (Nuuk), the national capital (population 12,000). The fjord area covers nearly 1,000 square kilometers along the coast of Nordlandet (Akia). The fjord is characterized by deep, branching straits between mountains with steep slopes. Mountain peaks are numerous, with characteristic profiles, and they reach altitudes close to 1,500 meters in the central part of the region. From the eastern area three glaciers are constantly pouring icebergs into the fjord, making sailing difficult in the inner waters. Nevertheless, small vessels are the most popular way of getting around, and several interesting localities can be reached in this way.

Geologically the area is famous for the oldest known rocks in the world, isotopically age dated at close to 3.8 billion years. A well documented stratigraphy includes basement and supracrustal rocks, ceasing with the intrusion of a huge granite complex and associated pegmatites 2.6 billion years ago.

MINERALOGY

Chromian Muscovite ("Fuchsite") $K(CrAl)_2(Si_3Al)O_{10}(OH,F)_2$

From a sequence of supracrustal rocks at the Isukasia locality a "fuchsite"-rich quartzite is related to banded iron formations in oxide, sulfide, carbonate and silicate facies. The intense green fuchsite-bearing rock has long been known as "grønlandite," the "oldest" gemstone of the world, with an age close to 3.8 billion years. The rock is simply a homogeneous quartzite, rich in microscopic flakes of fuchsite resulting in a nice blue-green to grass-green appearance with bands of pure white quartz. Fuchsite crystals are minute, but at some localities flakes can attain a size up to 1 cm. The original locality at Isukasia has for several years supplied collectors and jewellers. The occurrence is still productive, and several new localities have also been found in the area. The "fuchsite" is most frequently cut and polished as cabochons and as plane polished slabs, and takes a perfect polish. One prominent application of the "grønlandite" is as a decoration in the insignia of the Bishop of Greenland.

Scheelite $CaWO_4$ and **Molybdenite** MoS_2

Younger supracrustal units in the area there have yielded minerals which are otherwise uncommon in the Precambrian of Greenland. Scheelite and molybdenite occur as crystals to several centimeters, although faces are only rarely discernible. Just south of Godthåb (Nuuk), near the abandoned village Narssaq (Narsaq), molybdenite grains are found associated with scapolite crystals. The scapolite occurs in veins in green skarn rocks as crystals to 3 cm with well-developed {100} faces and a gray to white color.

Anthophyllite $(Mg,Fe^{+2})_7Si_8O_{22}(OH)_2$

Anthophyllite-gedrite masses are common in some of the supracrustal rocks, typically as elongated to fibrous masses characterized by an iridescent metallic luster in blue and orange. Such intergrowths have recently been marketed as gem material under the name "nuummite," after the Greenlandic name for the capital Nuuk. Iridescent orthoamphiboles were first described by Bøggild in specimens collected by Giesecke in 1810 in the Godthåb (Nuuk) area. This iridescent orthoamphibole has been found at several localities in a sequence of Precambrian supracrustals enclosed in gneiss. The gem-quality material occurs as thin bands and lenses up to 1 meter wide, in layers consisting almost exclusively of orthoamphiboles, which can be traced for several hundred meters. Cut and polished cabochons show a sparkling iridescence ranging from metallic blue and green through yellow to golden, reddish and rarely violet colors. The matrix of the iridescent grains ranges from pale gray to almost black, sometimes with a brown hue.

Tourmaline complex borosilicate

Another place in the southern part of the area at the small cape Qârusulik (Qaarusulik) in Lysefjord (Ameralik), is a famous locality for tourmaline that has been known since 1798. In early times the material was found by local collectors. Giesecke rediscovered the locality in 1808 and was impressed by the size of the crystals. One crystal is reported to measure 13 cm in length and to weigh 1.972 kg. The crystals are often curved and show a typical trigonal habit with the forms $\{10\bar{1}0\}$, $\{11\bar{2}0\}$, $\{\bar{1}01\bar{1}\}$, $\{10\bar{1}1\}$ and $\{02\bar{2}1\}$ developed. The color is black, and the faces are very glossy and shiny. The tourmaline from this locality is really of outstanding quality. It is found in micaschist layers in the gneiss together with quartz and actinolite. In the 18th century these crystals were shipped to Europe in large amounts; Robert Allan stated in 1813 that "they are not lacking in any collection."

Pegmatite Minerals

A particular geological feature of the Godthåbsfjord (Nuup Kangerlua) area, the pegmatite, deserves special attention due to the existence of generally large crystals of several species. Pegmatites are widespread in the area, in several generations of emplacement. Many are characterized by the presence of radioactive minerals, e.g. allanite, euxenite, xenotime, uranothorite and uraninite. These have been useful in regional geophysical mapping. The radioactive species are most commonly found as small, less than 1-cm crystals, all of them metamict to some degree and therefore dull and unattractive. In addition, pegmatites carry large crystals of tourmaline, beryl, garnet and magnetite. Tourmaline reaches sizes up to 3 x 10 cm at the island of Sermitsiaq and at the Ivisârtoq (Ivisaartoq) peninsula. The tourmaline is very similar to the type described from the micaschist, with well developed, black glossy faces. At Ivisârtoq (Ivisaartoq) one large crystal of beryl has been collected; it measures 4 x 15 cm and has a pale green color, although non-transparent and with irregular faces. Tourmaline is also common in supracrustal sequences, together with scheelite. The only Greenland occurrence of gahnite has been reported from here as well, as microscopic grains.

Central and Northwestern Greenland

Prominent mineral localities in the Precambrian terrain north of the Godthåbsfjord (Nuup Kangerlua) area are scarce and consist only of small occurrences.

MINERALOGY

Lazurite $(Na,Ca)_{7-8}(Al,Si)_{12}(O,S)_{24}[(SO_4),Cl_2,(OH)_2]$

Sixty km east of the town Sukkertoppen (Maniitsoq) in the inland area, at Tupertalik, a small occurrence of a Precambrian carbonatite sheet is known. The carbonatite has an age of 2.6 billion years and is thus one of the oldest carbonatites known; it has suffered several metamorphic episodes. The intrusion has a sheet-like shape, exposed over an area 200 x 500 meters, and is composed exclusively of calcitic carbonatite. At the contact areas with the surrounding basement gneiss a suite of reaction minerals has developed: calcite, clinopyroxene, amphibole and scapolite together with attractive blue lazurite. This occurrence, discovered by one of us (KS) has yielded a mixture of approximately 80% lazurite and 20% marialite. Lazurite crystals have not developed; it is always found as dense, pale blue masses with dark green inclusions (salite and pargasite) and later veinlets with a mixture of a white unidentified zeolite and mica. This is the only occurrence of lazurite in Greenland. It has been marketed as a gem material. It takes a good polish, and the inclusions and crack fillings of dark and white minerals make a delicate structure. The most prominent example of its use as gem material is as a stone component in the official neck-chain for the Major of Sukkertoppen (Maniitsoq).

Kyanite Al_2SiO_5

In the same area, 25 km north of the lazurite locality, a supracrustal layer 1 km wide, running northeast-southwest in the Kangerdluarssuk (Kangerluarsuk) Fjord, displays some interesting features. In the aluminum-rich supracrustal rock, mapped as garnet micaschist, one of us (KS) has observed exceptionally large concentrations of kyanite. Locally within the schist lenses up to 50 cm x 10 meters made of pure ice-blue, coarse crystalline kyanite as single crystals with fibrous to prismatic habit, have been found.

Corundum Al_2O_3

Within the same sequence, at the eastern end of the fjord, the supracrustal rocks have reacted with the rocks in an ultramafic pod, giving rise to the development of corundum crystals of well developed form and large size. The habit of the crystals is characteristic elongated bipyramidal. The faces are weathered, with only a weak adamantine luster. The largest crystal found measures approximately 6 x 15 cm, weighs 1.085 kg, and is doubly terminated. The crystals are embedded in phlogopite schist and are rather easy to free. The color is pink, with a common tendency to pale blue in the center of the crystals. Smaller crystals are pink or even red throughout.

Cordierite $Mg_2Al_4Si_5O_{18}$

In the region around Ndr. Strømfjord (Nassuttooq), midway between the major towns Holsteinsborg (Sisimiut) and Egedesminde (Aasiaat), another pegmatite province has been located. Geologically the area is situated within the Nagssugtoqidian mobile belt, characterized by gneiss and amphibolite and, to the south, layers of marble. Some of the gneiss south of the fjord carries attractive violet cordierite grains up to 2 cm, but unfortunately never with crystal faces developed. However, the cordierite is mentioned because the mineral is reasonably transparent, allowing the pronounced dichroism to be observed.

Graphite C

North of Ndr. Strømfjord (Nassuttooq) the gneiss carries graphite at several sites. The graphite is found disseminated as well as in quartz veins within the gneiss. Locally the rock consists of rather pure graphite with massive aggregates of tabular or columnar crystals up to several centimeters across. These graphite crystals are often bent or curved, and in hand specimens they often resemble the famous graphite from Sri Lanka.

Monazite-(Ce) $(Ce,La,Nd,Th)PO_4$

Especially worth mentioning from the area are the beautiful crystals of monazite found in biotite-rich pegmatites. The monazite crystals are easy to locate due to a high content of radioactive elements. The crystals are up to 2 cm, tabular on {100}, with the common monoclinic habit of monazite. The color is amber-yellow with a vitreous luster. Crystals occur scattered in pegmatite bodies 50 cm to 10 meters wide, as single crystals and small clusters.

Magnetite $Fe^{+2}Fe_2^{+3}O_4$

Close to the town Frederikshåb (Paamiut) in Southwest Greenland ultramafic pods have yielded unusually nice crystals of magnetite in cavities. The crystals, showing perfect octahedral habit with good luster on all faces, occur intergrown in rows or groups of individuals up to 3 mm.

Garnet $A_3B_2(SiO_4)_3$

North of the inactive Frederikshåb Isblink (Sioraq) glacier, close to the island Ravns Storø, a belt of supracrustal mica schist carries garnet of perfect rhombododecahedral habit, of moderate size and in notable abundance. The crystals, which are easy to work out of the host rock, have a color varying from brownish red to purplish red but without transparency. The size varies from millimeters to centimeters; the largest garnet collected is about 11 cm across.

Olivine $(Mg,Fe)_2SiO_4$

In a suite of dunites, known from several localities in the inner Fiskefjord (Niagununaq) north of Godthåbsfjord (Nuup Kangerlua), large olivine crystals can be found. Dunite pods and larger bodies up to a few square kilometers consist of saccharoidal olivine masses. Sometimes coarse crystals of olivine are as large as 3–6 cm in length, showing all faces, but the faces are uneven due to adhering olivine grains.

Sulfide Minerals

Sulfide minerals are widespread in the Precambrian rocks of Greenland. They are, however, only rarely found as display-quality specimens. The sulfides generally occur as fine-grained masses, disseminations and massive vein-fillings. Famous sulfide deposits are situated at Amitsoq in the Nanortalik area (Ni-Pt); Frederik VII mine near Julianehåb (Qaqortoq) (Cu-Se-Te); Kobbermine Bugt and the Sermiligârssuk (Sermiligaarsuk) Fjord in the Ivigtut (Ivittuut) area (Fe-Cu-As-Au); the Sukkertoppen (Maniitsoq) area (Cu-Ni-Pt); Lersletten (Naternaq) east of Egedesminde (Aasiaat) (Fe-Cu) and the Black Angel (Pb-Zn-Ag) at Mârmorilik (Maarmorilik). The Mârmorilik (Maarmorilik) deposit is the only one which has been exploited, as of 1990; the ore consists of impressive coarse-grained pieces of massive galena, tennantite, sphalerite, chalcopyrite and pyrite.

Gold Au

The Precambrian of Greenland also hosts pronounced primary occurrences of gold, most often associated with sulfides. Gold is typically observed as microscopic grains disseminated in the host sulfide: in Kobbermine Bugt together with bornite, in Mârmorilik (Maarmorilik) along with tennantite and in Sermiligârssuk (Sermiligaarsuk) together with arsenopyrite. Placer gold is found in South Greenland, in the

Figure 12. The central part of the Godthåbsfjord (Nuup Kangerlua) area overlooking the island Storø (Qeqertarsuaq); photo by K. Secher.

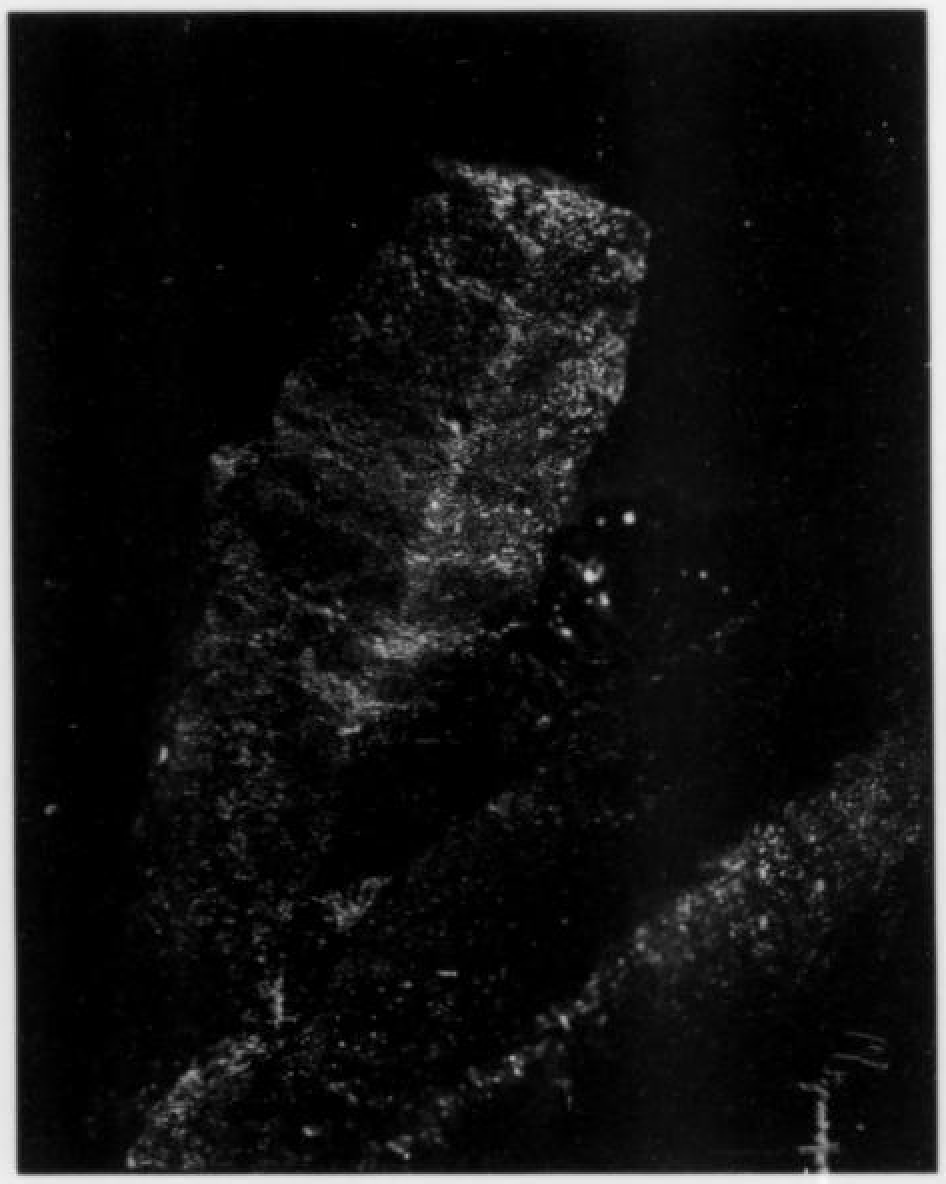
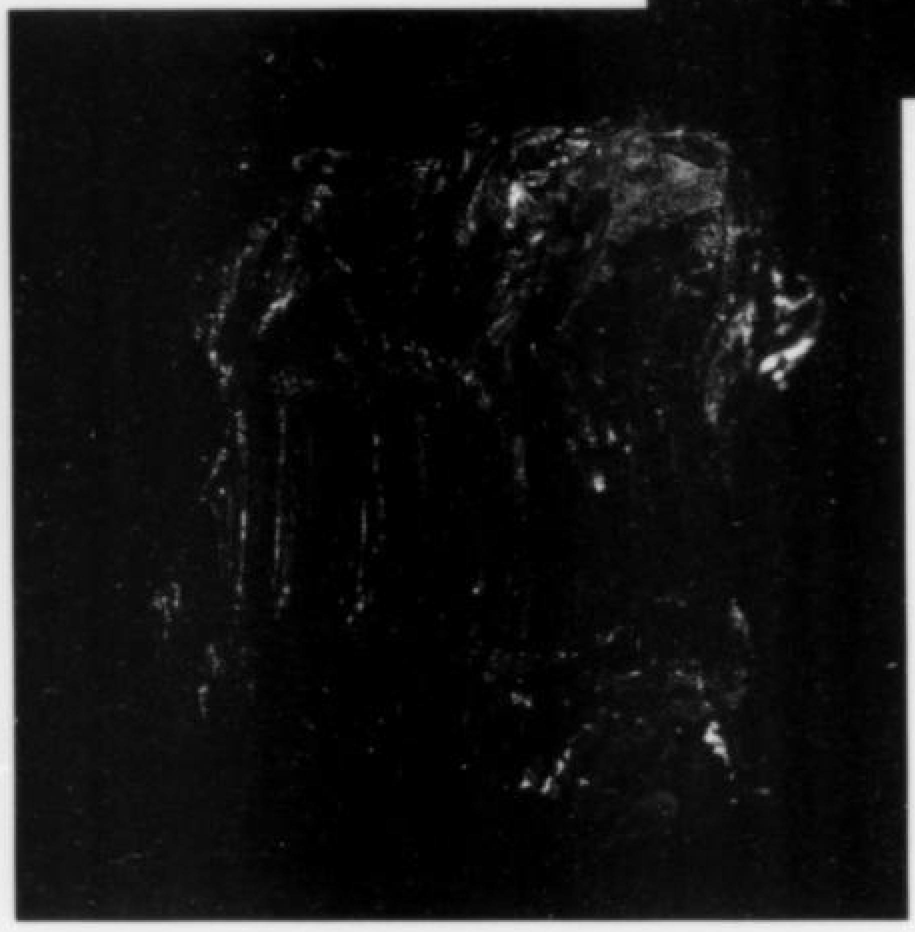


Figure 13. This fantastic group of ruby crystals was found by Karsten Secher in 1983 at the Kangerdluarssuk (Kangerluarssuk) Fjord and is now in the collection of the Geological Museum, Copenhagen; the central 9-cm crystal is one of the largest known from Greenland; photo by R. Bode.

Figure 14. (below) Graphite is known from many places in Greenland, and has at times even been mined commercially. This 5-cm specimen is typical of Greenland graphite; photo by R. Bode.



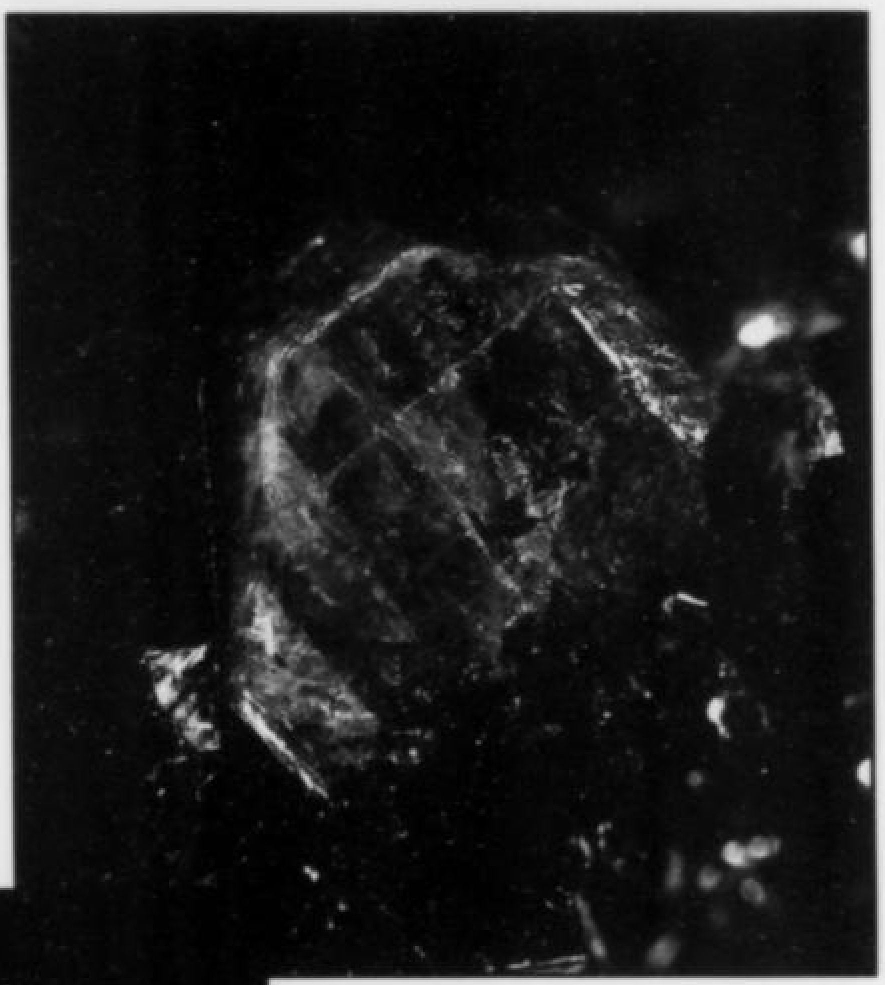


Figure 15. (above) Very well-developed monazite crystals—like the 3-mm example shown here—are, if not plentiful, then at least not uncommon in the biotite-rich pegmatites on the coasts of Nordre Strømfjord (Nassuttooq); photo by R. Bode.

Figure 16. **The Kangerdluarssuk (Kangerlluarsuk) Fjord near the town Sukkertoppen (Maniitsoq), the locality for the most impressive group of ruby crystals in Greenland; photo by K. Secher.**

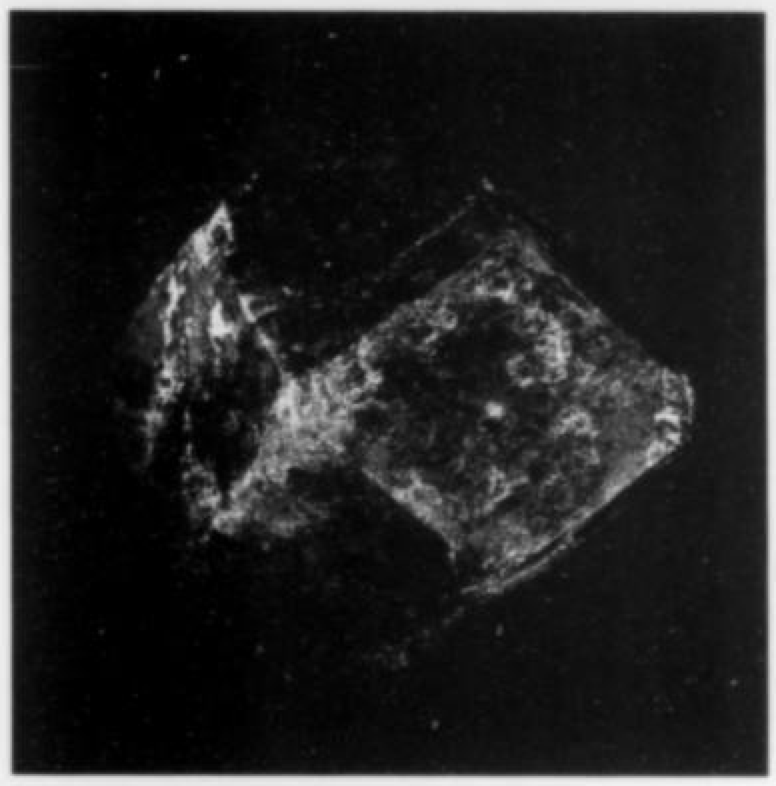


Figure 17. **Idiomorphic crystals of garnet are known from several places in Greenland. The 5-cm crystal show here is from Ravns Storø, where crystals occur particularly plentiful in micaschists; photo by O. Medenbach.**

Figure 18. **An approximately 5-cm, perfectly shaped olivine crystal from Fiskefjord (Niagununaq). The crystals occur abundantly, weathered out of ultrabasic rocks, and hence have rather pitted surfaces; photo by R. Bode.**

Nanortalik area, where it occurs as flakes in stream sediments. Gold nuggets have thus far not been found in Greenland.

Allanite-(Ce) $(Ce,Ca,Y)_2(Al,Fe^{+2},Fe^{+3})_3(SiO_4)_3(OH)$

Allanite is very common in Greenland and has been found at several localities, frequently in large quantities. Allanite is by no means rare in other parts of the world, but it was found for the first time in Greenland by Giesecke in 1806. The locality was given as "Qaqarssuatsiaq at Aluk," situated on the southeastern coast just north of the Prins Christianssund weather station. The crystals were found in granite, along with small hematite crystals. Giesecke's first shipment fell into the hands of the Scottish mineralogist Robert Allan who, together with Giesecke, thought it to be gadolinite. Later, in 1811, Thomas Thomson proved it to be a new mineral and named it after Allan.

Microcline (var. *Amazonite*) $KAlSi_3O_8$

Microcline (var. *amazonite*) has been known from the Nunarssuit Peninsula in South Greenland since the 1960's. The Proterozoic Julianehåb Granite covering a major part of the area is associated with several pegmatites, most of them characterized by the existence of green microcline. In the area around Torsukattak Fjord, especially, the pegmatites are producing nice examples of well-developed crystals of turquoise-green microcline. Single crystals may measure up to 10 cm in length, embedded in quartz and gray microcline.

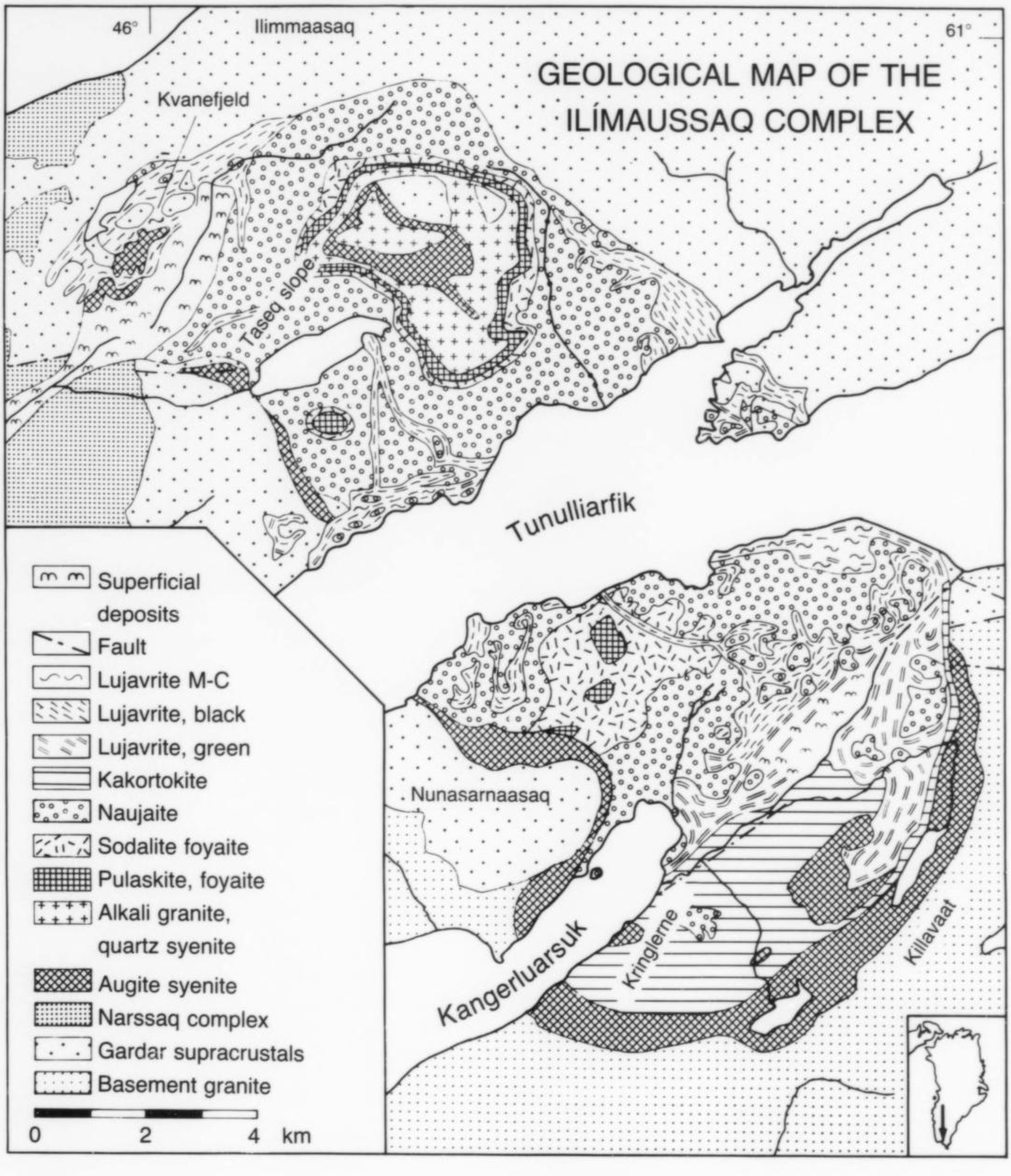


Figure 34. **Geological map of the most exciting of all the Gardar complexes, the Ilímaussaq complex. Based on the map of Ferguson (1964), this map has been corrected and improved by a team from the Institute of Petrology of the University of Copenhagen. The exotic rock types—naujaite, lujavrite, kakortokite—are not only mineralogically highly interesting; some are also very beautiful.**

Figure 20. **Traveling by boat definitely was, and probably still is, the most important way of getting around during the summer field season. The abundant fjords, with their numerous inlets, often cutting deep inland, are convenient access roads for geologists. Photo by O. V. Petersen.**

LATE PRECAMBRIAN ALKALINE IGNEOUS AREAS

In southern Greenland, eroded granites are overlain by more than 3,000 meters of continental sandstones intercalated with basaltic lavas. The extrusion of basaltic rocks was accompanied by dike emplacement and a major suite of alkaline igneous rocks. The period of formation of the sandstones, lavas, dikes and the alkaline intrusions has been termed the Gardar period, after the ancient Norse Bishop of Gardar. (Gardar is the site of the present-day village of Igaliko (Igaliku).) There are approximately ten major intrusive complexes, ranging in age from 1.32 to 1.12 billion years: Kûngnât, Ivigtut, Grønnedal-Ika, Nunarssuit, Puklen, Central Tugtutôq, Dyrnæs-Narssaq, Ilímaussaq, Igaliko and Klokken. All of these are within an area of 200 km (east-west) by 70 km (north-south). They vary in size from small (a few hundred meters across, as at Ivigtut) to large, cropping out over areas exceeding a thousand square kilometers (as at Nunarssuit). The ensemble constitutes one of the most remarkable alkaline igneous provinces in the world. The complexes are predominantly composed of alkaline to peralkaline rocks, and fall naturally into two categories: those involving rocks over-saturated in silica and those involving under-saturated rocks. Only one complex, Ilímaussaq, includes rocks from both categories. The various units of the complexes are steep-sided, commonly composed of several separate intrusions, and transgressive towards earlier structures; igneous layering is the hallmark of the intrusive units of this province.

The exotic rocks, with their rare and beautiful minerals, have attracted the attention of geologists and mineralogists since the beginning of the 19th century. The most famous of these complexes—Ilímaussaq, Ivigtut, Kûngnât and Igaliko (Narssârssuk)—are described individually below.

The Ilímaussaq alkaline complex

HISTORY

The Ilímaussaq complex, beyond any doubt the most mineral-rich area in Greenland, has attracted the attention of Danish and foreign geologists for generations. The complex was discovered by Giesecke, who visited the region twice (in 1806 and 1809) during his mineralogical expedition in Greenland in the years 1806–1813. As mentioned, part of his collection, sent back after the first two years, was captured by British warships and landed in Leith, Scotland, where it was bought at auction by the Scottish mineralogist Robert Allan. From this material the minerals sodalite and arfvedsonite were first described by Thomas Thomson in 1812 and by H. S. Brooke in 1823, respectively. Giesecke's extensive collection from his last five years in Greenland was eventually deposited in mineral collections in Copenhagen and in other European cities, where it was studied in later years by a number of eminent mineralogists. Eudialyte was described by Friedrich Stromeyer in 1819.

***Figure 21*. Ilímaussaq is, with its almost 200 mineral species, the most mineral-rich area in Greenland. Minerals can be found literally everywhere, that is if one works hard enough; photo by K. Secher.**

Specimens collected by Greenlanders and sent home by government officials also fell into the hands of mineralogists; aenigmatite appears to have been described from such material by J. F. A. Breithaupt in 1866. However, very little happened in Ilímaussaq until the expeditions of Steenstrup in the years 1874, 1876 and 1877. A considerable part of Steenstrup's material was lost when the Christiansborg Palace in Copenhagen was destroyed in a fire in 1884. In order to replace the material lost, Steenstrup revisited Ilímaussaq in 1888 and 1899. The specimens he brought home were examined by Lorenzen who described the new minerals steenstrupine, polylithionite and rinkite (1881 and 1893). Gustav Flink, who visited Narssârssuk in 1897, also collected extensively at Ilímaussaq. His material was studied by Bøggild and Winther, who described the new minerals britholite, epistolite, naujakasite and schizolite on the basis of this material. Ussing, accompanied by Bøggild, mapped both the Ilímaussaq and the Igaliko complexes, and studied a number of other alkaline complexes in southern Greenland, in 1900. Ussing revisited Ilímaussaq in 1908, Bøggild described in 1904 and 1913 the new minerals erikite (subsequently proven to be a mixture of monazite and an unidentified species) and ussingite on specimens collected during Ussing's expeditions. Ussing's petrographic and petrological work impressed Danish scientists as being so definitive that very little happened in Ilímaussaq for almost half a century, and no other new minerals were described from there until 1959.

The intensive activity at Ilímaussaq during recent decades was triggered by a decision of the Danish government in 1955 to evaluate the possible uranium resources of Greenland. Detailed field and laboratory work; drilling programs in 1958, 1962, 1969 and 1977; and the recovery of approximately 5,000 tons of potential ore in 1979–1980 for a pilot plant, from a 1,000-meter exploration drift, have led to an understanding of the extent of the uranium deposit at Kvanefjeld in the northwesternmost part of the complex. The complex was remapped by J. Ferguson, who published a geological map in 1964.

In the early 1960's the study of the complex was taken over by the University of Copenhagen. It was H. Sørensen, from the Institute of Petrology, who planned the investigations, directed the detailed mapping of selected areas, and directed the extensive mineralogical, petrological and geochemical studies of selected key areas in the complex, beginning in 1964. These investigations are still yielding a steady stream of publications. The rocks and minerals of Ilímaussaq closely resemble those of the Khibina and Lovozero complexes, Kola Peninsula, Russia, for which reason close contact and extensive cooperation with Soviet-Russian scientists has been maintained for the last 30 years. Thus, the mineralogical research program received inestimable inspiration from E. I. Semenov, who paid a one-month visit to the intrusion in 1964.

New minerals described from Ilímaussaq since 1959 include: igdloite (= lueshite) described by Sørensen and Danø in 1959; tugtupite described by Sørensen (1960, 1963); sorensenite, chalcothallite and ilimaussite described by Semenov *et al.* in 1965, 1967 and 1968, respectively; cuprostibite described by Sørensen *et al.* in 1969; tetragonal natrolite (= tetranatrolite) described by Andersen *et al.* in 1969; semenovite described by Petersen and Rønsbo in 1972; skinnerite described by Karup-Møller and Makovicky in 1974; rohaite described by Karup-Møller in 1978; vitusite described by J. G. Rønsbo *et al.* in 1979; kvanefjeldite and tuperssuatsiaite described by Petersen

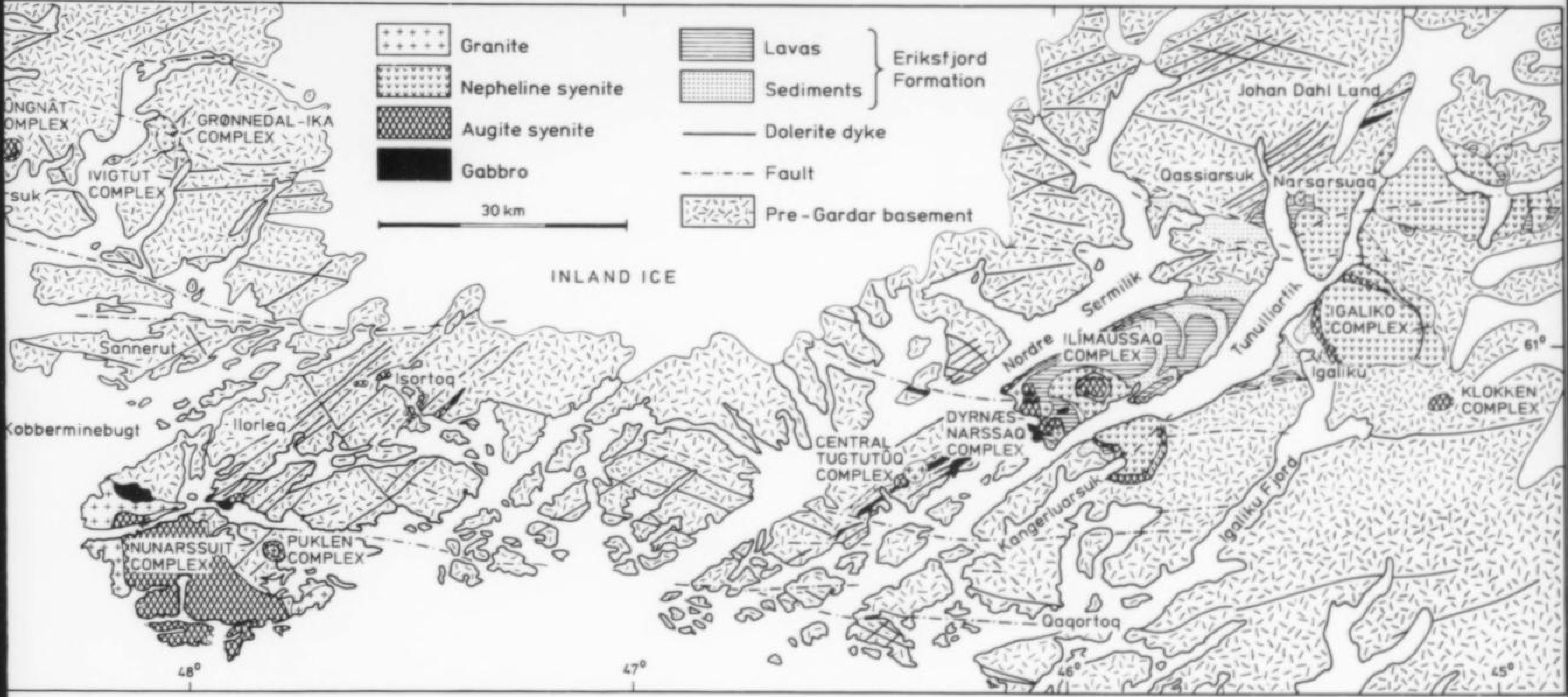


***Figure 22*. Map showing the ten intrusive complexes, ranging in age from 1,320 to 1,120 m.y. and varying in size from small (a few hundred meters across) to large (exceeding a thousand square kilometers), which together constitute one of the most remarkable alkaline igneous provinces of the world, the Gardar province.**

et al. and Karup-Møller and Petersen, both in 1984; and the latest in this long series, nacareniobsite-(Ce), described by Petersen *et al.* in 1989.

GEOGRAPHY and GEOLOGY

The Ilímaussaq complex is oval in shape, measuring 8 x 17 km. The complex straddles Tunugdliarfik (Tunulliarfik) Fjord; the central point lies approximately 11 km east of the town Narssaq (Narsaq). The Ilímaussaq complex forms a spectacular landmark; due to the very rapid weathering of the friable syenites the mountains are almost free of vegetation and the gentle gray and reddish colors of the rocks contrast markedly with the intense deep blue color of the fjord and its white icebergs. Further to the southeast the spectacular igneous layering in the equally well exposed rocks of the bottom part of the complex, which borders the scenic Kangerdluarssuk (Kangerluarsuk) Fjord, adds a dramatic effect to the scenery. The relief is moderate, rising from southeast to northwest, where the highest point is 1,390-meter Ilímaussaq (Ilimmaasaq) Mountain, just outside the complex, after which the intrusion is named. The southern part of the complex intrudes the Julianehåb granite; the northern part further intrudes the supracrustal series of basaltic lavas and continental sandstones overlying the granite.

The complex is composed of three units. Geological and geochemical evidence suggest that the units represent three intrusive events separated in time. The first pulse of magma formed a shell of augite syenite along the sides and roof of the intrusion; the second, comprising an alkali granite and an alkali syenite, was emplaced as two thin sheets in the uppermost part of the intrusion; the third, and main, pulse of magma formed a layered sequence of highly under-saturated syenites in the center of the intrusion. The most important rock types in this sequence are a sodalite-nepheline syenite called *naujaite*, an arfvedsonite-aegirine-bearing nepheline syenite called *lujavrite* and a eudialyte-bearing nepheline syenite called *kakortokite*. The spectacular layered sequence was formed by crystallization and differentiation in one magma chamber. The rocks formed underneath the roof are the earliest agpaitic rocks and have crystallized downwards from the roof. The sequence consists of pulaskite, foyaite, sodalite foyaite and naujaite. The naujaite is considered to be a flotation cumulate, in which crystals of sodalite were poikilitically enclosed in large crystals of feldspar, eudialyte and arfvedsonite. The kakortokite—the lowermost exposed rocks—are younger than the naujaite and formed as an accumulate on the bottom. The kakortokite is spectacularly layered: 29 layered units each consisting of a lower black layer rich in arfvedsonite, a red layer rich in eudialyte and an upper white layer rich in feldspar and nepheline. Whereas the single black, red and white units can be satisfactorily explained as a result of gravitational separation, opinions still vary as to the mechanism causing the repetitions of the sequence. The lujavrite—continuously overlaying the top of the kakortokite, but brecciating and intruding the latest formed naujaite of the roof—crystallized from the rest of the magma between the two other rock types.

MINERALOGY

Ilímaussaq is the most mineral-rich area in Greenland; almost 200 minerals have been identified within the intrusion. More than half of this number are silicates; there are six native elements, 26 sulfides, four sulfates, 11 carbonates, ten arsenides and antimonides, two halides, 24 oxides and six phosphates. The minerals from Ilímaussaq, divided into chemical classes, show a percentage distribution that differs significantly from the distribution in the mineral world as a whole. The most remarkable differences are the far higher (more than twice as high) percentages of silicates at Ilímaussaq. A large proportion of the 200 minerals are known from only very few other localities; around ten are known only from Ilímaussaq.

The main characteristics of the Ilímaussaq minerals are: the large number of minerals with Si-Al, Na, Ca-REE, Ti-Nb and Be; abundance

Table 2. **Minerals from Ilímaussaq.**

- Aegirine
- Aenigmatite
- Albite
- Allanite
- Allargentum
- Analcime
- Antigorite
- Antimony
- Apatite
- Apophyllite
- Arfvedsonite
- Argentite
- Astrophyllite
- Augite
- Avicennite (?)
- Azurite (?)
- Barylite
- Bastnäsite
- Bertrandite
- Beryllite
- Beudantite
- Biotite
- Bornite
- Breithauptite
- Britholite
- Brochantite
- Calcite
- Cancrinite
- Carbonate-hydroxylapatite
- Catapleiite
- Cerussite
- Chabazite
- Chalcedony
- Chalcocite
- Chalcopyrite
- Chalcostibite
- Chalcothallite
- Chkalovite
- Chlorite (group)
- Chrysocolla
- Connellite
- Cookeite
- Copper
- Covellite
- Cuprite
- Cuprostibite
- Diaspore
- Digenite
- Diopside (variety Ferrosalite)
- Djerfisherite
- Djurleite (?)
- Dyscrasite
- Elpidite
- Ephesite
- Epididymite
- Epidote
- Epistolite
- Erikite†
- Eudialyte
- Eudidymite
- Evenkite (?)
- Famatinite
- Fayalite
- Ferrohortonolite
- Fluorite
- Galena
- Garnet (group)
- Gelbertrandite (?)†
- Genthelvite
- Gerasimovskite
- Gibbsite
- Gmelinite
- Goethite
- Graphite
- Gudmundite
- Halloysite
- Hastingsite
- Hedenbergite
- Helvite
- Hemimorphite
- Herschelite
- Hiortdahlite
- Hisingerite
- Hydrargillite = Gibbsite
- Hydrocerussite
- Hydronephelin†
- Ilimaussite
- Ilmenite
- Ilvaite
- Joaquinite
- Katophorite
- Kvanefjeldite
- Lead
- Lepidolite (?)
- Leucophane
- Leucosphenite
- Limonite = mostly Goethite
- Linarite
- Litharge
- Löllingite
- Lomonosovite
- Lomonosovite, β-
- Lorenzenite
- Lovozerite
- Lueshite
- Magnetite
- Malachite (antimonian)
- Marcasite
- Microcline
- Molybdenite
- Monazite
- Montmorillonite
- Mosandrite
- Murmanite
- Muscovite
- Nacareniobsite-(Ce)
- Nahcolite
- Na-Komarovite
- Narsarsukite
- Natrolite
- Naujakasite
- Nenadkevichite
- Nepheline
- Neptunite
- Nickeline
- Niobophyllite
- Nontronite
- Palygorskite
- Pearceite (?)
- Pectolite
- Pectolite (manganoan)
- Plagioclase
- Plattnerite
- Polybasite
- Polylithionite
- Potassium feldspar
- Prehnite
- Pyrite
- Pyrochlore
- Pyrolusite
- Pyrophanite
- Pyrrhotite
- Quartz
- Rhabdophane
- Riebeckite
- Riebeckite (variety Crocidolite)
- Rinkite
- Rinkolite†
- Rohaite
- Rosenbuschite
- Rutile
- Sauconite
- Seinäjokite
- Semenovite
- Senarmontite
- Sepiolite
- Scrandite
- Siderite
- Silver
- Skinnerite
- Skutterudite
- Sodalite
- Soda-microcline
- Soda-orthoclase
- Sorensenite
- Sphaerobertrandite†
- Sphalerite
- Stannite (?)
- Steenstrupine
- Stilbite
- Stillwellite
- Synchysite
- Tetrahedrite
- Tetranatrolite
- Thalcusite
- Thermonatrite
- Thorianite
- Thorite
- Tin (?)
- Titanite
- Titanomagnetite
- Todorokite
- Troilite
- Trona
- Tugtupite
- Tundrite
- Tuperssuatsiaite
- Uranothorite
- Ussingite
- Valentinite
- Vesuvianite
- Villiaumite
- Vinogradovite
- Vitusite
- Vrbaite (?)
- Vuonnemite
- Westerveldite
- Whewellite
- Willemite
- Zircon

? Identity/locality uncertain

† Dubious species

of minerals rich in volatile components, H_2O, F and Cl; an abundance of sodic rather than potassic minerals; and the low silica content—the rock-forming minerals include alkali feldspar, nepheline, sodalite, arfvedsonite, aegirine and eudialyte. Although even some of the rock-forming minerals at Ilímaussaq are rare and beautiful, by far the major part of the interesting minerals occur in the numerous pegmatites and hydrothermal veins, streaks and patches. These latter can be found all over the intrusion, but are particularly plentiful in two areas. To the southeast the name Kangerdluarssuk (Kangerluarsuk) has been famous for many, many generations; to the northwest the names Kvanefjeld and Taseq slope are equally familiar, but have not been so for quite as long.

It is not within the scope of this work to describe in detail the 200 Ilímaussaq minerals, but the most interesting features of a number of selected species can be given.

Eudialyte $Na_4(Ca,Ce)_2(Fe^{+2},Mn^{+2},Y)ZrSi_8O_{22}(OH,Cl)_2$

Kangerdluarssuk (Kangerluarsuk) is the place where eudialyte was first found. Giesecke was the first to collect the mineral, but erroneously took it for garnet, an error repeated by others. Allen who, as mentioned, investigated a large part of Giesecke's material, mentions a "garnet of an otherwise entirely unknown form."

With regard to the first mention of eudialyte in the literature, opinions vary, but Stromeyer made the first analysis on material collected

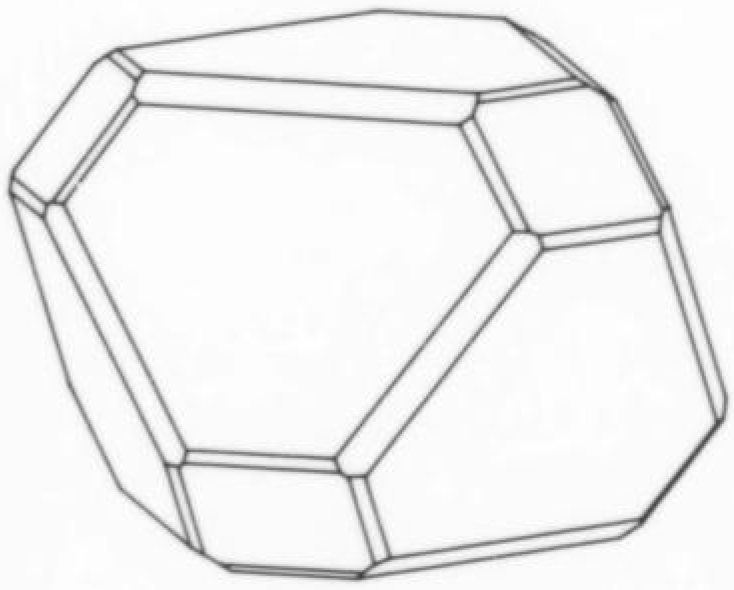


Figure 23. **Drawing of an idealized crystal of eudialyte; at Ilímaussaq, where the crystals are most often distinctly isometric in appearance, the true trigonal symmetry of the crystals is not always easy to recognize. This crystal shows the forms $\{0001\}$, $\{11\bar{2}0\}$, $\{10\bar{1}1\}$, $\{10\bar{1}4\}$, $\{01\bar{1}2\}$, $\{01\bar{1}3\}$, $\{02\bar{2}1\}$ and $\{11\bar{2}3\}$.**

by Giesecke, and named the mineral because of its easy solubility (from the Greek for *good* and *soluble*). It is found in very large quantities, as a constituent of the nepheline syenites as well as many pegmatites. The most spectacular accumulation of eudialyte is found in the kakortokites, where layers up to 1 meter thick consisting of nearly pure eudialyte have been found. Eudialyte has most frequently crystallized before the other minerals with which it is associated, for which reason it often has a well developed crystal form, typically pseudo-octahedral. The most impressive crystals in the possession of the Geological Museum, Copenhagen, were collected by Flink during his 1897 visit to Ilímaussaq at a small spot called Naujakasik on the coast of the Tunugdliarfik (Tunulliarfik) Fjord. The size of the crystals varies from microscopic to about 10 cm; the color varies from bright red to dark reddish brown and grayish red. Eudialyte is frequently found heavily altered to species such as catapleiite, zircon, feldspar, acmite, analcime and various zeolites. Several attempts to utilize these vast accumulations of zirconium have been made; the latest attempt plans to use eudialyte as an advanced ceramical material.

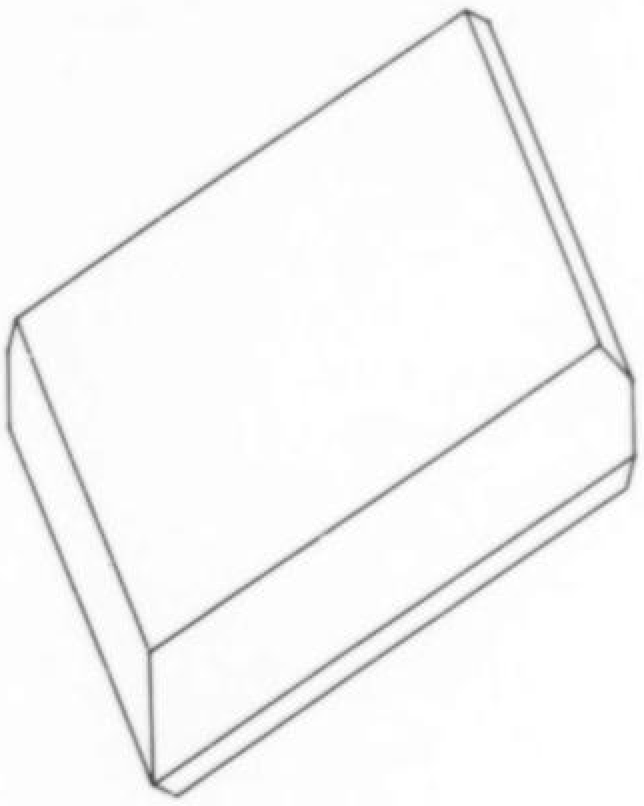


***Figure 24*. Drawing of an idealized crystal of naujakasite. In 1972 a limited number of quite large crystals—up to 2 cm—were found that are suitable for goniometric measurements. Besides the silvery white $\{001\}$ faces, with their characteristic pearly luster, the forms $\{110\}$ and $\{\bar{1}11\}$ have also been identified.**

Naujakasite $Na_6(Fe^{+2},Mn^{+2})Al_4Si_8O_{26}$

Naujakasite is one of the minerals unique to Ilímaussaq. This is surprising because, not only is it a rock forming mineral (sometimes constituting as much as 75% of the rock), but, as can be seen from the formula, naujakasite contains no rare elements or unusual combinations of elements. Besides being an interesting one-locality mineral, naujakasite is also a good example of how slowly the wheels of science can turn.

Naujakasite was first described by Bøggild in 1933, from a 350-gram loose boulder collected by Gustav Flink in 1897 at Naujakasik (this is the spot on the coast of Tunugdliarfik (Tunulliarfik) where he also found the excellent eudialyte crystals mentioned earlier). It was found in outcrops for the first time in 1955 in Tuperssuatsiait Bay, and since then it has been found in many places all over the intrusion. A complete redescription based on the rich new material was published by one of us (OVP) in 1966. The last loose ends were tied up in 1975 with the publication of a complete description of the structure, not quite 100 years after the mineral was first found.

Naujakasite crystallizes monoclinically; the crystals are diamond shaped, and platy. Crystals as large as 5 x 10 x 20 mm have been found. The cleavage is mica-like, parallel to the platy development; the cleavage planes are silvery white with an almost metallic, pearly luster.

Sorensenite $Na_4Sn^{+4}Be_2Si_6O_{16}(OH)_4$

Sorensenite is one of the ten minerals which are thus far unique to Ilímaussaq. It was first observed in 1962 in the Kvanefjeld area. No closer examination was carried out until Semenov in 1964 found a similar appearing mineral on the north slope of Nákâlâq (Nakkaalaaq), which he suspected to be a new mineral. His samples were examined immediately after his return to Moscow, and when it turned out that they did indeed contain a new mineral, the samples from Kvanefjeld kept in Copenhagen were also examined, and it was demonstrated that they contained the same new mineral. Sorensenite crystallizes monoclinically. It occurs in analcime-rich bodies as elongated tabular crystals up to 10 cm in size. The single crystals are straight or bent. Most often sorensenite is found as aggregates of lath-shaped crystals. Such aggregates, often intergrown with analcime, may attain considerable sizes. Rarely it forms complicated interpenetration trillings. Sorensenite is translucent and colorless to pinkish or white. It shows a fine silky luster with opalescence for the less colored varieties. Specimens consisting of black, medium to coarse-grained lujavrite prolifically covered with aggregates of pink sorensenite are certainly among the most beautiful from Ilímaussaq. The formula not only illustrates perfectly the main characteristics of the Ilímaussaq minerals (i.e. rich in sodium, beryllium and volatile components), but also shows that sorensenite belongs to the small, exclusive group of tin silicates.

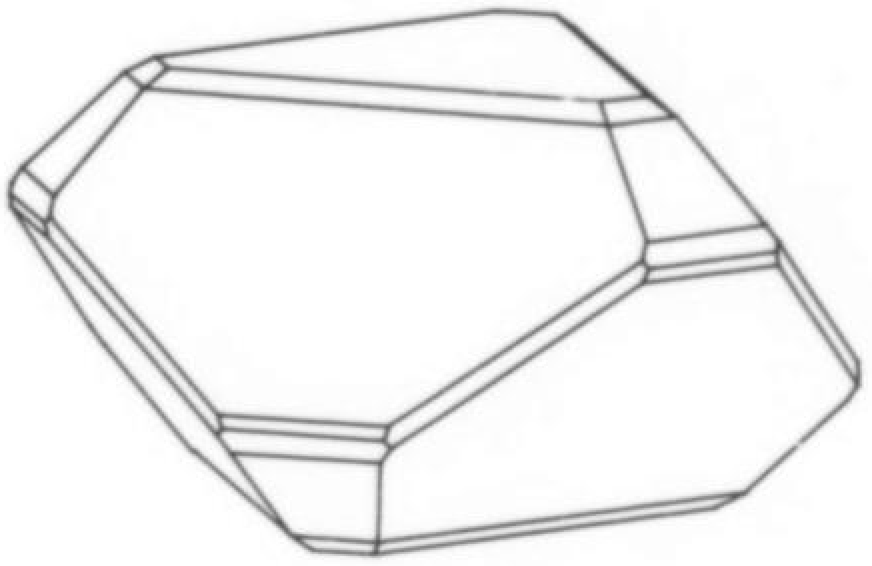


***Figure 25*. Drawing of an idealized crystal of steenstrupine. Steenstrupine crystallizes trigonally; in the most common habit the crystals are—like the one shown here—pseudo-isometric with either $\{10\bar{1}1\}$ or $\{02\bar{2}1\}$ as the dominating forms accompanied by $\{0001\}$; further forms shown here are: $\{11\bar{2}0\}$, $\{40\bar{4}1\}$, $\{50\bar{5}9\}$, $\{01\bar{1}2\}$ and $\{04\bar{4}5\}$.**

Steenstrupine-(Ce) $Na_{1-12}H_{7-0}CaRE_6Me_6(Si_6O_{18})_2$
$[(P,Si)O_4]_6(F,OH)\cdot nH_2O$; $n < 15$

Steenstrupine was first described from pegmatoid veins; it is now known to be of widespread occurrence in the massif, being present in many of the syenites and in the late hydrothermal veins. The mineral has very often been formed before the other minerals of the veins, for which reason it commonly shows crystal faces. Steenstrupine crystallizes trigonally with quite varying habits. In the most common type the crystals are equant, with either $\{10\bar{1}1\}$ or $\{02\bar{2}1\}$ as the dominating forms besides $\{0001\}$. In a more rare form the crystals are regular, hexagonal tables with the positive and negative rhom-

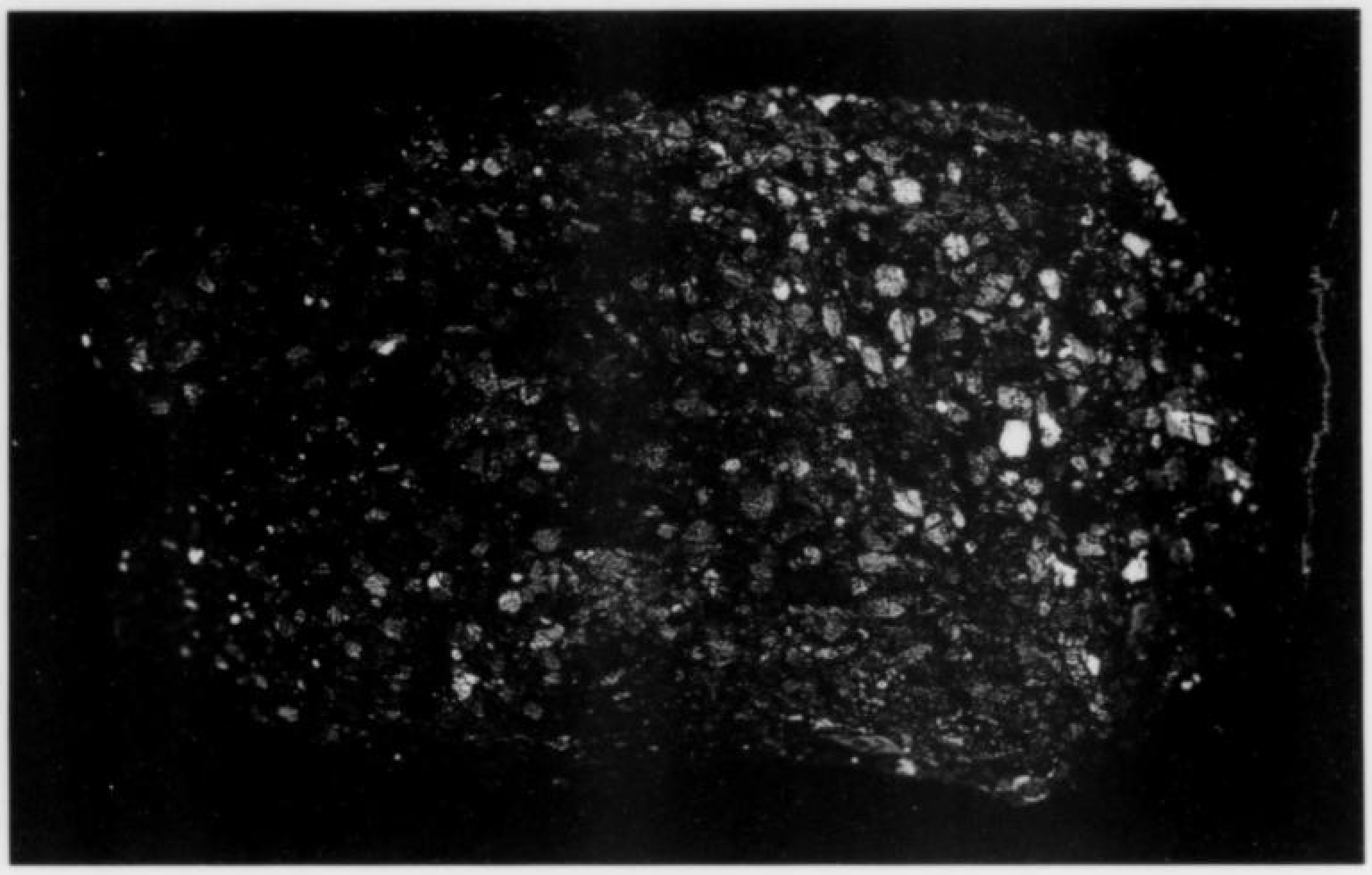


Figure 26. **Naujakasite is one of several minerals that has never been found outside of Ilímaussaq. It was described in 1933 by O. B. Bøggild on this 350-gram boulder—which consists of nearly 75% naujakasite—found on the south coast of Tunugdliarfik (Tunulliarfik) by G. Flink in 1897. Since then this mineral has been found in large amounts at several places all over the intrusion; photo by R. Bode.**

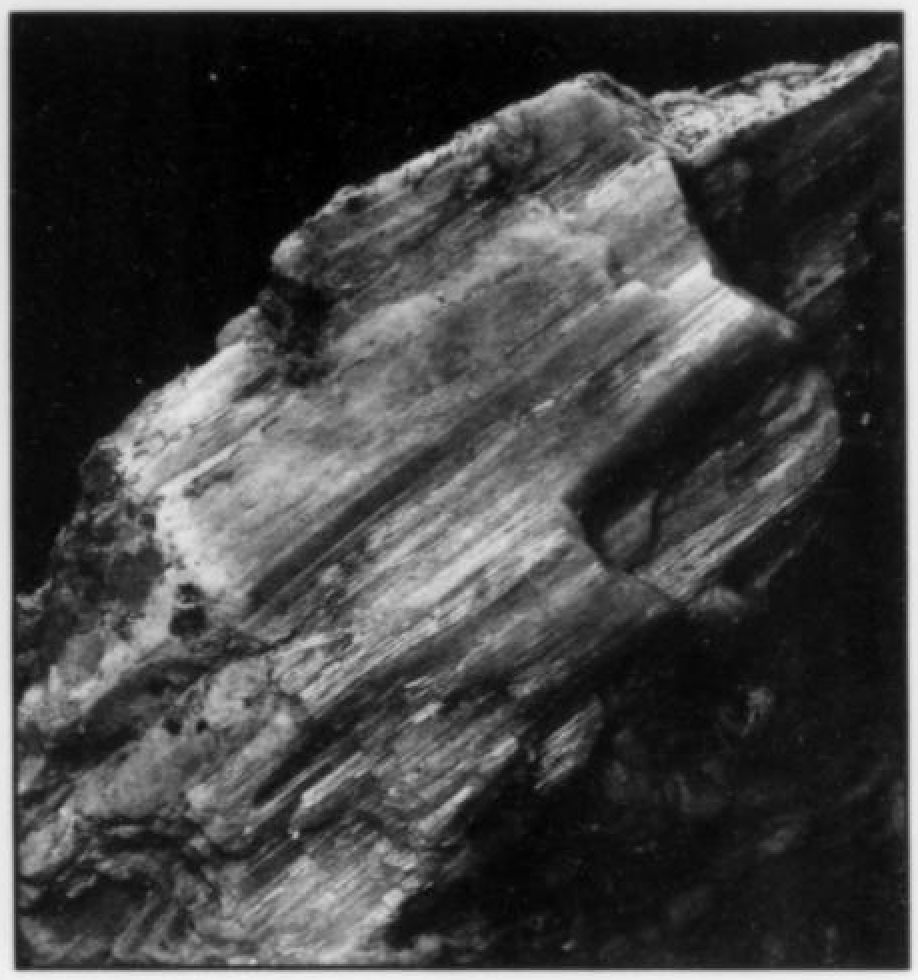


Figure 27. **Sorensenite was first described from Ilímaussaq in 1965 and has not since been found anywhere else in the world. It is a sodium-beryllium-tin silicate and hence belongs to a rather exclusive group of the mineral world. The aggregate of lath-shaped crystals shown here is one of the larger found at the type locality, Kvanefjeld. The largest group consists of crystals almost 5 cm long; photo by O. B. Berthelsen.**

Figure 28. **In the more rare habit the crystals of steenstrupine are hexagonal tablets, much like the magnificent, unusually sharp-edged, approximately 1-cm large crystal shown here sitting on violet ussingite; photo by O. Medenbach.**

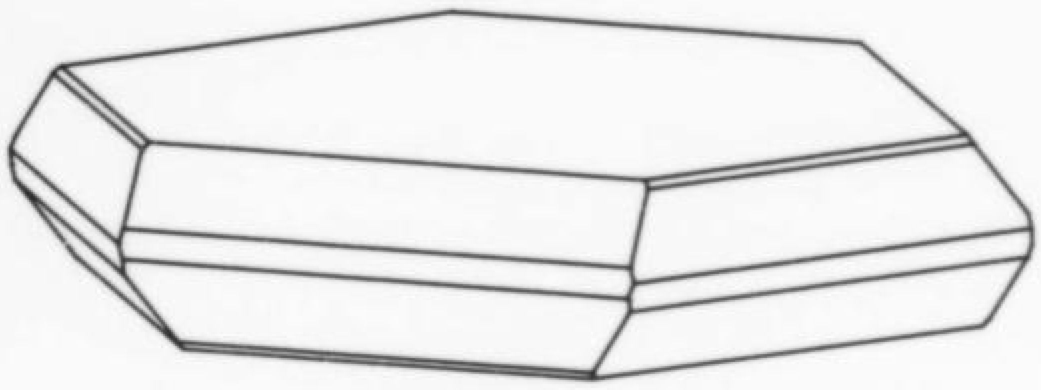


Figure 29. **Drawing of an idealized crystal of steenstrupine corresponding to the one shown in the previous figure. The forms developed are: {0001}, $\{40\bar{4}1\}$, $\{01\bar{1}\bar{1}\}$, $\{02\bar{2}1\}$ and $\{04\bar{4}5\}$.**

bohedrons equally developed. The color is black or dark brown. Nearly all steenstrupine is metamict or altered. The most recent analysis of steenstrupine yields: $Na_{3.41}H_{6.96}Ca_{1.04}(La_{1.98},Ce_{2.88},Pr_{0.23},Nd_{0.71},Gd_{0.02},Sm_{0.02},Er_{0.01},Y_{0.19})\Sigma_{6.03}(Th_{0.48},U_{0.05},Zr_{0.41},Mn_{1.80},Fe_{1.69},Al_{0.07},Ti_{0.10})\Sigma_{4.60}[Si_{12}O_{36}][(P_{4.61}Si_{1.39})O_{24}](F,OH) \leqslant 14.45H_2O$.

Steenstrupine was correctly recognized as a new species by Lorenzen on material collected by Steenstrup. After the description appeared, several specimens with good crystals were found in the collection where they had rested for many years, labeled wolframite!

Tundrite-(Ce) $Na_3(Ce,La)_4(Ti,Nb)_2(SiO_4)_2(CO_3)_3O_4OH\cdot 2H_2O$

Tundrite was first described from the Lovozero complex, Kola Peninsula, Russia, by Semenov in 1963. A year later he discovered tundrite in pegmatites in the kakortokites in the southeastern part of the Ilímaussaq complex. Here it forms spherulitic masses and stellate groups up to 3 cm across. It is associated with feldspar, aegirine, natrolite, eudialyte, rinkite and fluorite. In 1967 one of us (OVP) discovered tundrite in the opposite end of the intrusion, in the border pegmatite at Kvanefjeld. Here the tundrite forms very beautiful fan-shaped coarser-grained aggregates up to about 2 cm, but only half a dozen specimens were found. Since then a large amount of material has been collected in the kakortokites.

The tundrite aggregates of ruler-shaped crystals may resemble aegirine in appearance, but are easily distinguishable by their bright yellow-green color, and their almost adamantine luster. With the exception of one analysis published by Semenov that seems to suggest that tundrite-(Nd) occurs at Ilímaussaq, all other analyses of tundrite from Ilímaussaq show that the Ilímaussaq tundrite is tundrite-(Ce).

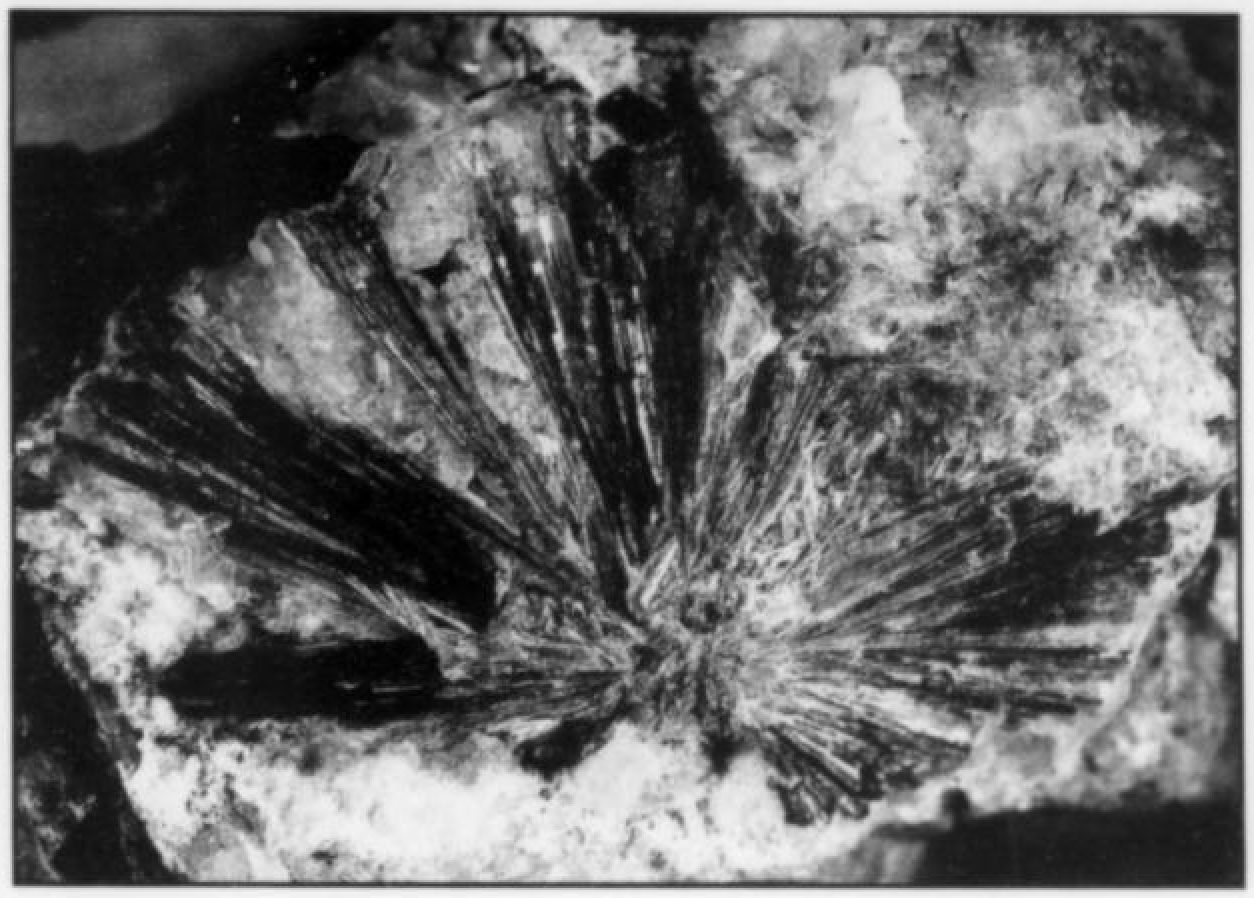


Figure 30. This nearly 2-cm, star-shaped aggregate is probably one of the largest ever found of tundrite, a mineral known from only three localities (Kola Peninsula, Russia; Ilímaussaq; and Mont Saint-Hilaire, Quebec). It was found with half a dozen others in 1968 by Ole V. Petersen in the border pegmatite in the Kvanefjeld area; photo by R. Bode.

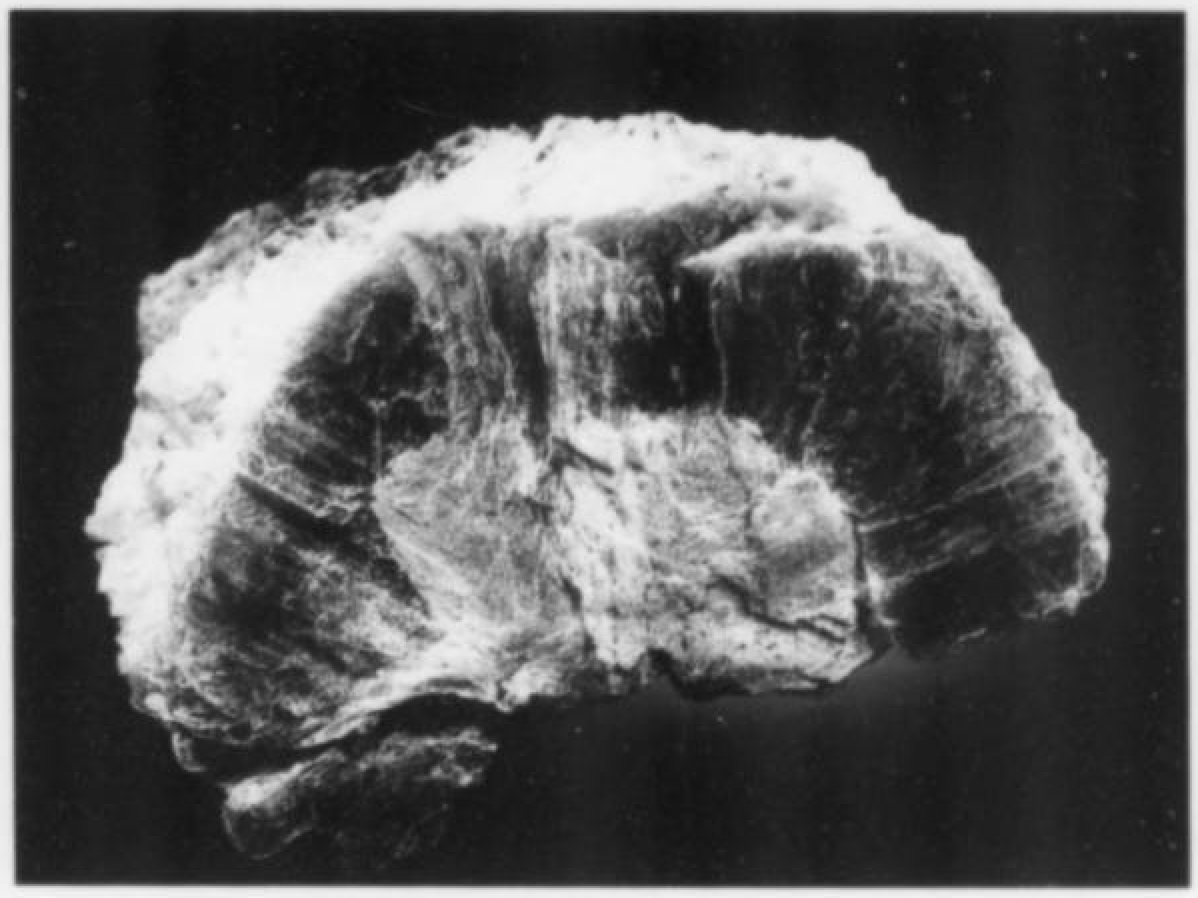


Figure 31. Polylithionite, a rather common mineral in Ilímaussaq, most often forms large greenish tablets. It is often found, as is shown here, epitaxially overgrown on epistolite, with which it shares irregular boundaries. This aggregate is nearly 7 cm across; photo by R. Bode.

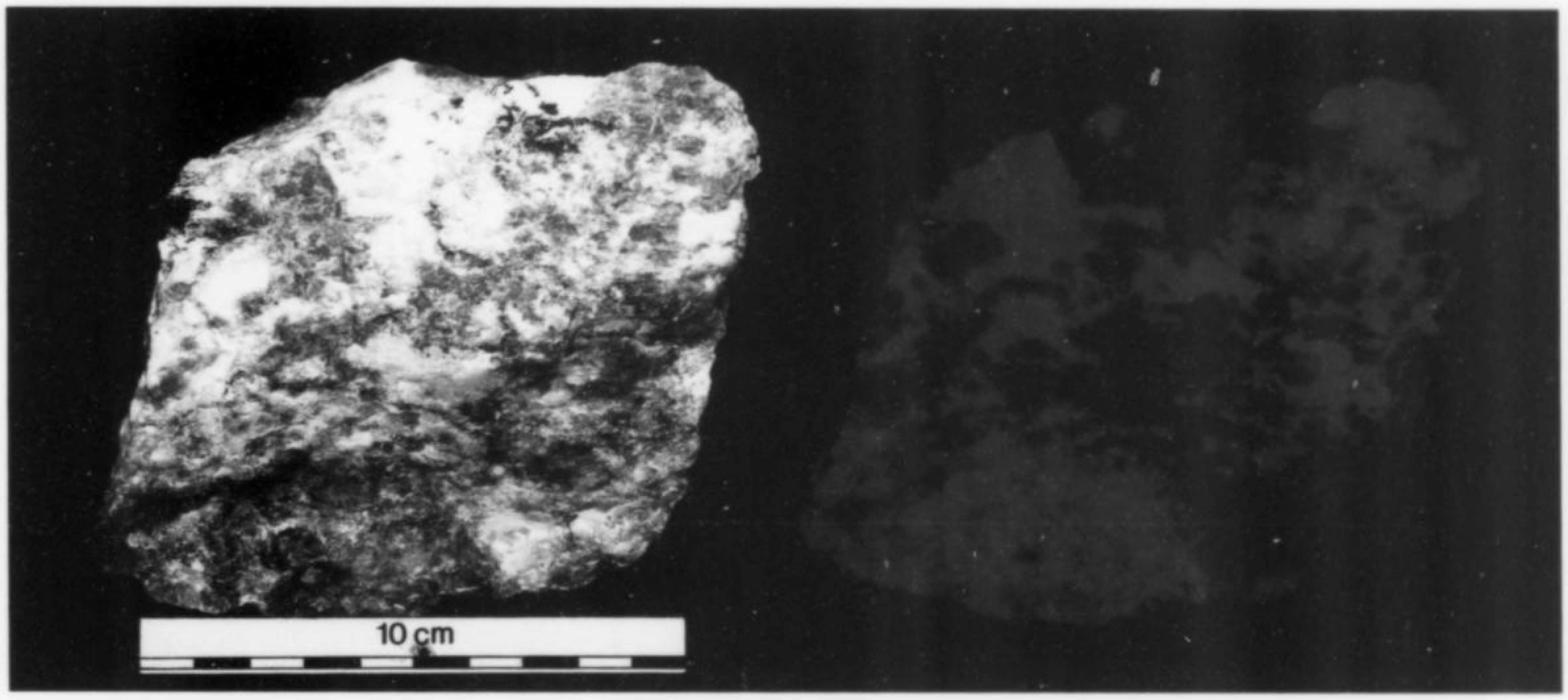


Figure 32. Tugtupite shows a very intense fluorescence when exposed to ultraviolet light. To the left is shown a specimen rich in tugtupite in an albite matrix from the Kvanefjeld area; to the right the same specimen is shown in shortwave ultraviolet light, where the vivid red fluorescent color is most distinct; photo by O. B. Berthelsen.

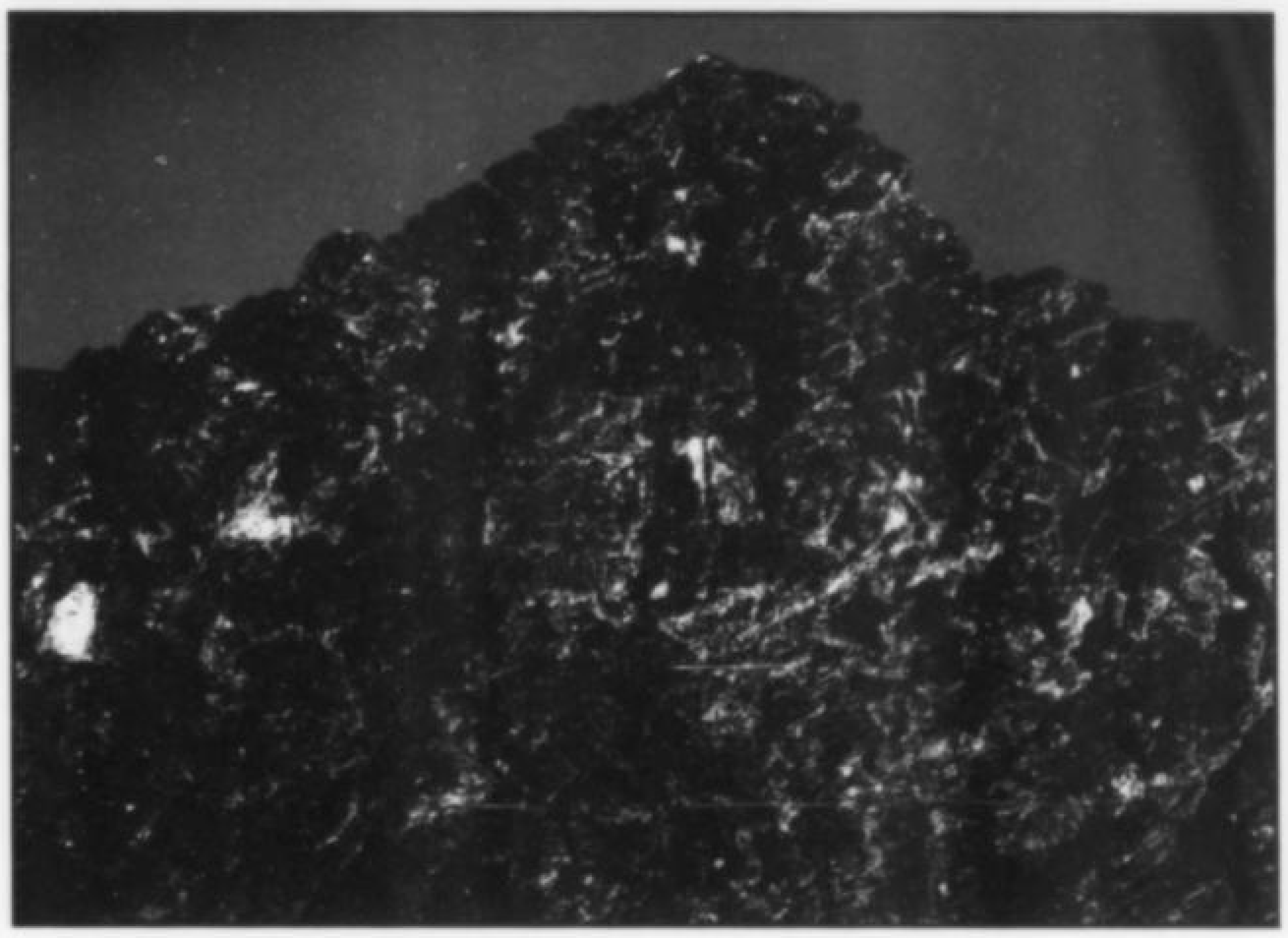


Figure 33. Villiaumite in small amounts was known from drill cores from Ilímaussaq for several years before it was found in large quantities during the construction of an exploration drift at Kvanefjeld in 1979–80. The specimen, part of which is shown here, is probably the richest villiaumite specimen ever found anywhere; actual size, 8 cm across; photo by O. Medenbach.

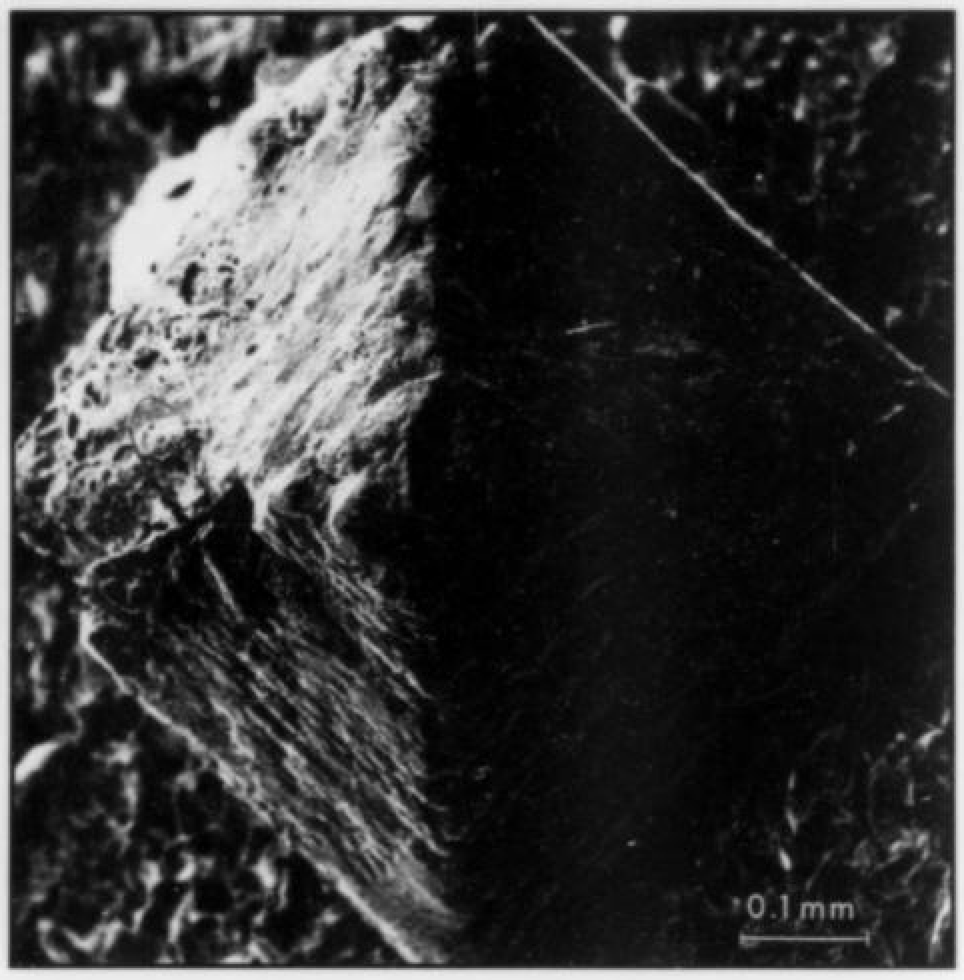


Figure 34. **Scanning electron micrograph of a crystal of the rare mineral semenovite, found by Ole V. Petersen during field work on the Taseq slope in 1968. The step-like appearance of the crystal faces is due to the fact that what appear to be individual crystals are complex interpenetration twins.**

Semenovite $(Ca,Ce,La,Na)_{10-12}(Fe^{+2},Mn)(Si,Be)_{20}(O,OH,F)_{48}$

Semenovite, another one of the Ilímaussaq minerals that has never been found outside the complex, was encountered during mineralogical field work on the Taseq slope in the summer of 1968. Here it occurs in small quantities in the border zone of the only epididymite-eudidymite-bearing albitite in Ilímaussaq. Semenovite forms groups of what appear to be well-developed single crystals, attached to or half sunk into lath-shaped well-developed epididymite crystals. The size of the apparently tetragonal bipyramidal crystals generally ranges from 0.1 to 1 mm, but a few crystals as large as 1 cm have been found. The faces of the crystals are rather uneven, because in fact what appear to be individual crystals are actually complex twins. The color varies according to the degree of alteration: fresh semenovite is transparent brown, and in rare cases orange brown, whereas altered semenovite is dull gray-reddish brown to gray with a brown hue. Semenovite is a REE-silicate with nearly 20 weight % REE-oxides and a complicated formula.

The semenovite locality has been more or less lost for many years, but was rediscovered during a short visit to the Taseq slope in 1988.

Polylithionite $KLi_2AlSi_4O_{10}(F,OH)_2$

Polylithionite was named by Lorenzen in accordance with the large amount of lithium in it—at that time the greatest amount known in any mineral. It is found everywhere in the pegmatite dikes in the nepheline syenites. Polylithionite forms up to 10-cm tablets, often together with steenstrupine, aegirine and analcime. Particular attention should be paid to the frequent association with epistolite, which often is found in the middle of the plates, grading irregularly toward the polylithionite; the two minerals have parallel cleavage directions. The plates of polylithionite, faintly greenish in color, are distinguished by a star-shaped structure consisting of six sectors each with a fine radiating striation.

Epistolite $Na_2(Nb,Ti)_2Si_2O_9\cdot nH_2O$

Epistolite at Ilímaussaq occurs most notably in pegmatites and hydrothermal veins, but also as disseminations in lujavrite and naujaite. Large amounts of specimen material rich in epistolite have been found in the exploration drift at Kvanefjeld, where it occurs associated with natrolite, sodalite and steenstrupine; in the tugtupite-bearing albite-analcime vein; and at Kvanefjeld and in ussingite-bearing veins at several localities in the complex, particularly on the Taseq slope. Epistolite forms irregular tablets up to 10 cm in diameter and 5 mm in thickness. The color varies from pure white to cream-colored, sometimes with a pink hue. Some of the Ilímaussaq epistolite may resemble the closely related mineral murmanite which, at Ilímaussaq, occurs exclusively in the lavas and gabbro intruded by lujavrite. The Ilímaussaq murmanite is closely related to lomonosovite and often appears as pseudomorphs after this mineral.

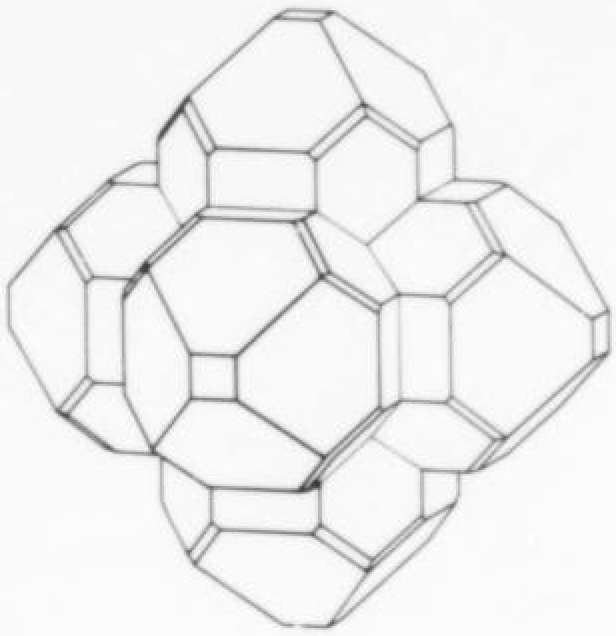


Figure 35. **Tugtupite forms complex twins. The figure shows a drawing of an idealized pseudocubic interpenetration trilling, twin planes {101} and {001}, of a type that could be expected from a tetragonal pseudocubic mineral.**

Tugtupite $Na_4AlBeSi_4O_{12}Cl$

The mineral now known as tugtupite was discovered in 1957 by Sørensen in the coastal cliffs of Tugtup agtakôrfia on the coast of Tunugdliarfik (Tunulliarfik). It was first mentioned under the provisional name "Beryllium sodalite" in 1960. Coinciding with the presentation of this new mineral from Ilímaussaq, a description of an apparently identical mineral called "beryllosodalite" was published by Semenov and Bykova. The material they described came from the Lovozero complex, Kola Peninsula, Russia; at this locality the mineral is rather rare and has never been found in masses larger than 3 mm.

Additional data were published by Sørensen in 1963. He concluded that the mineral was a new species and proposed the name tugtupite, derived from the name of the type locality. Further data have since been published in 1966, 1971, 1978 and 1982. Since tugtupite was first discovered in very sparse amounts at Tugtup agtakôrfia, it has been found in several places all over the intrusion. The mineral is confined to hydrothermal veins, where it is associated with albite, analcime, aegirine, neptunite and pyrochlore. Most tugtupite is massive, only a few well-developed crystals have been found, growing on the walls of cavities in massive tugtupite; the size of these crystals varies from 1 x 1 x 1 mm to 2 x 2 x 3 mm.

Tugtupite crystallizes tetragonally, and forms complex twins. As might be expected, it forms pseudocubic interpenetration trillings; surprisingly, however, it also forms pseudotrigonal contact twins. The formula, when compared with that of sodalite $(Na_8Al_6Si_6O_{24}Cl_2)$, shows that in the tugtupite structure there is a BeAl substitution for AlAl. The tugtupite from the type locality was described as white, but it was mentioned that the color changes to pale pink when the mineral is exposed to sunlight. In 1962 pink tugtupite was found at Kangerdluarssuk (Kangerluarsuk), and in 1965 dark crimson-red tugtupite was found at Kvanefjeld. The entire occurrence covers an area

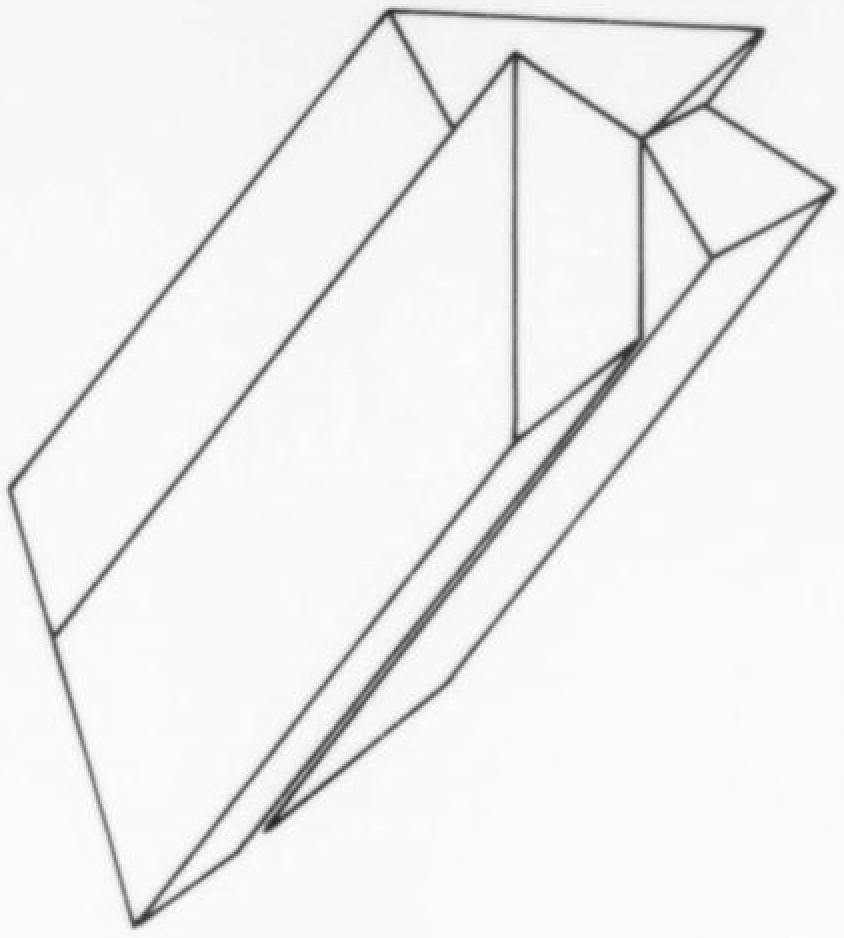


***Figure 36.* Surprisingly, tugtupite also forms pseudotrigonal contact trillings with the composition planes (which are also the twin planes) {10$\bar{1}$} and {01$\bar{1}$}. A drawing of an idealized trilling of this peculiar type of twinning is shown here.**

no more than 5 x 25 meters, with the tugtupite scattered in a set of highly irregular hydrothermal veins, up to 50 cm wide. These veins, cutting augite syenite, are mainly composed of fine-grained albite; they may be zoned, with tugtupite concentrated in the central part.

It is the deep red tugtupite from this locality that has been, and still is, used for lapidary purposes. Cabochons of red tugtupite were introduced as a new gem material by the jeweller A. Dragsted in Copenhagen, Denmark in 1965 and presented at the 11th International Gemmological Conference in Barcelona in 1966. Most tugtupite has been made into cabochons. Faceting-quality tugtupite is very, very rare; only a few faceted stones, 0.5–2.0 ct, have been cut. Tugtupite is the Greenland gemstone *par excellence*. The color of the red tugtupite fades when the stones are kept in darkness, but is regained when the stones are exposed to sunlight or ultraviolet radiation. Tugtupite does show a very intense fluorescence when exposed to ultraviolet light. As to the color of tugtupite fluorescence, opinions seem to differ, but the colors are probably most conveniently described as dark crimson-red in shortwave, and cinnabar-red to pale crimson-red in longwave ultraviolet light. Only a few years ago a pale blue variety of tugtupite was found, also at Kvanefjeld.

The discovery of tugtupite in Mont Saint-Hilaire, Quebec, Canada, has very recently made this species a three-locality mineral.

Villiaumite NaF

Although the silicates are by far the most dominant group at Ilímaussaq, there are many non-silicates which might be mentioned as well. Villiaumite, for example, has been described from only a few localities worldwide: Rouma, one of the Los Islands, Guinea; Chinglusuai Valley, Lovozero, Kola Peninsula, Russia; Lake Magadi, Kenya; and Ilímaussaq, where it was found in 1962 in several drill cores. Quite recently villiaumite has been identified at Mont Saint-Hilaire, Quebec. There are two good reasons for mentioning the Ilímaussaq villiaumite: (1) in 1979–1980, during the construction of an exploration drift, a large quantity of material rich in villiaumite was found, and (2) on one of these specimens several well-developed, complex crystals to 0.4 mm were found.

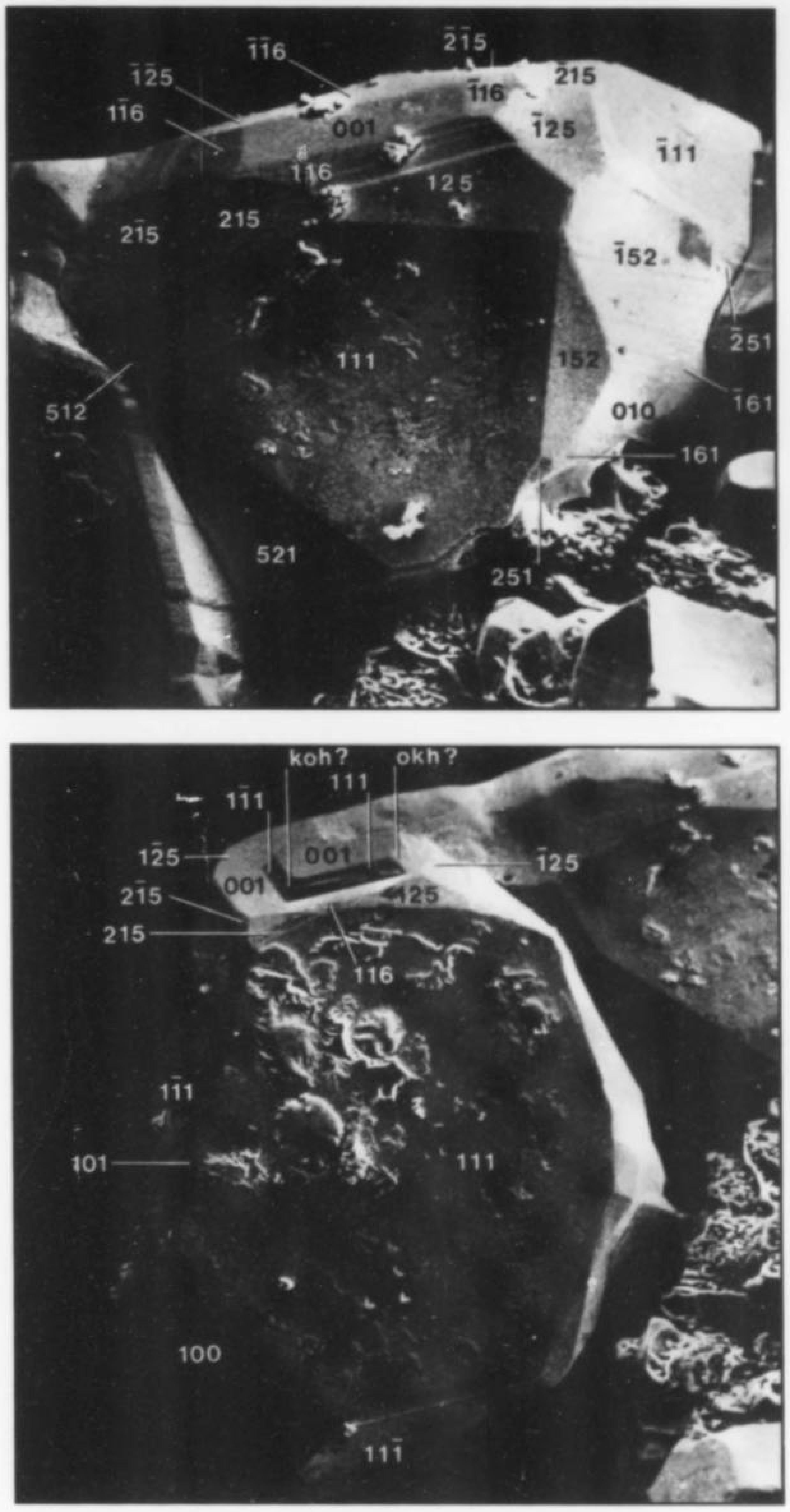


***Figure 37.* Among the extensive material collected by Ole V. Petersen in the exploration drift made in 1979–80 at Kvanefjeld was one specimen with the first natural crystals of villiaumite ever found. These SEMs of the crystals, only a few tenths of a millimeter in size, show two slightly different habits.**

In addition to villiaumite, this drift has yielded such interesting minerals as vuonnemite and lomonosovite, as well as two new species, kvanefjeldite and nacareniobsite-(Ce).

Narsarsukite $Na_2(Ti,Fe^{+3})Si_4(O,F)_{11}$

Igdlutalik (Illutalik) is a small fertile island with billions of biting flies, where the inhabitants of Narssaq (Narsaq) used to pick bilberries. Here, B. G. J. Upton in 1974 found, within a small gully, a trachyte dike about 20 m wide and traceable for about 50 meters, with a very interesting mineralogy. The dike rocks are fine-grained, with principal constituents albite and aegirine. Two of the minerals from this dike deserve a few words. They are narsarsukite and emeleusite.

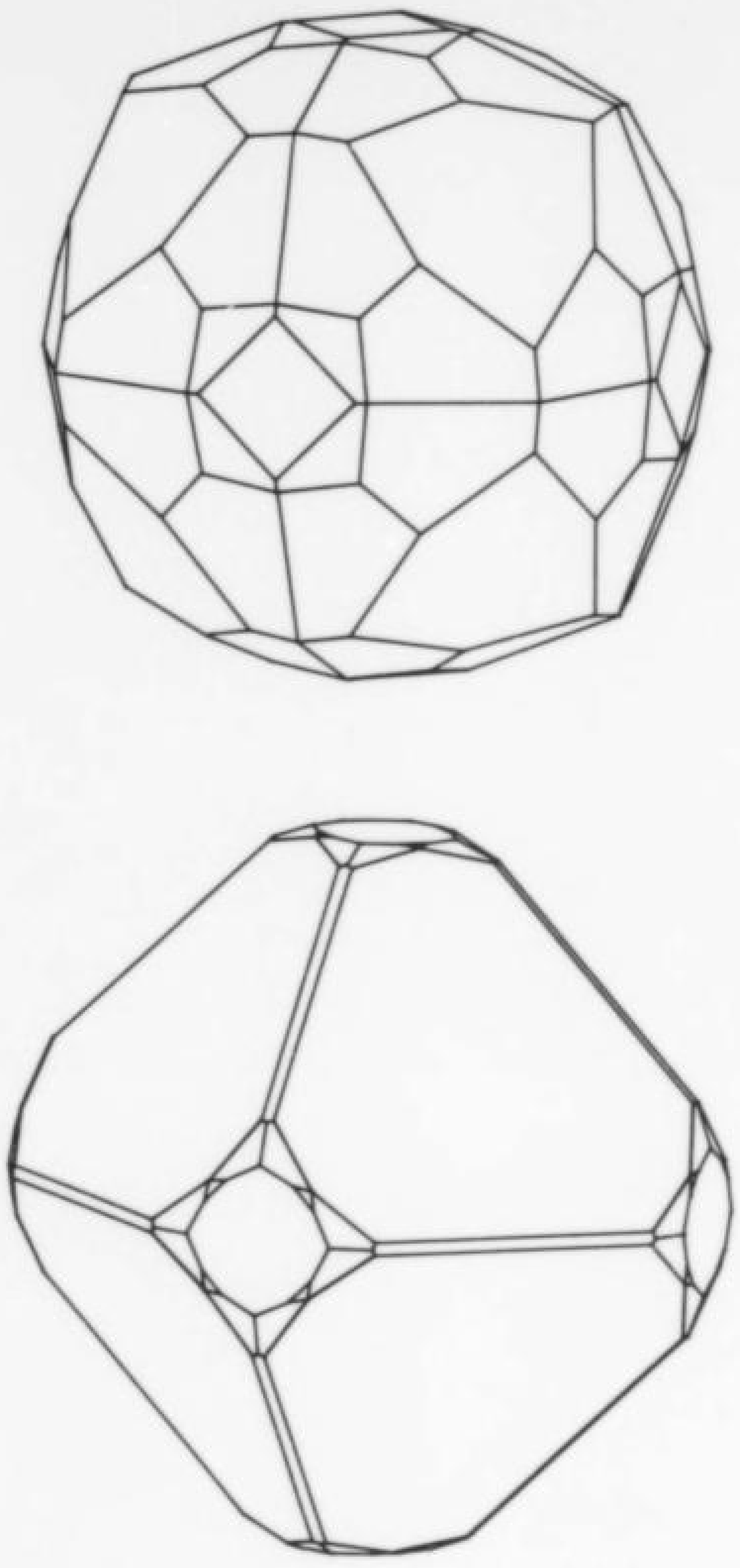


Figure 38. **Drawings of idealized villiaumite crystals corresponding to the ones shown in the previous figure. Forms developed are: {100}, {111}, {611} and {521}; and {100}, {110}, {111}, {611} and {521} respectively.**

Narsarsukite crystals are abundant in the dike interior, occurring as green square-sectioned prisms up to 1 cm long. The habit of the Igdlutalik (Illutalik) narsarsukite appears to be unique; the crystals occur as stumpy prisms at least twice as long as they are broad, while narsarsukite described from other localities (including the type locality at Narssârssuk) are invariably tabular parallel to {001}. The crystals are tetragonal, the forms {100} and {001} being dominant, with slender prism faces of the form {110}. Whereas the narsarsukites from the type locality and from Ilímaussaq are invariably yellow to brownish yellow, the narsarsukite from Igdlutalik (Illutalik) originally is colorless or rose colored, but with very few exceptions is always altered to a green mixture of aegirine and albite.

Emeleusite $Na_4Li_2Fe_3^{+2}Si_{12}O_{30}$

Among the specimens collected by Upton in 1974 was one weighing about 1 kg that, upon investigation, proved to be largely composed of a new mineral. The mineral was named in honor of Charles Henry Emeleus. The sample shows a creamy-pinkish core enveloped in green (aegirine-rich) and white (albite-rich) layers. The core is a dense aggregate composed almost wholly of emeleusite, as equidimensional crystals up to 2 mm in length. Emeleusite is transparent and has a glassy luster. The mineral is orthorhombic and the crystals display the forms {100}, {010}, {001}, {110} and {001}. The crystals are tabular parallel to {010}. Emeleusite forms pseudohexagonal interpenetration trillings with {110} as the twin planes. In these trillings the single individuals are tabular parallel to {010} and strongly elongated along [100]. The *c*-axis forms the pseudo-sixfold axis of these trillings. In many of the trillings each of the three orientations is represented by several parallel individuals. The mineral is closely related to tuhualite and zektzerite.

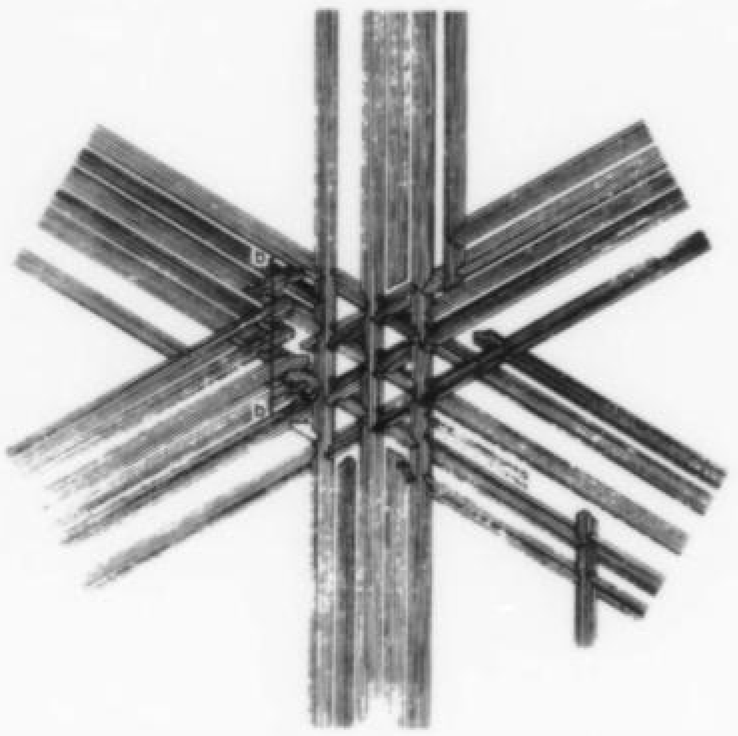


Figure 39. **Emeleusite, the relatively new lithium-sodium-iron silicate from Igdlutalik (Illutalik) forms intricate interpenetration trillings with {110} and {1$\bar{1}$0} as the twin planes. The figure shows a drawing of an idealized trilling as seen in thin section.**

Figure 40. **The exploration drift constructed in 1979–80 at Kvanefjeld uncovered a mineralogical treasure. The drift was made to obtain material to evaluate possibilities for uranium mining. Rich specimens of villiaumite, interesting minerals like vuonnemite and lomonosovite as well as the two new species kvanefjeldite and nacareniobsite-(Ce) were among the exciting material collected in the tunnel; photo by O. V. Petersen.**

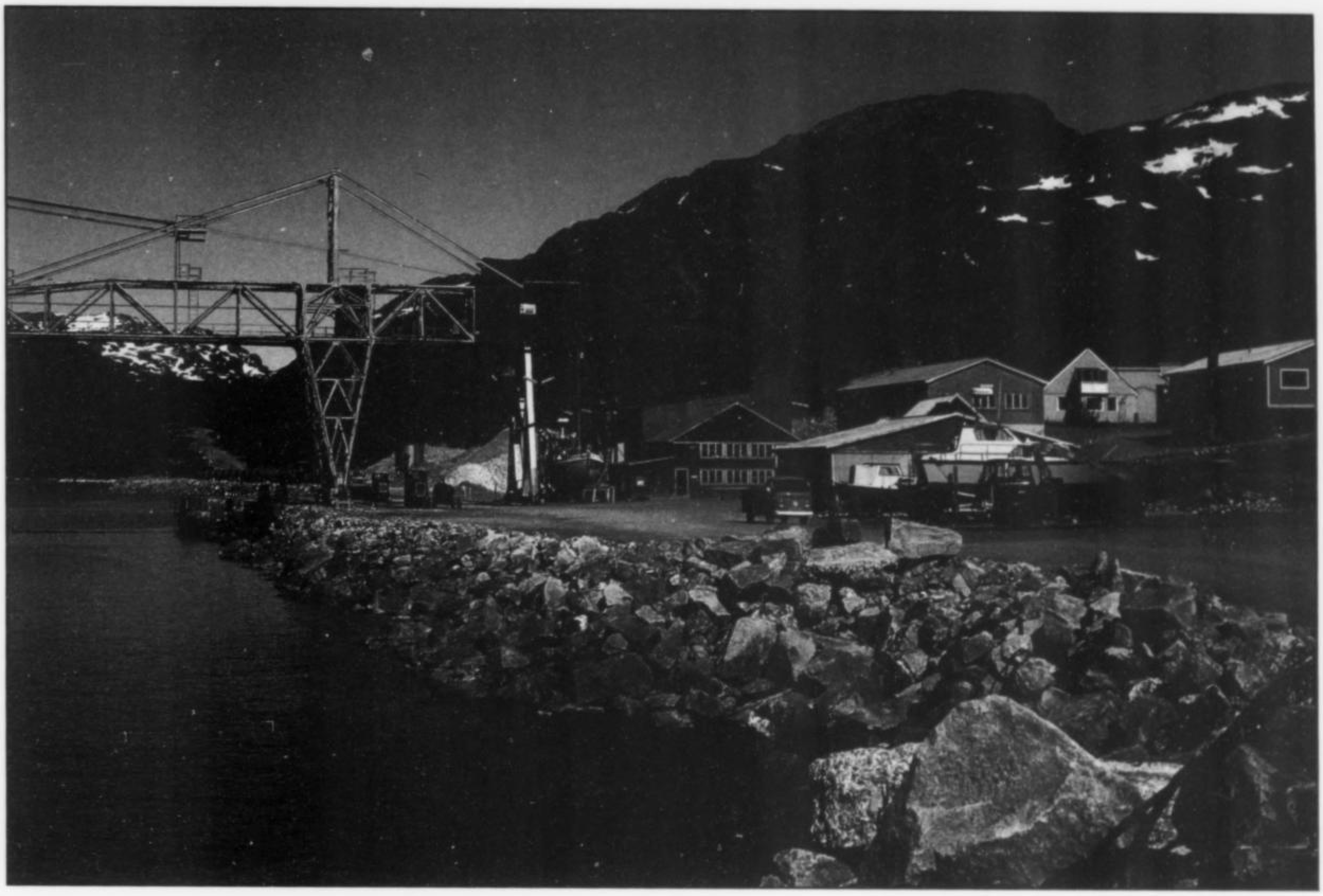


Figure 41. **The cryolite ore from Ivigtut (Ivittuut) was shipped to overseas destinations. The quay was built of cryolite ore tailings, which turned out to be of ore grade in modern times, and were accordingly excavated; photo by K. Secher.**

The Ivigtut Cryolite Stock

HISTORY

Cryolite was established as a mineral species in 1802 by Klaproth, but at that time nothing was known about the origin of the material, except that it came from Greenland. It was Giesecke who, during his seven years stay in Greenland, found the deposit which he visited twice; the first time in 1806. It should be noted that, whereas his diary generally can be considered as extraordinarily reliable, the finding of the cryolite occurrence constitutes a peculiar exception. From the diary one gets the impression that he did not know where the cryolite could be found until, in August 1809, he passed Arsuk Fjord (Ilorput) for the third time. However, from his article "On cryolite" in the *Edinburgh Philosophical Journal* (1822) it appears that as early as September 1806 he visited Ivigtut (Ivittuut) and investigated the place thoroughly; in this article there is no mention of a visit to the place in August 1809.

Mining in Ivigtut (Ivittuut) began in 1854; the first mining was not for cryolite, but for argentiferous galena, found in the contact between the cryolite body and the surrounding granite. These mining activities lasted only six months before the English mining engineer J. W. Tayler realized that the quantity of galena was too low to sustain a profitable mining operation.

Ivigtut was the only cryolite occurrence in the world worth mining and, apart from this awkward start, the history of mining in Ivigtut (Ivittuut) is linked with the use of cryolite. In the years 1849–1852 the Danish industrial chemist J. Thomsen discovered a process through which cryolite could be converted into soda and alunite. The first cryolite, paltry 15 tons, was shipped to Copenhagen in 1854, but owing to ice barriers in the Arsuk Fjord (Ilorput), nothing was shipped in 1855. In the following years, large amounts of cryolite were shipped from Ivigtut, part of which was sold to a factory in France which wanted to produce the new metal aluminium directly from cryolite. Other ore was used in the production of, among other things, mirror glass. In 1859 a factory for the production of soda and alunite after Thomsen's patent was established in Copenhagen, and in the following years mining in Ivigtut accelerated. Several companies participated in the activities until 1864, when the whole area was taken over by one company, "Kryolit Mine og Handels Selskabet." In the following years several small open pits and one underground mine were developed. Right from the beginning the quarried material was hand-sorted because the ore shipped had to contain more than 85% cryolite.

The use of cryolite in soda production did not last very long, but other uses were at hand. For a time cryolite was used for enameling iron ware and for making opalescent glass. The major breakthrough in the use of cryolite came in 1886–1887 when the Hall-Héroult process was discovered in which metallic aluminum can be obtained by electrolysis of alumina from solution in molten cryolite. This became, and still is, the process through which aluminum is obtained.

Due to the situation of the cryolite mine, right at the beach of the Arsuk Fjord (Ilorput), cryolite mining was carried out in a constant fight with incoming water. In 1878 a carefully planned and meticulously executed dam was completed and soon thereafter the quarries developed into one open pit 180 meters by 30–40 meters. For the next 30 years approximately 20,000 tons of crude cryolite were produced

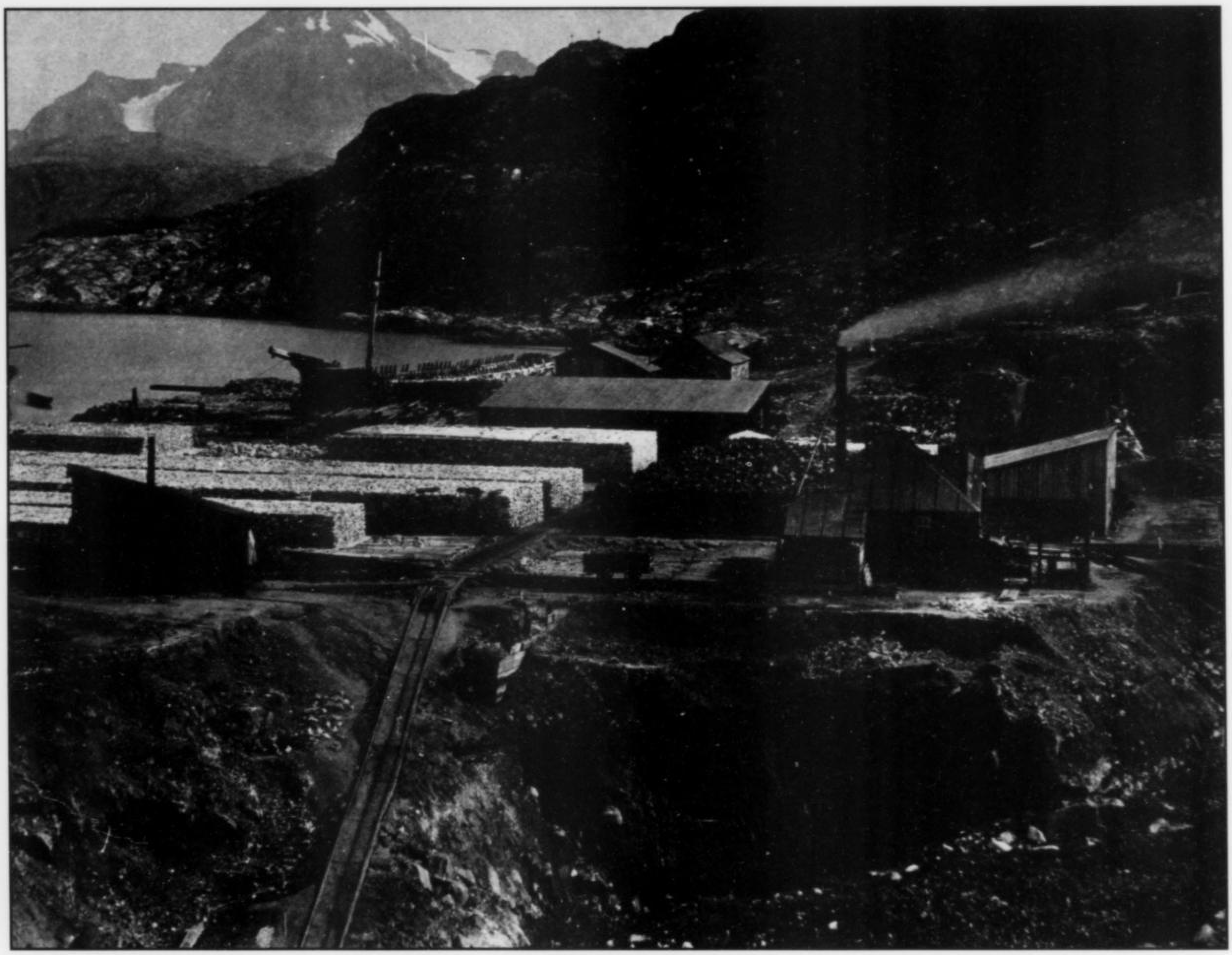
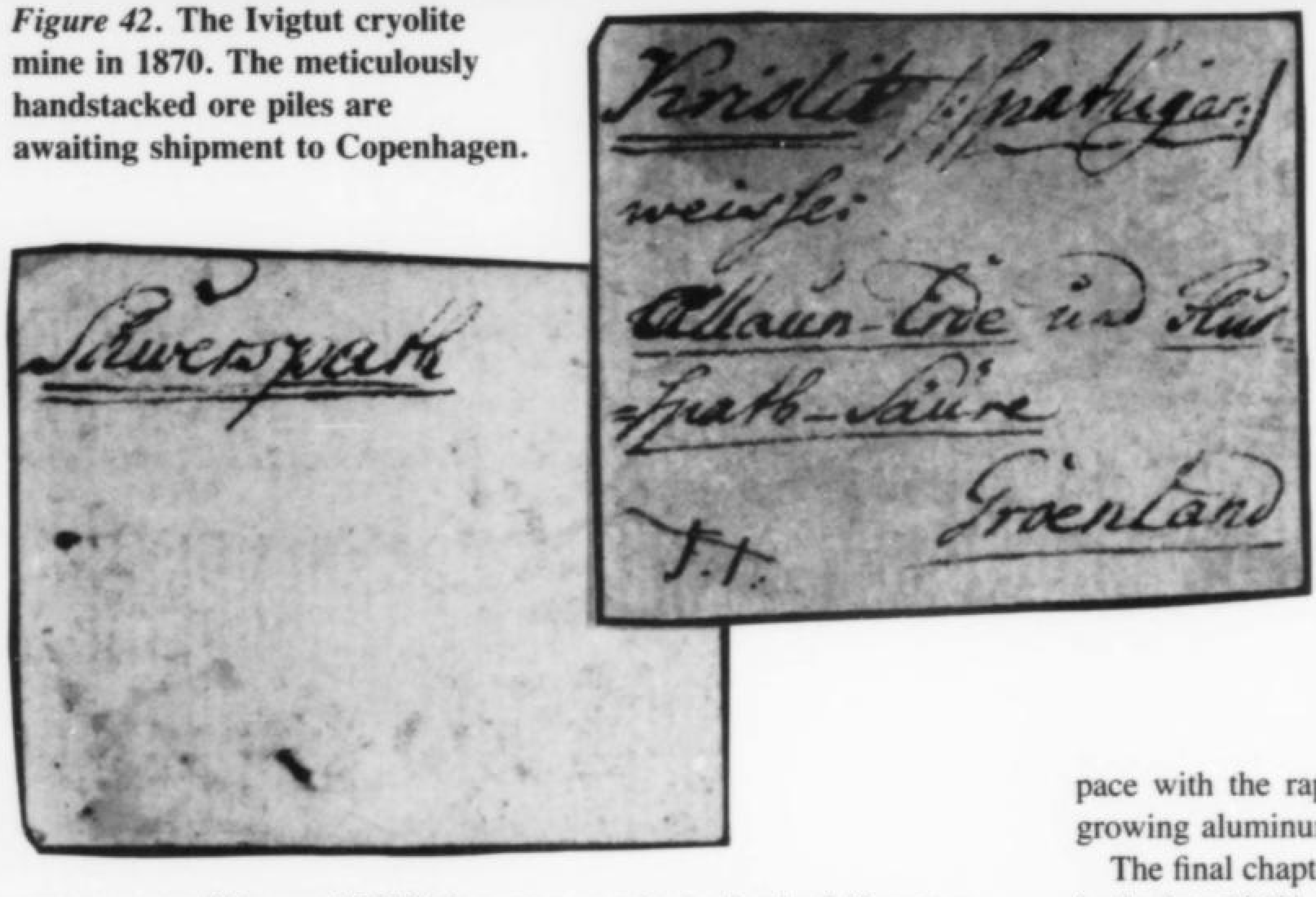


Figure 42. **The Ivigtut cryolite mine in 1870. The meticulously handstacked ore piles are awaiting shipment to Copenhagen.**



Schwerspath

Kriolit, spathiger:
weisser:
Allaun-Erde und Fluss-
spath-Säure
Groenland
F.I.

Figure 43. **Back and front of a label accompanying one of the oldest cryolite specimens in the Geological Museum, Copenhagen; the word "Schwerspat" on the back could have been written by C. F. Schumacher, the first to make mineralogical investigations of the very first specimens of cryolite brought to Europe at the end of the 18th century. The words "Kriolit, spathiger weisser, Allaun-Erde und Flusspath-Säure, Groenland" were undoubtedly written by P. C. Abildgaard. It was he who analyzed the material a few years later, and identified two of the three main components of this new species; on the suggestion of the Portuguese mineralogist J. B. d'Andrada, Abildgaard named it for its visual appearance as well as for its low melting point—"icestone."**

every year until (around 1910) the quarry reached a depth of 40 meters. Up to that time the quarried masses had been loaded into small wagons and pushed on tracks across the bottom of the pit, to where they were coupled to a chain and drawn to the surface via an inclined track. The establishment of a hoist in 1912 and the conversion of an old pumping shaft into a hoist shaft in 1927, as well as the introduction of modern drilling and quarrying equipment, helped the company keep pace with the rapidly increasing demand for cryolite from the fast growing aluminum industry.

The final chapter in the history of mining at Ivigtut (Ivittuut) began in the late 1940's, with new developments in ore-dressing technology enabling the plant in Copenhagen to treat all grades of cryolite ore. Construction of yet another dam, and the completion of a 500-meter incline from the bottom of the pit to the surface, made it possible to use large dumpsters to bring ore and waste rock to the surface.

After approximately 3.5 million tons of cryolite material had been mined, it was decided in 1962 to cease the operation. During the following 19 years roughly 500,000 tons of cryolite was still shipped as regular stock, which had originally been dumped into the sea along the dam as coast protection, and which had been used for piers and road construction. In 1983 the mine was emptied of the water which had run into it since 1962. In 1987 the shipment of cryolite was finally concluded, after the small amount of ore that had been left in 1962 was quarried. Presently (fall of 1992) the mill, located at the same place in Copenhagen for all 140 years, has been demolished to make room for an apartment building. A unique adventure has finally come to an end. [Ed. note: There is currently a small hotel at Ivigtut serving visiting tourists and collectors.]

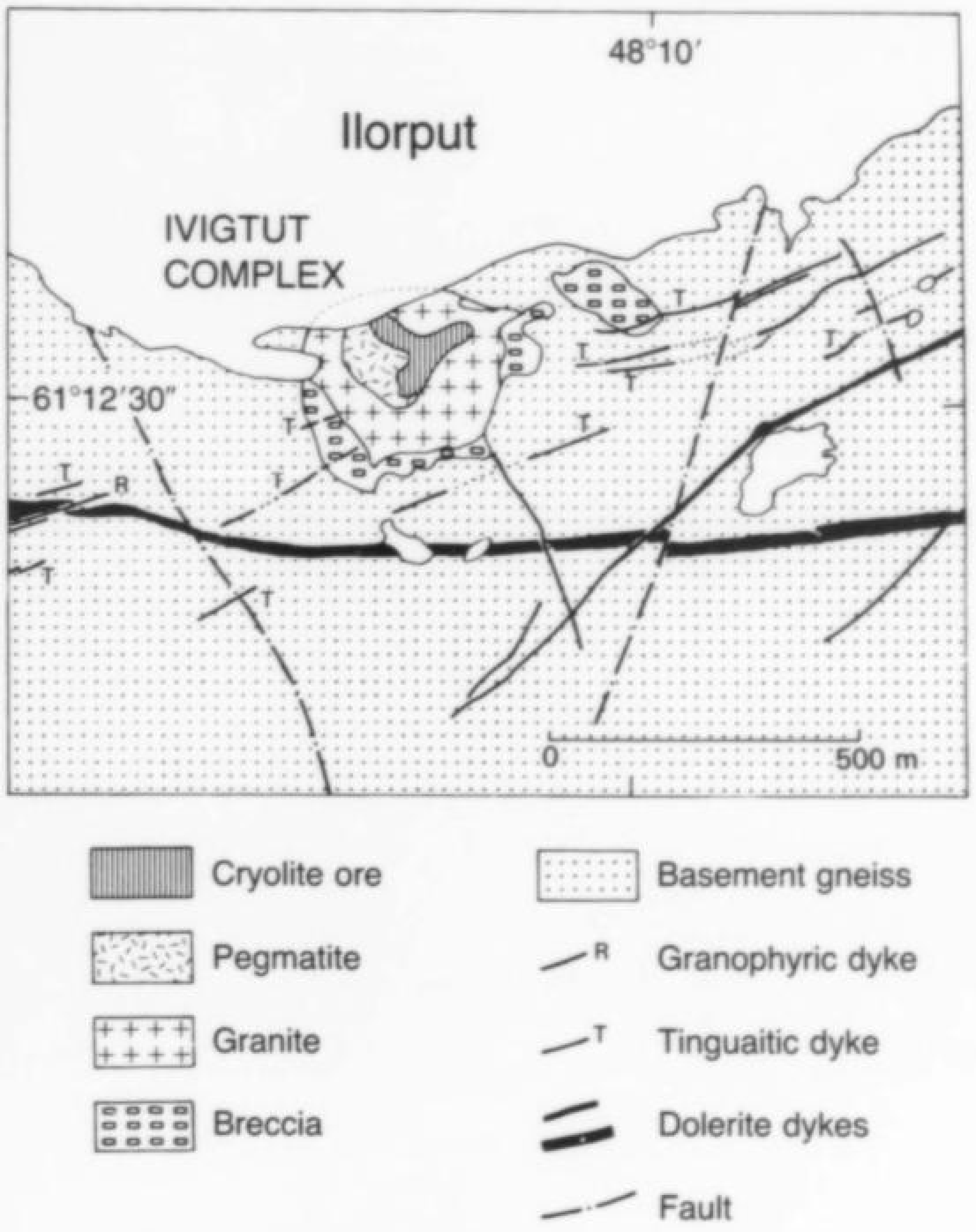


***Figure 44.* Geologic map of the Ivigtut cryolite deposit and its surroundings. From the map it appears very clearly that the cryolite body was entirely enclosed in a granite stock. Note also that with a few more meters of erosion the deposit would have been below sea level, and probably would never have been found.**

GEOGRAPHY and GEOLOGY

Ivigtut (Ivittuut) is situated on the south coast of the Arsuk Fjord (Ilorput), no more than 10 km from the estuary. The fjord is surrounded by high mountains, of which the snow-covered Kûngnât (Kuunnaat) can be seen in the distance; mountains protect the place from the cold winds of the Davis Strait. Consequently at Ivigtut (Ivittuut) the climate is excellent and both the flora and fauna thrive.

The word Ivigtut in Greenlandic means "a place rich in grass." Also flowers, such as milkwort, dandelion, saxifrage, buttercups, cinquefoils and berries, such as bilberries, cranberries and juniper berries, flourish in this small valley. The fauna is also plentiful: ptarmigan, mountain hare and arctic fox are commonly seen, and the coastal cliffs are inhabited by gulls, guillemots, razorbills and other web-footed birds. The only "snake" in this paradise is the incredible number of mosquitoes. The original cryolite outcrop was right on the beach, separated from the fjord by only a narrow strip of land, and partly flooded at high tide. Here, at a small lagoon, the Greenlanders used to pitch their tents in summer when they entered the fjord to catch small fish called capelin.

The cryolite mass consisted of cryolite with about 20% siderite and 1–2% quartz and sulfides, pure white cryolite and fluorite mixed with cryolite constituting more than two-thirds of the total mass. The orebody originally formed an irregular dome-shaped mass measuring about 50 by 155 meters in plan and about 70 meters in depth. A siderite zone with more than 90% siderite underlay the main siderite-cryolite body to the east; in the western part the main body was underlain by a shell very rich in fluorite. The formation of the fluorite mass began with the consolidation of the siderite-cryolite which, apart from some violent brecciation during the initial stage, took place under quiet conditions, this led to a distinct layering, with siderite-rich and siderite-poor meter-thick layers. Finally the body of white cryolite was formed. At this point in the development a marked change took place. Fluorite and topaz crystallized together with cryolite under brecciation of the surrounding masses. Underneath the fluorite-cryolite, a cryolite-free mass of fluorite and topaz formed. At deeper levels a huge mass of sulfide-bearing quartz separated the cryolite body from the underlying granite. The cryolite mass, together with the quartz mass, was enclosed in the top part of a granite stock having the diameter of about 300 meters. The mechanisms of formation of this peculiar intrusion is still the subject of study; the favored theory is that the cryolite is a product of the granite, an extreme pegmatitic or rather pneumatolytic formation, formed by accumulated fluorine-rich gases trapped in the central upper part of the already partly solified stock.

MINERALOGY

At least 90 minerals have been found at Ivigtut in the cryolite mass, in the large granite pegmatite associated with the cryolite mass, and in veins in the enclosing granite and its surroundings. Only eight of the sulfides can be considered as common: sphalerite, galena, chalcopyrite and pyrite in the siderite-cryolite, pyrrhotite and marcasite in the siderite and arsenopyrite and molybdenite in the pegmatite. Three native elements and about 40 different other sulfides and sulfosalts have been found as microscopic grains, predominantly in the galena. Of the ten or more oxide species, columbite, which occurs both in the pegmatite and in the greisen rock around the cryolite mass, attracts special attention because of the beautiful well-developed crystals. Of the carbonates and sulfates, siderite is the most prominent and among the 15 silicates, topaz is the mineral which stands out. It always occurs as microscopic crystals forming dense, hard masses, most often white but occasionally colored purple by fluorite or greenish by mica.

However interesting the above mineral groups are, none of them accounts for the worldwide interest from professional mineralogists and amateur collectors which Ivigtut attracts. It is the fluoride group, represented by 16 different minerals. In the following descriptions some interesting details of a number of selected fluorides, and one oxide, will be given, starting with the undoubtedly best-known mineral from Ivigtut, cryolite.

Cryolite Na_3AlF_6

As early as the beginning of the 18th century there was limited trade in cryolite among the natives of the western coast of Greenland. The Greenlanders used cryolite as sinkers on their fishing lines and nets; the mineral is, owing to its softness, easy to shape and bore holes into. It was also ground as an additive to snuff.

The first samples of cryolite had been brought to Copenhagen by missionaries, as curiosities, by the middle of the 18th century. It was a regimental surgeon, at that time assistant professor in mineralogy at a private natural science society, C. F. Schumacher, who in 1795 and again in 1798 described some of the physical properties of some

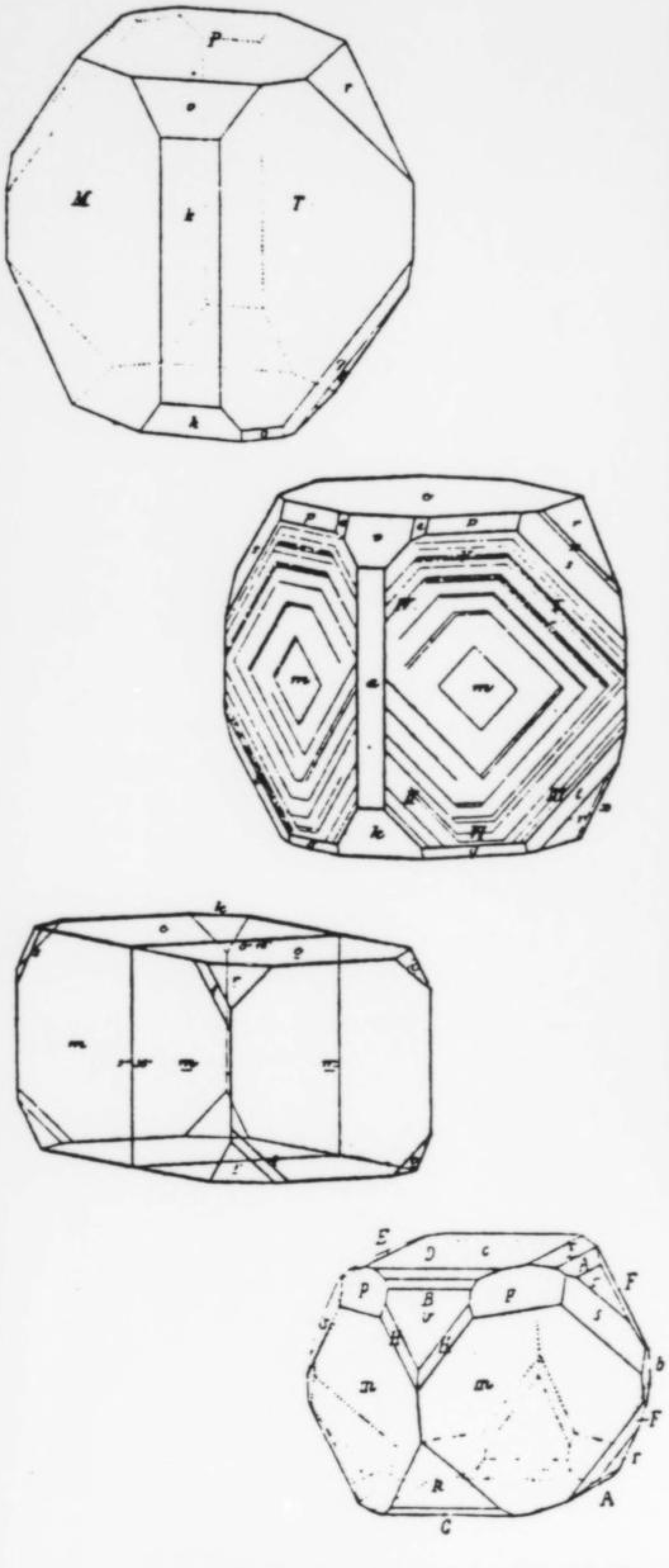


Figure 45. **Drawings of crystals of cryolite. This monoclinic mineral closely resembles a cube modified by the octahedron, when developed with the forms {001}, {110}, {101}, {$\bar{1}$01} and {011}. (Goldschmidt, 1918)**

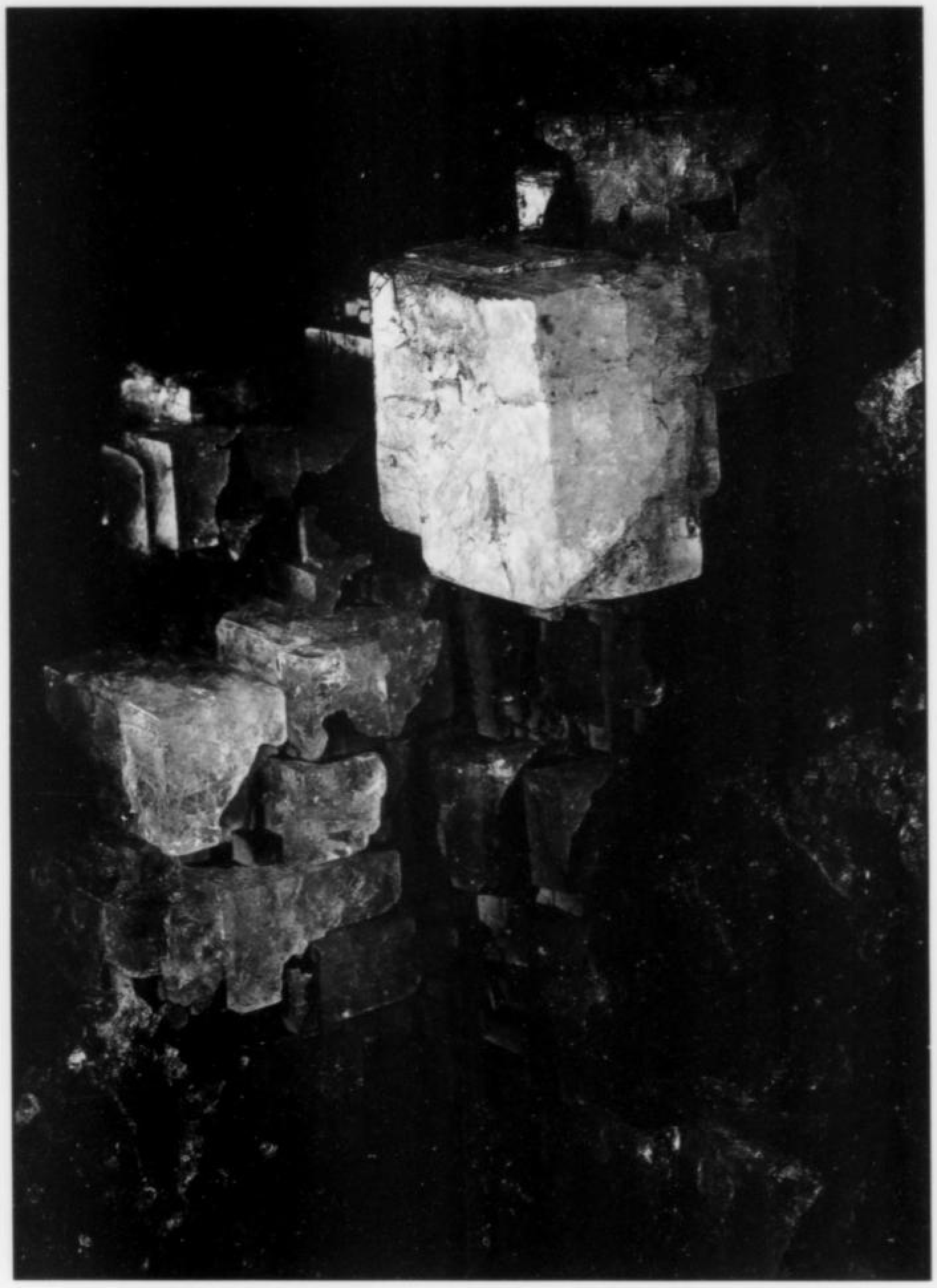


Figure 46. **Specimens with cryolite crystals are rare. Only two specimens with crystals like the ones shown here are known, both in the Geological Museum, Copenhagen. The central crystal, twinned like almost every cryolite crystal, is close to 4 cm across; photo by O. Medenbach.**

of the above-mentioned specimens. Unfortunately his conclusion that it was a known mineral, barite, was wrong. P. C. Abildgaard, the father of Danish veterinary science, and all his life interested in geology, was the next person to occupy himself with cryolite. At the request of the Brazilian-Portuguese mineralogist J. B. d'Andrada, whom he had contacted, he succeeded in demonstrating that the mineral contained Al and F, but he did not succeed in making quantitative analyses. In his 1799 paper, Abildgaard used the name cryolite (at that time spelled "Kriolit") for the first time. The Geological Museum in Copenhagen possesses a few small, very old specimens of cryolite. On the label of one of these specimens, is written on the one side *"Schwerspat,"* on the other *"Kriolit, spathiger weisser, Allaun-Erde und Flusspath-Säure, Groenland."* This specimen is undoubtedly one investigated by Schumacher, and determined to be *Schwerspat* (barite); later this same specimen fell into the hands of Abildgaard who analyzed it and identified aluminum (-oxide) and hydrofluoric (-acid).

Whether the "Schwerspat" on the one side of the label is written by Schumacher himself is difficult to tell, but there seems to be little doubt that the above-quoted German description on the other side was indeed written by Abildgaard. The well-chosen name of this mineral was suggested by d'Andrada, and derived from the Greek words for *ice* and *stone*, i.e., "icestone," alluding not only to the visual appearance of this mineral, but also, indirectly, to the low melting point.

Cryolite crystallizes monoclinically. Free crystals are very rare. The most common forms are {001} and {110}, together forming a figure completely resembling a cube. The vast majority of the cryolite occurs as massive, very coarse-grained aggregates, in the mine individuals up to 6-meters have been observed. Cryolite is almost invariably twinned; 13 different possible twin laws have been described, often

Figure 47. **Considerably rarer than cryolite is cryolithionite, with Li_3Na_3 rather than Na_6 in the formula. It is always found completely enclosed in cryolite, and is most easily spotted when (as here) it is in the black variety of cryolite. Size of the specimen, 10 cm; photo by R. Bode.**

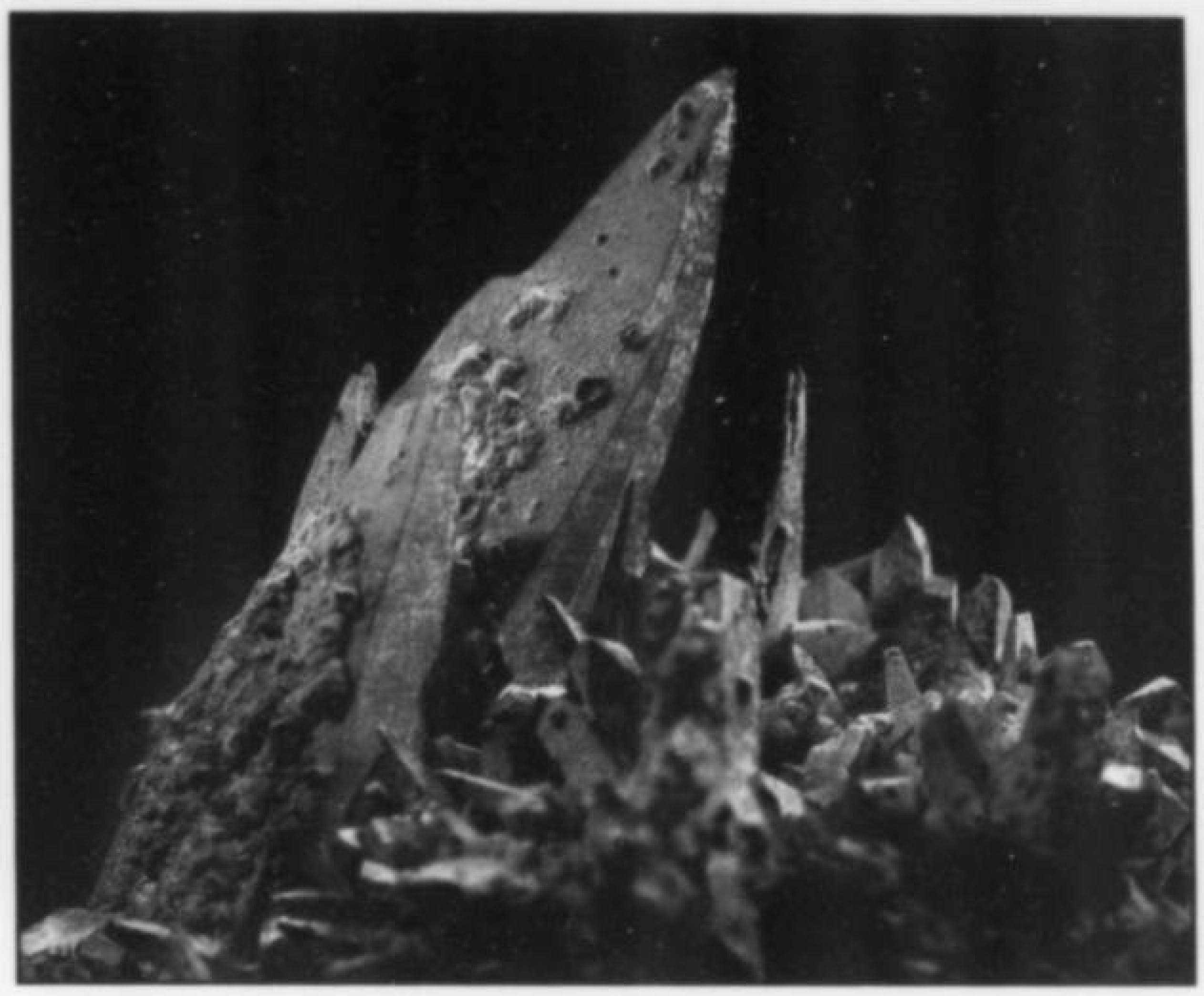


Figure 48. **The most common of the minerals found in the dissolution cavities in cryolite is thomsenolite. The central crystal in this group is among the largest ever found, fully 5.5 cm! Photo by R. Bode.**

Figure 49. **Pachnolite is another of the secondary minerals found in dissolution cavities in the cryolite. This magnificent specimen was donated to the Geological Museum, Copenhagen, about 10 years ago. With its well-developed crystals, the largest of which is 4.5 cm, it is among the most spectacular of all the Ivigtut specimens in the museum, and probably the best pachnolite specimen in the world; photo by R. Bode.**

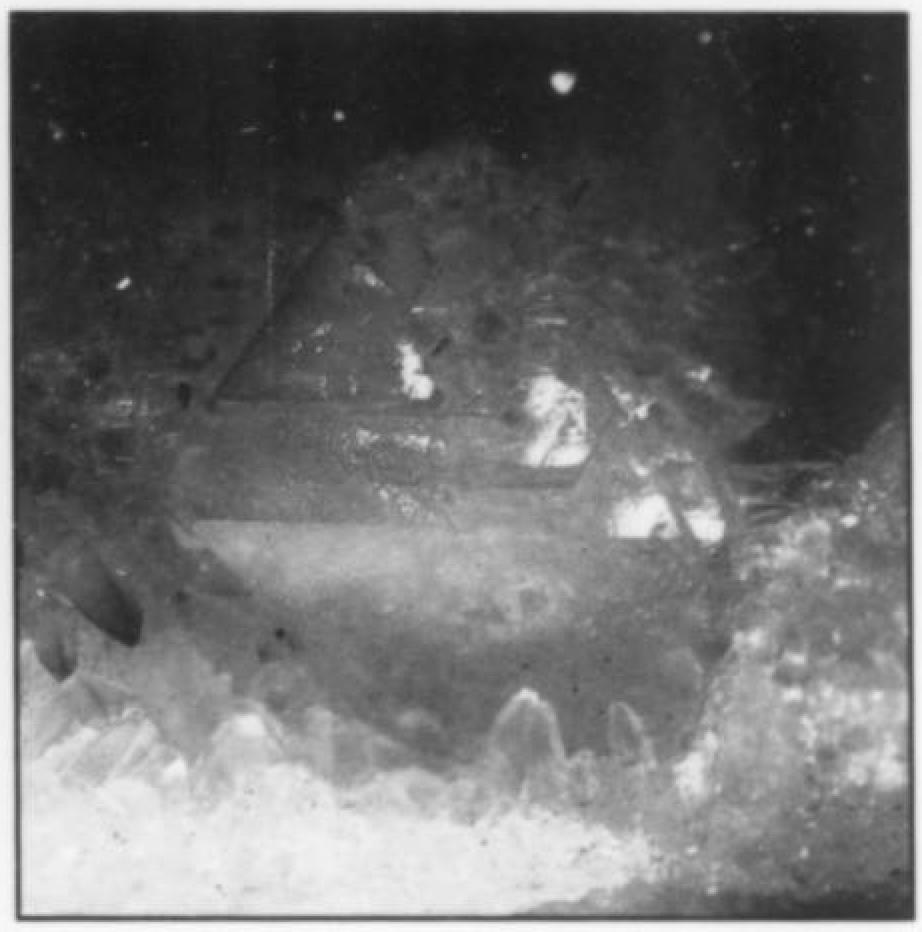


Figure 50. **Ralstonite—one of the rarer minerals in the dissolution cavities in the cryolite—crystallizes as cubes, octahedra or as combinations of these. The 6-mm octahedron shown here sits on a background of thomsenolite, as is most often the case; photo by R. Bode.**

5 or more have been identified on a single specimen. Cryolite appears to have no cleavage, but an excellent parting; this often causes the pure white cryolite to appear in box-like fragments. Cryolite is colorless, but the large-grained form is mostly white and semitransparent; more rarely the color is smoky or even black. Finally it should be noted that it was the presence of cryolite which caused Thomas Allan to buy the portion of Giesecke's collection which had been captured by English warships. Allan himself had privately estimated the value of the cryolite to be as much as £5,000, but he was able to buy the whole collection, including the cryolite, for only £40.

Cryolithionite $Na_3Li_3Al_2F_{12}$

The first small fragments of cryolithionite were found by Steenstrup in 1899, but not investigated in detail. Ussing's 1904 description of

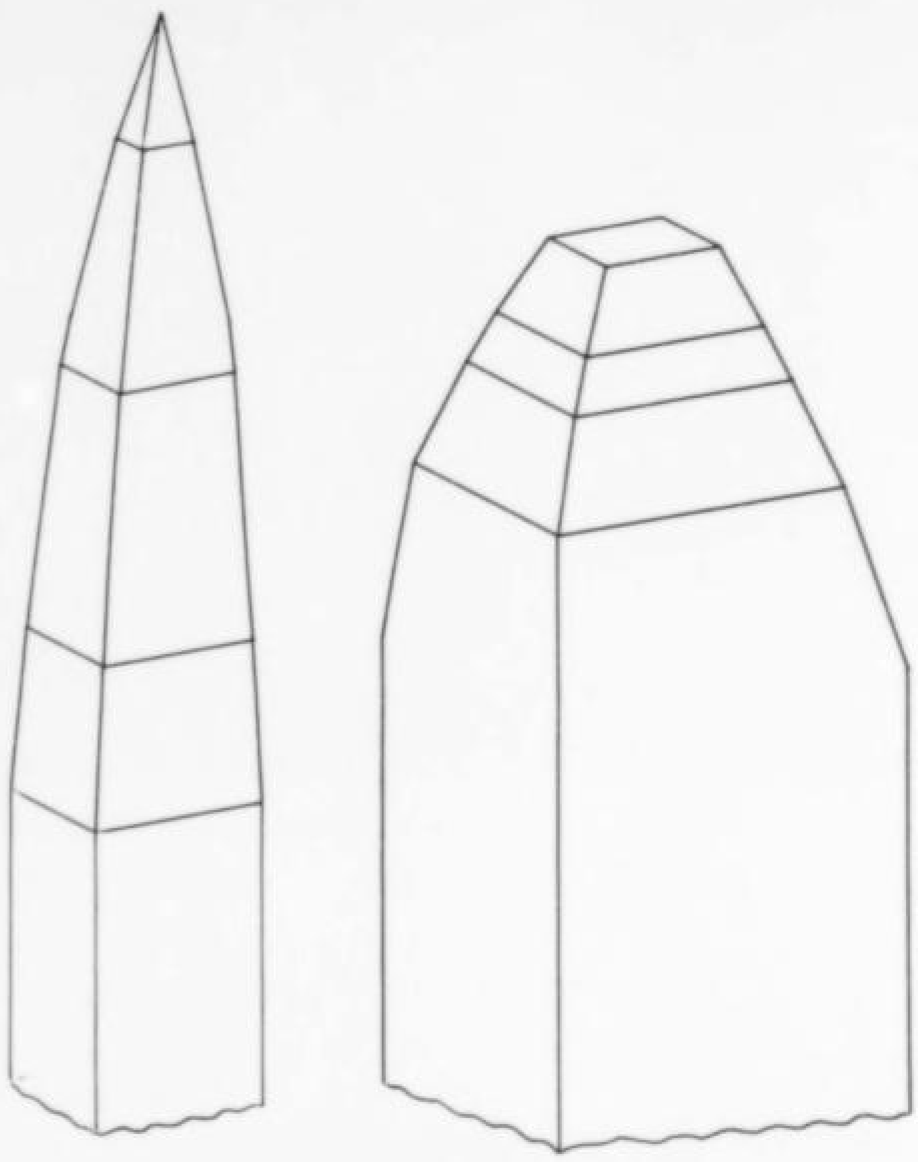


***Figure 51*. Drawings of idealized crystals of thomsenolite. The habit of the thomsenolite crystals varies considerably. The two types shown here, the slender, prismatic with numerous pyramids, and the short, prismatic type with fewer pyramids and the basal pinacoid, are the most common.**

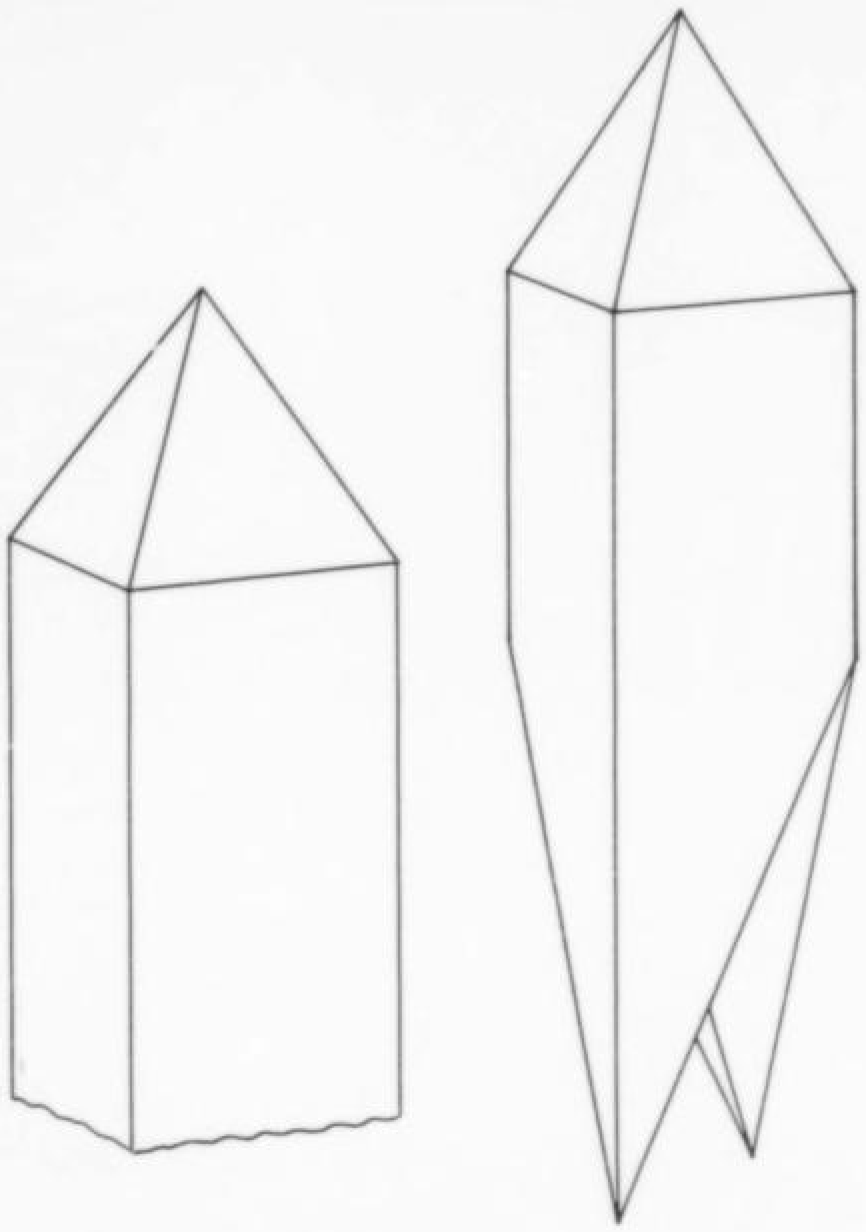


***Figure 52*. Drawings of idealized twinned crystals of pachnolite. The crystals are most commonly bounded by {110} and {111} but are always developed as parallel twins with [001] as the twin axis; only very rarely can the re-entrant angles be observed.**

this new species was based on a considerable quantity of material sent to the Geological Museum, Copenhagen, in 1903 by the manager of the mine. The cryolithionite crystals are always completely enclosed in cryolite. In the original material the mineral forms white crystals up to 17 cm in white cryolite. In the material found later, the cryolithionite forms small, centimeter-sized white crystals in black cryolite.

Cryolithionite is cubic in habit; no other form than {110} is found. The hardness is 4 (compared to 2.5 for cryolite); the specific gravity is 2.78 (compared to 2.97 for cryolite) and the refractive index is exactly that of cryolite. All things considered, cryolithionite is not always easily distinguishable from cryolite, except where it occurs in black cryolite. The formula of cryolithionite, when compared with the formula of cryolite, indicates a substitution of half the sodium by lithium.

Chiolite $Na_5Al_3F_{14}$

Chiolite, the third primary fluoride, crystallizes tetragonally but is never found in freely developed crystals. Chiolite occurs as irregularly bounded grains up to 10 cm; it is colorless or whitish, and transparent. It is easily recognized by its very strong {001} cleavage, the cleavage faces always being somewhat curved.

Thomsenolite and **Pachnolite** $NaCaAlF_6 \cdot H_2O$

For collectors of well-crystallized minerals, the three most interesting minerals from Ivigtut are thomsenolite, pachnolite and ralstonite. All three minerals are found in solution cavities in cryolite, crystallized from calcium/magnesium bearing solutions.

Thomsenolite and pachnolite are so intimately related that they cannot be dealt with separately, and their histories are too long to fully recount here. Briefly: in 1866 Knop described "pachnolite, a new mineral," having two different orthorhombic crystal forms. He considered both varieties, called *pachnolite A* and *pachnolite B*, to be identical because of their identical physical and chemical properties. Hagemann described in 1866 a "dimetric pachnolite," chemically hardly different from pachnolite and probably identical with a mineral already mentioned by J. Thomsen. Des Cloizeaux determined in 1867 that pachnolite is monosymmetric, and recognized that the apparently rhombic pyramids were twins. Hagemann's "dimetric pachnolite" was determined in 1868 to be monosymmetric by E. S. Dana, who named the mineral *thomsenolite* in the honor of its original discoverer. The debate in the years preceding 1877, on whether pachnolite and thomsenolite were two distinct mineral species or merely different crystal shapes of the same mineral, arose because the two types of crystals were found to have the same chemical composition. The investigations of Krenner and Klein in 1877 led to the conclusion that pachnolite and thomsenolite were dimorphs (same composition but different structure) of $NaCaAlF_6 \cdot H_2O$.

Thomsenolite crystals are most commonly bounded by {110} and {001}, which may, now and then, form a pseudocubic shape. But more often the habit is long prismatic. In addition to the forms mentioned, {331} and {111} also occur. Crystals of thomsenolite are frequently found in parallel orientation (parallel bases and prism faces). As a rule the length and width of the crystals are 5 mm to 2 cm, but they may be found as large as 5 cm. Thomsenolite is white or colorless and waterclear. It has a very strong {001} cleavage, and the cleavage plane shows a pronounced pearly luster.

Pachnolite crystals are most frequently bounded by {110} and {111}; the crystals are always twins, most appropriately described as parallel twins with [001] as the twin axis. The ordinary, freely developed crystals of pachnolite occur in cavities, nearly always together with and on thomsenolite. In general the crystals are very small, 0.1 to 2 mm, but in material collected in 1960, crystals as large as 4.5 cm were found. Pachnolite is white or colorless, and has a less perfect to good {001} cleavage.

The two minerals are not always easy to distinguish from each other, but the following might be helpful: (a) Where the two minerals occur together, which they most often do, the thomsenolite crystals are the larger, the pachnolite crystals the smaller ones. (b) Thomsenolite crystals are frequently in parallel orientation, which is almost never the case with pachnolite. (c) Pachnolite crystals most often occur growing on the thomsenolite crystals. (d) The prism angle in thomsenolite is very near 90° whereas the prism angle in pachnolite is distinctly different from 90°; hence pachnolite seen along the *c*-axis of a twinned individual has a rhomb-shaped outline. (e) The very strong basal cleavage of thomsenolite contrasts with the less perfect basal cleavage of pachnolite. And (f) the pyramids of thomsenolite crystals are generally steeper than those of pachnolite crystals.

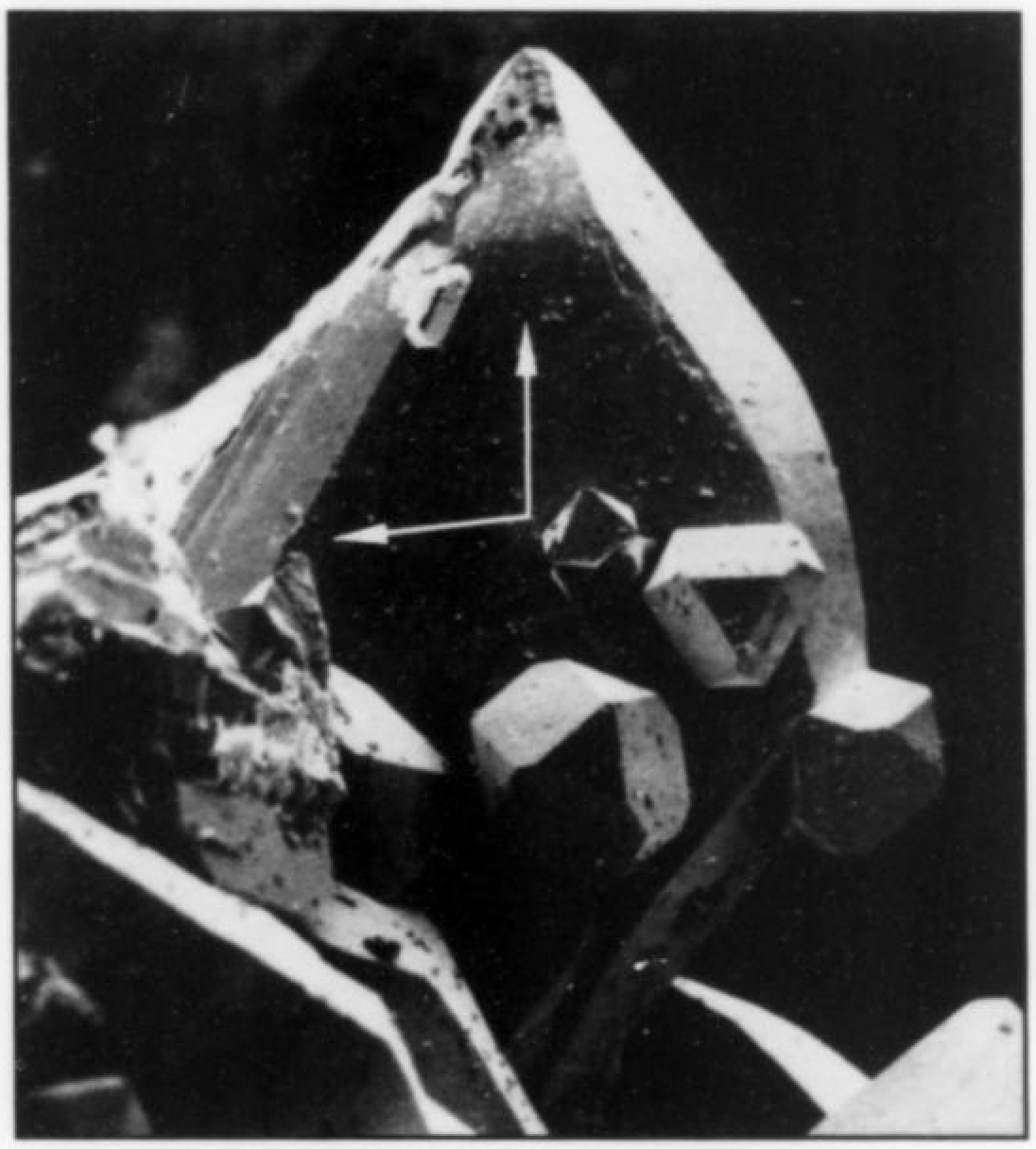


Figure 53. **Rarer than ralstonite is prosopite, until a few years ago known only in massive form. The figure shows a SEM of one of the numerous crystals (1 mm tall) found in the last few years; a few ralstonite crystals are perched on the prosopite.**

Ralstonite $Na_xMg_xAl_{2-x}(F,OH)_6 \cdot 6H_2O$

A description and preliminary analysis of ralstonite was given in 1871 by Bruch, who named it in honor of its discoverer. Ralstonite crystallizes cubically; the crystals are cubes and cuboctahedrons. Crystal size is generally 1–3 mm but may reach 1 cm. It is colorless, transparent, or whitish and semitransparent. Ralstonite is in most cases closely interspersed with thomsenolite.

Ralstonite, thomsenolite and pachnolite, like many other Ivigtut minerals, are very often found partially covered by various iron oxides. This limonitic material sometimes hides the beautiful crystal groups in a most unsatisfactory way, but in other cases may lend a pleasant contrast making the specimens even more attractive.

Prosopite $CaAl_2(F,OH)_8$

Prosopite is an alteration product of cryolite. Until a few years ago it was known exclusively in massive form, from small veins and cracks in cryolite and as crusts and agate-like masses in larger cavities.

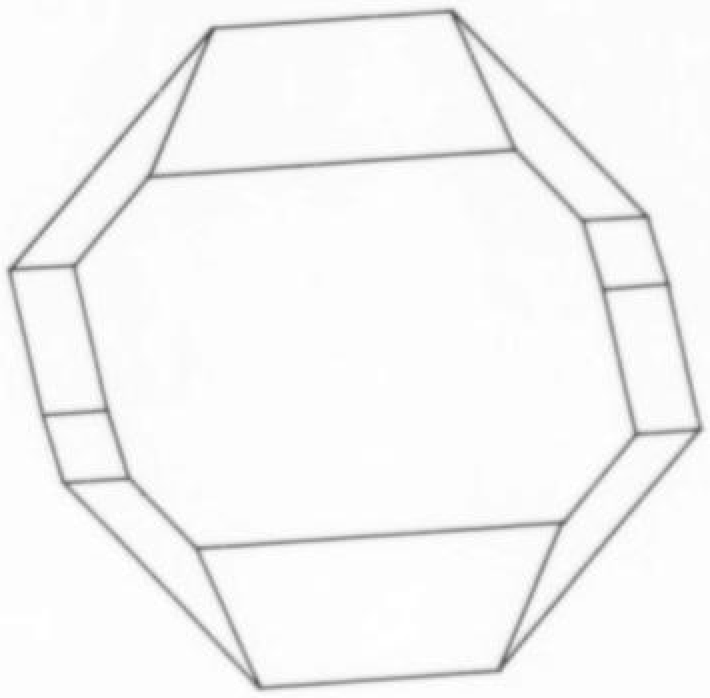


Figure 54. **Drawing of an idealized crystal of prosopite with the forms: {010}, {021}, {111}, and several $\{\bar{h}kl\}$ where $1 \leq h = k \leq 4$ and $l = 1$.**

In recent years a relatively large number of crystal specimens have been found. The crystals, generally less than 1 mm but in some cases up to 6 mm, occur on the walls of cavities in massive blue prosopite, often partly covered by later-formed crystals of ralstonite.

Figure 55. **SEM of a typical (0.25-mm) sheaf-like aggregate of platy crystals of jarlite, another one of the many Ivigtut minerals that forms nice microcrystals.**

Jarlite $NaSr_3Al_3(F,OH)_{16}$

Of the five strontium minerals known from Ivigtut, jarlite is common, stenonite and bøggildite uncommon, bøgvadite rare and acuminite extremely rare.

Jarlite occurs associated with barite in columnar, radiating aggregates which form irregular masses in the cryolite at a few locations within the deposit. In these aggregates, plenty of cavities are present in which the jarlite crystals, often associated with crystals of thomsenolite and ralstonite, are found. The habit of the jarlite crystals varies widely. The monoclinic crystals may be elongated along the *b*-axis; or they may be "blocky" single crystals (rare); or, more often, they are platy on {100} and form sheaf-like aggregates. In the most extreme forms these aggregates form balls of bladed crystals.

***Figure 57*. Drawing of an idealized crystal of acuminite. The two forms {110} and $\{\bar{1}11\}$ constitute together what appears to be a steep, bipyramid resembling a spear point (hence the name, from the Latin *acumen*).**

Acuminite $SrAlF_4(OH)\cdot H_2O$

That new and interesting minerals can still be found in Ivigtut is evidenced by the discovery of the two new species acuminite and bøgvadite in 1987 and 1988 respectively.

Acuminite is a very rare mineral. It was found as crystals and crystal groups in a 2 x 3-cm cavity in a single sample consisting mainly of the characteristic radiating aggregates. In this sample, fluorite in thin blades appears to have given rise to this radiating structure. Other associated minerals include jarlite, thomsenolite, pachnolite and ralstonite, the latter three in the form of porous white masses. The crystals, up to 1 mm, show the forms {110} and $\{\bar{1}11\}$, and rarely $\{\bar{1}12\}$; an equally developed combination of {110} and $\{\bar{1}11\}$ yields what appears to be a very steep, slightly oblique bipyramid resembling a spear point, hence the name (from the Latin *acumen* = a sharp point). The crystals are colorless and transparent, though often faintly yellowish due to a thin coating of limonite. Acuminite is the second monoclinic polymorph of $SrAlF_4(OH)\cdot H_2O$; the other is tikhonenkovite, which differs from acuminite in its unit cell, crystal habit and optical properties.

Bøgvadite $Na_2SrBa_2Al_4F_{20}$

Bøgvadite is found in the radiating aggregates in which jarlite occurs in Ivigtut, mentioned above. Thin sections showed bøgvadite as rectangular, uniformly oriented crystals 0.1 to 0.2 mm across, arranged as a somewhat irregular pavement covering a few square centimeters in the central part in a few of these radiating aggregates. The crystals, partially overgrown with ralstonite, occur embedded in a matrix of fine-grained barite and a kaolinite-like mineral. Bøgvadite crystallizes orthorhombically; the somewhat rounded and strongly corroded, blocky crystals show {010}, {110} and {012}. The crystals are colorless, transparent, and have a vitreous luster. Bøgvadite is named after the late R. Bøgvad, chief geologist at the Ivigtut mine until his death in 1952.

Columbite $(Fe^{+2},Mn^{+2})(Nb,Ta)_2O_6$

Columbite was first found in Greenland by J. W. Tayler in 1851, and described by Breithaupt as a new mineral under the name "grønlandite"; but the mistake was soon corrected. It was always found crystallized—in the pegmatite bordering the cryolite mass. Columbite is the first-formed of all the minerals, and is generally fully euhedral. The size of the crystals varies from about 2 mm to 2 cm. The crystals of Ivigtut columbite have the greatest abundance of faces known: in all 24 different forms have been described. The faces are generally very lustrous, and the small crystals can therefore be very attractive.

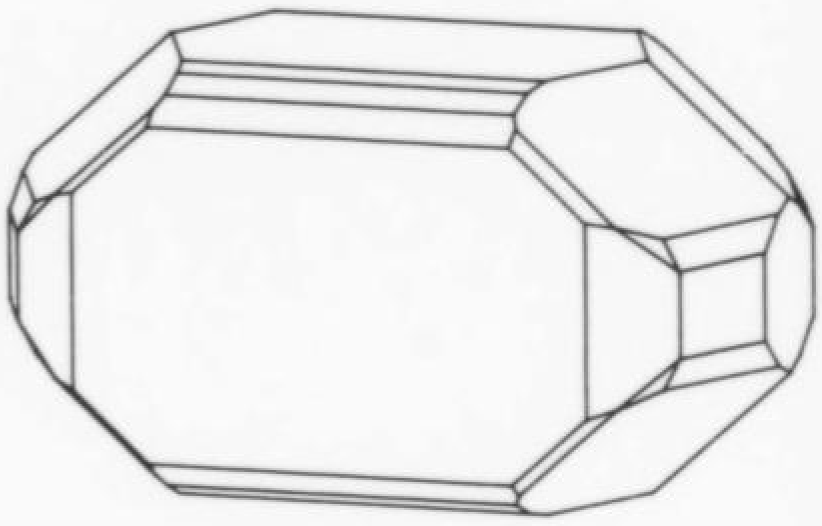


***Figure 56*. Drawing of an idealized crystal of columbite. The crystals from Ivigtut have the greatest abundance of faces known; 24 different forms have been identified. On typical crystals like the one shown here "only" 12 are present: {100}, {010}, {001}, {110}, {130}, {103}, {106}, {203}, {121}, {133}, {233} and {263}.**

***Table 3*. Minerals from Ivigtut.**

Acanthite
Acuminite
Aikinite
Albite
Apatite
Arcubisite
Arksutite†
Arsenopyrite
Barite
Barytocelestine
Berryite
Biotite
Bismuth
Bismuthinite
Bøggildite
Bøgvadite
Böhmite
Boulangerite
Bournonite
Canfieldite
Cassiterite
Celestine
Chalcopyrite
Chalcocite
Chiolite
Chlorite (group)
Coffinite
Columbite
Cosalite
Covellite
Cryolite
Cryolithionite
Cubanite
Diaspore
Elpasolite
Emplectite
Enargite
Eskimoite
Fluorite
Freibergite
Galena
Gearksutite
Goethite
Gold
Gustavite
Hagemannite†
Hematite
Hessite
Hexastannine†
Hornblende
Ilmenite
Ivigtit†
Jarlite
Kaolinite
Kesterite
Lepidocrocite
Mackinawite
Magnetite
Malachite
Marcasite
Matildite
Metajarlite†
Microcline
Molybdenite
Muscovite
Orthoclase
Ourayite (?)
Pachnolite
Prosopite
Pyrargyrite
Pyrite
Pyrrhotite
Quartz
Ralstonite
Rutile
Siderite
Silver
Sphalerite
Stannite
Stenonite
Tapalpite†
Teallite
Thomsenolite
Thorite
Thorogummite
Topaz
Uraninite
Vikingite
Volynskite
Weberite
Wittichenite
Wolframite
Wulfenite
Zinnwaldite
Zircon

? Identity/location uncertain
† Dubious species

Figure 58. **It is hard to imagine any mineral locality more beautifully situated than Narssârssuk. This picture illustrates what meets the eye at the Tunugdliarfik (Tunulliarfik) Fjord: a row of icebergs produced by the glacier in the Qoroq (Qooroq) Fjord and stranded on an old terminal moraine. Photo by O. V. Petersen.**

The Narssârssuk Pegmatite

HISTORY

In 1893 the great Swedish mineralogist Gustav Flink had the opportunity to examine a large and very interesting collection of Greenland minerals. These had been collected by Eskimos, then sent by Danish colonists to Sweden and there sold anonymously. When Flink published his first description of the minerals in 1893 (including neptunite, epididymite, catapleiite, aegirine, arfvedsonite, quartz, orthoclase, plagioclase, mica, epidote, eudialyte, calcite, fluorite and graphite—neptunite and epididymite were at that time new species), he did not know with certainty where in Greenland the minerals had come from. On the basis of the presence of eudialyte, arfvedsonite and aegirine in the collection, Flink concluded that the minerals originated from the pegmatites of Kangerdluarssuk (Kangerluarsuk) or Tunugdliarfik (Tunulliarfik) in the well-known Ilímaussaq complex not far from Julianehåb (Qaqortoq), even though pegmatitic pockets, like the ones in which the minerals in the collection had obviously grown, were not known to occur here.

Shortly after Flink's publication appeared, the Danish mineralogists Ussing and Steenstrup expressed their doubt that these minerals came from Ilímaussaq; they were both of the opinion that they came from a locality called "Narsasik near Igaliko," visited by Steenstrup in 1888.

Figure 59. **In 1968 Ole V. Petersen began digging a trench across the central part of the Narssârssuk occurrence, a trench that in 1969 reached a depth of more than 3 meters. A plastic cover protected, at least to some extent, the author and his assistant from the rainy Greenland weather; photo by O. Johnsen.**

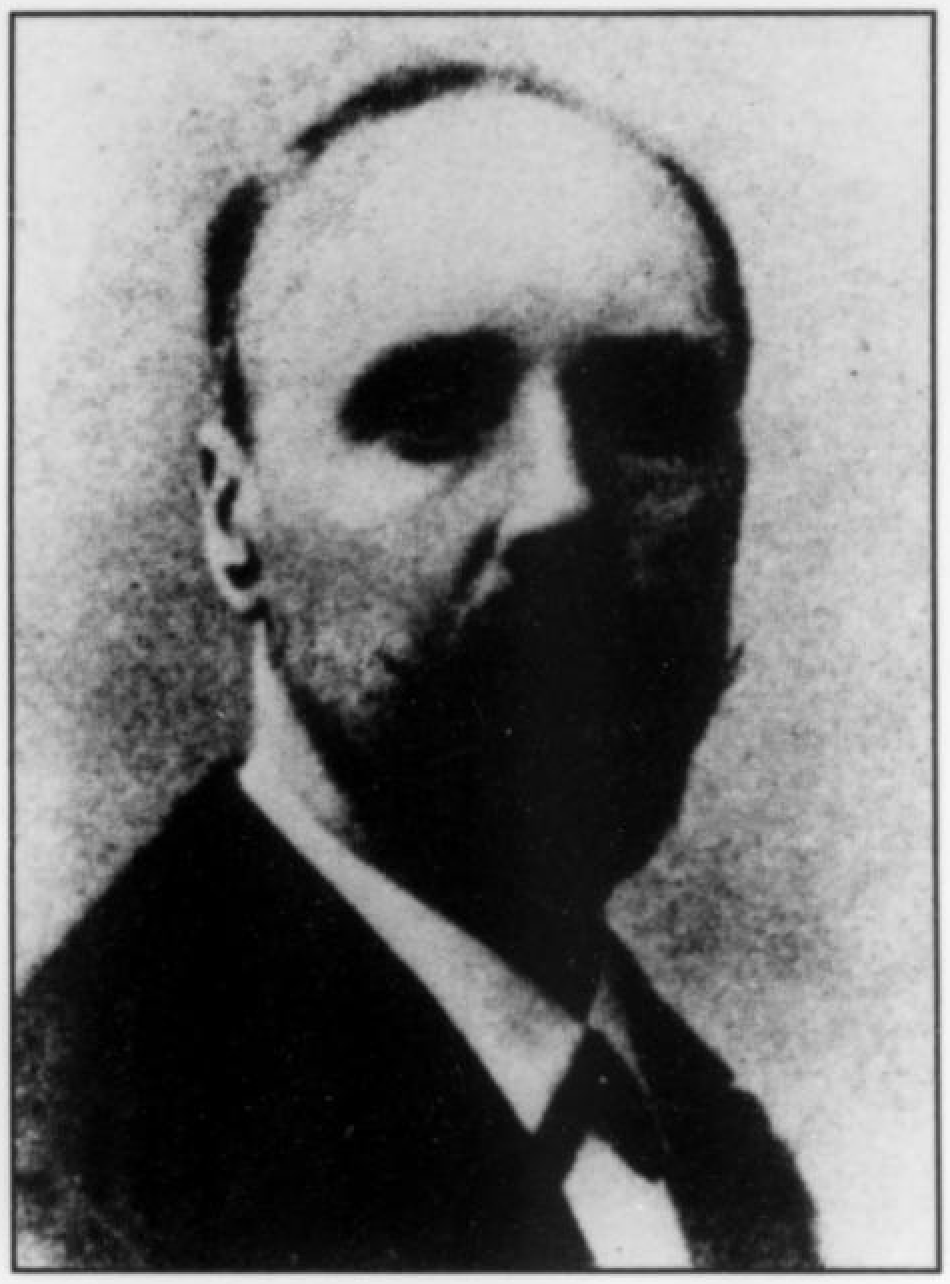


***Figure 60.* The Swedish mineralogist Gustav Flink (1849–1932) described in 1893 a highly interesting mineral collection including specimens of the new species neptunite and epididymite. In 1897 he found the small outcrop from which the material originated—now-famous Narssârssuk on the narrow strip of land between the two fjords Tunugdliarfik (Tunulliarfik) and Igaliko (Igaliku).**

It is understandable that Flink was interested in visiting the locality where this rich collection had originated. In addition to neptunite and epididymite, a third new species, *elpidite*, had been found in the collection and described by Lindström in 1884. However, the opportunity did not arise until 1897 when the "Commission for the Direction of Geological and Geographical Investigations in Greenland" hired Flink to undertake mineralogical investigations in certain parts of South and southwest Greenland. Because his account of the journey gives not only a good picture of the conditions under which the pioneers of mineralogy worked in Greenland in the last century, but also an exciting account of how he found the place where the minerals in the collection had originated, a shortened and translated version of his account is reproduced here:

> I left Copenhagen on the 2nd of June in the *Fox II*, belonging to the Cryolite Mining and Trading Company. After a pleasant journey we arrived at the Arsuk-Fjord on the 15th of June; as usual at that time of the year, the passage to Ivigtut was complicated by ice, and we did not reach Ivigtut until the 17th. Since my instructions were to finish the summer season in Ivigtut, the most important problem was to find transportation to the main working area near Julianehåb as soon as possible. I was able to leave on the 21st in a small boat manned by people from the small trading post at Arsuk. After three days of rowing, we reached Kagsimiut, where we had to change boat and crew. In a normal *umiak* (a boat for about ten persons, made of wood and seal skin and rowed by women) we reached Julianehåb in two days.
>
> After my arrival I learned from the people in Julianehåb that people from Igaliko periodically brought minerals to the foreman, and that they had done so at the time when Lytzen was foreman. [This information apparently led Flink to the conclusion that the collection he had examined in 1893 originated with Lytzen; in subsequent publications Flink refers to this as the "Lytzen collection."] I therefore decided to continue to Igaliko. A small sailing boat with a crew consisting of a mate, three male and one female rowers, all Greenlanders, and all other necessary equipment for the summer were placed at my disposal. Although the crew and I could hardly speak together, we succeeded, due to good will, in making ourselves understood to each other. On the whole they followed me the entire summer and did almost all they were ordered to, to my entire satisfaction.
>
> Shortly after my arrival [at Igaliko] I learned from an elderly Greenlander that minerals like the ones I was looking for (large aegirine crystals) were to be found in the direction of Igdlerfigssalik Mountain, and he offered to guide me to the place. We (my mate Paulus, the above-mentioned Greenlander Job, and I) started from Igaliko in the morning of June the 27th at 8:30. After about two hours' walk, including an ascent to about 300 meters, we found ourselves on a plateau, called Narsársuk Kaká. The plateau is bounded on the east by Igdlerfigssalik peak, almost 1,800 meters high; towards the west by a small depression; and to the south and north by the steep walls of the Igaliko and the Tunugdliarfik Fjords, respectively. On our way across the plateau from south to north, we walked along the borderzone of a granite, but very soon we were in typical syenite gravel. The gravel, which from the beginning was very uniformly grained, soon started to contain larger fragments of arfvedsonite and feldspar. As we progressed the number of fragments of these two minerals increased and fragments of aegirine and quartz emerged; suddenly we found ourselves standing in an area consisting entirely of loose crystals and fragments of crystals! Some of the scattered mineral treasures had been heavily weathered, but other crystals were as fresh and shiny as when they were released from their pockets. The crystals of aegirine, epididymite and elpidite were identical with those I had described from the Lytzen collection. [Flink ends his account with the following remarks:] This very peculiar mineral occurrence is quite small; one can walk around the entire area in less than 20 minutes. Nevertheless, few, if any, mineral occurrences show so many interesting things directly spread on the ground, not to mention the treasures which must be hidden under the surface.

Flink collected a very large amount of material, much of which is now in the mineral collection of the Geological Museum, Copenhagen, and the National Museum of Natural History, Stockholm. In the following years up to 1905 a very large amount of material, some of it quite valuable, was collected by Greenlanders and sent to Copenhagen, Denmark. Since then, several geologists and mineralogists have visited the occurrence, including Samuel G. Gordon of the Academy of Natural Sciences in Philadelphia. He visited Narssârssuk in the early 1920's and, with the help of Greenlanders, made extensive excavations. The material he collected is still in the possession of the Academy of Natural Sciences in Philadelphia.

One of us (OVP) visited Narssârssuk for the first time in 1963; in 1968, 1969 and in 1970, I spent altogether approximately four months at the occurrence. Extensive excavations to depths of several meters brought fresh, new material to light and yielded information about the pockets in which the minerals occur. From the material collected the rare minerals barylite and nordstrandite were identified, both species that were previously not known from Greenland. My latest visit to the occurrence was in 1988 when I led a Danish international scientific expedition, with participation from Canada and Australia. The main purpose of the expedition was to study the distribution, the form and the paragenesis of the mineral pockets, to collect material

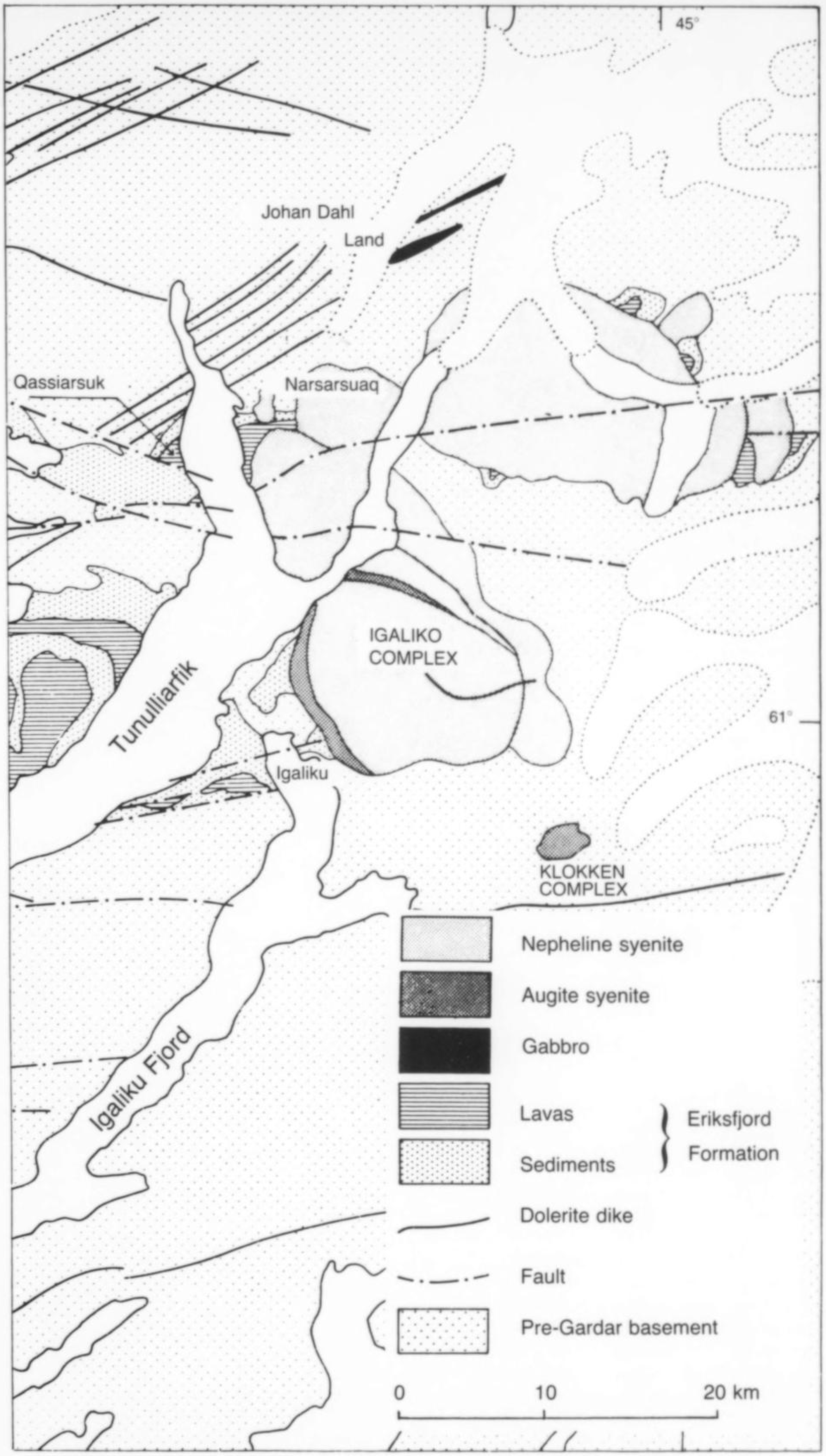


Figure 61. Geological map showing the Igaliko complex. The map shows particularly well the four major intrusive centers. The Narssârssuk pegmatite is situated at the westernmost margin of the Igdlerfigssalik center.

for modern mineralogical investigations of the minerals for which Narssârssuk is the type locality, and to begin cooperation with our Canadian colleagues on a comparison of the minerals and parageneses of Narssârssuk and Mont Saint-Hilaire, Quebec. The work on the collected material is still proceeding, but it can already be concluded that several exciting specimens were contained in the large amount of material collected. One, for example, shows the world's largest specimen of the extremely rare mineral leifite, named after Leif the Lucky, son of Eric the Red, the discoverer of Greenland in 982.

GEOGRAPHY and GEOLOGY

The Igaliko nepheline syenite complex covers an area of about 450 square kilometers between Tunugdliarfik (Tunulliarfik) and Igaliko Fjords (Igalikup kangerlua) to the west and the Inland Ice to the east. The scenic beauty of this part of Greenland, with its contrasts between the relatively fertile lowland areas between the fjords and the rough, barren and glaciated highlands crowned by the 1,752 meter Igdlerfigssalik (Illerfissalik) peak, is well-known and appreciated by the tourists visiting the area every year. In addition to great scenic beauty, this area possesses a profusion of historical monuments from the Viking Age.

The complex consists of four major intrusive centers and several small satellite stocks. Within each center the individual intrusions have arcuate, steep-sided outcrops with discordant, intrusive relations toward earlier members. Igneous layering and mineral lamination are common internal structures within the individual intrusions. The mineralogy of the syenites is usually simple: perthitic alkali feldspar and alkali pyroxene are the dominant minerals, accompanied by fayalitic olivine, alkali amphibole, biotite, analcime, natrolite and apatite. Except where locally contaminated by assimilation of country rock, the Igaliko syenites are all nepheline-bearing; the most common type is foyaite.

The comparatively small outcrop of the celebrated Narssârssuk pegmatite is in the westernmost margin of the Igdlerfigssalik center, and appears to be genetically related to the intrusion of a porphyritic microsyenite.

MINERALOGY

Minerals occur in a very large number of pegmatite pockets. Their habit is very irregular; generally they may be designated as more or less spherical, but they do not extend so as to form veins or layers. The size of the pockets range from a few centimeters to more than a meter.

Potassium feldspar constitutes, together with aegirine, the main mass of the pegmatitic pockets. For the most part the feldspar, which forms the outer zone of the pockets, is found in the form of irregularly bounded individual crystals frequently epitaxially overgrown with extremely well-developed, colorless and transparent crystals of albite. Aegirine is the only other mineral also present in the pockets.

The first generation of aegirine, which forms stout crystals on and in between those of the feldspar, has a crystal habit, but as a rule only the prismatic zone is developed. Both minerals often occur as very large individuals. With a few exceptions, all the other minerals at Narssârssuk form relatively well-developed crystals in the interstices between the feldspar and aegirine crystals, or project into the drusy cavities in the central part of the pockets.

In addition to feldspar and aegirine, the first phase of crystallization consisted of normal nepheline syenite pegmatite minerals: eudialyte, elpidite, astrophyllite, eudidymite, narsarsukite, catapleiite, neptunite, polylithionite and many others, possibly also including fluorite. This first cycle seems to have ended with the crystallization of quartz in the interstices between the other minerals, and with the formation of rather large crystals of quartz in the central part of many pockets.

Following the period of crystallization, new hydrothermal solutions of different compositions caused dissolution, especially of the quartz. Most of the crystals are strongly etched, frequently so much that the forms are quite effaced. On the somewhat less corroded crystals, regular etching figures are frequently seen. Renewed crystallization from these solutions, mainly carrying CO_3^{-2} but also F^{-1} and OH^{-1}, initially caused the formation of the calcite-rhodochrosite. A great variety of minerals, some very rare and many of them first described from Narssârssuk, belong to this phase of crystallization: fluorite, synchysite, cordylite, ancylite, chalcolamprite, endeiolite, apatite, (yttrian), tetranatrolite-gonnardite and nordstrandite.

Partly contemporaneous with this crystallization, new hydrothermal solutions of compositions comparable to those of the first phase caused some dissolution of the just-formed calcite-rhodochrosite, followed by renewed crystallization of late generations of aegirine, astrophyllite, epididymite and a few other species abundant in the first phase. Very late alteration of the calcite-rhodochrosite has led to the formation of different alteration products (oxides of manganese and iron) which in many cases constitute an essential part of the contents of the pockets. In other cases they have been more or less washed out of the pockets.

The investigations in 1988 showed that near the border of the porphyritic microsyenite (in which the above-mentioned pockets are found) another type of pegmatites occurs. These pegmatites are found in connection with cubic-meter, recrystallized sandstone inclusions, which they surround completely. These pegmatites are coarse-grained, and their mineralogy is simple: besides feldspar and aegirine, they consist of eudialyte and plenty of quartz, the only rare mineral seems to be narsarsukite.

Close to 60 minerals are known from the Narssârssuk pegmatite; 12–13 of these must be regarded as rare, having been found at very few other localities. Sixty minerals, considering the size of the area in question, is a relatively large number. But it is not because of its richness in minerals that Narssârssuk is famous. Two factors have contributed: (1) the fact that 16 of the 60 minerals were found here for the first time, i.e. Narssârssuk is the type locality of 16 mineral species, and (2) that the majority of the minerals occur as well-developed microcrystals.

The minerals from Narssârssuk, divided into chemical classes, show a distribution that differs significantly from the distribution in the mineral world as a whole. The most remarkable differences are the far higher, more than twice as high, percentages of silicates and carbonates at Narssârssuk. The minerals from Narssârssuk contain the following elements: Al, B, Ba, Be, C, Ca, F, Fe, K, Li, Mg, Mn, Na, Nb, O, P, Pb, S, Sn?, REE (Ce, La, etc.), Ta, Ti, Y, Zn and Zr, not to mention trace elements. Some of these elements occur in several of the 60 minerals, others in only a few; oxygen is, of course, the most widespread, and Si is the second most common, followed by Na, Ca, Fe, Al, and REE, calculated from the number of minerals in which they occur; B, Sn? and Ta are the rarest.

A detailed description of all the minerals is beyond the scope of this work, but some of the most interesting features of a number of selected species are given below.

Orthoclase $KAlSi_3O_8$

Orthoclase constitutes, together with aegirine, the main mass of the pegmatite bodies. It occurs, for the most part, in the form of irregularly bounded individuals, but a number of crystals have been found which are very well developed. The faces may be very flat and lustrous, but the form {110} is more commonly overgrown with albite; many crystals are entirely enclosed in albite, in crystallographic continuity. The color is whitish to grayish. The crystals are often twinned, almost always according to the Carlsbad law.

Albite $NaAlSi_3O_8$

Albite occurs in more beautiful specimens than orthoclase. It is found in large quantities, scattered about on many different minerals. As already mentioned, it is very often found on the potassium feldspar crystals as parallel overgrowths. The individual crystals are not par-

Figure 62. **This particularly well-developed Carlsbad twin of orthoclase was found by Ole V. Petersen during his first visit to Narssârssuk in 1963. Note particularly that both individuals on this 6-cm twin have two different prisms and also pyramids; photo by O. Johnsen.**

ticularly large, rarely exceeding 2 cm, but they are extremely well developed and rich in faces which are completely smooth and lustrous. Thirty-two crystal forms have been identified with certainty. The crystals are mostly transparent and colorless, but a few of them are beautifully rose-colored. With 0.02 weight % CaO and no detectable K_2O, this albite from Narssârssuk is among the purest albitic albites known, surpassed only by the albite from the nearby Ilímaussaq complex, which contains no detectable CaO or K_2O.

Aegirine $NaFe^{+3}Si_2O_6$

Next to feldspar, aegirine is the most common mineral at Narssârssuk and the only other mineral always present in the pegmatite pockets. Because aegirine is more apt to resist decomposition than most other minerals, the crystals are (as already observed by Flink) found in large numbers lying loose in the residual gravel. The size of the crystals varies; the largest are about 20 cm long and 8 cm thick. The crystals of this first generation of aegirine are simple, with lustrous prism faces, but striated, the others are uneven and dull, the crystals of the later generations are smaller and considerably more complicated.

Eudialyte $Na_4(Ca,Ce)_2(Fe^{+2},Mn^{+2},Y)ZrSi_8O_{22}(OH,Cl)_2$ (?)

At Narssârssuk eudialyte occurs as crystals and as irregularly shaped masses filling interstices between feldspar, aegirine and quartz. The crystals, up to 5 cm in size, always have uneven, dull faces. Some eudialyte is transparent and shows a purer, more intense red color. Eudialyte crystals to 8 cm occur pseudomorphically replaced by a mixture of aegirine and elpidite; some of these are brick-red in color, like unaltered elpidite, and others are pale gray.

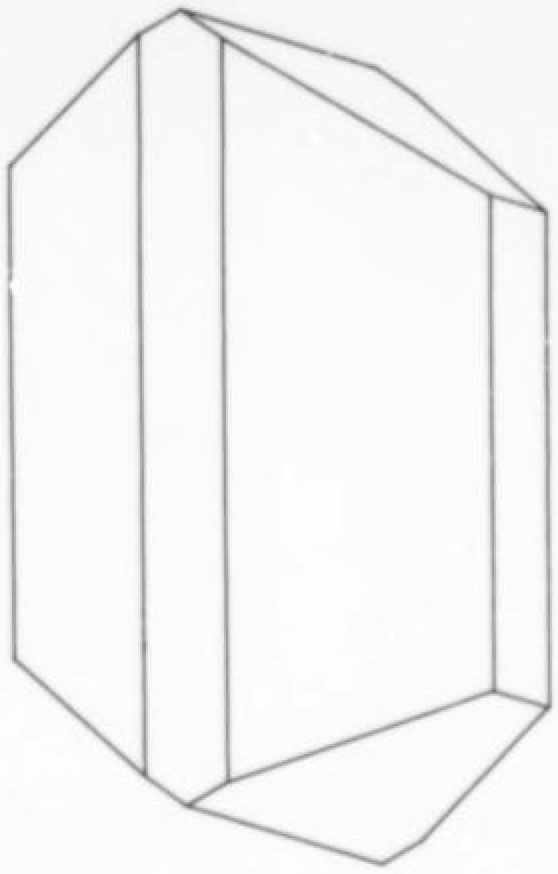


Figure 63. **Drawing of an idealized crystal of aegirine. At Narssârssuk the first-generation crystals are normally quite simple and show nothing but the forms $\{100\}$, $\{010\}$, $\{110\}$ and $\{\bar{1}11\}$, like the one shown here.**

Neptunite $KNa_2Li(Fe^{+2},Mn^{+2})_2Ti_2Si_8O_{24}$

Two of the mineral species described by Flink in his first treatise on the minerals in the Lytzen collection, neptunite and epididymite, were at that time new to science. Most mineral collectors are familiar with the spectacular neptunite specimens from San Benito County, California, where it occurs associated with benitoite, jonesite, natrolite and joaquinite. Only a few, however, are aware that Narssârssuk is the type locality for this species and that it, too, has yielded crystals

Table 4. **Minerals from Narssârssuk.**

Acmite
Aegirine
Aenigmatite
Albite
Analcime
Ancylite
Apatite
Apatite (yttrian)
Arfvedsonite
Ashcroftine
Astrophyllite
Barylite
Bastnäsite
Biotite
Calcite
Catapleiite
Cerussite
Chalcolamprite†
Cordylite
Elpidite
Endeiolite†
Epididymite
Epidote
Eucolite†
Eudialyte
Eudidymite
Ferrohornblende
Fluorite
Galena
Gaydonnayite
(catapleiite-alpha)
Goethite
Gonnardite
Graphite
Hematite
Hemimorphite
Ilmenite
Leifite
Lepidocrocite
Leucophanite
Leucosphenite
Lorenzenite
Magnetite
Microcline
Microlite
Narsarsukite
Natrolite
Neptunite
Nordstrandite
Orthoclase
Polylithionite
Pyrochlore
Pyrolusite
Quartz
Rhodochrosite
Riebeckite
Riebeckite (variety
Crocidolite)
Röntgenite
Smithsonite
Soda-orthoclase (?)
Sphalerite
Spodiophyllite†
Synchysite
Taeniolite
Tetranatrolite
Xenotime
Zircon

? Identity/location uncertain
† Dubious species

***Figure 64*. This particularly well-developed eudialyte crystal, about 1.4 cm, is intergrown with an aegirine crystal. Like many of the eudialyte crystals from Narssârssuk, it is actually a pseudomorph consisting of mixtures of aegirine, elpidite and possibly zeolites; photo by R. Bode.**

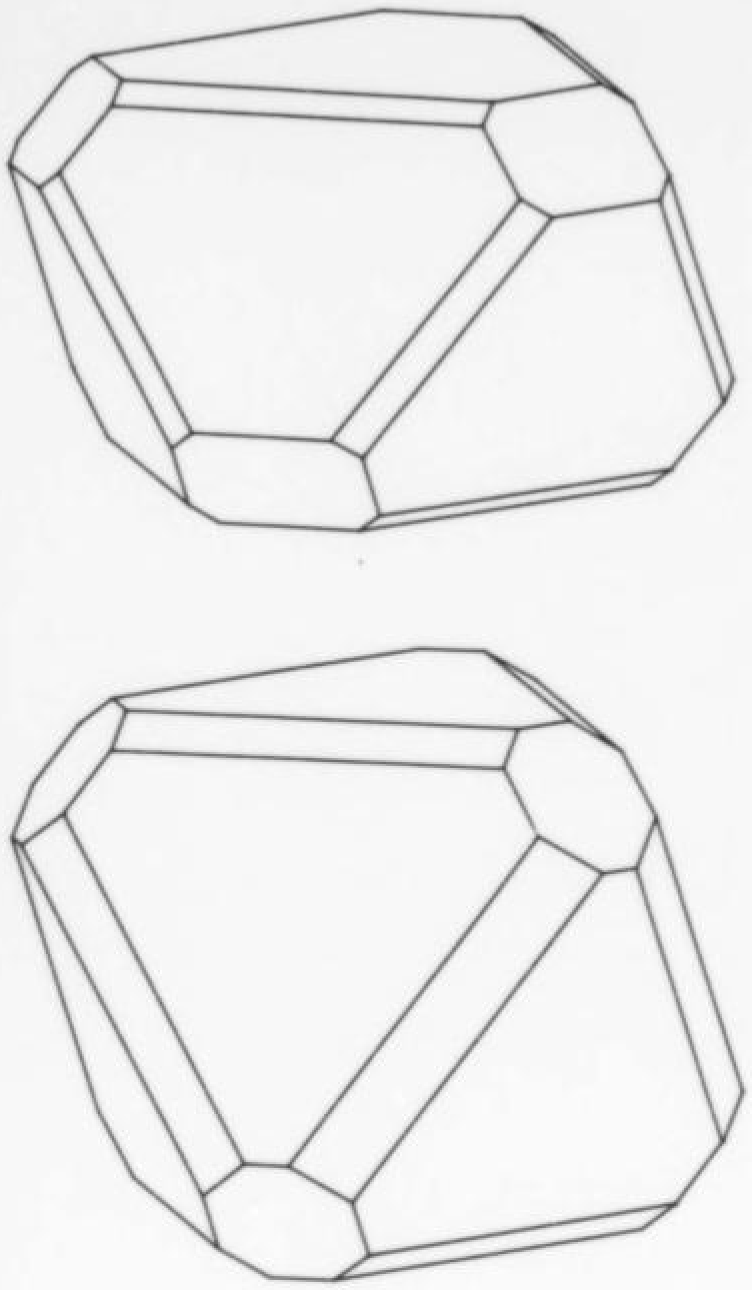


***Figure 65*. Drawing of idealized crystals of eudialyte. The following forms are developed: $\{0001\}$, $\{11\bar{2}0\}$, $\{10\bar{1}1\}$, $\{10\bar{1}4\}$ and $\{01\bar{1}2\}$.**

of good quality. The habit of the crystals from Narssârssuk varies considerably; altogether five different habits have been described. Most of the crystals are found on either aegirine or feldspar. The crystals are black, up to 5 cm (!) in size, and with generally flat and very lustrous faces. Neptunite at Narssârssuk resembles some titanite, but may be distinguished by the deep blood-red color of thin shards. Flink named the mineral after Neptune, because aegirine had been named after Aegir, the Scandinavian god of the northern seas. It is remarkable that, although the Lytzen collection and Flink's own collection contained rather large numbers of neptunite specimens (in fact the Lytzen collection contained so many that Flink called Narssârssuk "the neptunite occurrence"), not very many specimens have been found since then.

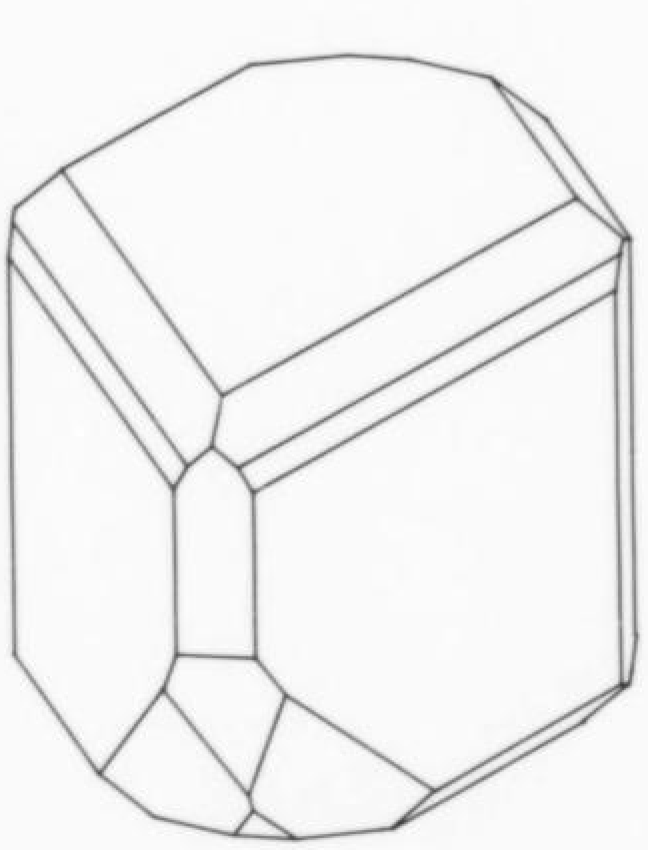


***Figure 66*. Drawing of an idealized crystal of neptunite corresponding to the one shown in the previous figure. The forms developed are: $\{100\}$, $\{010\}$, $\{001\}$, $\{110\}$, $\{\bar{2}10\}$, $\{\bar{3}01\}$, $\{111\}$, $\{\bar{1}11\}$, $\{221\}$ and $\{\bar{5}12\}$.**

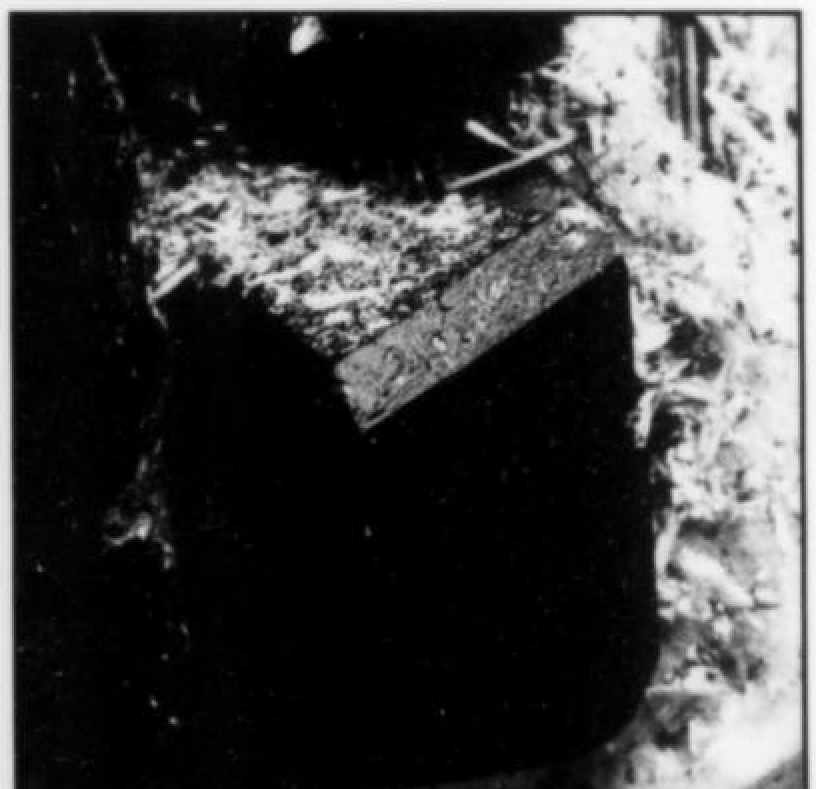


***Figure 67*. The habit of the neptunite crystals from Narssârssuk varies considerably. The type shown here has been found in rather large crystals up to almost 5 cm. This well-developed crystal, partly covered by elpidite, is no more than 5 mm; photo by M. Hansen.**

Figure 68. Epididymite often forms interpenetration trillings with {110} and {1$\bar{1}$0} as the twin planes. The figure shows a particularly large such trilling, fully 2 cm across; photo by R. Bode.

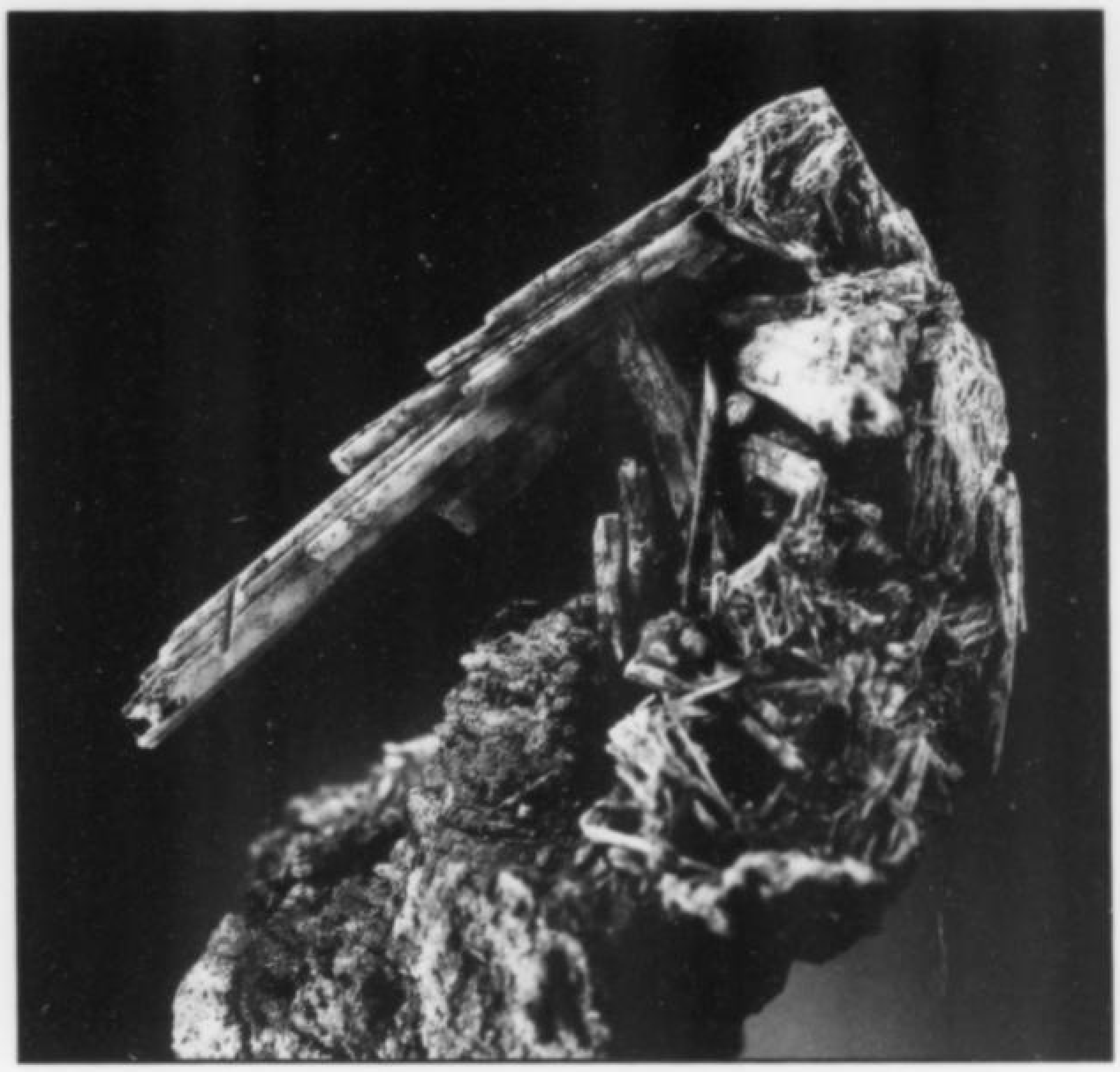


Figure 69. Elpidite rarely forms well-developed crystals. Most often the crystals are grown together in a felt-like mass. Shown here is a particularly large one—5.5 cm—with its characteristic brick-red color; photo by R. Bode.

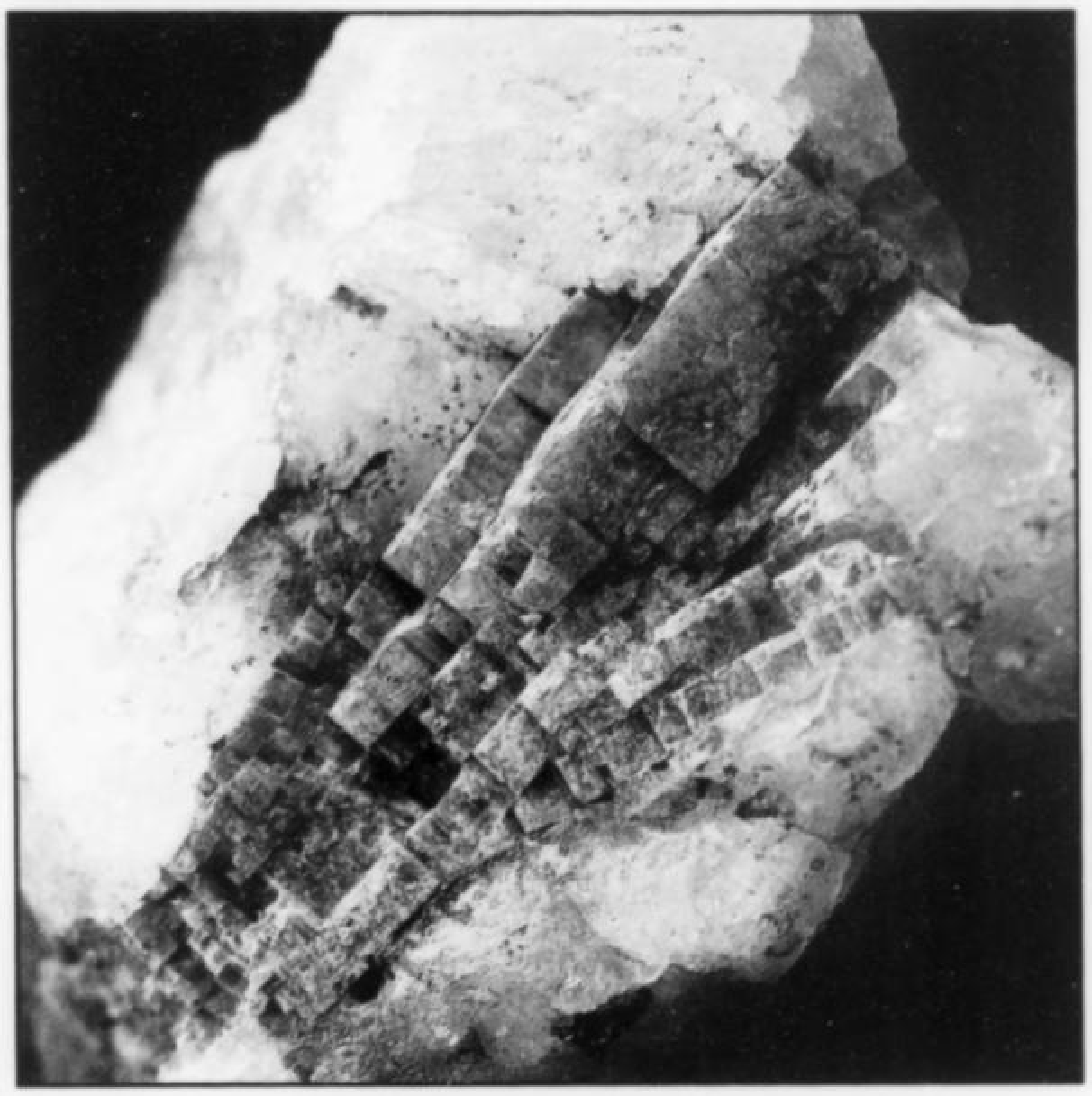


Figure 70. The 5.5-cm narsarsukite aggregate of yellow, platy crystals in quartz shown here is one of the largest, very typical of Narssârssuk. The name, given by G. Flink, is particularly justified as the mineral occurs here in large quantities; photo by R. Bode.

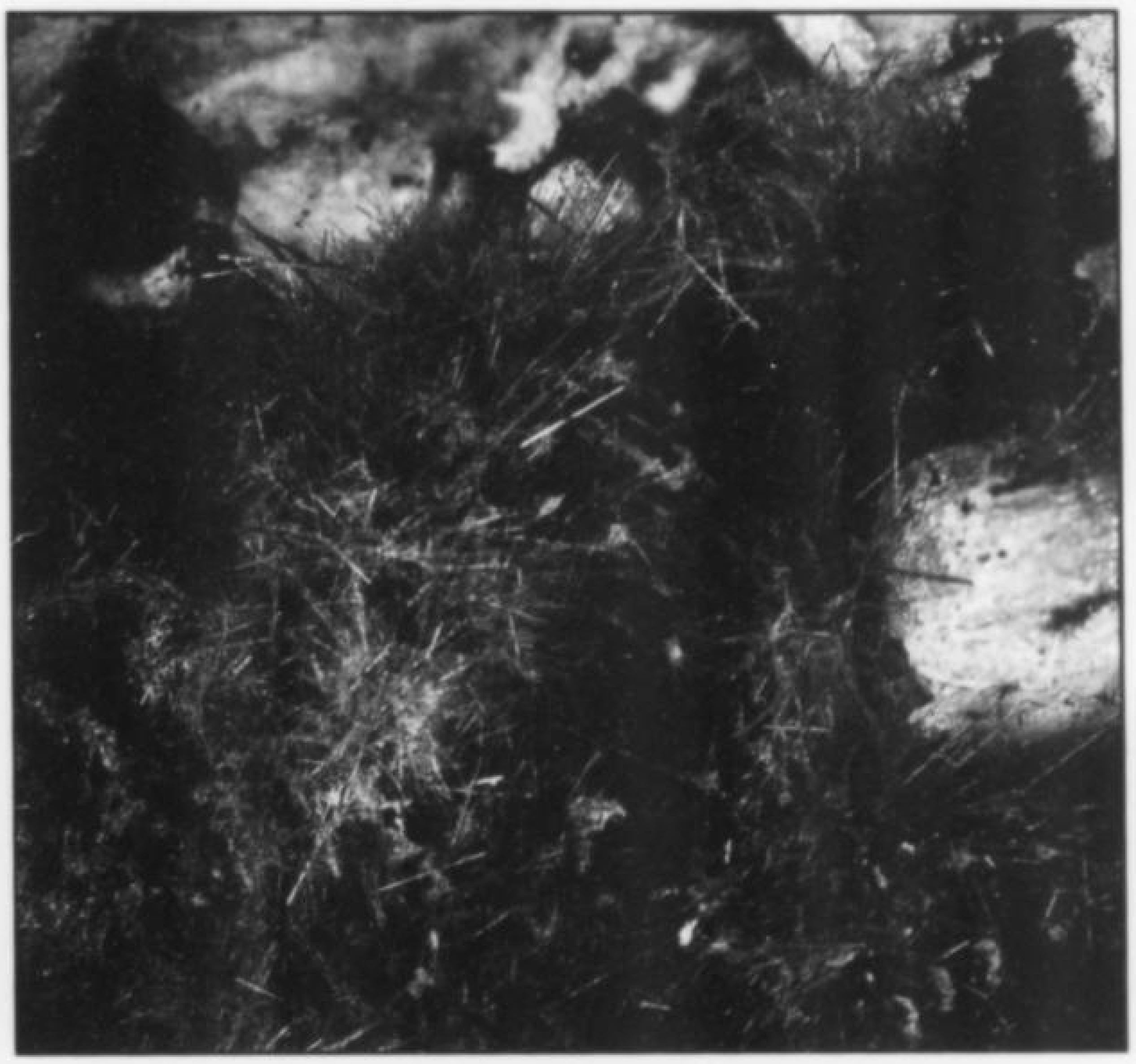


Figure 71. Astrophyllite is one of the most beautiful minerals found at Narssârssuk. Felt-like masses of ruler-shaped, golden colored crystals with almost metallic luster, like those shown here, are typical; actual size, 5.5 cm; photo by R. Bode. This mineral was not among those identified by G. Flink; the first specimens were found by Greenlanders and sent to the Geological Museum, Copenhagen, in 1905.

Epididymite $NaBeSi_3O_7(OH)$

The second new mineral species which Flink recognized in the Lytzen collection is the orthorhombic dimorph of eudidymite, first described by W. C. Brøgger from the Oslo region, Norway, in 1887. It has been found in rather large quantities, alone and in association with several of the minerals characteristic of the occurrence. The pseudohexagonal crystals are commonly very well developed, rich in faces, and considerably varied in habit. Epididymite often forms very

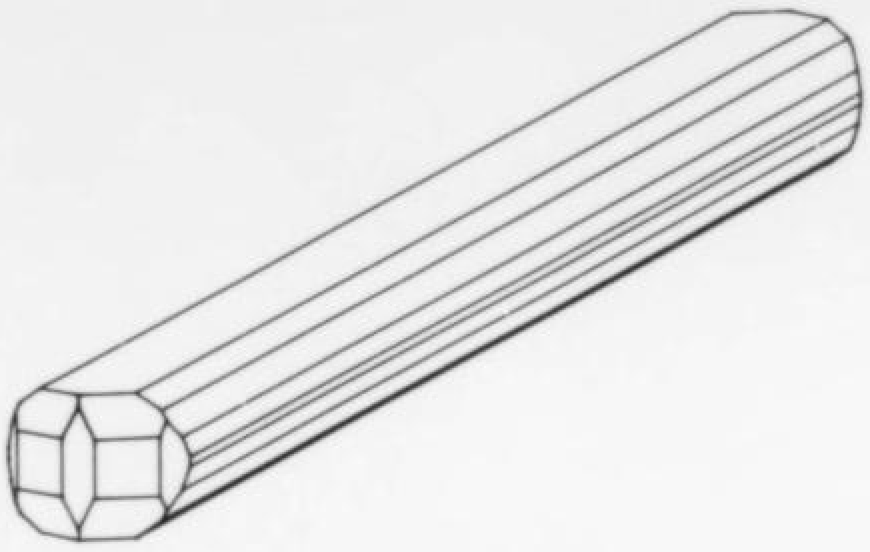


***Figure 72*. Drawing of an idealized crystal with the most common habit of epididymite from Narssârssuk, elongated along the *a* axis and slightly flattened parallel with {001}. The forms developed are: {100}, {$\bar{0}$10}, {001}, {110}, {310}, {011}, {021}, {038} and {311}.**

beautiful penetration twins or trillings. It is colorless and transparent, with a vitreous luster. The optical properties, however, are very peculiar; the mineral shows what is called crossed axial plane dispersion. Only four other mineral species are known to show the same effect, brookite being the best known of these.

Elpidite $Na_2ZrSi_6O_{15}\cdot 3H_2O$

Within a year of Flink's first work on the minerals in the Lytzen collection (describing the two new species neptunite and epididymite) Lindström and Nordenskiöld presented a third new species found in the collection, elpidite. The name is derived from the Greek word meaning "hope," as this mineral and the minerals occurring together with it in the Lytzen collection made it likely that the locality might prove to be a very rich mineral occurrence.

Elpidite is one of the most widely distributed of the rarer minerals at Narssârssuk. The elongated, rhombic crystals are rarely well-developed, and then always very small. The larger crystals, up to 10 cm long and 2 cm thick, are always incomplete and frequently distorted and broken or cleft into thin points at one end. The crystals are often grown together in confused, more or less compact felt-like masses. The larger crystals and the felt-like masses are opaque, whitish, grayish or yellowish; most characteristic, however, is a brick-red color by which the mineral is easily distinguishable. The luster is silky or entirely dull; the crystals are generally very inconspicuous in appearance, resembling half-rotted wood.

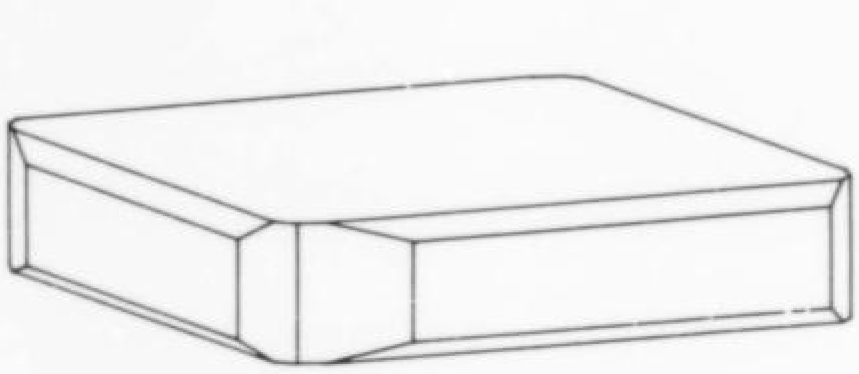


***Figure 73*. Drawing of an idealized crystal of narsarsukite, platy on {001}, and with the following additional forms: {100}, {110}, {210} and {111}.**

Narsarsukite $Na_2(Ti,Fe^{+3})Si_4(O,F)_{11}$

Narsarsukite is among the best-known minerals from Narssârssuk. The name was given by Flink, who in his first treatise called it "yellow tabulae." The name is well justified, considering that the mineral occurs in large quantities at this locality. It is generally accompanied by the most common pegmatite species at this locality—feldspar and aegirine. But it nearly always occurs together with quartz as well. Narsarsukite crystallizes tetragonally; most crystals are poorly developed and tabular parallel to the base. The luster is vitreous (on the cleavage faces pearly), and the color is honey-yellow to brownish gray when decomposed.

Astrophyllite $(K,Na)_3(Fe^{+2},Mn)_7Ti_2Si_8O_{24}(O,OH)_7$

Astrophyllite is among the most beautiful of all the minerals found at Narssârssuk. Considering its abundance, it is surprising that specimens were not included in the Lytzen collection, nor were any among the minerals collected by Flink in 1897. The first specimens, collected by Greenlanders, were sent to the Geological Museum in Copenhagen in 1905; during the years immediately following a rather large amount of additional material was collected. In most species the mineral occurs as very thin needles and ruler-shaped crystals. The greater part forms acicular crystals and loose felted masses, but the needles may also be found penetrating other minerals, such as albite and catapleiite. The crystals attain lengths up to several centimeters. The color is yellow-brown to golden-yellow, and the luster is almost metallic.

Material like this—felted masses of fragile, acicular crystals—suffers under conditions, like those at Narssârssuk, which promote fast decomposition of the host rock and rapid weathering of minerals. In most of the material collected prior to a spectacular find by one of us (OVP) in 1969, of fresh material from a pocket at nearly 4 meters depth, the potential beauty of the species has not been well represented. Like all other pockets at Narssârssuk, this one consisted of an outer zone of feldspar, followed inwards by a zone of aegirine. From the roof and the walls fantastic formations of acicular astrophyllite projected into the pocket. The work of detaching these specimens, in a narrow trench, standing almost up-side-down, without destroying the specimens was rather exciting. In addition to a profusion of undamaged and completely fresh astrophyllite specimens of a hitherto unseen beauty, this pocket produced very beautiful, large, pink albite crystals; fresh deep green crystals of aegirine; and a wealth of cordylite crystals of an unusual habit.

Optically astrophyllite (although triclinic) shows parallel extinction on all faces in the zone [100] including the two pinacoids (001) and (010), as well as on the third pinacoid (100). On (100) and (010) the extinction is parallel to the trace of the mica-like cleavage, and on (010) and (001) it is parallel to the needle axis.

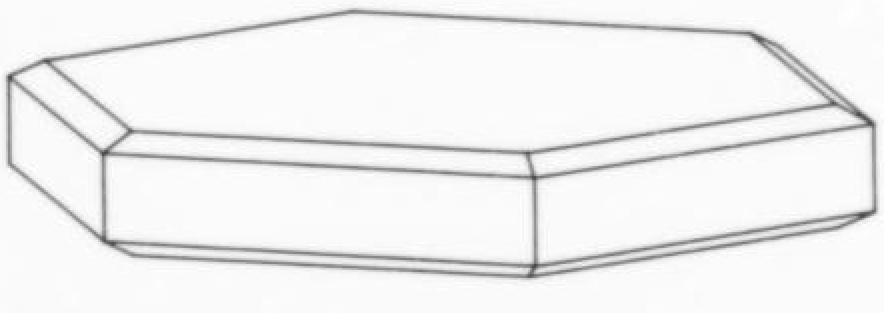


***Figure 74*. Drawing of an idealized crystal of catapleiite; the forms developed are: {0001}, {10$\bar{1}$0} and {10$\bar{1}$3}.**

Catapleiite $Na_2ZrSi_3O_9\cdot 2H_2O$

At the time Flink recognized catapleiite among the minerals present in the Lytzen collection, it was known only from the Langesund area, Norway. With the exception of some crystals mentioned by Gordon, all the Greenland crystals of catapleiite have a pronounced hexagonal form; they are tabular parallel with the base, and the edges are bounded by a prism and one or more pyramids. When optically investigated the crystals have proven to be composed of lamellae of lower symmetry. When the mineral is heated, all the lamellae disappear, but reappear when it is cooled. Several crystal types can be distinguished; the size varies from a few millimeters to 5 cm. The crystals are colorless to yellowish, or gray and gray-green, and are transparent with an adamantine luster (particularly on the base). The crystals are almost opaque, with the faces shining and iridescent with different colors.

In 1934, after his visit to Narssârssuk, Gordon described some crystals several millimeters in size and completely rhombic in habit, appearing not the least bit hexagonal; he called the mineral α-catapleiite. The material collected, kept in the Academy of Natural Science of Philadelphia, consists solely of two small hand specimens with a few crystals; similar material has not subsequently been found at Narssârssuk. However, almost half a century after Gordon's description, a mineral identical with his α-catapleiite was described from Mont Saint-Hilaire, Quebec, under the name of gaidonnayite.

Zircon $ZrSiO_4$

Narssârssuk zircon crystals are always well-developed, showing combinations of {111} with {110} or rarely {100}. The size of the crystals is generally 1 cm or less, but crystals as large as 3.5 cm have been found. The faces are lustrous, the color normally brownish, and rarely ash-gray. The most interesting feature of these Narssârssuk zircon crystals is the epitaxial overgrowth of xenotime-(Y), (YPO_4) found in the unweathered material, collected in 1969. The xenotime-(Y) forms colorless, transparent layers up to 1 mm thick on all crystal faces of the zircon.

Leifite $Na_2(Si,Al,Be)_7(O,OH,F)_{14}$

When Bøggild described leifite in 1915 he stated that nothing was known for certain about the occurrence. The type material, four small specimens weighing between 20 and 40 grams, was collected by Greenlanders and sent to the Geological Museum of Copenhagen, together with minerals from Narssârssuk. Among the accompanying minerals there are none of the rare species characteristic of the occurrence. Not until a few additional small specimens were collected in situ at Narssârssuk in the late 1960's and early 1970's, was the type locality for this species confirmed. Leifite occurs as incompletely developed, hexagonal prismatic crystals which are frequently deeply striated. The crystals may reach 2 cm long and 5 mm thick, but they may also be fine as hair. The mineral is colorless, transparent or white, and with a vitreous luster. The 3.8 weight % BeO was detected during a reinvestigation of the type material and the isotypical karpinskite from the Kola Peninsula, Russia, an investigation that ultimately led not only to the redefinition of leifite, but also to the discreditation of karpinskite.

Leucosphenite $BaNa_4Ti_2B_2Si_{10}O_{30}$

Leucosphenite was recognized as a distinct species and referred to as a "petalite-like" mineral by Flink in 1898. Three years later he gave a comprehensive description and named it; the name, which means "white wedge," is an allusion to the two most characteristic properties of the mineral. Narssârssuk leucosphenite crystals are monoclinic and always elongated parallel to the *a*-axis. The crystals are small (up to 5 mm in length), white with a gray-blue tint, and transparent or semitransparent. It has been found only in a small area, most often in association with masses of elpidite needles. Since the first discovery of this beautiful mineral, no more has been collected at Narssârssuk, and not until half a century later was the second occurrence of leucosphenite reported, this time from an entirely different environment—as an authigenic mineral in sedimentary rocks of the Green River Formation in northeastern Utah.

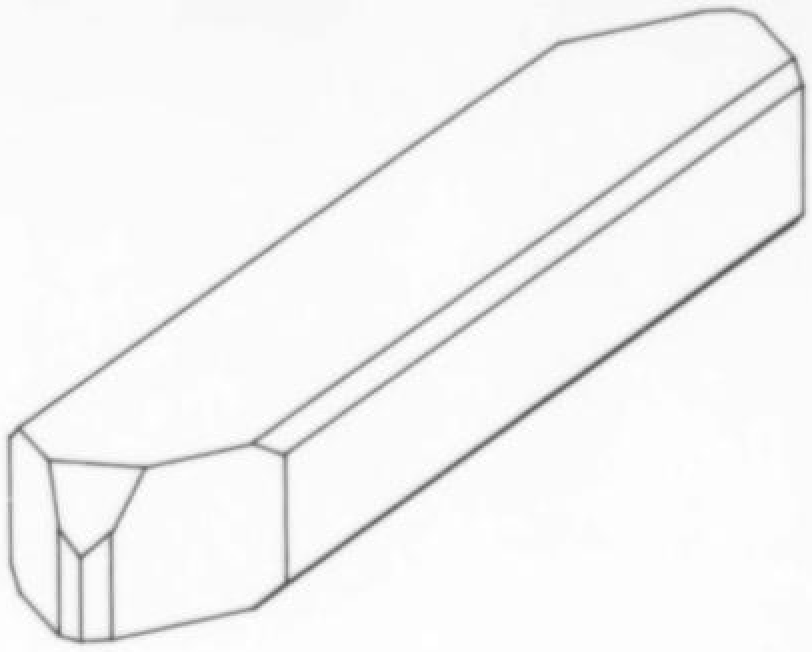


***Figure 75.* Drawing of an idealized crystal of leucosphenite. The forms developed are: {010}, {001}, {110}, {130}, {101} and {011}.**

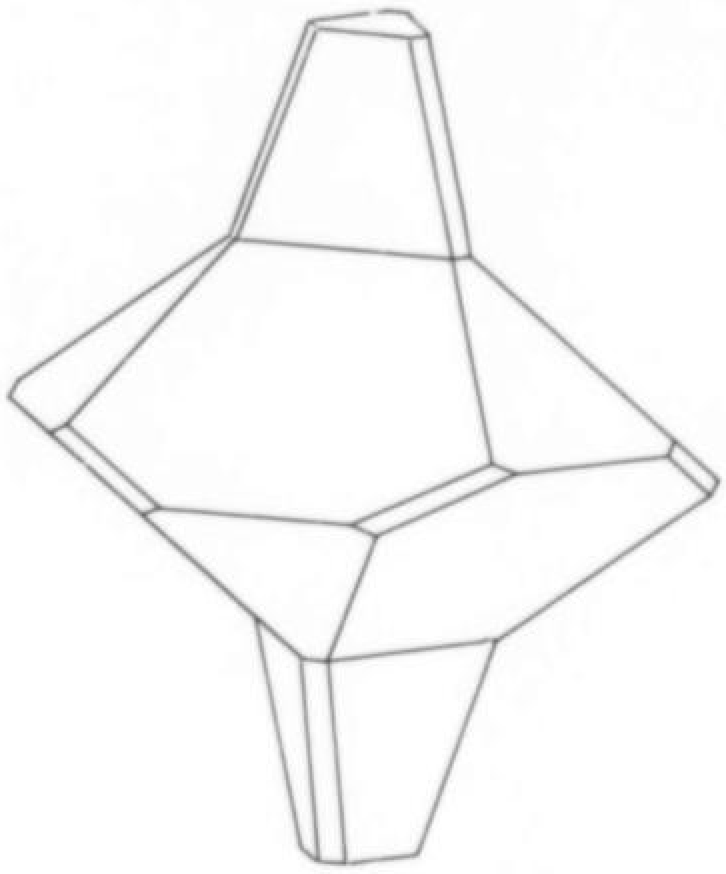


***Figure 76.* Drawing of an idealized crystal of synchysite. The forms developed are: {0001}, {11$\bar{2}$0}, {20$\bar{2}$9}, {30$\bar{3}$2}, {02$\bar{2}$9} and {03$\bar{3}$4}.**

Synchysite-(Ce) $Ca(Ce,La)(CO_3)_2F$

What G. Flink called synchysite is found in rather large quantities, principally as quite small crystals of an elongated, pointed habit, 1 or 2 mm in length, about 0.5 mm in width, bounded by a rhombohedron and base. Some of the larger crystals have a very unusual shape, tapering at both ends, and bounded by the two mentioned forms, whereas they are swollen in the middle part and bounded by several other forms. The largest crystals are more or less skeletally developed, as much as 6 cm long and 3 cm thick. It is characteristic that the base, as opposed to the other faces, is always glossy and shining. The color varies a good deal, from gray to brown, but many fresh crystals recovered in the late 1960's and early 70's are reddish yellow. Synchysite has only been found crystallized. It occurs most frequently in association with neptunite, epididymite, aegirine and orthoclase (which are all older than the synchysite), and also with albite, elpidite, fluorite, cordylite and polylithionite (which are contemporaneous with or younger than the synchysite).

The synchysite literature up to 1953 deals largely with its similarity to parisite. In Nordenskiöld's 1894 treatise and in Flink's first treatise, the mineral is simply called parisite. In Flink's second treatise, he concluded that the mineral must be different, but it was not until a new description of the original parisite appeared that Flink established the mineral from Narssârssuk to be a new species, which he called synchysite, from the Greek words meaning "mistaken identity." The

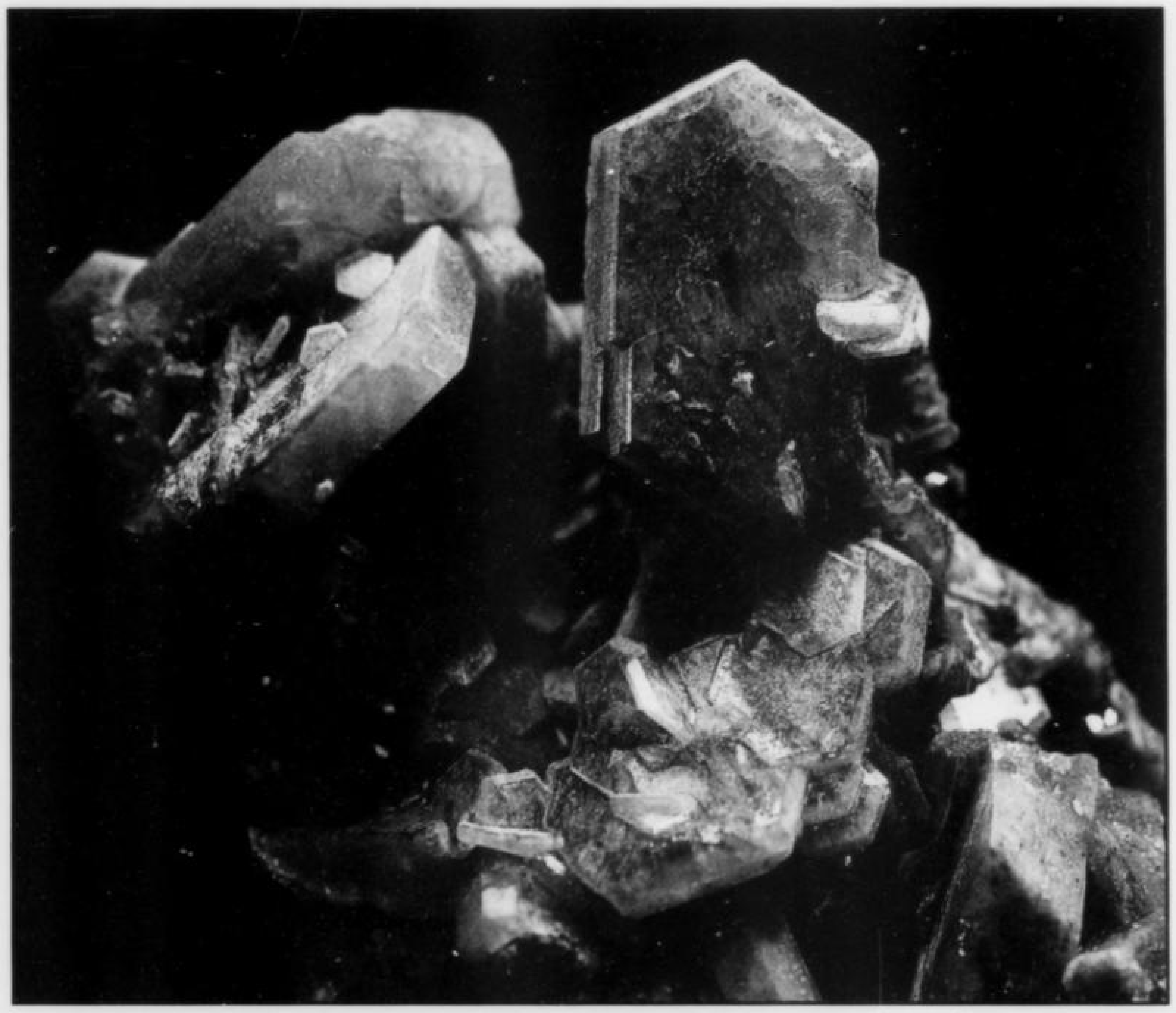
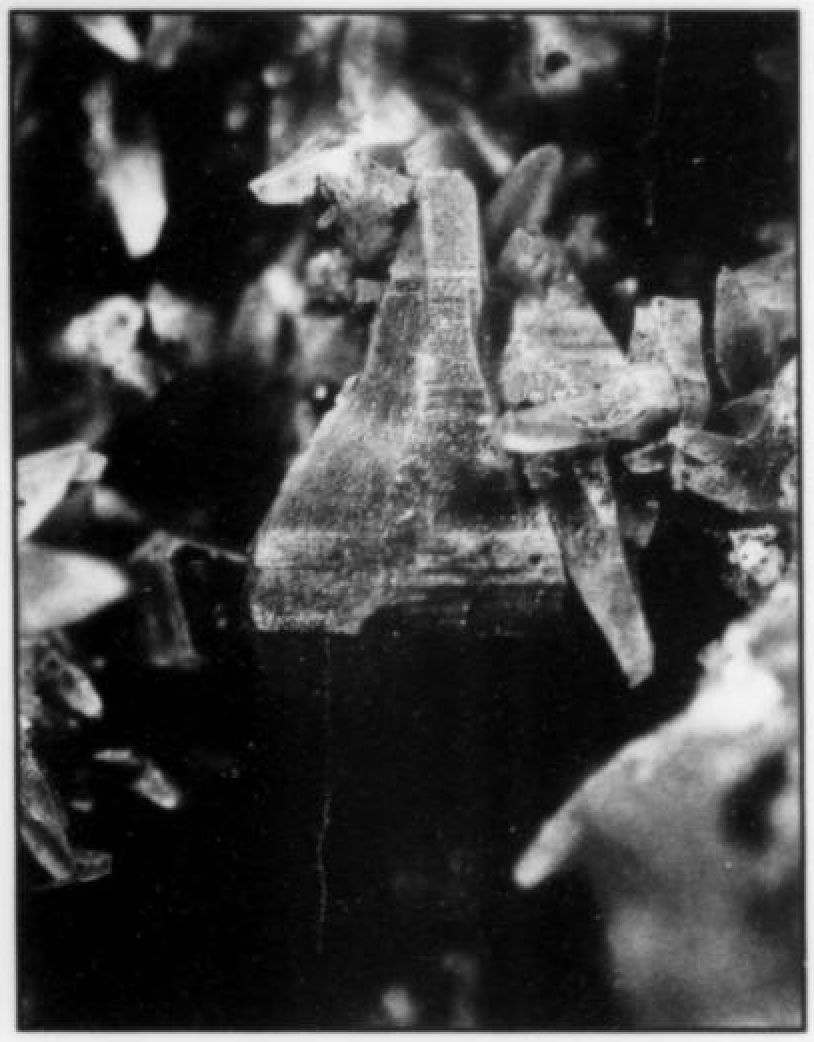


Figure 77. All Greenland catapleiite crystals have a pronounced hexagonal form. They are, like the crystals of the small group shown here, tabular parallel with {0001} and the edges are bounded by a prism and one or more pyramids; photo by R. Bode.

Figure 78. Many of the synchysite crystals at Narssârssuk, like the nearly 1-cm example shown here, have a very unusual shape, tapering at both ends and swollen in the middle. According to Donnay and Donnay, most of these crystals are polycrystals of two of the following four minerals: bastnäsite, parisite, röntgenite and synchysite. Photo by R. Bode.



study of parisite performed by Donnay and Donnay in 1953 contributed significantly to the understanding of this complex problem, and offers good explanations for the many different peculiar habits of the crystals. Their detailed X-ray studies of crystals from many localities established the existence of no less than four species: bastnäsite, parisite, röntgenite and synchysite, all REE-Ca-F carbonates. According to Donnay and Donnay, single crystals occur only rarely; most specimens

Figure 79. This rather fantastic, slightly more than 1-cm synchysite crystal is one of the best of a limited number of well-developed crystals found in a pocket particularly rich in astrophyllite. It was found at the bottom of the trench dug in 1968 and 1969. The many reentrant angles and, to a lesser extent, the splitting of the crystal towards the distal end into several individuals, are quite typical of synchysite from Narssârssuk; photo by R. Bode.

are polycrystals, syntaxic intergrowths of two species. The two species are in contact along an irregular surface or along repeated planes parallel to {0001}. Today synchysite has been divided in three species, depending upon whether the dominant REE is Ce, Nd or Y.

Figure 80. **Frequently the cordylite crystals from Narssârssuk are developed like the 1-mm example shown here. The prism faces are found at the lower end, whereas the upper end—bounded by pyramids—is somewhat swollen, thus resembling a club in shape; hence the name. Photo by O. V. Petersen.**

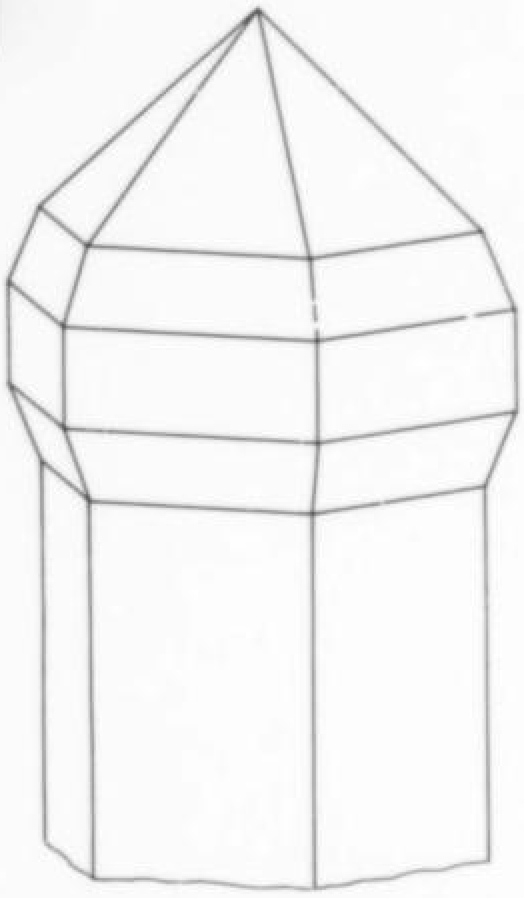


Figure 81. **Drawing of an idealized crystal corresponding to the one shown in the previous figure. The forms developed are: $\{10\bar{1}0\}$, $\{20\bar{2}3\}$, $\{20\bar{2}\bar{3}\}$, and $\{40\bar{4}15\}$.**

Cordylite-(Ce) $Ba(Ce,La)_2(CO_3)_3F_2$

Cordylite is found as small crystals bounded by prisms, various pyramids and a base; frequently the crystals are developed in such a manner that the prism faces are found at the lower end, whereas the upper end is bounded by the pyramids and somewhat swollen, the crystals thus resembling a club in shape (hence the name). The crystals are always very small, generally less than 1 mm; the largest known are 3 mm in length and 1 mm in width. In 1969 a large number of cordylite crystals of another type showing only one bipyramid and a base was discovered. The color may vary from nearly white to brownish yellow, but most commonly is pale yellow. Cordylite frequently occurs in association with synchysite, ancylite, astrophyllite and aegirine, with which it is partially intergrown. It appears to have been one of the last minerals to crystallize at Narssârssuk.

Ancylite-(Ce) $SrCe(CO_3)_2(OH)\cdot H_2O$

Ancylite occurs exclusively as crystals. Flink regarded them as combinations of two domes; Gordon as being composed of the prism {110} and the pyramid {111}. The faces, particularly of the pyramid, are always curved. The larger crystals, up to 4 mm, are usually completely enveloped in a tangled mass of acicular aegirine, but some are also found with albite and zircon crystals. The smaller, imperfectly developed crystals generally form continuous crusts and cavity fillings between other minerals like feldspar and aegirine. The color is brownish or yellowish in variable shades; the crystals are semitransparent, which is due to innumerable inclusions of acicular aegirine.

The Kûngnât complex

GEOGRAPHY and GEOLOGY

Kûngnât (Kuunnaat) is a 1,420-meter mountain near the entrance to Arsuk Fjord (Ilorput). It rises high above the surrounding gneiss, and is one of the well-known landmarks of the southwestern Greenland coastline.

The complex, which covers an area of 2.5 x 5 km, consists principally of two intersecting syenite stocks and a narrow, complete ring dike. The western stock is divided horizontally by a raft-like mass of roofing material, and displays both rhythmic and cryptic layering; the rocks grade up from quartz-free to quartz-bearing types. The ultimate differentiates are represented by peralkaline granitic dikes and sheets. The eastern stock consists mainly of more basic syenites and the ring dike of alkali gabbro.

MINERALOGY

Soda-orthoclase $(K,Na)(Si,Al)_4O_8$

The first specimens which are known with certainty to come from Kûngnât were collected by Giesecke during his stay in Greenland from 1806 to 1813. However, the Geological Museum, Copenhagen, does possess a few specimens greatly resembling them in every respect, originating from the time before Giesecke, possibly from the same locality. Very little is known as to the exact localities within the intrusion of the limited material collected since, but most likely it is all from the pegmatites of the eastern central area.

All of the material consists of cleavage fragments, up to 10 cm, of intergrown blocky crystals, single crystals, and twins from 5 to 10 cm. The crystals are grayish or brownish, and translucent or transparent and glassy clear. The major part of this material is a cryptoperthitic feldspar with the well known gray-blue "moonstone" iridescence. Even though many local collectors know of the existence of the stone, it has never achieved an image as a Greenland gemstone, but rather as a desired object for collectors. The locality can be characterized as non-exhaustible.

Quartz

Crystals of smoky quartz are very common in cavities and veins of the syenitic and granitic rocks. The largest crystal reported from the area is 10 cm long. It is particularly easy to pick up loose crystals in down-slope areas in the eastern part of the complex. Amethyst crystals and druses have been observed as well, but specific information is lacking.

Grønnedal-Ika Complex

Only 20 km east of the Kûngnât complex, another Gardar complex is located. This is the Grønnedal-Ika complex, a nepheline-syenite-carbonatite intrusion. There are no spectacular mineral occurrences reported from this complex, apart from vein fillings and disseminations of ultramarine-blue sodalite. The sodalite is found within the nepheline-syenite, disseminated and as veinlets without visible crystals, together with pink cancrinite grains. The color is intense, and specimens are popular with local collectors. The blue sodalite is rather well suited for polishing. The REE-carbonate mineral burbankite, otherwise only known from the Qaqarssuk carbonatite (see next chapter) has been reported from here too, as fine-grained material with cancrinite.

Figure 82. **A view from the interior of the Qaqarssuk carbonatite complex. The weathering of the carbonatite is creating a fertile ground for luxuriant vegetation. Photo by K. Secher.**

PALEOZOIC and MESOZOIC AREAS

Paleozoic rocks cover North Greenland and a major part of northeast Greenland. In the remaining areas only very minor amounts of Paleozoic rocks are found in central West Greenland, in the form of a down-faulted wedge of fossiliferous sedimentary rocks near the town of Sukkertoppen (Maniitsoq), and a carbonatite complex near Sdr. Strømfjord (Kangerlussuaq).

Mesozoic rocks cover a large part of central East Greenland, and important sequences are located in the Disko Bay area of western Greenland. Additionally, one Jurassic carbonatite is found in western Greenland.

In spite of the huge extent of exposed rocks in North and East Greenland, only a few mineral localities are known from these areas. One example from Devonian volcanic rocks in northeast Greenland is treated here, together with a locality for unique secondary minerals from the lower Paleozoic of North Greenland. The "Sarfartôq" Lower Paleozoic carbonatite complex in central West Greenland is also an unusual mineral locality, and is described below. The Mesozoic is represented by only one locality—the "Qaqarssuk" Jurassic carbonatite complex in West Greenland.

The Qaqarssuk Carbonatite Complex

The Mesozoic Qaqarssuk carbonatite complex, emplaced 173 million years ago, is located southeast of the town Sukkertoppen (Maniitsoq) in southwestern Greenland. The complex forms a concentric, steeply dipping ring dike structure, 3 x 5 km, enclosed in an aureole of altered (fenitized) Archaean gneiss. Carbonatite of varying composition is the predominant intrusive rock type, forming approximately 15% of the exposure.

Calcite and dolomite are the main minerals, with phlogopite, magnetite and apatite as the most common accessories. A late stage REE carbonatite occurs as veins, up to 4 meters in thickness, containing a suite of unique carbonates, together with calcite, dolomite, barite and strontianite. Some of these minerals have been found at this locality for the first time in Greenland.

Ancylite and alstonite occur intergrown as fine-grained irregular aggregates. Huanghoite is seen in medium-grained crystal aggregates, often in a quartz matrix. Burbankite has been identified in one sample of radiating, coarse, pale yellowish green crystals. Lanthanite has also been identified, by X-ray diffraction.

Additionally, several of the rocks within the complex carry minerals of the pyrochlore family: pyrochlore, bariopyrochlore, uranpyrochlore and betafite, most often as fine-grained euhedral octahedrons.

The Qaqarssuk carbonatite complex thus exhibits an outstanding suite of mineral species representing the Greenland carbonatite environment, resulting from magmatic and metasomatic processes.

The Sarfartôq Carbonatite Complex

This carbonatite complex was discovered in 1975, and has been investigated by one of us (KS). It is situated close to Sdr. Strømfjord (Kangerlussuaq), in a 1-km-wide valley bounded by steep slopes. The valley carries an impressive meandering river, and the exposure of the carbonatite complex is exceptionally good on these slopes, although a large part of the center is covered by Quaternary deposits of gravel and sand.

Geologically the complex is situated in the transition zone between the Archaean granulite facies block to the south and the Proterozoic Nagssugtoqidian mobile belt to the north. The complex has an oval shape and includes a core area of carbonatite sheets, covering 15 square kilometers, which is mantled by a marginal zone (75 square kilometers) of altered gneiss with carbonatite dikes and vein fillings.

The carbonatite complex was intruded during the Lower Paleozoic, around 600 million years ago. Hydrothermal stages terminated the magmatic activity and gave rise to several phases of mineralization in veins and shear zones.

The main rock-forming minerals are dolomite-ankerite, calcite, apatite, phlogopite, richterite and magnetite. Important accessories include pyrochlore, zircon and niobian rutile. In the hydrothermal vein-fillings the common minerals are fluorite, dolomite, calcite, pyrite, barite, pyrochlore and unidentified REE-Th minerals. The major rock types described from the complex are sövite, rauhaugite, beforsite and Na-fenite.

From a mineralogical point of view, only a few spectacular minerals are seen. Within the core carbonatite several massive layers of magnetite are found. Locally these layers carry perfectly formed octahedral magnetite crystals, with an edge length of up to 3 cm. The crystals are embedded in carbonatite and are easy to release from the matrix. The core carbonatite carries up to 30% volumetrically of apatite, commonly developed as well-formed crystals, with the hexagonal prisms dominating. The apatite can measure up to 5 cm as single crystals, but otherwise occurs clustered in lenses of flower-like rosettes. The crystals are often broken, with colors varying from dark green over light green or yellow to pink.

From the marginal zone dolomite and pyrochlore attract attention because of their unusual appearance. Dolomite is seen as single, elongated, pink crystals oriented perpendicular to the vein walls, creating a comb structure, with a matrix of gray-white REE-rich carbonate material (unidentified). The dolomite crystals are up to 5 mm x 4 cm, with a pseudohexagonal habit resulting in elongated prismatic crystals.

Table 5. **Minerals from Sarfartôq.**

Aegirine
Albite
Ankerite
Apatite
Augite
Barite
Biotite
Calcite
Chalcopyrite
Chlorite (group)
Diopside (variety Salite)
Dolomite
Ferriphlogopite
Fluorite
Galena
Gismondine (?)
Goethite
Graphite
Gypsum
Hematite
Hexahydrite
Hornblende
Ilmenite
Magnesio-arfvedsonite
Magnetite
Marcasite
Monohydrocalcite
Potassium feldspar
Pyrite
Pyrochlore
Pyrrhotine
Quartz
Richterite
Rutile (niobian)
Siderite
Sphalerite
Taeniolite (?)
Zircon

? Identity/location uncertain

The pyrochlore within the marginal zone occurs in massive veins several tens of meters long and 5–10 meters wide. The mineral is a U-rich variety, olive-brown to yellow-brown and with a typically greasy luster. Crystals are rare, but cavities are seen lined with crystals up to 1 mm, dominated by an octahedral habit.

A special aspect of the mineralogy is the secondary minerals. Hexahydrite is very common on surfaces as powdery coatings consisting of pure white acicular microcrystals. Gypsum is also observed as fibrous acicular crystals up to 1 cm in cavities.

The very rare and unusual secondary mineral monohydrocalcite is, however, quite common in all rock types in the area. The mineral locally creates large snow-like spots in the landscape. The monohydrocalcite is always found as botryoidal encrustations up to several millimeters across, showing concordant layering. The white color grades into pale brown near the surface of the matrix.

The Randbøldal area

The Randbøldal area in Northeast Greenland is a barren east-west running valley with steep slopes and gravel fans on both sides. In the middle of the valley a spectacular medium-sized pingo (frost mound) is located, reminding the observer of the arctic environment. The area is situated in a terrain of Devonian felsic volcanics characteristically weathered into deep rusty-brown colors. The mineral occurrences observed are strongly influenced by the presence of radioactive elements, which give rise to a rather unusual suite of minerals in a volcanic sequence. The radioactive hydrocarbon named carburan is common in some parts of the rhyolitic sequence as globular black grains up to 1 cm in diameter. Carburan is not, strictly speaking, a mineral, but an amorphous material resembling mountain pitch. It is found as isolated globules and disseminations in the volcanics, together with pyrite and rutile, and it is rather resistant to weathering. From galena-bearing associations one of us (KS) has described a new secondary uraniferous variety: barian wölsendorfite. This is found as coatings on felsic volcanic material in the vicinity of the carburan. The coatings consist of tiny flakes of orange-yellow microcrystals.

Pitchblende veinlets have been found in nearby sequences of rhyolite rocks, weathered into yellow microcrystalline masses of uranophane-beta. Fluorite accumulations are locally a common feature in this environment, developed as cavity and vein fillings of well-formed violet to white cubic crystals up to several centimeters in size. Radiation damage in the fluorite has created color zoning in violet and red at some localities having pitchblende mineralization.

SECONDARY MINERALS

At Navarana Fjord in the northeastern part of Freuchen Land, North Greenland, a fault structure carries a suite of hydrated sulfate minerals. These sulfates, which would normally be unstable at surface conditions, are preserved because of the very cold and dry climate in this high-arctic region. The minerals, for many of which this is the first and only locality in Greenland, include copiapite, fibroferrite, gypsum, rozenite, melanterite and römerite. A vertical profile (down to 1.35 meters) shows a typical and pronounced downward zonation.

These sulfate minerals are characterized by bright colors. The sulfur-like yellow copiapite at the top is followed downwards by yellowish green fibroferrite, gray swallow-tail gypsum, brown limonite, blue melanterite, and colorless rozenite. Finally, at the bottom of the profile, yellow-brown römerite in triclinic plates concludes the succession of sulfates. The formation of these conspicuous secondary sulfate minerals is considered to be a result of pyrite oxidation and hydration.

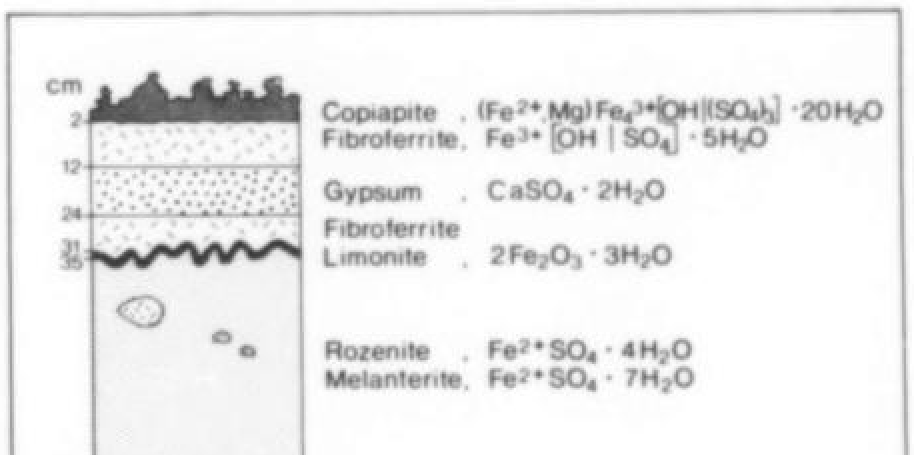


Figure 83. **Vertical profile showing the cross-section of the upper 1.5 meters of the sulfate crust at Navarana Fjord. Sketch by U. H. Jakobsen.**

Figure 84. **The figure shows the coast west of Godhavn on Disko Island (Qeqertarsuaq) where Tertiary basalts are overlaying Precambrian gneiss. The Disko basalts are world famous for their terrestrial native iron content. Photo by A. K. Pedersen.**

TERTIARY VOLCANIC AREAS

GEOGRAPHY and GEOLOGY

In the early Tertiary there was considerable magmatic activity in both central West and central East Greenland. In western Greenland the lavas, overlying marine and non-marine Cretaceous-Tertiary sediments, cover an area approximately 125 km wide and 370 km in north-south length, from Svartenhuk Halvø (Nunavik) in the north, on Ubekendt Ejland and Nûgssuaq (Nuussuaq), and to Disko Island (Qeqertarsuaq) in the south. The composite thickness of the lava pile approaches 8,000 meters and comprises a basal unit of pillow lavas of submarine origin, a thick sequence of picritic and olivine rich basalts and an upper unit of tholeiites.

The Tertiary igneous rocks of eastern Greenland are known from Kap Gustav Holm (Tasiilap Karra) in the south to Shannon in the north. In the southern part of the volcanic area the Tertiary igneous rocks overlie or are emplaced into mainly Precambrian gneiss; in the northern part these rocks largely overlie or have been emplaced into Devonian, Carboniferous and Mesozoic strata. The igneous activity began with the formation of tholeiitic, olivine tholeiitic and to a lesser extent alkaline plateau basalts. In the southern part of the area the basalts form a continuous cover, but further to the north the basalt cover is now discontinuous. The thickness of the pile of flood basalts was previously estimated as at least 7,000 meters; recent investigations, however, suggest that the thickness of the succession has been grossly overestimated. Dike swarms can be found throughout the coastal region, but are particularly plentiful at the Blosseville Kyst. Large dolerite sills characterize much of the coastal region from approximately 72° to 74°30′N. In eastern Greenland, in contrast to West Greenland, the volcanic phase was followed by a period of plutonic intrusion, the first episode of which was basic in character; the latest evidence suggests that the major gabbroic plutons of this first phase were emplaced largely subsequent to the coastal dike swarm (the best known of these intrusion being the Skaergaard layered complex). The second and last igneous event was the intrusion of syenitic, nepheline syenitic and, to a lesser extent, granitic magmas. Altogether more than 100 intrusions have been identified in the eastern Greenland Tertiary volcanic province.

MINERALOGY

With the exception of iron and its associated minerals, which will be treated separately below, the Tertiary basalts in West Greenland contain no famous mineral localities with suites of interesting and/or beautiful minerals, nor any with a single mineral of particular interest and/or beauty. From a large number of localities, half a dozen of the most common zeolites plus the minerals often accompanying them (calcite, aragonite, dolomite, analcime, apophyllite and prehnite) and a suite of Ca-silicates (pectolite, okenite, gyrolite, reyerite and xonotlite) have been reported from amygdules and veinlets in the basalt.

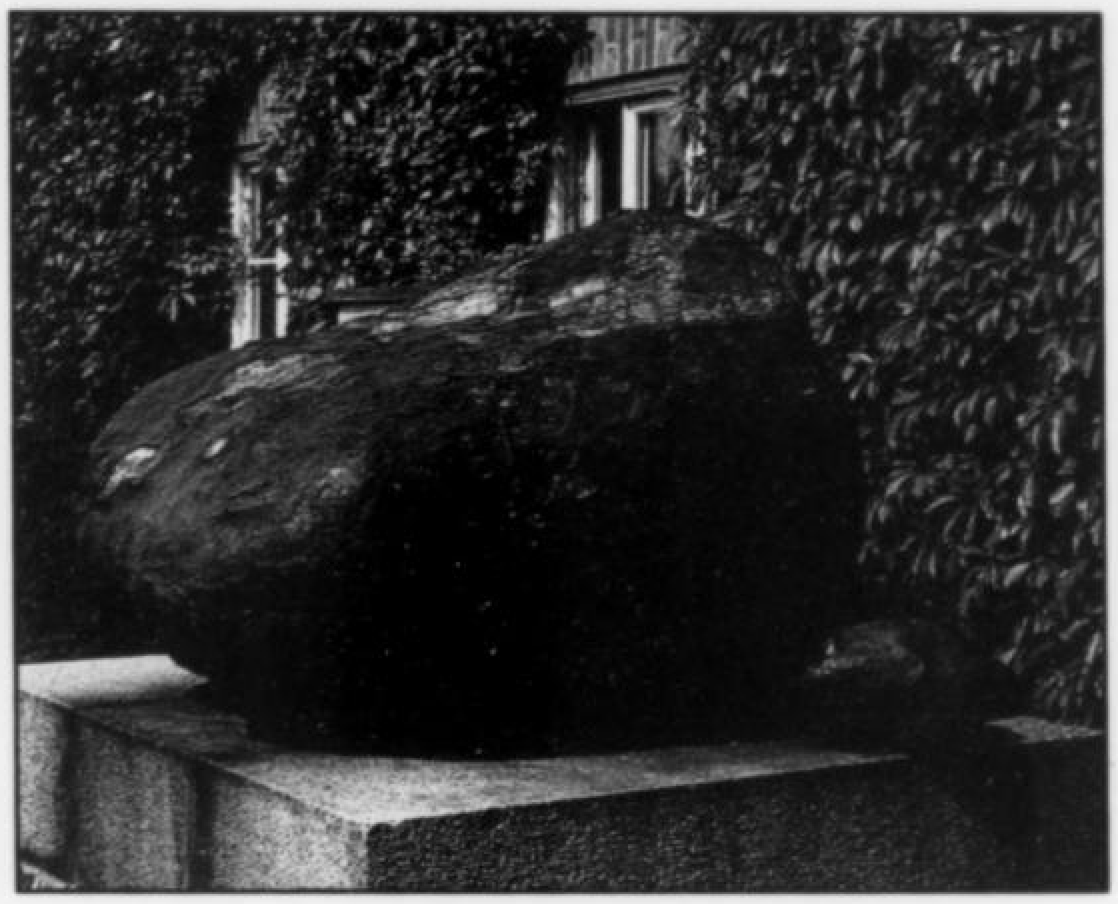


Figure 85. **This is the largest boulder of native iron ever found on Disko Island (Qeqertarsuaq), 25 tons! and can be seen at the National Museum of Natural History in Stockholm. Photo by O. Medenbach.**

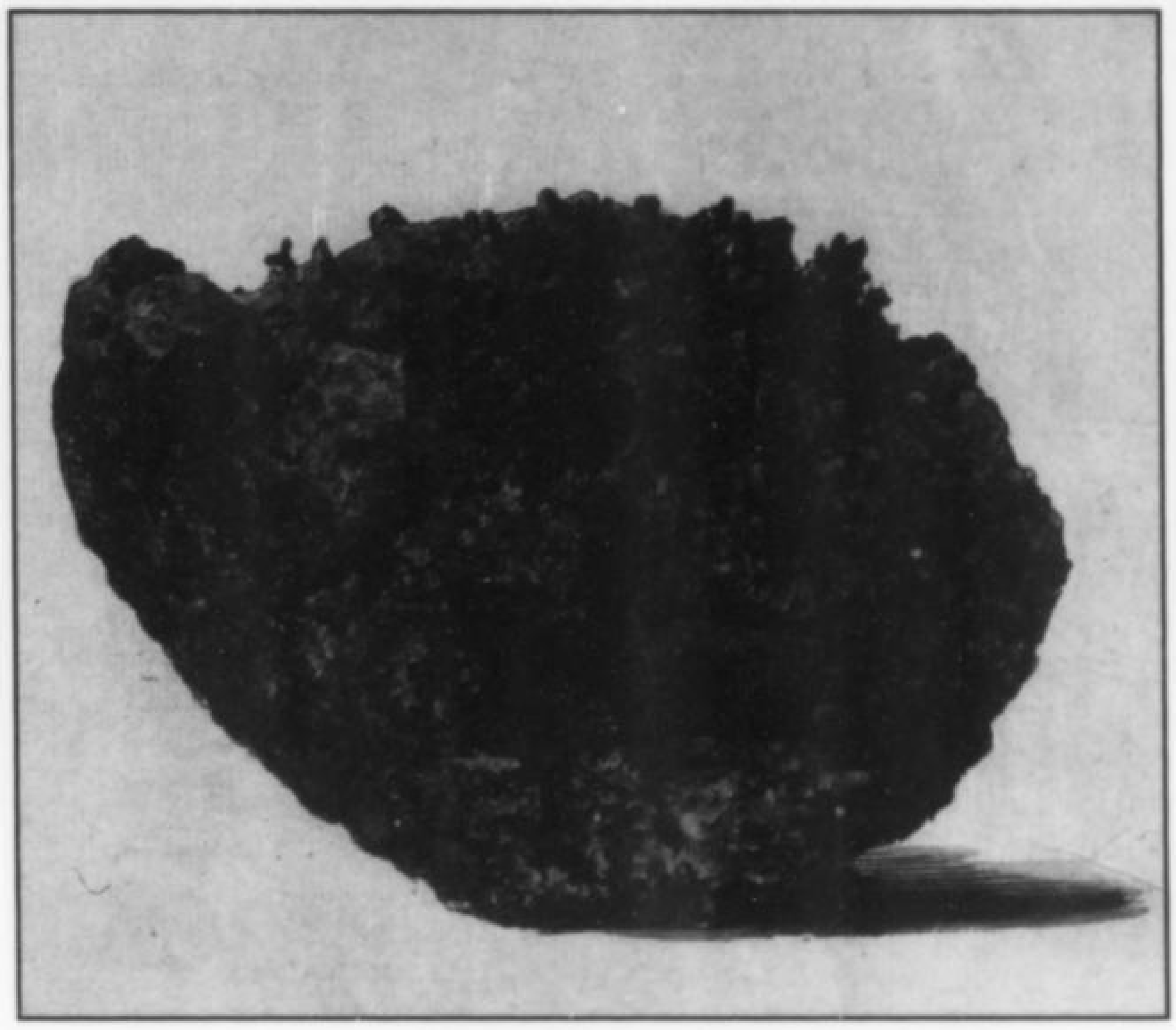


Figure 86. **Large lump of Greenland basalt containing numerous blebs of native iron. This specimen, illustrated in the 1769 collection catalog of the Leipzig collector Christian Ludwig Stieglitz (1724–1772), is surely among the first Disko Island (Qeqertarsuaq) iron specimens to reach Europe. (R. A. Bideaux library)**

Also found in the amygdules and veinlets are cryptocrystalline varieties of SiO_2 (mainly chalcedony), quartz crystals, opal and ferrisepiolite. Kaersutite has been found in several dikes, and from the sediments have come retinite and doubly terminated crystals of quartz (see below).

The Tertiary plateau basalts in eastern Greenland do contain the same amygdules and veinlets with the same zeolites, associated minerals, cryptocrystalline varieties of silica and ferrisepiolite (gunnbjarnite) as do the basalts in western Greenland. From a mineralogical point of view, however, the central igneous complexes, particularly

Figure 87. **Large boulders of terrestrial native iron on the beach at Uivfaq (Uiffaq) eroded from the basalt (reproduced from a 100-year-old print).**

the syenitic and the nephelinitic ones, are of much greater interest. The three most important are the Kangerdlugssuaq Complex, by far the largest syenitic intrusion; the Werner Bjerge Complex, with its wide range of rock types ranging from ultramafic to nepheline syenites; and the Gardiner Complex. Of these, only the latter will be treated separately in detail below. With the exception of the Gardiner Complex, which has definitely proven to be a new famous mineral locality, they contain a whole suite of minerals known from the alkaline intrusions in southwestern Greenland, including aegirine, arfvedsonite, aenigmatite, nepheline, sodalite, eudialyte, narsarsukite and astrophyllite. They even contain a few minerals unknown from other localities in Greenland (such as chevkinite and kupletskite). But, although many interesting mineral localities have been found, none thus far can qualify as worthy of being famous. Late pneumatolytic and hydrothermal activity associated with the Werner Bjerge complex has given rise to two mineralizations of particular economic, but limited mineralogical interest: Malmbjerget, a major disseminated molybdenum deposit, and Blyklippen, a now-exhausted galena-sphalerite vein deposit at Mesters Vig.

Native Iron Fe

The unique iron-bearing Tertiary volcanic rocks of western Greenland, particularly well represented on Disko Island (Qeqertarsuaq), have been known for many years. Discoveries of raw and worked iron in old Greenland graves prove that the Greenlanders did know and use the local iron long before the metal was brought to Greenland by European whalers. The first written mention of the iron, in 1730, is a report from a local foreman complaining about Dutch whalers who without permission had removed "a large boulder of iron"; apparently the boulder was brought to the Netherlands, but there is no further record of what happened to it. The first scientific report of native iron from Greenland is by Forchhammer, who described a 10-kg lump brought to Denmark by Rink from his expedition in 1848–1850; it was collected at Niakornaq, east of Disko Island (Qeqertarsuaq), on the Greenland mainland. It was Nordenskiöld who in 1871 brought to Scandinavia the huge boulders from Blaafjeld, Uivfaq (Uiffaq), where they were found on the shore. Since Steenstrup's visits to the region in 1871 and the following years, the area has been visited by, and is still frequented by, a large number of geologists. The iron occurs in the lavas as well as in the subvolcanic intrusions, both contaminated by sediments rich in organic material.

The mode of occurrence of the iron falls largely within two broad categories. In the first, the iron forms cumulates and iron-carbide-sulfide bodies in the basalts. This mode of occurrence, exemplified by the best known locality for native iron at Uivfaq (Uiffaq), is the most exciting. The largest iron blocks found have the following weights: 25 tons, now in the National Museum of Natural History, Stockholm, Sweden; 6.5 tons, now in the Geological Museum, Copenhagen; and 4.1 tons, now in Helsingfors, Finland. A large number of blocks weighing less than one ton have also been recovered. In the second mode of occurrence, iron and sulfide are disseminated throughout the rocks. The Disko Island (Qeqertarsuaq) iron occurs in highly diverse assemblages composed of iron, cohenite, troilite, schreibersite and various Fe-Ti-Cr oxides and Cu-Ni sulfides. Nordenskiöld considered the iron to be meteoritic; it was Steenstrup who first put forward the now generally accepted opinion that the iron formed through reduction processes when basic magmas reacted with carbonaceous sediments.

A particularly interesting mineral assemblage has been described by Pauly (1958) from an approximately 28-ton block found at a locality first visited by Nordenskiöld and later briefly described by Steenstrup at Igdlukúnguaq. The mineral assemblage consists of pentlandite, chalcopyrite, pyrrhotite, cubanite, valleriite, bravoite and hisingerite.

In 1989 F. Ulff-Møller described a complex mineral paragenesis, with a highly interesting Pb mineral assemblage, from a lens, the Kitdlît lens, in a basalt dike on Disko Island. The 100-kg lenticular body was deposited as coexisting immiscible metal and sulfide liquids, and the Pb minerals are concentrated in the upper portion of the lens. The following phases have been identified in the metallic and sulfide-rich part of the lens: iron, cohenite, a eutectic intergrowth of Fe_3P-Fe_3C-Fe-FeS, troilite, chromite, wüstite (pseudomorphs), chalcopyrite and pentlandite. The Pb mineral assemblage includes such minerals as native lead, galena, shandite, altaite, cubanite and an Ni_3Sn_2 alloy.

Extensive work on Disko Island by A. K. Pedersen during the last 20 years, published in a large number of papers, has unveiled several highly interesting mineral assemblages. In 1978 Pedersen described stoichiometric and non-stoichiometric magnesian spinels from graphite-rich xenoliths in an iron-bearing andesite at Asuk. The spinel composition varies within the compositional field MgO-FeO-Al_2O_3-Cr_2O_3, through substitution of the type $3(Mg,Fe)^{+2} = 2(Al,Cr)_2^{+3}$ + vacancy. The spinels vary from stoichiometric $(Mg,Fe)^{+2}(Al,Cr)_2^{+3}O_4$ toward $(Al,Cr)_2O_4$. In 1981 he described iron-bearing lavas from northwestern Disko Island having dispersed graphite and early-formed phenocrystic ilmenite. The ilmenite was altered by reduction to form aggregates of ilmenite, rutile and (most interesting) armalcolite which is compositionally almost identical to that first described from the Apollo 11 high-Ti mare basalts. In 1987 he described naturally occurring magnéli phases, Ti_nO_{2n-1} with the range n = 4 to 7, from xenoliths in an andesitic breccia containing native iron at Asuk.

Quartz SiO_2

Quartz, as already mentioned, is quite common in amygdules and veinlets in the basalts and associated rocks, and although sometimes nicely crystallized, deserves no further mention. However, in 1938 the Danish geologist Alfred Rosenkrantz (1898–1974) brought home a large quantity of small, transparent, well-developed quartz crystals from a different type of occurrence. These crystals, some of them doubly-terminated, are from a place called Scaphites Ravine, Kugssinínguaq, where they were found scattered in cavities in ammonite (Scaphites) fossils enclosed in concretions.

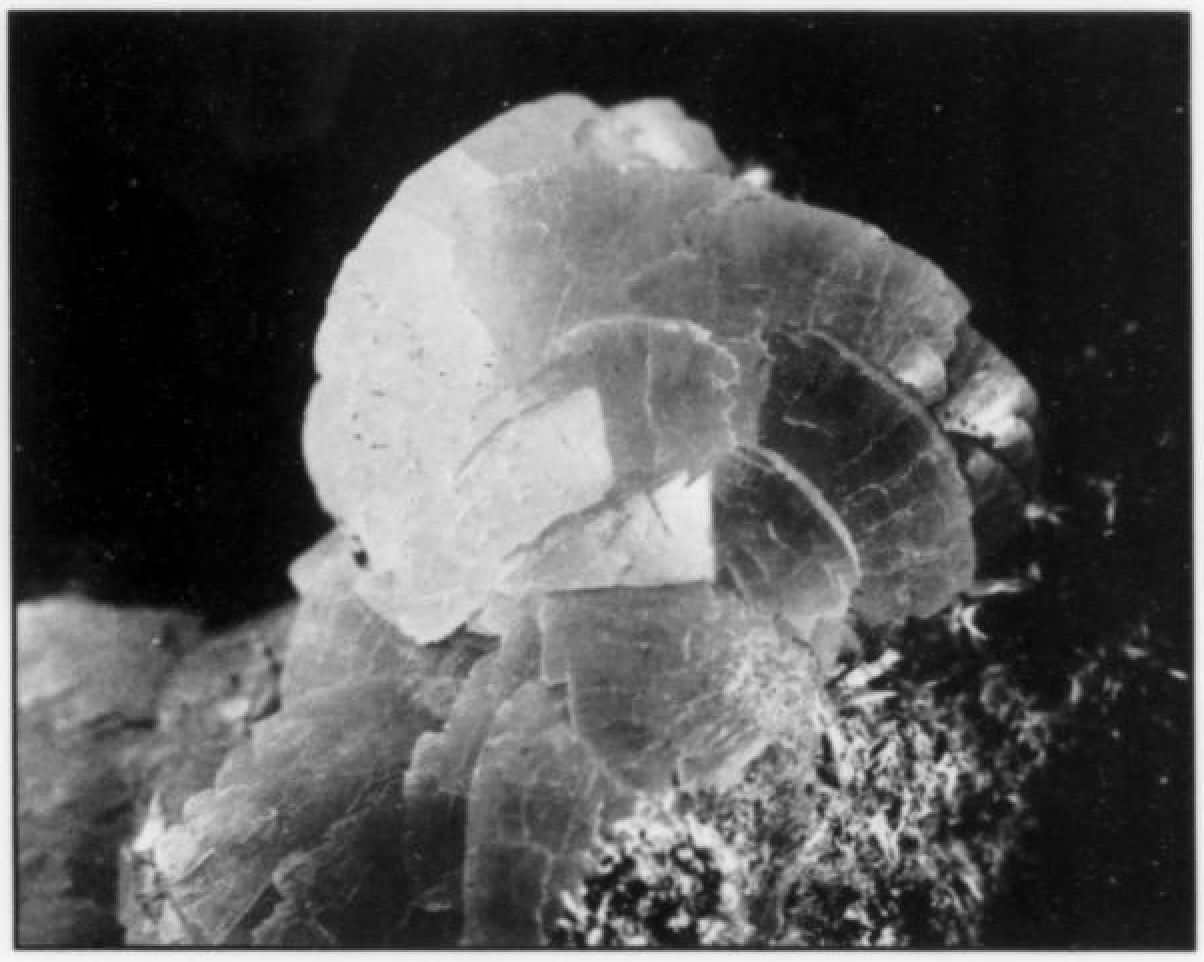


Figure 88. **Nice prehnite has been found in rather large quantities at a place called Sødalen in Mikis Fjord. The cockscomb-like, spherical groups of curved crystals have a very lovely pale green color. The one shown here measures a little more than 2 cm. Photo by R. Bode.**

Prehnite $Ca_2Al_2Si_3O_{10}(OH)_2$

Prehnite has in recent years been found in considerable quantity at a place called Sødalen in the innermost part of Miki Fjord. Here it occurs in 10-cm cracks and druses, both in the basalts and in dikes

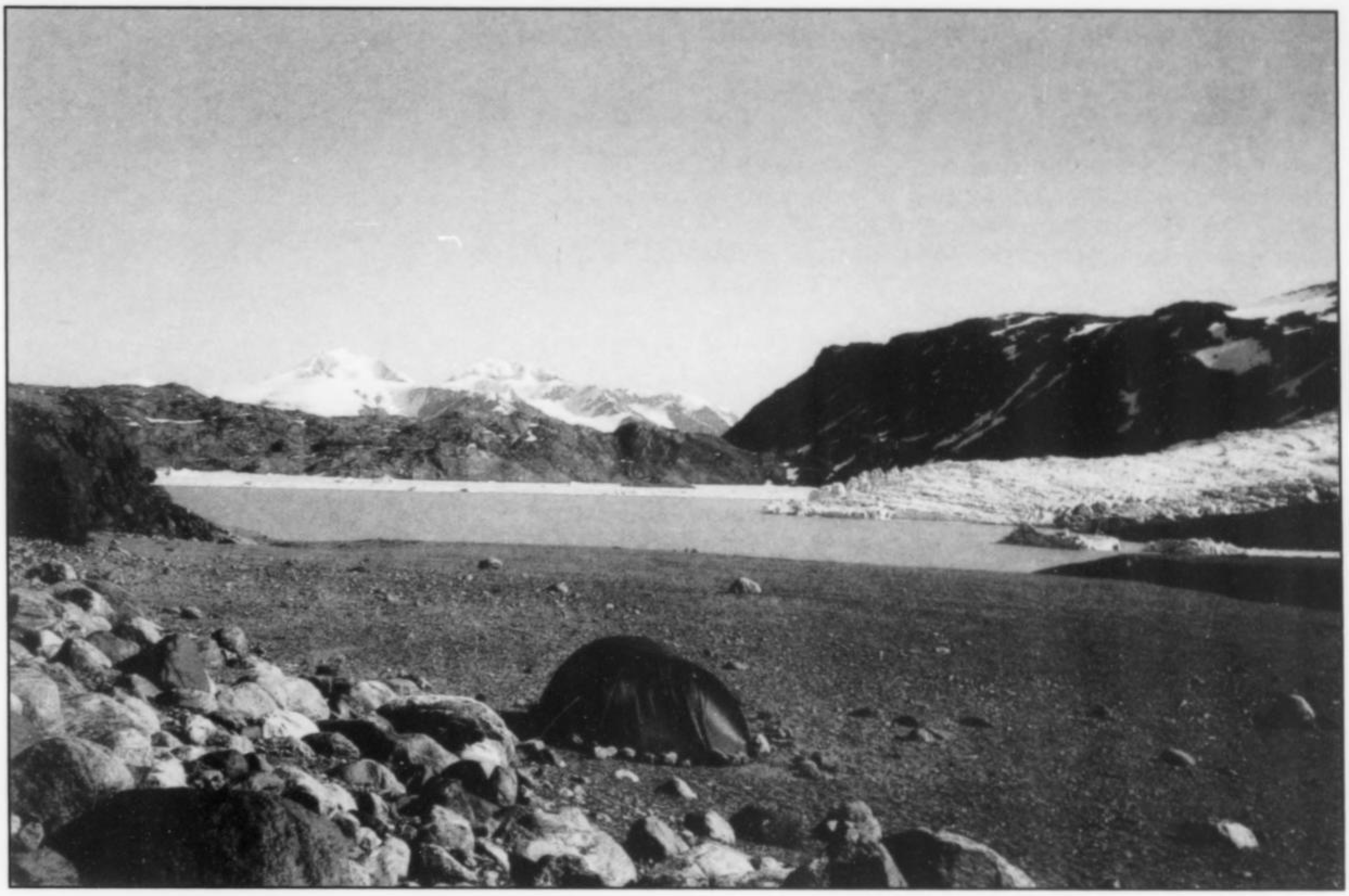


Figure 89. **View over Gardiner Lake toward the high mountains of the Kangerdlugssuaq (Kangerlussuaq) area. Field work at the Gardiner complex is severely hampered by the ever-present, very strong winds, as illustrated by the heavily pressed tent in the foreground and the drift ice packed at one end of the lake. Photo by O. Johnsen.**

cutting the basalts. The curved prehnite crystals form large cockscomb-like and spherical groups, up to several centimeters in size. The coarsely crystalline nature of the aggregates and the lovely bluish green color of the prehnite make these specimens rather attractive.

Astrophyllite $(K,Na)_3(Fe^{+2},Mn)_7Ti_2Si_8O_{24}(O,OH)_7$

Astrophyllite has already been mentioned in detail as among the most beautiful minerals from Narssârssuk, where it forms aggregates of acicular to ruler-shaped crystals. Recently astrophyllite has been found in the central quartz core of a pegmatite at Jagtlejren in the Kræmer Ø intrusion, Kangerdlugssuaq (Kangerlussuaq), but here the astrophyllite forms broad tabular crystals nearly 10 cm across. The pegmatite cuts a quartz-bearing syenite to which it is genetically related. Other minerals identified include potassium feldspar, arfvedsonite, aegirine, zircon and fluorite. The impressive astrophyllite crystals, with their reddish coppery luster, are no less beautiful than the acicular kind.

The Gardiner Complex

GEOGRAPHY and GEOLOGY

The Gardiner Complex was visited briefly in 1935–36, but was rediscovered in 1971 during prospecting work for Nordisk Mineselskab. The first descriptions, by W. Frisch and H. Keusen, appeared in 1975 and 1977. The complex was revisited in 1975 and 1982, and additional papers by T. F. D. Nielsen (dealing mainly with petrology) were published in 1979, 1980 and 1981. It is the material collected during the 1975 and 1982 visits that forms the basis for the following descriptions.

The ring-shaped complex, with a diameter of about 6 km, is exposed in three areas, separated by glaciers, on the innermost westerly nunatak of the head of Kangerdlugssuaq (Kangerlussuaq) Fjord. Not only is the area extremely difficult of access, even by Greenland standards (the only realistic approach is by helicopter), but work in the area is severely hampered by the weather, particularly the unrelenting strong winds. Nevertheless, it is an area of great beauty and grandeur.

The Gardiner complex is a zoned ultramafic complex intruded by a large number of alkaline dikes and sheets including carbonatites. It intruded Precambrian basement and alkaline Tertiary lavas. The evolution of the complex can be divided into four phases: (1) An older ultramafic cumulate series, constituting the major part of the complex and forming a succession of rings inward from the contact. (2) A shonkinite to nepheline syenite suite of minor cone sheets and dikes that separate, in time, the older sequence from (3) the younger massive melilitolite and ijolite ring dikes and sheets, nearer to the center, and related melteigite veins and dikes. Finally there are melanite-natrolite-calcite veins and coarse-grained magnetite-phlogopite-diopside-calcite pegmatites and dolomite rocks, the latter formed by the strong metasomatism that accompanied the emplacement of the rocks of the third phase, and (4) a volumetrically less important terminal suite of *inter alia* nepheline syenite and apatite-rock dikes and sheets.

MINERALOGY

In total about 60 minerals, most of them silicates, are known from the Gardiner complex. The most interesting and spectacular are related to the melilitolites (locally enriched particularly in perovskite and magnetite, but also in apatite, phlogopite and titanian andradite), the titanian andradite-natrolite-calcite veins and pegmatites of the third phase, and the shonkinite and nepheline syenites of the second phase.

Perovskite $CaTiO_3$

Perovskite is by far the most spectacular of the minerals from the Gardiner complex. It forms single crystals and clusters intimately intergrown with apatite, and also sometimes with diopside and feldspar. The perovskite was in most cases the first mineral to crystallize, for which reason it occurs as well-developed crystals. The apatite-rich rocks in particular crumble very easily and yield many nice "floater" crystals.

The crystal habit of Gardiner perovskite is somewhat unusual. The most frequent habit is a combination of {110} and {001} (or, to phrase it in pseudocubic terms, the octahedron only). In rare cases small faces corresponding to the cube, {101} and {010} are also found. The color ranges from black to grayish black and brownish black. Some crystals have shiny faces with metallic to adamantine luster, but most are somewhat dull.

The perovskite specimens originate from enrichments in the rocks of the third phase (the melilitolites), where they form separate zones, and from layers and pockets several meters in size containing up to 50% perovskite, in the altered ultramafic rocks surrounding the melilitolites. There it occurs in association with melilite, apatite, magnetite, diopside and phlogopite. Three things make the Gardiner perovskite unique: its abundance, which exceeds anything known to the authors; its predominantly pseudo-octahedral habit—the "cube" being the most common crystal form of perovskite from elsewhere; and most notably the size of the largest crystals, *8 cm* along an edge, which far exceeds the crystals from any other locality.

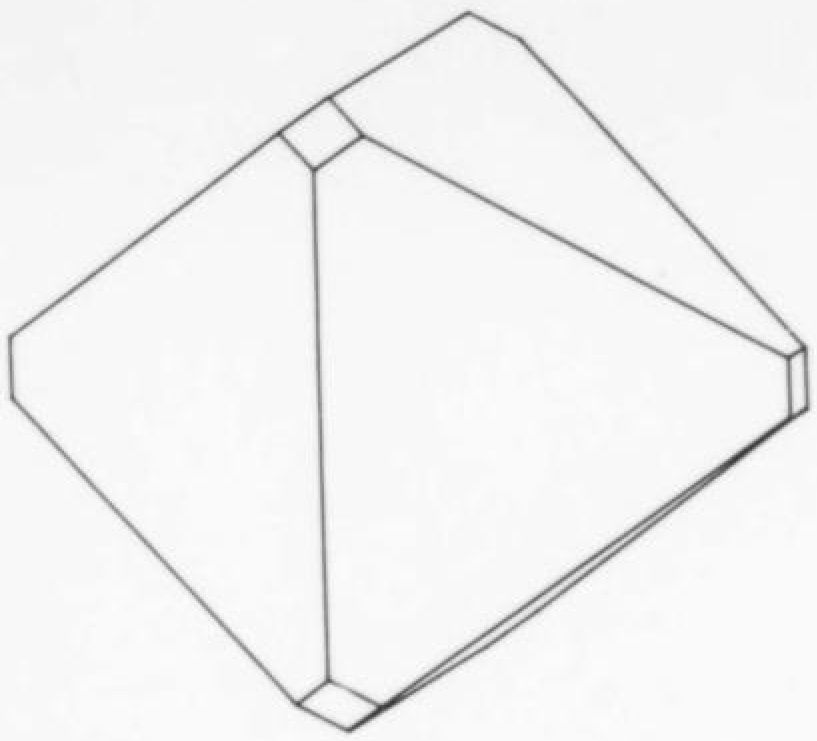


***Figure 90*. Drawing of an idealized crystal of perovskite. In the monoclinic setting the forms developed are: {110} and {011}; together they constitute something very close to an octahedron; {101} and {010} together constitute something very close to the cube.**

Magnetite $Fe^{+2}Fe_2^{+3}O_4$

Magnetite, like perovskite, forms single crystals and clusters of 4–10 crystals. It is most often found in association with phlogopite. Matrix specimens are rare, but in 1982 a small number of specimens

***Figure 91*. Perovskite crystals to 2 cm, from the Gardiner complex. Photo by O. Medenbach.**

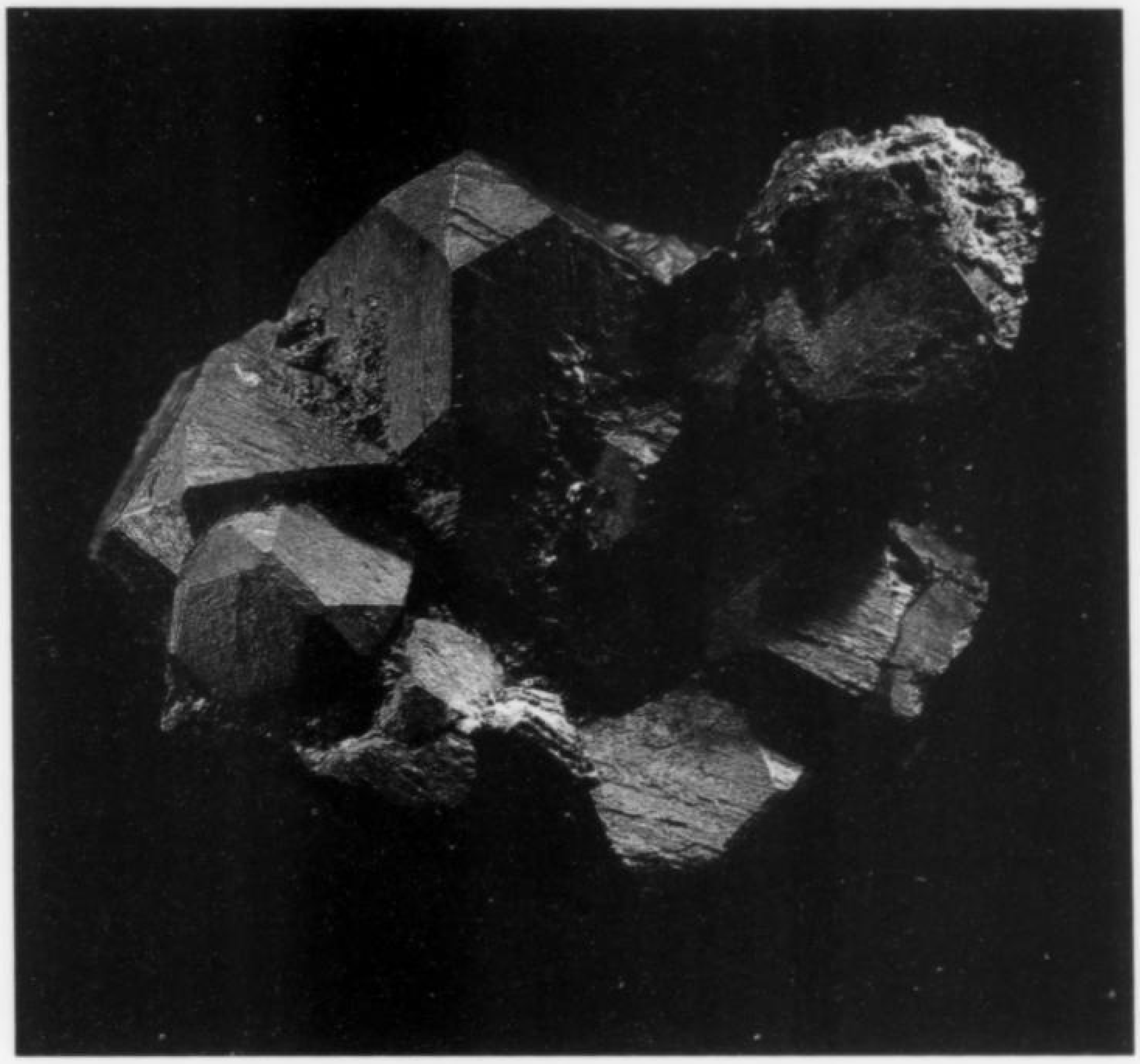


Figure 92. **A particularly interesting group of magnetite crystals from the Gardiner complex. In addition to the octahedron, all the crystals show the icositetrahedron {311}, some also the rhombic dodecahedron. This specimen, which is only 2.6 cm, shows very well the corroded surfaces so typical of the Gardiner magnetite crystals. Photo by R. Bode.**

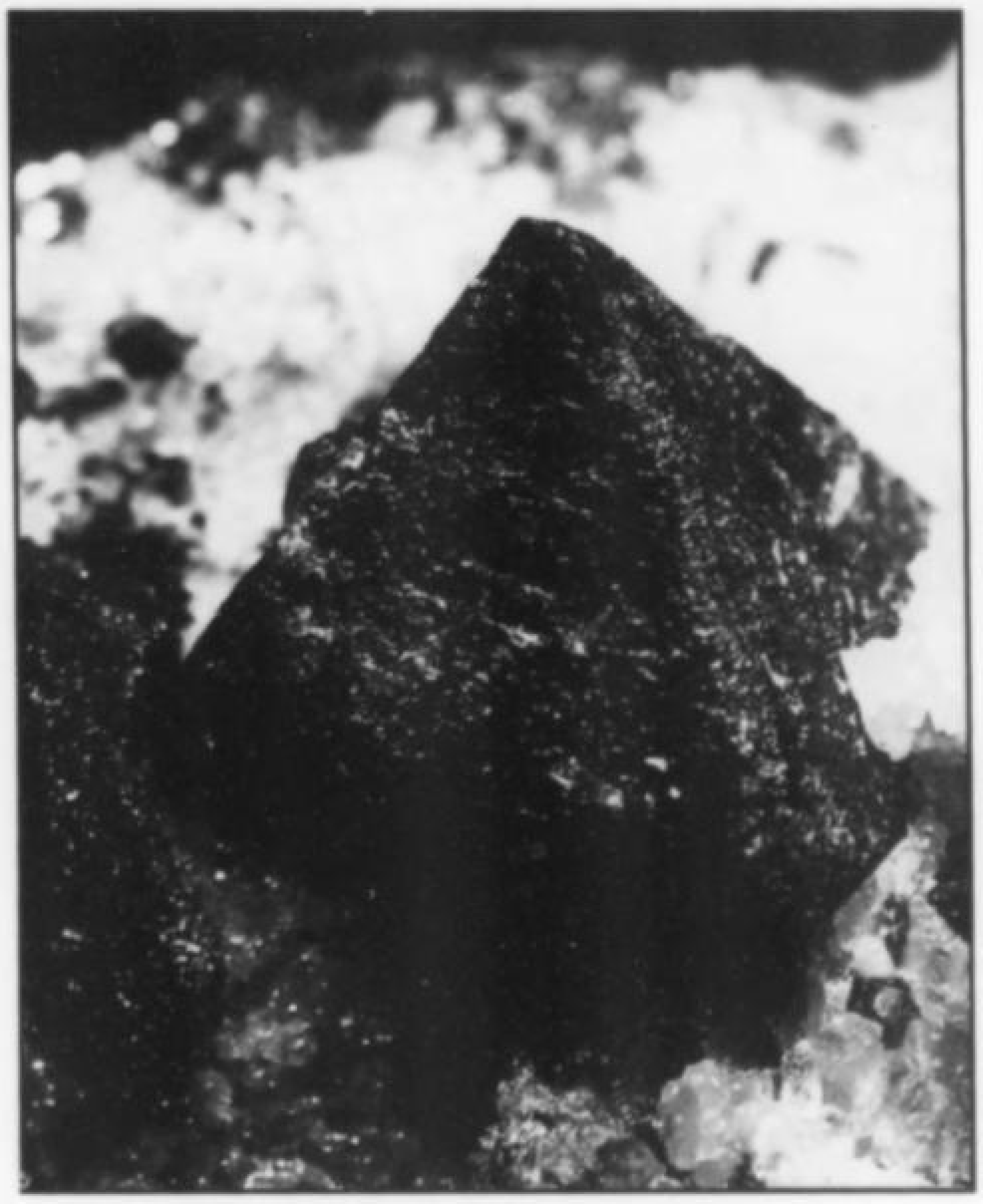


Figure 94. **Perovskite crystal in hydroxylapatite. 1.5 cm; photo by O. Medenbach.**

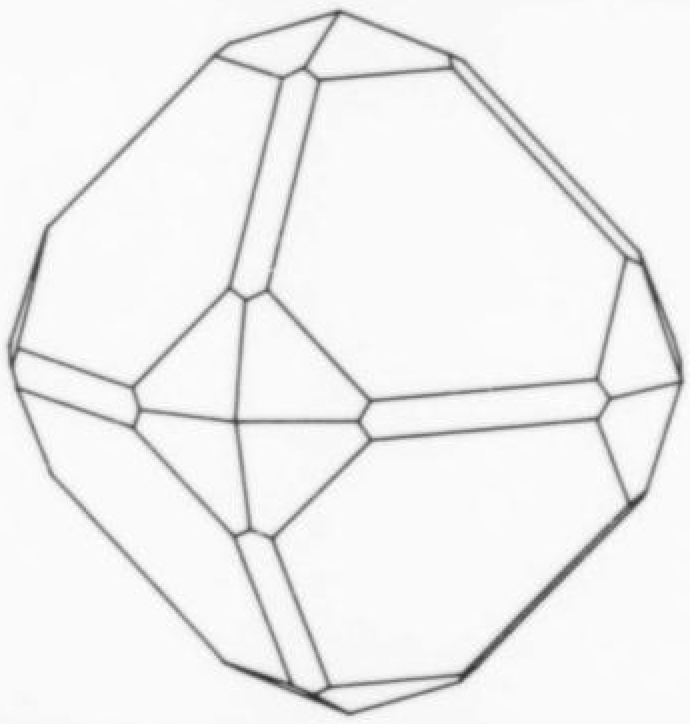


Figure 93. **Drawing of an idealized crystal of magnetite; forms developed are: {111}, {110} and {311}.**

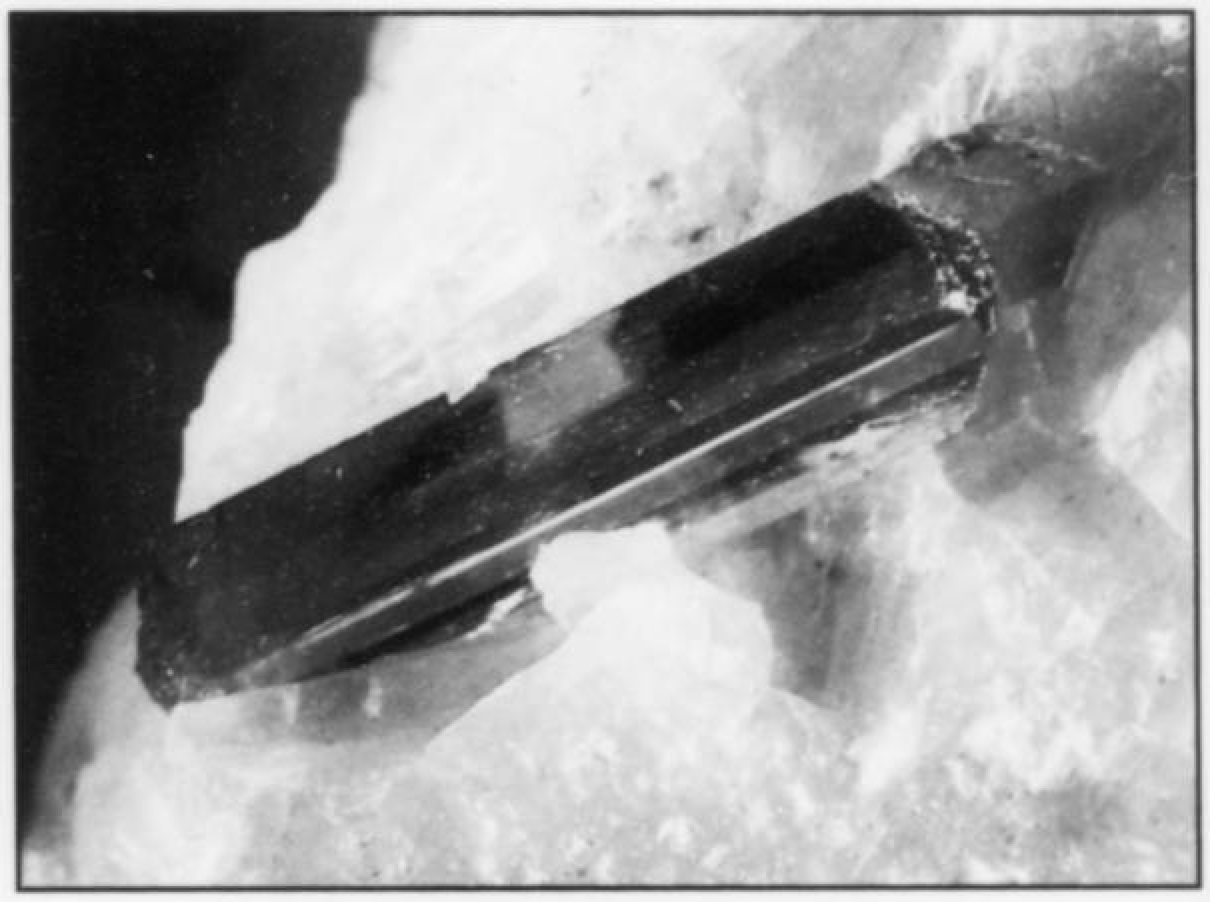


Figure 95. **This 1.4-cm gem-quality titanite crystal, embedded in natrolite, is by far the best ever found in the Gardiner complex. Unfortunately it is also the only specimen of this quality. Photo by R. Bode.**

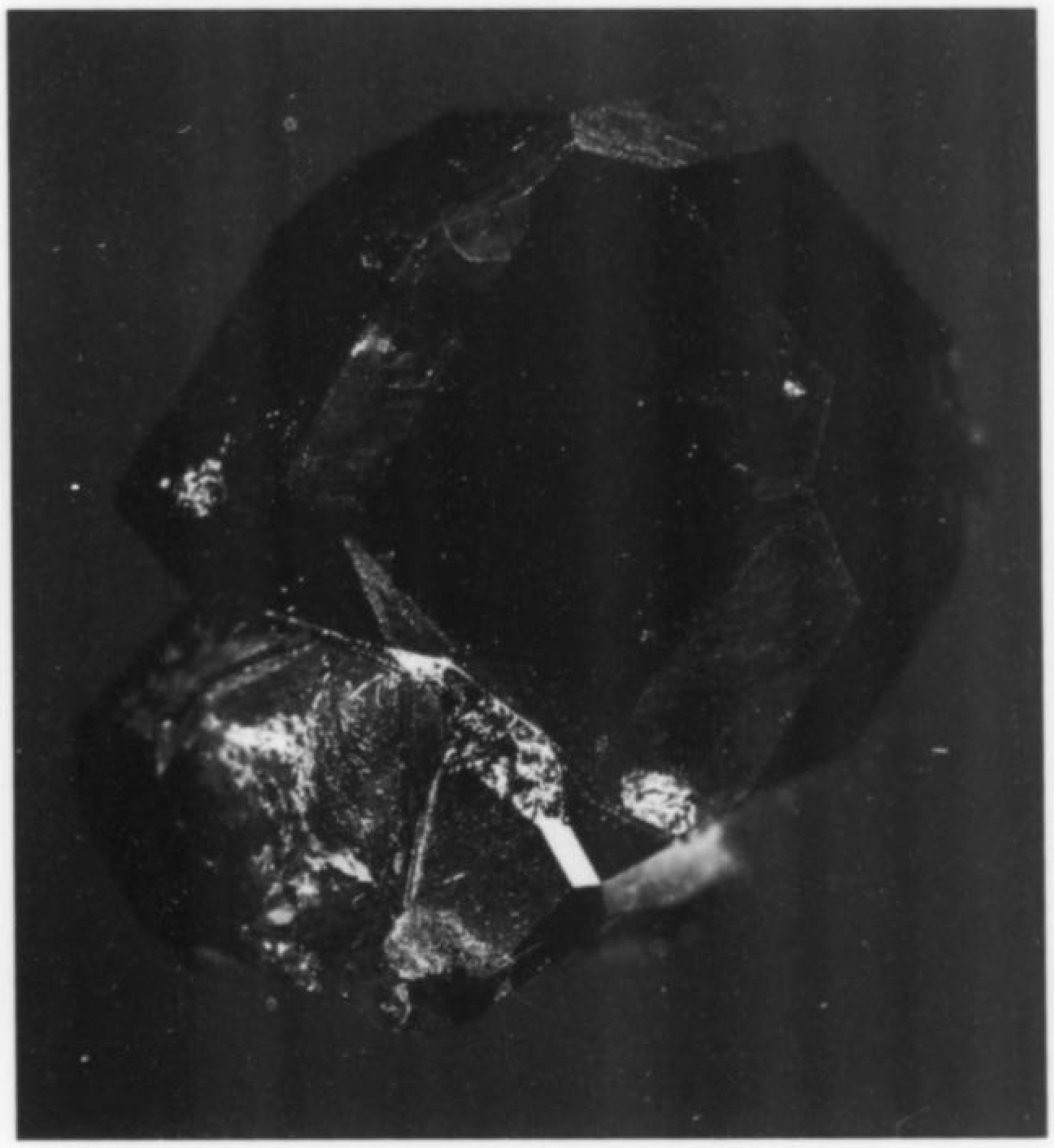


Figure 96. **Melanite crystal, 1.2 cm, from the Gardiner complex. Photo by O. Medenbach.**

consisting mainly of tremolite and well-developed crystals of magnetite up to 5 cm were found. Many well-developed crystals have been collected, both in 1975 and in 1982. The dominant (and often the only) crystal form developed is {111}, but a few crystals also show {110} and {311} faces. The smaller crystals in particular have sharp edges; some crystals have rounded edges and show corrosion and sometimes even appear to have been partially melted. Crystal size varies from a few centimeters to 20 cm! The crystals are black, and many have more or less dull faces. All the specimens collected originated from a single zone several meters wide which is traceable for about 1 km, and from a number of veins and lenses up to 10 meters in size, in the metasomatically altered ultramafic rocks adjacent to the melilitolites. The zone, as well as the veins and lenses consists of little but phlogopite and magnetite.

Andradite (titanian) $Ca_3(Fe,Ti)_2(SiO_4)_3$

Black titanian andradite occurs as compact, 10-cm aggregates of intimately intergrown, 5-mm to 6-cm crystals, and also as single crystals and clusters in a natrolite matrix. This matrix sometimes includes minor calcite, phlogopite and diopside in crystals from 1 to 7 cm. A single incomplete titanian andradite crystal found in 1975 measures fully 12 cm in diameter. Complete, well-developed crystals are rare in the compact aggregates, where the crystals show no faces, but only contacts with other titanian andradite crystals. The crystals in the natrolite matrix are only rarely more than fragments of complete crystals. The dominant, and often the only form is {110}, but some of the crystals also show minor faces of the {211} form. The crystals are black and highly lustrous. All of the black titanian andradite specimens come from layers, veinlets and pockets in the melilitolites or in the 200 to 400-meter zone of alteration surrounding the melilitolites.

Titanite $CaTiSiO_5$

Titanite is the Gardiner species which shows the largest variation in habit and color. In the majority of specimens it forms fan-shaped aggregates or complete rosettes in a matrix of acicular natrolite and stumpy amphibole prisms with minor apatite and melanite. The individual crystals of the aggregates are generally 2–4 mm wide and may attain lengths of almost 8 cm. The yellow or pale yellowish brown crystals are mostly translucent, but are in places transparent. Another habit consists of fan-shaped aggregates, but these are coarser, with crystals up to 13 cm in length. These titanites are reddish brown and non-transparent; the only accompanying mineral is amphibole. In a third habit the titanite forms complete rosettes of acicular red-brown crystals, the rosettes attain sizes of 3–4 cm. The first two habits occur in pockets and as fracture fillings in the melilitolites and the ultramafic rocks adjacent to the melilitolites. The latter habit occurs in syenite veins in association with typical nepheline syenite pegmatite minerals.

Apatite $Ca_5(PO_4)_3(F,OH,Cl)$

Apatite is a common accessory mineral in the Gardiner Complex, but from a specimen point of view only the blocky, pale green prisms in a matrix of white natrolite and minor black titanian andradite are of interest. Most of the crystals show only the prism, but a few also show pyramid and basal pinacoid; all are heavily fractured and broken. The size of the partially transparent crystals varies from 1 to 5 cm. The pockets with this apatite are found in the melilitolites and in the altered ultramafic rocks near the melilitolites. Impressions of apatite crystals as large as 30 cm have been found in the huge phlogopite zone.

Phlogopite $KMg_3Si_3AlO_{10}(F,OH)_2$

Phlogopite is particularly common in the later phases where it forms typically large, anhedral, golden brown plates. The largest, up to 50 cm, have been found in the huge 6–8 meter phlogopite zone which can be traced for over 1 km through the altered dunite not far from the contact of the melilitolite.

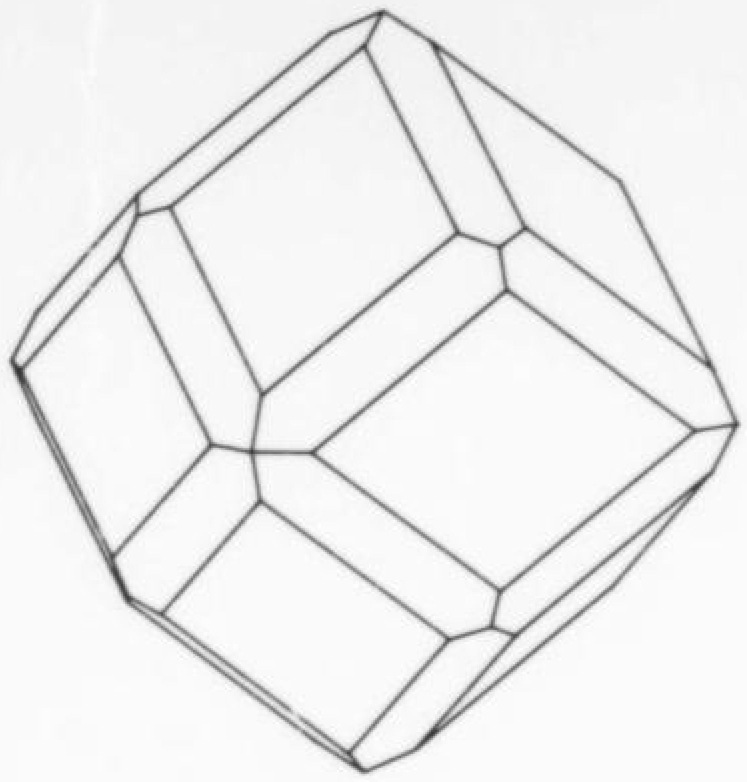


***Figure 97*. Drawing of an idealized crystal of titanian andradite; the forms developed are: {110} and {211}.**

Others

Several others of the Gardiner minerals deserve to be mentioned. The snow-white natrolite, which forms the decorative matrix for a number of the mentioned minerals (particularly for the titanian andradite); the lamprophyllite and the barytolamprophyllite, which form large platy crystalline aggregates with beautiful coppery red-brown colors; and the titanian aegirine and titanclinohumite so interesting from a compositional point of view.

However, the above-mentioned minerals are the most spectacular of all the interesting minerals from this new locality. In spite of its recent discovery, and the fact that only relatively short visits have been paid to it, the Gardiner complex has already proven to be the most prolific new Greenland source for display-quality specimens.

***Table 6*. Minerals from Gardiner.**

Aegirine
Aegirine (titanian)
Aegirine-augite
Alkali feldspar
Albite
Anatase (?)
Andradite (titanian)
Antigorite
Apatite
Arfvedsonite
Augite
Barite
Barytolamprophyllite
Biotite
Calcite
Cancrinite
Catapleiite
Cebollite
Chalcopyrite
Chlorite (group)
Chromite
Clinochlore (variety sheridanite)
Diopside
Diopside (variety Salite)
Dolomite
Eckermannite (?)
Eudialyte
Garnet (hydro)
Hauyne or Nosean
Hematite
Hydronepheline†
Ilmenite
Kaersutite
Katophorite (magnesian)
Lamprophyllite
Loparite
Lorenzenite
Magnesio-arfvedsonite
Magnesio-hastingsite
Magnetite
Melilite (group)
Microcline
Monticellite
Natrolite
Nepheline
Nosean or Hauyne
Olivine
Pargasite
Pectolite
Perovskite
Phlogopite
Plagioclase
Potassium feldspar
Pyrite
Quartz
Sodalite
Sphalerite
Strontianite
Tenorite
Titanite
Titanclinohumite
Tremolite
Vermiculite
Vesuvianite
Vishnevite
Xonotlite
Zircon

? Identity/location uncertain
† Dubious species

SUMMARY OF MINERAL SPECIES

TYPE SPECIMENS

The specimens studied in order to describe a new mineral species and specimens on which subsequent or additional descriptions are based are known as "types." Fortunately, in many cases some fragments from the original specimens used to describe the "old" minerals are preserved. In the case of "new" minerals, it is mandatory that the corresponding type material is deposited in, and taken care of, by a major national museum; because only by studying the type material is there a possibility that inadequacies or errors in the original descriptions can be corrected.

From the preceding chapters of this book we have learned that quite a large number of minerals were found for the first time in Greenland, which is to say that Greenland is the type locality for a large number of species. Below is a complete list of all the species for which Greenland is the type locality, and of which type materials are kept in the mineral collection of the Geological Museum, Copenhagen.

Although most of the specimens listed fall into the categories of holotype, cotype, metatype and plesiotype, all categories listed and defined below are represented.

Holotype

Holotypes are specimens used for the original descriptions, e.g. powdered samples for chemical analysis, crystals measured on the two-circle goniometer, single crystal(s) for X-ray diffraction, and so on. Holotype(s) should be selected by the author(s).

Cotype

Cotypes are specimens other than the holotypes, used and referred to in the original description. Cotypes are selected by the author(s), who alone can recognize them as such.

Metatype

Metatypes are specimens compared with the above types by the author(s) and determined to be co-specific.

Ideotype

Ideotypes are metatype specimens from different localities.

Plesiotype

Plesiotypes are specimens upon which subsequent or additional descriptions are based. They may in some cases be neotypes.

Neotype

Neotypes are plesiotypes used for the redescription.

Topotype

Topotypes are specimens from the original locality and corresponding to the original description.

Nekrotype

Nekrotypes are specimens of a discredited mineral used in the rejection and selected by the author(s).

In the following list the localities given are the type localities; the references given are to the first descriptions of the species and/or to the articles in which the material preserved is described.

A complete catalogue of all the type specimens in the collection is presently being prepared and will be published separately.

- ACUMINITE, Ivigtut
  - Pauly, H., and Petersen, O. V. (1987) *Neues Jahrbuch für Mineralogie, Monatshefte*, **11**, 502
- ALLANITE, Qáqarssuatsiaq at Aluk
  - Allan, T. (1812) *Transactions of the Royal Society, Edinburgh*, **6**, 345
  - Thomson, T. (1811) *Tillock's Philosophical Magazine*, **37**, 278
  - Thomson, T. (1812) *Transactions of the Royal Society, Edinburgh*, **6**, 371
  - Thomson, T. (1813) *(Gilbert's?) Annals of Philosophy, London*, **44**, 113
  - Thomson, T. (1811) *Journal des Mines*, **30**, 281
- ANCYLITE, Narssârssuk
  - Flink, G. (1901) *Meddelelser om Grønland*, **23**, 49
- ARCUBISITE, Ivigtut
  - Karup-Møller, S. (1976) *Lithos*, **9**, 253
- ASHCROFTINE (previously KALITHOMSONITE), Narssârssuk
  - Gordon, S. G. (1924) *Proceedings of the Academy of Natural Sciences, Philadelphia*, **76**, 261
- ASTROPHYLLITE, Narssârssuk
  - Petersen, O. V. (1982) *Bulletin of the Geological Society of Denmark*, **30**, 67
- BERRYITE, Ivigtut
  - Karup-Møller, S. (1966) *Canadian Mineralogist*, **8**, 414
- BØGGILDITE, Ivigtut
  - Bøgvad, R. (1951) *Meddelelser Dansk geologisk Forening*, **12**, 109
  - Pauly, H. (1956) *Meddelelser om Grønland*, **137** (6), 1
- BØGVADITE, Ivigtut
  - Pauly, H., and Petersen, O. V. (1988) *Bulletin of the Geological Society of Denmark*, **37**, 21
- BRITHOLITE, Naujakasik, Ilímaussaq
  - Winther, C. (1901) *Meddelelser om Grønland*, **24**, 190
- BUCHWALDITE, in the Cape York iron meteorite
  - Olsen, E., *et al*. (1977) *American Mineralogist*, **62**, 362

- CARLSBERGITE, in the Agpalilik iron meteorite
  - Buchwald, V. F., and Scott, E. R. D. (1971) *Nature. Physical Science*, **233**, 113
- CHALCOLAMPRITE, Narssârssuk
  - Flink, G. (1901) *Meddelelser om Grønland*, **24**, 160
- CORDYLITE, Narssârssuk
  - Flink, G. (1901) *Meddelelser om Grønland*, **24**, 42
  - Bøggild, O. B. (1907) *Meddelelser om Grønland*, **33**, 101
- CRYOLITE, Ivigtut
  - Schumacher, C. F. (1798) *Naturhistorie-Selskabets Skrifter, Kiøbenhavn*, **4** (2), 230
  - Abildgaard, P. C. (1799) *Scherer's Allgemeine Journal der Chemie?*, **2**, 502
  - D'Andrada, E. Silva, J. B. (1800) *Ibid.*, **4**, 38
  - Abildgaard, P. C. (1800) *Kongelige Danske Videnskabernes Selskab Skrifter*, **1**, 311
  - Giesecke, K. L. (1821–22) *Edinburgh Philosophical Journal*, **6**, 141
  - Bøggild, O. B. (1912) *Meddelelser om Grønland*, **50**, 1
- CRYOLITHIONITE, Ivigtut
  - Ussing, N. V. (1904) *Oversigt Kongelige Danske Videnskabernes Selskab Forhandlinger*, **1**, 3
- CUPROSTIBITE, Ilímaussaq
  - Karup-Møller, S., *et al.* (1978) *Bulletin Grønlands geologiske Undersøgelse*, **126**, 1
- ELPIDITE, Narssârssuk
  - Flink, G. (1901) *Meddelelser om Grønland*, **24**, 146
- EMELEUSITE, Igdlutalik
  - Upton, B. G. J., *et al.* (1978) *Mineralogical Magazine*, **42**, 31
  - Johnsen, O., *et al.* (1978) *Zeitschrift für Kristallographie*, **147**, 297
- ENDEIOLITE, Narssârssuk
  - Flink, G. (1901) *Meddelelser om Grønland*, **24**, 166
- EPIDIDYMITE, Narssârssuk
  - Flink, G. (1893) *Geologiska Föreningen i Stockholm, Förhandlingar*, **15**, 201
  - Flink, G. (1894) *Zeitschrift für Kristallographie und Mineralogie*, **23**, 353
  - Petersen, O. V. (1966) *American Mineralogist*, **51**, 916
  - Semenov, E. I., and Sørensen, H. (1966) *Meddelelser om Grønland*, **181** (2), 1
- EPISTOLITE, Tugtup agtakôrfia, Ilímaussaq
  - Bøggild, O. B. (1901) *Meddelelser om Grønland*, **24**, 183
- ERIKITE, Nunarssuatsiaq, Ilímaussaq
  - Bøggild, O. B. (1904) *Meddelelser om Grønland*, **26**, 93
  - Danø, M., and Sørensen, H. (1959) *Meddelelser om Grønland*, **162** (5), 1
- ESKIMOITE, Ivigtut
  - Karup-Møller, S. (1977) *Bulletin of the Geological Society of Denmark*, **26**, 41
- GEARKSUTITE, Ivigtut
  - Thomsen, J. (1862) *Tidsskrift for Physik og Chemie*, 328
  - Dana, J. D. (1868) *System of Mineralogy*, Fifth edition, 130
- GIESECKITE, Akuliaruseq (Akuliarusiarsuk)
  - Allan, T. (1813) *Annals of Philosophy, London*, **2**
  - Stromeyer, F. (1819) *Göttingische Gelehrte Anzeigen*, **200**, 1993
  - Ussing, N. V. (1898) *Meddelelser om Grønland*, **14**, 121
- GUNNBJARNITE = FERRISEPIOLITE, Steensby's Bjerg, Hold-with-Hope
  - Bøggild, O. B. (1951) *Meddelelser om Grønland*, **142** (8), 3
- GUSTAVITE, Ivigtut
  - Karup-Møller, S. (1970) *Canadian Mineralogist*, **10**, 173
  - Karup-Møller, S. (1973) *Meddelelser om Grønland*, **196** (5), 1
  - Karup-Møller, S. (1977) *Bulletin of the Geological Society of Denmark*, **25**, 56
- IGALIKITE, 35 km east of Igaliko
  - Bøggild, O. B. (1933) *Meddelelser om Grønland*, **92**, 9
  - Danø, M., and Sørensen, H. (1959) *Meddelelser om Grønland*, **162** (5), 1
- IGDLOITE = LUESHITE, Igdlunguaq, Ilímaussaq
  - Danø, M., and Sørensen, H. (1959) *Meddelelser om Grønland*, **162** (5), 35
  - Sørensen, H. (1962) *Meddelelser om Grønland*, **167** (1), 1
- JARLITE, Ivigtut
  - Bøgvad, R. (1933) *Meddelelser om Grønland*, **92** (8), 1
  - Bøgvad, R. (1951) *Meddelelser Dansk geologisk Forening*, **12**, 109
  - Petersen, O. V., and Johnsen, O. (1985) *Neues Jahrbuch für Mineralogie, Monatshefte*, **12**, 543
- KAERSUTITE, Østerfjeld near Qaersut
  - Ussing, N. V. (1905) *in* Rosenbusch: *Mikroskopische Physiographie der Mineralien und Gestein. Band 1. Die petrographisch wichtigen Mineralien, Stuttgart*, **1** (2), 236
- KORNERUPINE, Fiskenæsset area
  - Lorenzen, J. (1884) *Meddelelser om Grønland*, **7** (1), 19
  - Ussing, N. V. (1889) *Öfversikt Kungliga Vetenskaps-Akademiens Förhandlingar, Stockholm*, **1**, 15
  - Ussing, N. V. (1889) *Zeitschrift für Kristallographie*, **15**, 605
- KVANEFJELDITE, Kvanefjeld, Ilímaussaq
  - Petersen, O. V., *et al.* (1984) *Canadian Mineralogist*, **22**, 465
  - Johnsen, O., *et al.* (1983) *Neues Jahrbuch für Mineralogie, Monatshefte*, **11**, 505
- LEIFITE, Narssârssuk
  - Bøggild, O. B. (1915) *Meddelelser om Grønland*, **51**, 429
  - Micheelsen, H., and Petersen, O. V. (1970) *Bulletin of the Geological Society of Denmark*, **20**, 134
- LEUCOSPHENITE, Narssârssuk
  - Flink, G. (1901) *Meddelelser om Grønland*, **24**, 137
- LORENZENITE, Narssârssuk
  - Flink, G. (1901) *Meddelelser om Grønland*, **24**, 130
- METAJARLITE, Ivigtut
  - Bøgvad, R. (1933) *Meddelelser om Grønland*, **92** (8), 1
  - Bøgvad, R. (1951) *Meddelelser Dansk geologisk Forening*, **12**, 109
- NACARENIOBSITE-(Ce), Ilímaussaq
  - Petersen, O. V., *et al.* (1989) *Neues Jahrbuch für Mineralogie, Monatshefte*, **2**, 84
- NARSARSUKITE, Narssârssuk
  - Flink, G. (1901) *Meddelelser om Grønland*, **24**, 154
- NAUJAKASITE, Naujakasik and Ilímaussaq
  - Bøggild, O. B. (1933) *Meddelelser om Grønland*, **92** (9), 7
  - Petersen, O. V. (1967) *Meddelelser om Grønland*, **181** (6), 1
  - Petersen, O. V., and Andersen, S. (1975) *Bulletin Grønlands geologiske Undersøgelse*, **116**, 5
- NEPTUNITE, Narssârssuk
  - Flink, G. (1893) *Geologiska Föreningen i Stockholm, Förhandlingar*, **15**, 196
- PACHNOLITE, Ivigtut
  - Pauly, H., and Petersen, O. V. (1983) *Neues Jahrbuch für Mineralogie, Monatshefte*, **6**, 241
- POLYLITHIONITE, Kangerdluarssuk area, Ilímaussaq
  - Lorenzen, J. (1881) *Meddelelser om Grønland*, **2**, 70
  - Lorenzen, J. (1882) *Mineralogical Magazine*, **5**, 49
- PROSOPITE, Ivigtut
  - Petersen, O. V. (1986) *Neues Jahrbuch für Mineralogie, Monatshefte*, **7**, 329
- RALSTONITE, Ivigtut
  - Pauly, H. (1965) *American Mineralogist*, **50**, 1851
- REYERITE, Niaqornat
  - Cornu, F. (1906–07) *Mineralogisch Petrographische Mitteilungen (Tschermak)*, **25**, 211
- RINKITE, Kangerdluarssuk area, Ilímaussaq
  - Lorenzen, J. (1893) *Meddelelser om Grønland*, **7**, 4

ROHAITE, Ilímaussaq
Karup-Møller, S. *et al.* (1978) *Bulletin Grønlands geologiske Undersøgelse*, **126**, 31
SCHIZOLITE = Pectolite (manganoan), Kangerdluarssuk area, Ilímaussaq
Winther, C. (1901) *Meddelelser om Grønland*, **24**, 196
Bøggild, O. B. (1904) *Meddelelser om Grønland*, **26**, 121
SEMENOVITE, Taseq Slope, Ilímaussaq
Petersen, O. V., and Rønsbo, J. G. (1972) *Lithos*, **5**, 163
Mazzi, F., *et al.* (1979) *American Mineralogist*, **64**, 202
SKINNERITE, Kangerdluarssuk Plateau, Ilímaussaq
Karup-Møller, S. (1974) *Neues Jahrbuch für Mineralogie, Abhandlungen*, **129** (3), 291
SORENSENITE, Kvanefjeld, Ilímaussaq
Semenov, E. I., *et al.* (1965) *Meddelelser om Grønland*, **181** (1) 1
SPODIOPHYLLITE, Narssârssuk
Flink, G. (1901) *Meddelelser om Grønland*, **24**, 85
STEENSTRUPINE, Kangerdluarssuk area, Ilímaussaq
Lorenzen, J. (1881) *Meddelelser om Grønland*, **2**, 73
Moberg, J. C. (1898) *Zeitschrift für Kristallographie*, **29**, 385
Moberg, J. C. (1899) *Meddelelser om Grønland*, **20**, 245
Sørensen, H. (1962) *Meddelelser om Grønland*, **167** (1), 1
STENONITE, Ivigtut
Bøggild, O. B. (1953) *Meddelelser om Grønland*, **149** (3), 164
Pauly, H. (1965) *Meddelelser om Grønland*, **169** (9), 1
SYNCHYSITE, Narssârssuk
Flink, G. (1901) *Meddelelser om Grønland*, **24**, 29
Bøggild, O. B. (1907) *Meddelelser om Grønland*, **33**, 99
TAENIOLITE, Narssârssuk
Flink, G. (1901) *Meddelelser om Grønland*, **24**, 115
THOMSENOLITE, Ivigtut
Hagemann, G. (1866) *American Journal of Science*, **41** (2), 119
TUGTUPITE, Tugtup agtakôrfia, Ilímaussaq
Sørensen, H. (1960) *Report of the 21st International Geological Congress, Norden*, **17**, 31
Sørensen, H. (1963) *Ibid.*, **27**, Cont. to Disc., 157
Danø, M. (1966) *Acta Crystallographica*, **20** 812
Sørensen, H. (1971) *Meddelelser om Grønland*, **181** (13), 1
Petersen, O. V. (1978) *Mineralogical Magazine*, **42**, 251
TUPERSSUATSIAITE, Tuperssuatsiait, Ilímaussaq
Karup-Møller, S., and Petersen, O. V. (1984) *Neues Jahrbuch für Mineralogie, Monatshefte*, **11**, 501
USSINGITE, Kangerdluarssuk, Ilímaussaq
Bøggild, O. B. (1914) *Meddelelser om Grønland*, **51**, 105
VIKINGITE, Ivigtut
Karup-Møller, S. (1977) *Bulletin of the Geological Society of Denmark*, **26**, 41
VILLIAUMITE, Kvanefjeld, Ilímaussaq
Petersen, O. V. (1981) *Neues Jahrbuch für Mineralogie, Monatshefte*, **3**, 111
VINOGRADOVITE, Ilímaussaq
Rønsbo, J. G. *et al.* (1984) *Neues Jahrbuch für Mineralogie, Monatshefte*, **11**, 481
VITUSITE, Kvanefjeld, Ilímaussaq
Rønsbo, J. G. *et al.* (1979) *Neues Jahrbuch für Mineralogie, Abhandlungen*, **137**, 42
VUONNEMITE, Kvanefjeld, Ilímaussaq
Rønsbo, J. G. *et al.* (1983) *Neues Jahrbuch für Mineralogie, Monatshefte*, **10**, 451
WEBERITE, Ivigtut
Bøgvad, R. (1938) *Meddelelser om Grønland*, **7**, 119
Pauly, H., and Petersen, O. V. (1981) *Neues Jahrbuch für Mineralogie, Monatshefte*, **11**, 511

***Table 7.* All minerals found in Greenland.**

Acanthite
Acmite
Actinolite
Acuminite
Aegirine
Aegirine-augite
Aegirine (titanian)
Aenigmatite
Aikinite
Albite
Algodonite
Alkali feldspar
Allanite
Allargentum
Alstonite
Altaite
Aluminite
Analcime
Anatase
Ancylite
Andalusite
Andesine
Andradite (titanian)
Anhydrite
Ankerite
Annabergite
Anorthite
Anthophyllite
Antigorite
Antimony
Apatite
Apatite (yttrian)
Apophyllite
Aragonite
Arcubisite
Arfvedsonite
Argentite
Arksutite†
Armalcolite
Arsenopyrite
Ashcroftine
Astrophyllite
Atacamite
Augite
Augite (titanian)
Avicennite (?)
Axinite
Azurite
Babingtonite
Bariopyrochlore
Barite
Barylite
Barytocelestine
Barytolamprophyllite
Bastnäsite
Berryite
Bertrandite
Beryl
Beryllite
Betafite
Beudantite
Biotite
Bismuth
Bismuthinite
Bøggildite
Bøgvadite
Bohdanowiczite
Böhmite
Bornite
Boulangerite
Bournonite
Bravoite
Breithauptite
Britholite
Brochantite
Brucite
Buchwaldite
Bunsenite
Burbankite
Bytownite
Calcite
Cancrinite
Canfieldite
Carbonate-hydroxylapatite
"Carburan" (= "Thucolite")
Carlsbergite
Cassiterite
Catapleiite
Cebollite
Celadonite
Celestine
Cerussite
Chabazite
Chalcedony
Chalcolamprite†
Chalcopyrite
Chalcosite
Chalcostibite
Chalcothallite
Chalypite (?)†
Chevkinite
Chiolite
Chkalovite
Chlorite (group)
Chondrodite
Chromite
Chrysocolla
Chrysotile
Clausthalite
Clinochlore (variety sheridanite)
Clinozoisite
Clinozoisite (chromian)
Clintonite
Cobaltite
Coffinite
Cohenite
Columbite
Connelite
Cookeite
Copiapite
Copper
Cordierite
Cordylite
Corundum
Corundum (variety Ruby)
Corundum (variety Sapphire)
Cosalite
Covellite
Cryolite
Cryolithionite
Cubanite
Cummingtonite
Cuprite
Cuprostibite
Daubreelite
Davidite
Diamond
Diaspore
Digenite
Diopside
Diopside (chromian)
Diopside (variety Ferrosalite)
Diopside (variety Salite)
Djerfisherite
Djurleite (?)
Dolomite
Domeykite
Dumortierite
Dyscrasite
Eckermannite (?)
Electrum
Elpasolite
Elpidite
Emeleusite
Emplectite
Enargite
Endeiolite†
Enstatite
Enstatite (ferroan)
Ephesite
Epididymite
Epidote
Epistolite
Epsomite (?)
Erikite†
Erythrite
Eskimoite
Eucairite
Eucolite†
Eudialyte
Eudidymite
Euxenite

? Identity/location uncertain
† Dubious species

(continued)

***Table 7*. All minerals found in Greenland (continued).**

- Evenkite (?)
- Famatinite
- Fassaite
- Fayalite
- Fergusonite
- Ferriphlogopite (?)
- Ferrisepiolite
- Ferrohornblende
- Ferrogedrite
- Ferrohortonolite
- Ferrorichterite
- Ferrosilite
- Fibroferrite
- Fluorite
- Forsterite
- Freibergite
- Gadolinite
- Gahnite
- Gaidonnayite (catapleiite-alpha)
- Galena
- Garnet (group)
- Gearksutite
- Gedrite
- Geikielite
- Gelbertrandite (?)†
- Genthelvite
- Gerasimovkite
- Gersdorffite
- Gibbsite
- Gieseckite†
- Gismondine (?)
- Glauconite
- Gmelinite
- Godlevskite
- Goethite
- Gold
- Gonnardite
- Grandidierite
- Graphite
- Grossular
- Gudmundite
- Gustavite
- Gypsum
- Gyrolite
- Hagemannite†
- Halite
- Halloysite
- Halotrichite
- Hastingsite
- Hauyne (?)
- Heazlewoodite
- Hedenbergite
- Helvite
- Hematite
- Hemimorphite
- Hercynite
- Hercynite (chromian)
- Herschelite
- Hessite
- Heulandite
- Hexahydrite
- Hiortdahlite
- Hisingerite
- Högbomite
- Hornblende
- Huanghoite
- Hyalophane
- Hydrargilite = Gibbsite
- Hydrocerussite
- Hydronephelin†
- Hydronium jarosite
- Hyperstene
- Igalikite†
- Ikaite
- Ilimaussite
- Illite (group)
- Ilmenite
- Ilvaite
- Iron
- Ivigtit†
- Jarlite
- Joaquinite
- Kaersutite
- Kalsilite
- Kamacite
- Kaolinite
- Katophorite (magnesian)
- Kesterite
- Kornerupine
- Kupletskite
- Kvanefjeldite
- Kyanite
- Labradorite
- Lamprophyllite
- Lanthanite
- Laumontite
- Lavenite
- Lawrencite (?)
- Lazulite
- Lazurite
- Lead
- Leifite
- Lepidocrocite
- Lepidolite (?)
- Leucite
- Leucophanite
- Leucosphenite
- Levyne
- Limonite = mostly Goethite
- Linarite
- Litharge
- Löllingite
- Lomonosovite
- Lomonosovite, β-
- Loparite
- Lorenzenite
- Lovozerite
- Lueshite
- Luzonite
- Mackinawite
- Maghemite
- Magnesio-arfvedsonite
- Magnesio-hastingsite
- Magnesiohornblende
- Magnesite
- Magnetite
- Magnetite (chromian)
- Malachite
- Malachite (antimonian)
- Marcasite
- Margarite
- Marialite
- Martensit†
- Mascagnite
- Matildite
- Melanterite
- Melilite (group)
- Mesolite
- Metajarlite†
- Microcline
- Microlite
- Millerite
- Mirabilite (?)
- Molybdenite
- Monazite
- Monohydrocalcite
- Monticellite
- Montmorillonite
- Moonstone (soda-orthoclase)
- Mordenite
- Mosandrite
- Murmanite
- Muscovite
- Muscovite (chromian)
- Nacareniobsite-(Ce)
- Nahcolite
- Na-Komarovite
- Narsarsukite
- Natrolite
- Naujakasite
- Naumannite
- Nenadkevichite
- Nepheline
- Neptunite
- Nickeline
- Niobophyllite
- Nontronite
- Nordstrandite
- Nosean (?)
- "Nuummite"
- Okenite
- Oligoclase
- Olivine
- Opal
- Orayite (?)
- Orthoclase
- Pachnolite
- Palygorskite
- Pargasite
- Pavonite
- Pearceite (?)
- Pectolite
- Pectolite (manganoan)
- Pentlandite
- Pentlandite (chromian)
- Periclase
- Perovskite
- Phillipsite
- Phlogopite
- Pickeringite
- Plagioclase
- Platinum
- Plattnerite
- Polybasite
- Polydymite
- Polylithionite
- Portlandite
- Potassium feldspar
- Prehnite
- Prosopite
- Pumpellyite
- Pyrargyrite
- Pyrite
- Pyrochlore
- Pyrolusite
- Pyromorphite (?)
- Pyrophanite
- Pyroxene
- Pyrrhotite
- Quartz
- Ralstonite
- Retinite†
- Reyerite
- Rhabdophane
- Rhodochrosite
- Richterite
- Riebeckite
- Riebeckite (variety Crocidolite)
- Rinkite
- Rinkolite†
- Rohaite
- Römerite
- Röntgenite
- Rosenbuschite
- Rozenite
- Rutile
- Rutile (niobian)
- Sapphirine
- Sauconite
- Scapolite (group)
- Scheelite
- Schreibersite
- Scolecite
- Scorodite
- Seinäjokite
- Semenovite
- Senarmontite
- Sepiolite
- Serandite
- Sericite
- Serpentine (group)
- Shandite
- Siderite
- Sillimanite
- Silver
- Skinnerite
- Skutterudite
- Skutterudite (variety smaltitet)
- Sodalite
- Soda-microcline
- Soda-orthoclase
- Sorensenite
- Sphalerite
- Spherobertrandite†
- Spinel
- Spinel (chromian)
- Spinel (ferroan) (chromian)
- Spodiophyllite
- Stannite
- Staurolite
- Steenstrupine
- Stenonite
- Stibnite (?)
- Stichtite
- Stilbite
- Stillwellite
- Stilpnomelan
- Strontianite
- Sulfur
- Synchysite
- Tacharanite
- Taeniolite
- Taenite
- Talc
- Tapalpite†
- Teallite
- Tennantite
- Tenorite
- Tetrahedrite
- Tetranatrolite
- Tetrataenite
- Thalcusite
- Thenardite
- Thermonatrite
- Thomsenolite
- Thomsonite
- Thorianite
- Thorite
- Thorogummite
- Tin
- Titanclinohumite
- Titanite
- Titanomagnetite
- Todorokite
- Topaz
- Tourmaline
- Tremolite
- Tridymite
- Troilite
- Trona
- Tschermakite
- Tschermigite
- "Tucholite"
- Tugtupite
- Tundrite
- Tuperssuatsiaite
- Umangite
- Uraninite
- Uranophane, β-
- Uranothorite
- Uranpyrochlore
- Ussingite
- Valentinite
- Valleriite
- Vermiculite
- Vesuvianite
- Vikingite
- Villiaumite
- Vinogradovite
- Violarite
- Vishnevite
- Vitusite
- Vivianite
- Volynskite
- Vrbaite (?)
- Vuonnemite
- Wavellite (?)
- Weberite
- Westerveldite
- Whewellite
- Willemite
- Wittichenite
- Wolframite
- Wollastonite
- Wölsendorfite (barian)
- Wulfenite
- Wüstite
- Xenotime
- Xonotlite
- Yttrotantalite (?)
- Yttrotitanite (?)†
- Zaratite
- Zinnwaldite
- Zircon
- Zoisite
- Zoisite (variety thulite)

? Identity/location uncertain

† Dubious species

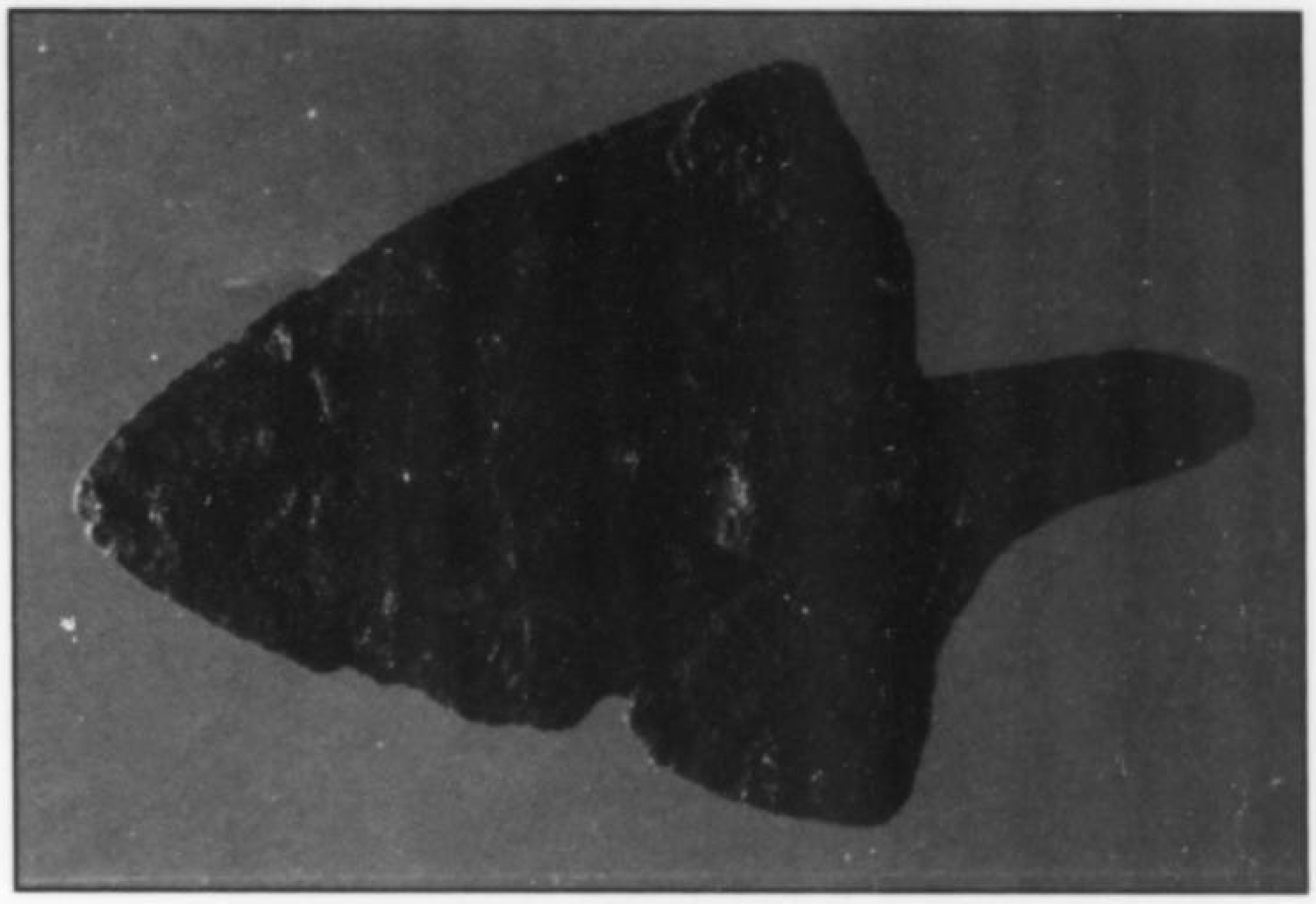


Figure 98. **Arrowhead made of meteoritic iron, found in the ruins of the 14th-century Norse farm at Nipâtsoq (Nipaatsoq) south of Godthåb (Nuuk). The meteoritic iron is known to have come from the Cape York fall, implying Norse relations with the Eskimos, 1500 km north of the farm area. Photo by Greenland National Museum.**

METEORITES

Greenland is the only country in the world in which both meteoritic and terrestrial iron has been found in large quantities. Although it is perhaps not customary to include the constituents of meteorites among the minerals found in a certain country, we consider it natural to do so in this case because of the parallelism. The terrestrial iron was treated on p. 50–52. In this chapter some details are given on the Greenland iron meteorites from the largest meteor shower ever recorded, the Cape York. An additional short mention of the world's northernmost stone meteorite, Ella Island, closes this chapter.

CAPE YORK METEORITES

When the 75- to 150-ton Cape York meteor hit the atmosphere above the Melville Bugt (Qimusseriarsuaq) area, it split into several fragments, eight of which were found where they fell. Their total weight was approximately 58 tons. The eight fragments, carrying individual names, are listed in the table below with the exact localities, weights and year of their discovery. The last four listed in the table are fragments transported by Eskimos and acquired in different settlements by archaeologists.

Name	Locality	Weight kg	Year of find
Ahnighito	Meteoritø	30,880	1894
Woman	Saveruluk	3,000	1894
Dog	Saveruluk	407	1894
Savik I	Saveqarfik	3,402	1913
Thule	Nunatak	48.6	1955
Savik II	Saveqarfik	7.8	1961
Agpalilik	Agpalilik	20,140	1963
Tunorput	Meteoritø	250	1984
Akpohon	Ellesmere Island	1.66	1914
Northumberland	Smith Sund	0.292	1928
Unnamed	Thule, Comers midden	0.078	1954
Unnamed	Thule, Comers midden	0.711	1954

No other meteorite has been so intimately connected with the life of so many people as Cape York. In the following we will give an inkling of the importance of Cape York for the Thule Eskimos, and a few details of the circumstances under which some of the larger fragments were found and recovered.

The fall probably took place long before the Eskimos inhabited the Melville Bugt (Qimusseriarsuaq) region around 1,000 A.D., but probably after 10,000 B.C.; the latter date is based on the relatively good state of preservation of the fragments. The Thule Eskimos lived a nomadic hunting life on the barren northwestern coast of Greenland. Having no outside supplies of iron, they learned at an early date to fit their hunting weapons (made of walrus tusk, narwhale tusk and reindeer antler) with cutting edges of meteoritic iron. In order to secure iron they regularly visited the site of the iron masses, 50 km east-northeast of Cape York. The discovery of small specimens in Eskimo possession and the recovery of small blocks through archaeological excavation of Eskimo settlements, suggest that at one time smaller, easily transportable blocks could be found on the ground. The 292-gram individual from Northumberland Ø, 250 km northwest of the fall area, listed in the table, is such a transported specimen, obtained by Knud Rasmussen in 1928. The most impressive evidence of the transportation of an iron block is provided by the discovery in 1914 of a 1.6-kg mass near an ancient settlement on Ellesmere Island, about 500 km by sled northwest of the fall. In our time it has been possible to trace the meteoritic iron, in the form of tools, over a still larger area: from the Disko Bugt (Qeqertarsuup Tunna), more than 1,000 km by sled to the south, to Ellesmere Island, Somerset Island, and Chesterfield Inlet in Canada, more than 2,000 km to the west. The Eskimos also worked the larger blocks known to them. Evidence of this is seen on the blocks themselves, but more strikingly on the ground around the blocks. In 1963 V. F. Buchwald relocated the four sites where major fragments had been found, and from the location of the 3-ton "Woman" reported the incredible amount of 10,000 rounded basalt hammer stones and fragments of basalt hammer stones, each weighing 1–10 kg, accumulated into a pile 8–10 meters in di-

Figure 99. **The 3.5-cm fragment of the Thule meteorite shown here was found in 1955 on a nunatak at the Harald Moltke Bræ. It was originally supposed to represent a separate fall; chemical and metallurgical investigations have, however, shown that it is probably a small fragment of the Cape York meteorites. Photo by Geological Museum, Copenhagen.**

ameter. For countless generations the Eskimos must have traveled to the distant place in order to renew their stock of iron for implements. Each sled party brought new hammer stones of hard and tough basalt with them, because the hunters knew that the gneissic boulders at the site were too fragile to be of any use in the tedious work of chipping small pieces of iron from the "Woman."

In the 19th century numerous expeditions to the region brought back a few knives and harpoons with cutting edges of meteoritic iron, and small fragments of iron even found their way to Europe. But it was not until 1894, when two Eskimos brought R. E. Peary on a sled trip to show him "Ahnighito," "Woman" and "Dog" that the Eskimos' source of iron was unveiled. Once he learned the Greenlanders' source of iron Peary decided to postpone his drive towards the North Pole and devote himself to the removal of these meteorites. The 3-ton "Woman" and the 400-kg "Dog" were shipped to New York in 1895, while the 31-ton "Ahnighito," originally believed to weigh between 90–100 tons, was shipped to New York in 1897. All three can be seen today in New York's Hayden Planetarium.

While operating the trading post at Thule (Qaanaaq), beginning in 1910, Knud Rasmussen encouraged the Eskimos to look for more fragments. A 3.4-ton mass, "Savik I," was the bonus; it was discovered in 1913, 10 km east of the place where "Woman" and "Dog" had been found. Like these, "Savik I" had been known to previous generations of Eskimos, since basaltic hammer stones were located around it. In 1923–24 the mass was hauled from the top of the cliff to the seashore. With 14 sleds and 175 dogs the meteorite was pulled across 25 km of sea ice to Bushnan Island, where open water allowed the *Søkongen* to pick it up and carry it to Copenhagen, where it can be seen at the Geological Museum.

Figure 100. **The second largest of the Cape York meteorites—Agpalilik—was found by V. F. Buchwald in 1963, resting on a slope solidly anchored in the permafrost. The picture shows Agpalilik very much as it was found, with only a few boulders removed from the top of this huge mass. Photo by V. F. Buchwald.**

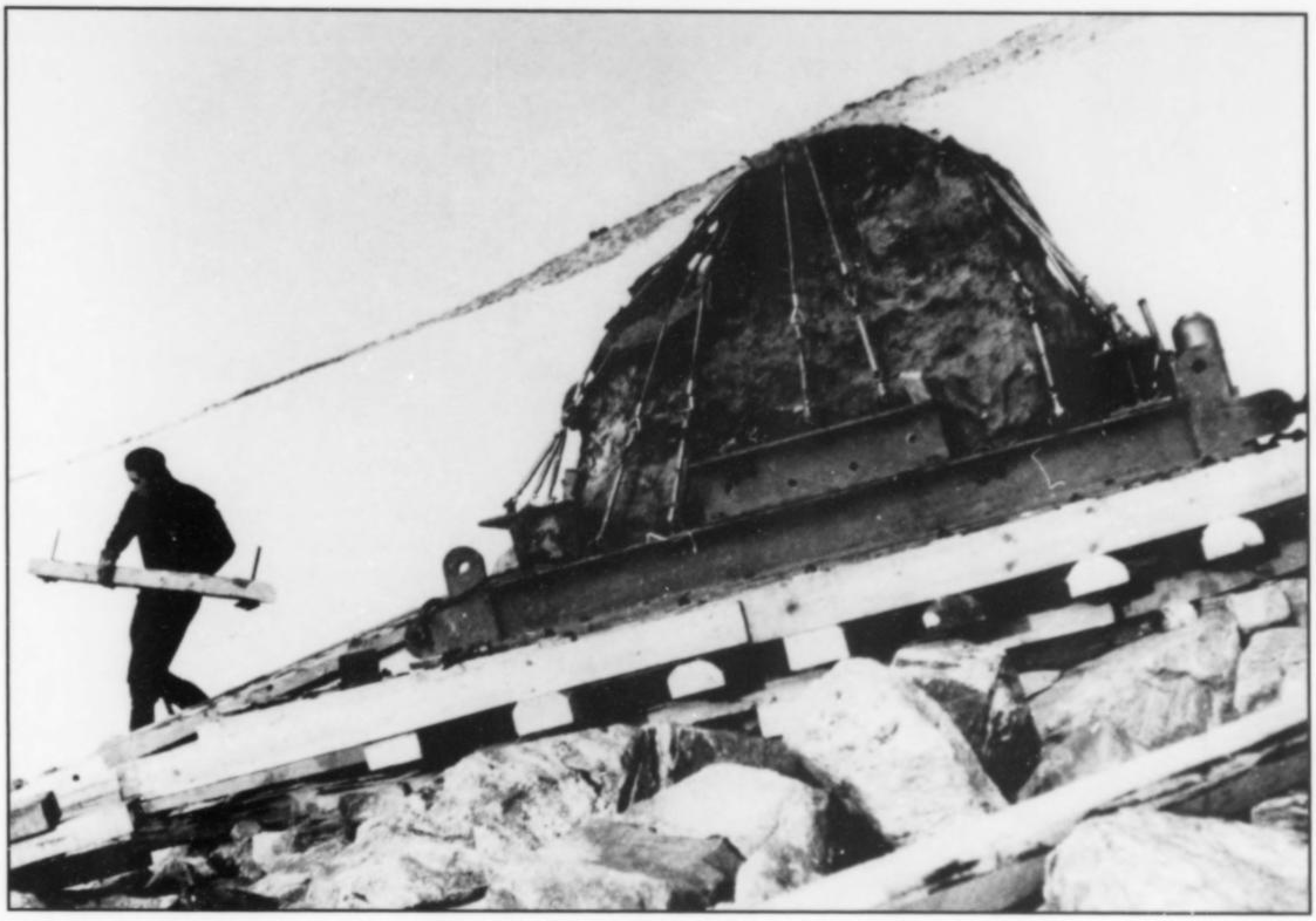


***Figure 101*. Preparations to remove Agpalilik took several years. In 1965 it was excavated. Photo by V. F. Buchwald.**

The Thule fragment was found in 1955 by a group of American glaciologists on a nunatak protruding through the Harald Moltke Bræ. The fragment has the shape of a resting goose, measuring 35 x 30 x 20 cm, and weighing 48.6 kg. Because of the 100-km distance between Thule and Cape York, Thule was originally supposed to be a separate fall. However, chemical and metallurgical investigations have shown that the Thule meteorite has so many points of similarity with the Cape York specimens that it is probably a small fragment of Cape York that had separated from the main mass high up in the atmosphere.

In 1961 a small mass of 7.8 kg, "Savik II," was discovered on the coast 1 km east of the site of "Savik I." It was found between boulders at the foot of a cliff by an Eskimo on a hunting trip; this too is now in the Geological Museum, Copenhagen.

In 1963 V. F. Buchwald found the second largest of the Cape York fragments, the 20-ton "Agpalilik." According to Buchwald, it was found resting on a slope solidly anchored in the permafrost ground, no Eskimo hammer stones were found around it, and the mass had apparently never been known to the Eskimos, probably because it was covered by snow and ice 11 or 12 months of the year. In 1965 "Agpalilik" was excavated and hauled to the beach on a prefabricated sled. In 1966 the ice conditions prevented the expedition from reaching Melville Bugt (Qimusseriarsuaq), but in August of 1967 the mass was hauled down into a landing craft and lifted onboard the *Edith Nielsen*. It arrived in Copenhagen in September of 1967. Of the seven slabs and end pieces from "Agpalilik," the largest—1.4 square meters, 5 cm thick, weighing 560 kg—was polished and etched on the lower half. It is now exhibited in the Geological Museum, Copenhagen. The remaining main mass, weighing around 15 tons, can be seen in the yard of the museum.

"Agpalilik" is, like the other fragments of the Cape York meteorite, a medium octaedrite, Om, group IIIA, with 7.8% Ni. It contains about 7 volume % troilite as parallel orientated inclusions up to a length of 18 cm and a width of 4–5 cm. Two mineralogical features of "Agpalilik" deserve special mention: (1) in 1971 Buchwald *et al.* described the new mineral species carlsbergite, found in "Agpalilik," where it occurs as slender, hard platelets and irregular hooks, typically 15 μ in size, in the kamacite; (2) thorough investigations have shown that above 700°C "Agpalilik" was one, huge, single austenite crystal more than 2 meters in diameter, and without indications of growth twinning.

The latest fragment of the Cape York meteorite to be discovered was found in 1984, less than 300 meters from where the largest of all the fragments, "Ahnighito," was located! It was found in the sea stock and has been named "Tunorput" after the name of the mountain ridge at the foot of which it was found. The fragment, originally stated to be "the size of a sleeping dog," weighs 250 kg. It was brought to Savigsivik (Savissivik) in a boat by the finder, J. Petersen, and three other hunters; from there it was shipped to Copenhagen for cutting and study. After cutting and investigations the specimens have been returned to Greenland, where they are on exhibit in the Greenland National Museum in Godthåb (Nuuk) and the local museum in Thule (Qaanaaq).

ELLA ISLAND METEORITE

The Ella Island stone meteorite was found by the American geologist K. Sweet in central East Greenland in 1971. It was found northwest of the Ella Ø station on the north side of the island. He broke the specimen and brought back 715 grams of what was estimated to have been a 3-kg meteorite. Altogether 1.3 kg of it have been recovered. In 1975, an additional 4.5 kg of material was found by the Geological Survey of Greenland and brought to the Geological Museum, Copenhagen. Apparently this material is from a single stone which broke into three fragments late in the flight or on impact; the fragments have partially disintegrated because of frost action. The meteorite has a dark reddish brown fusion crust over its rounded surface; a freshly broken surface is light gray with millimeter-sized "rusty brown" spots and a few chondrules under 1 cm in size. On the basis of the fayalite and ferrosilite content, poorly defined chondrules, absence of glass in chondrules, presence of well-developed feldspar in the matrix and chondrules, and the degree of recrystallization of the matrix, the Ella Island meteorite is classified as an L-6 chondrite.

ACKNOWLEDGMENTS

Since the references present only a narrow selection of principal works, major review articles and a few special publications from which general information has been extracted, we would here like to express our sincere thanks to the very large number of colleagues whose publications and works are not mentioned and from which we have used information and data.

Sincere thanks are also due to all the colleagues who have placed their photos at our disposal; special thanks are, in this respect, due to Rainer Bode who made most of his excellent mineral photos available. Thanks are also due to Ragna Larsen who made the maps and to Mogens Hansen who produced the computer crystal drawings. The secretary of the Geological Museum, Annemarie K. Brantsen, is thanked for her efforts to help the authors express the intended meaning of their words in English.

The director of the Geological Survey of Greenland has approved the publication and is thanked for invaluable cooperation.

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The list given below is by no means intended to be an ordinary list of references, for one thing because such a list would require far too many pages, but also because a large part, particularly of the older literature, is in Danish and Swedish. This list merely presents a narrow selection of review works like the *Geology of Greenland* and the *Mineralogy of Greenland*, major review articles and a few special publications from which general information has been extracted and in which a large number of additional references can be found.

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EPILOG:
RESCUE OF HISTORIC EARLY GIESECKE SPECIMENS AT NAIRN MUSEUM, SCOTLAND

Alec Livingstone
Department of Geology
Royal Museum of Scotland
Chambers Street, Edinburgh EH1 1JF

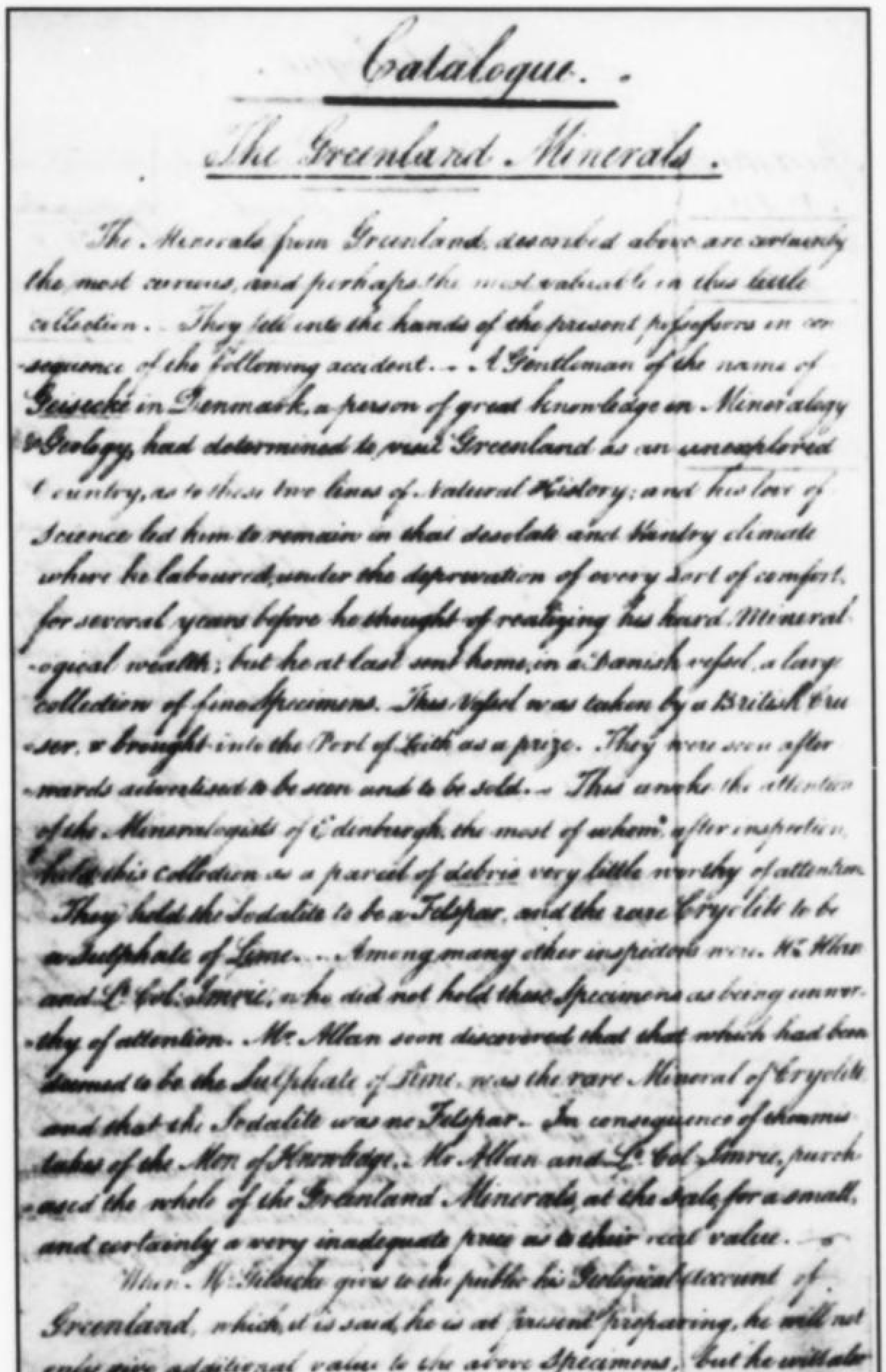
Seventy-seven historic specimens, including classic Greenland minerals collected by Giesecke in 1806, have been recovered from an attic storeroom in the Nairn Museum, Edinburgh. The exercise culminated in the discovery of an 1816 catalog detailing the specimens.

The study of the natural world burgeoned in the 19th century and many museums became beneficiaries of this. Regrettably many collections fell into rapid decline, with appreciable material loss or total disbandment. Inevitably considerable loss to science occurred. Randomly jumbled geological collections within the small museum at Nairn Literary Institute (founded 1858) had been stored for long periods without wrapping, and in very poor conditions which facilitated irreparable damage and loss. Fragile specimens were broken, parts separated and the majority were badly abraded and extremely dirty. Roughly 4,000 to 6,000 specimens stored in boxes and crates reposed in an attic. This situation typifies the lamentable state of some geological collections noted by Bertie (1980).

The historic Brodie Cabinet of minerals was donated to Nairn Museum "some few years" before 1884 (Anonymous, 1884). Its nucleus was Sir Charles Giesecke's rare mineral collection from Greenland which had passed through the hands of several noted mineral collectors of the day. (Lt. Col. Imrie, d. 1820; Lord Gray; the Duchess of Gordon; and Brodie of Brodie), each of whom made significant additions. In 1884 the cabinet numbered some 2,000 specimens and was valued at £700–800, being reckoned the Museum's most valuable possession.

Giesecke was commissioned by the Danish Government in 1806 to collect in Greenland. "Cryolith" was known to him at that time as occurring in Greenland, for it was described by his friend Professor Peter Christian Abildgaard (1740–1801) in 1799 (Sweet, 1974). In September of 1806 Giesecke went to Arsuk, Frederikshaab district and found cryolite *in situ* (he remained in Greenland until 1813). An account of the discovery was related by Giesecke (1822). His 1806 specimens were packed and forwarded to Copenhagen on the Danish ship *Der Freuhlin*. An English frigate captured the boat and brought it into Leith (Edinburgh) where Giesecke's impounded collection remained for some while in a Leith warehouse loft. Professor Robert Jameson (1774–1854, of *jamesonite*) examined the collection and identified the cryolite as "sulphate of calcium." Lt. Col. Imrie took his friend Thomas Allan (1777–1833, of *allanite*) to view the material. Together, in 1808, they purchased the lot for £40 (the cryolite specimens alone were considered to be worth £5,000). However, not until 1812 did they discover who had collected the minerals (Sweet, 1974).

George Bain in his museum account in the *Guide to Nairn* (ca.



Catalogue. -

The Greenland. Minerals.

The Minerals from Greenland, described above are certainly
the most curious, and perhaps the most valuable in this little
collection. . They fell into the hands of the present possessors in con-
-sequence of the following accident. . . A Gentleman of the name of
Geisecke in Denmark, a person of great knowledge in Mineralogy
& Geology, had determined to visit Greenland as an unexplored
Country, as to these two lines of Natural History; and his love of
Science led him to remain in that desolate and dreary climate
where he laboured, under the deprivation of every sort of comfort,
for several years before he thought of realizing his hoard. Mineral
-ogical wealth; but he at last sent home, in a Danish vessel, a large
collection of fine Specimens. This vessel was taken by a British Cru
-ser, & brought into the Port of Leith as a prize. They were seen after
-wards advertised to be seen and to be sold. - This awoke the attention
of the Mineralogists of Edinburgh, the most of whom, after inspection,
held this collection as a parcel of debris very little worthy of attention.
They held the Sodalite to be a Felspar, and the rare Cryolite to be
a Sulphate of Lime. . . Among many other inspectors were. Mr Allan
and Lt Col. Imrie, who did not hold these Specimens as being unwor-
-thy of attention. . Mr Allan soon discovered that that which had been
deemed to be the Sulphate of Lime, was the rare Mineral of Cryolite
and that the Sodalite was no Felspar. . In consequence of these mis-
-takes of the Men of Knowledge, . Mr Allan and Lt Col. Imrie, purch-
-ased the whole of the Greenland Minerals at the Sale for a small,
and certainly a very inadequate price as to their real value. - -
When Mr Giesecke gives to the public his Geological Account of
Greenland, which, it is said, he is at present preparing, he will not
only give additional value to the above Specimens, but he will also
add very interesting knowledge to those who dip into Geological re-
-search. . . -

Figure 1. **An introductory page in the catalog.**

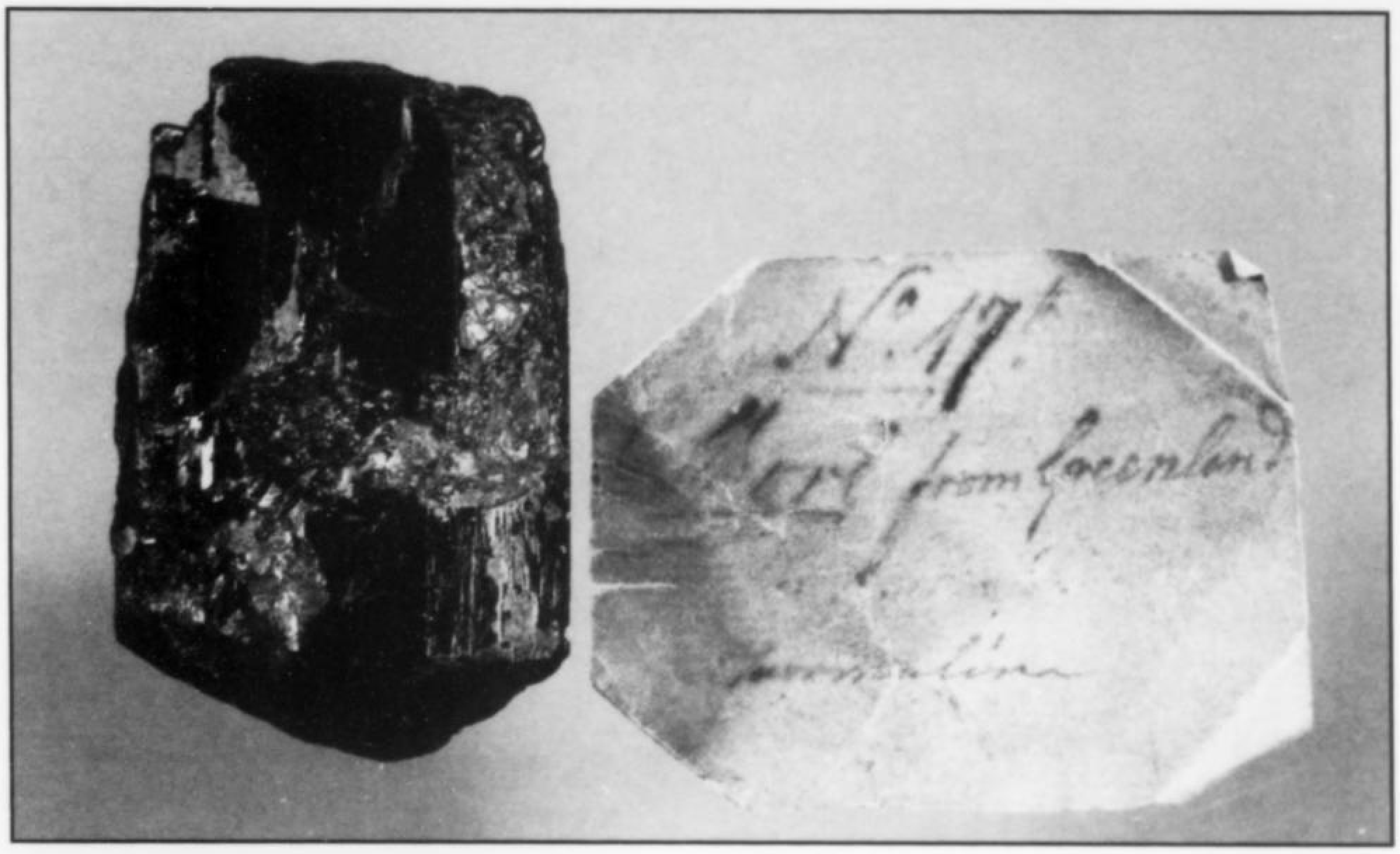


Figure 2. **A Greenland tourmaline crystal, 6.5 cm.**

Figure 3. **A Greenland cryolite specimen, 7 cm.**

1875) relates that 120 valuable mineral specimens were received by Lord Gray from Lt. Col. Imrie. During the Autumn of 1989, I sorted all jumbled geological material, identified 15 individual collections, and retrieved 77 high-quality mineral specimens including a cryolite specimen numbered "120." Additionally, classic Greenland minerals including sodalite and eudialyte were retrieved together with Norwegian (Fridricharven and Arandal) and Scottish minerals—all bearing numbers lower than 120. Fifteen labels were found (one watermarked 1794), all are readable and 11 can be matched to numbered specimens. All 77 specimens have been cleaned, identified and cataloged. A striking feature is the consistency in overall size and quality, hallmarks of a dedicated, experienced field collector working under adverse conditions.

The rescue exercise recently culminated in the discovery of a descriptive catalog of 120 specimens, from Norway, Scotland and Greenland, prepared by Lt. Col. Imrie in 1816, and now in the Russell Collection of Manuscripts held in the Natural History Museum, London. The Nairn Museum's 1806 Giesecke minerals must rank among the earliest classic Greenland material to reach Europe.

ACKNOWLEDGMENTS

I am indebted to the late Miss Sweet for her diligent historical searches; without them this work would be considerably impoverished. Thanks are also due to Dr. R. F. Symes for providing the microfilm copy of Lt. Col. Imrie's catalog, and to Mr. C. Chaplin for photographic work.

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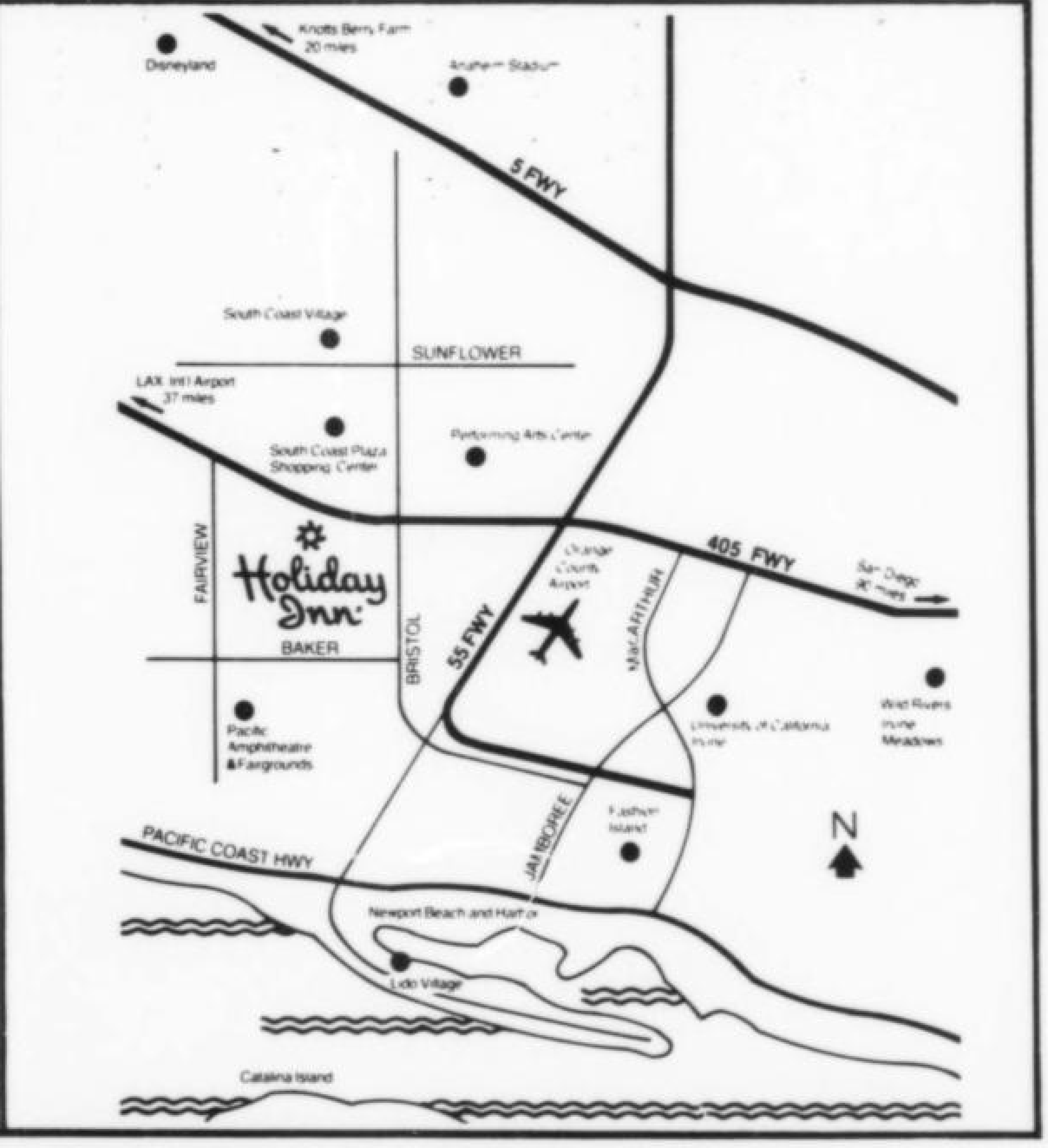

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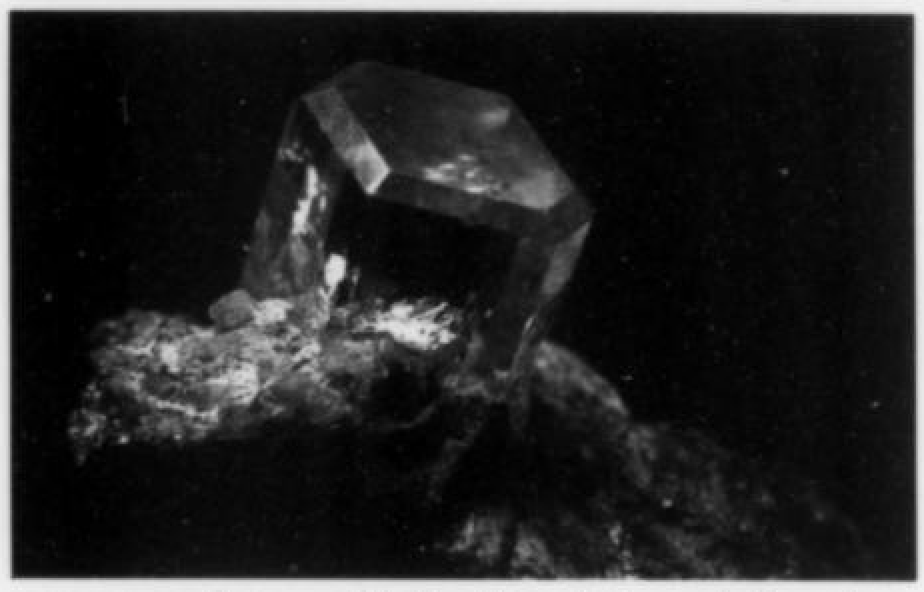

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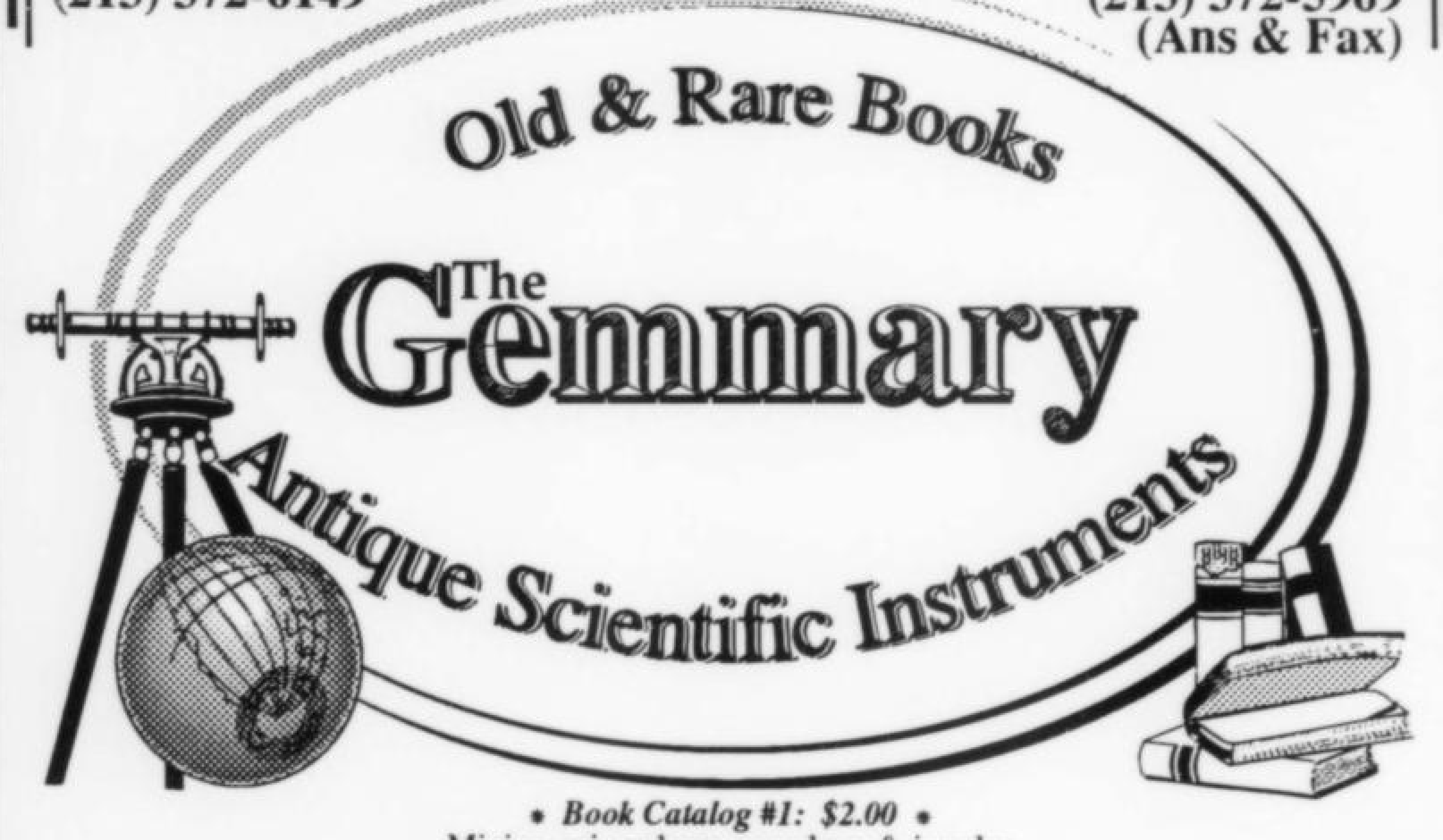
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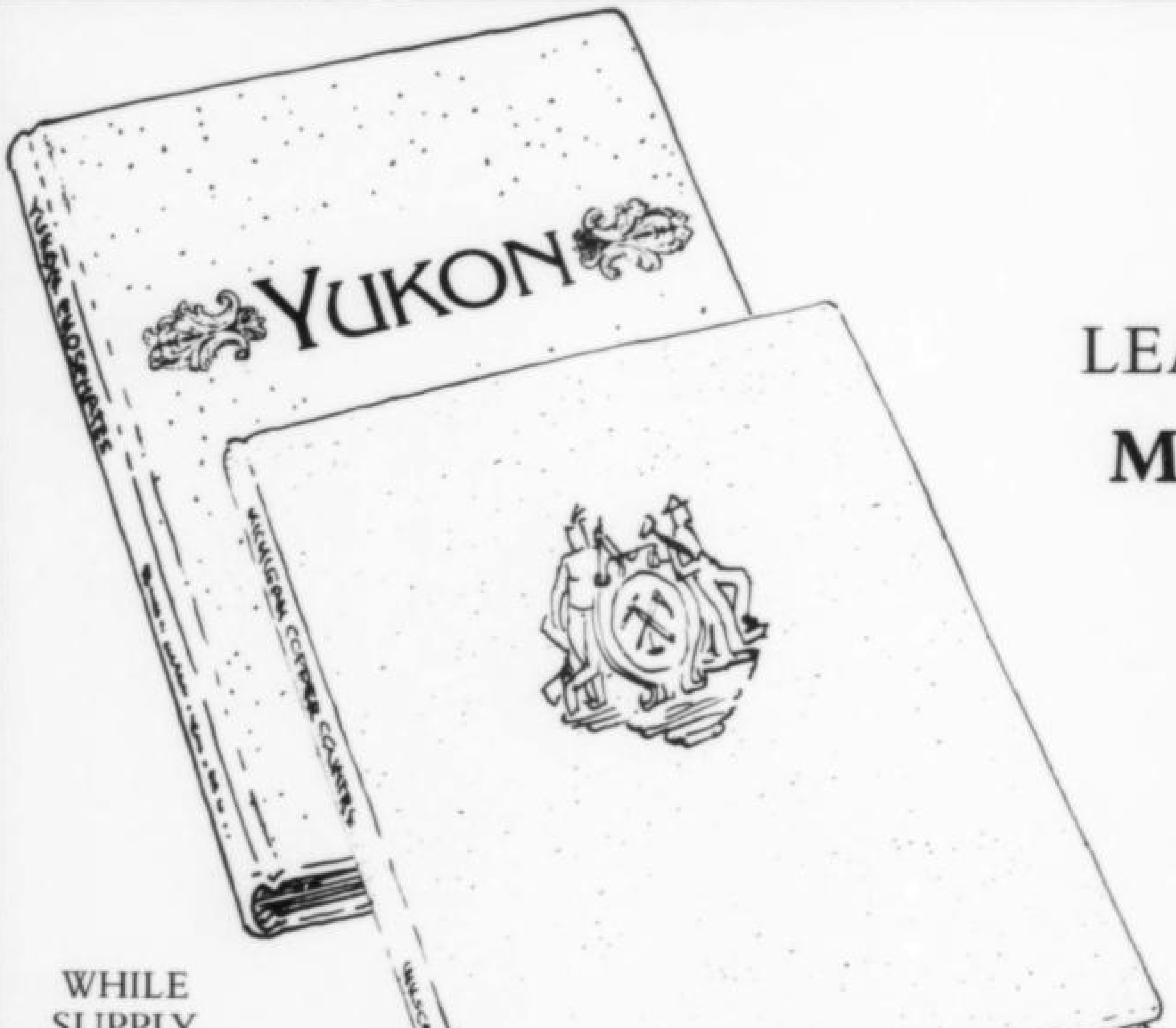
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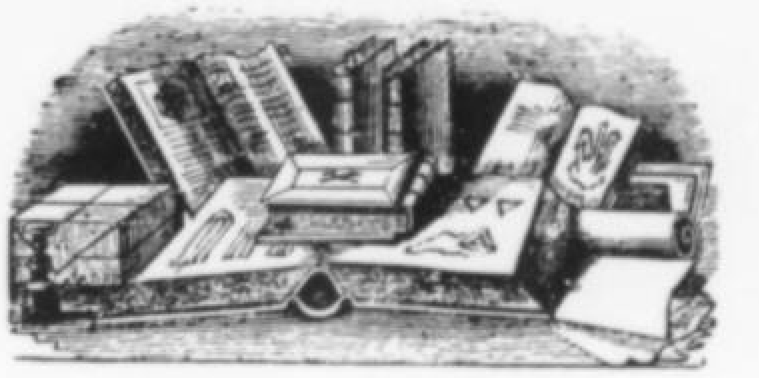

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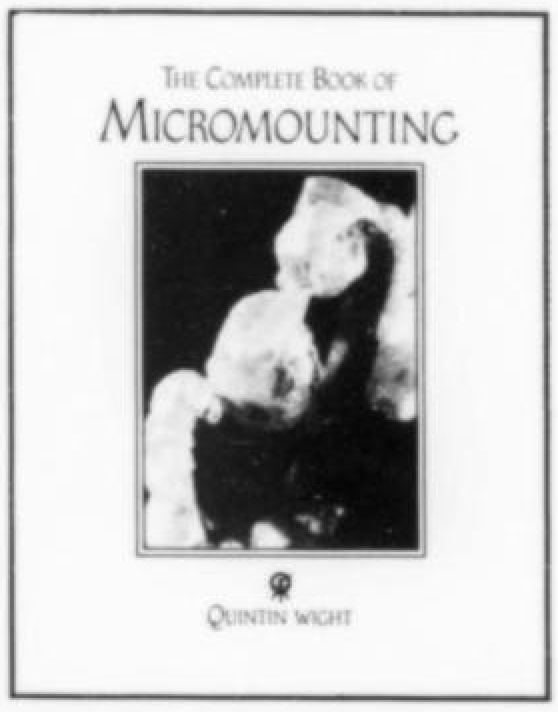

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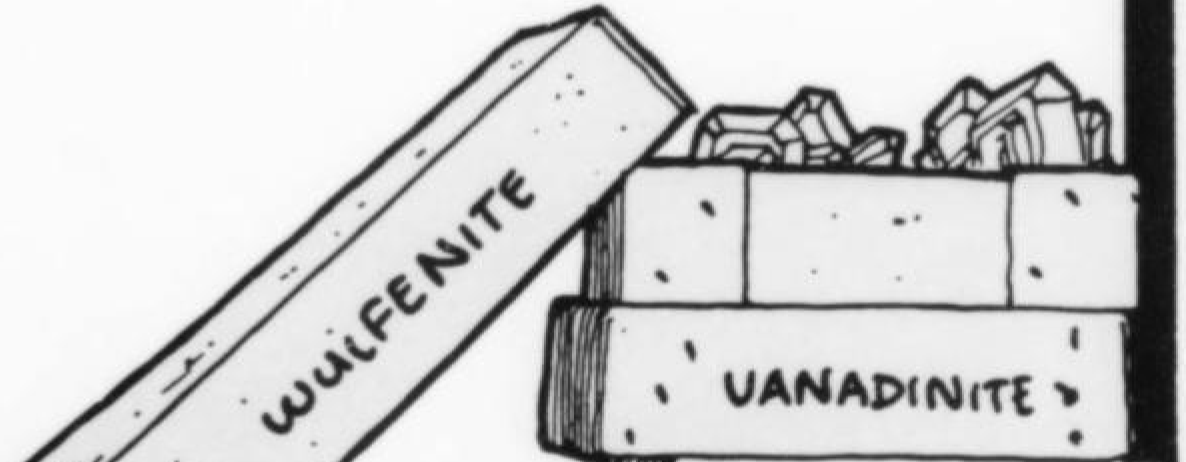
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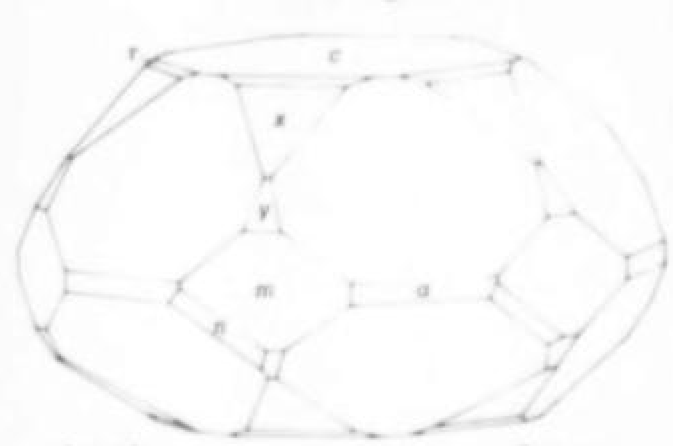

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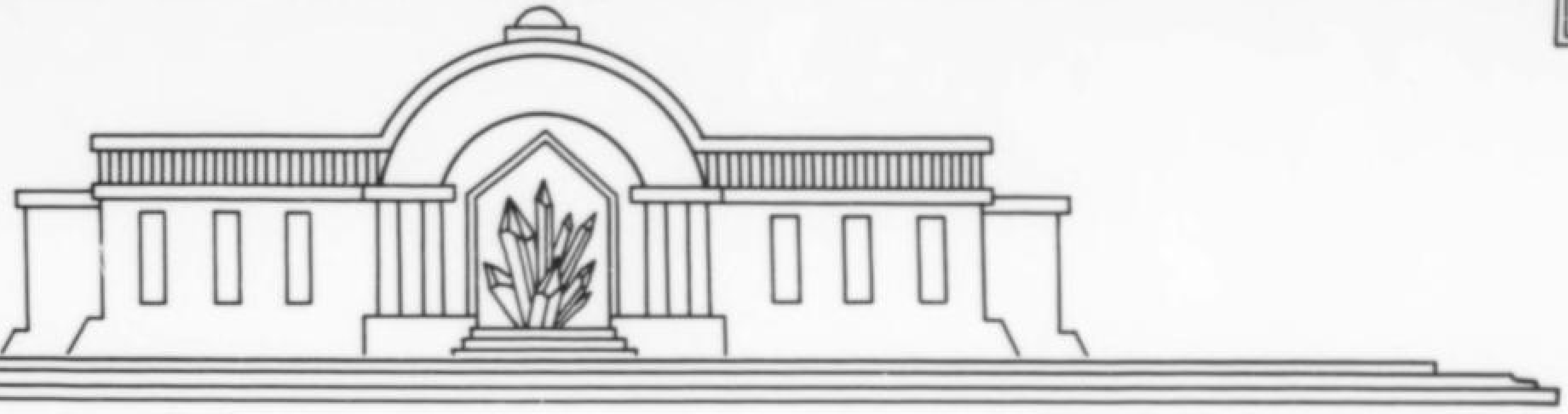

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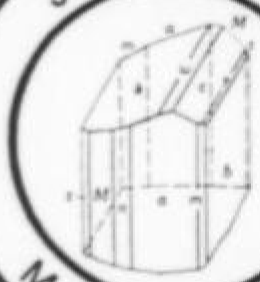

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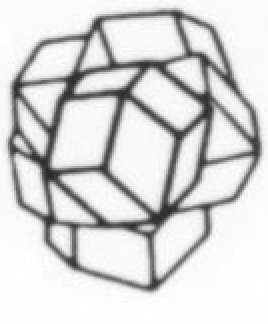

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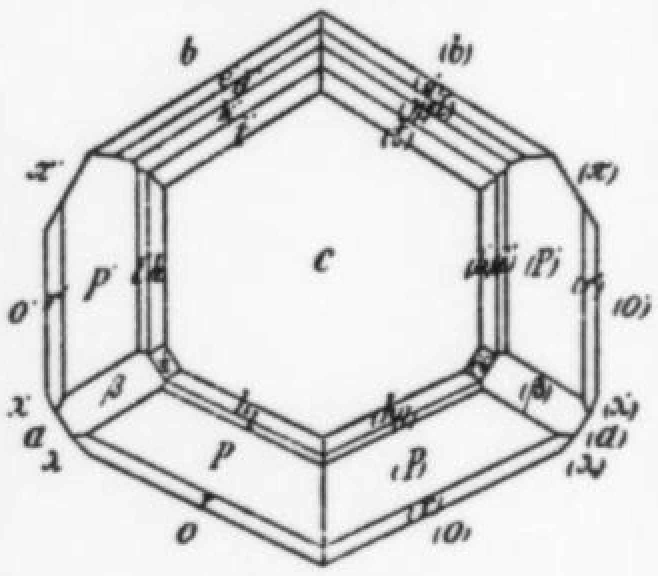
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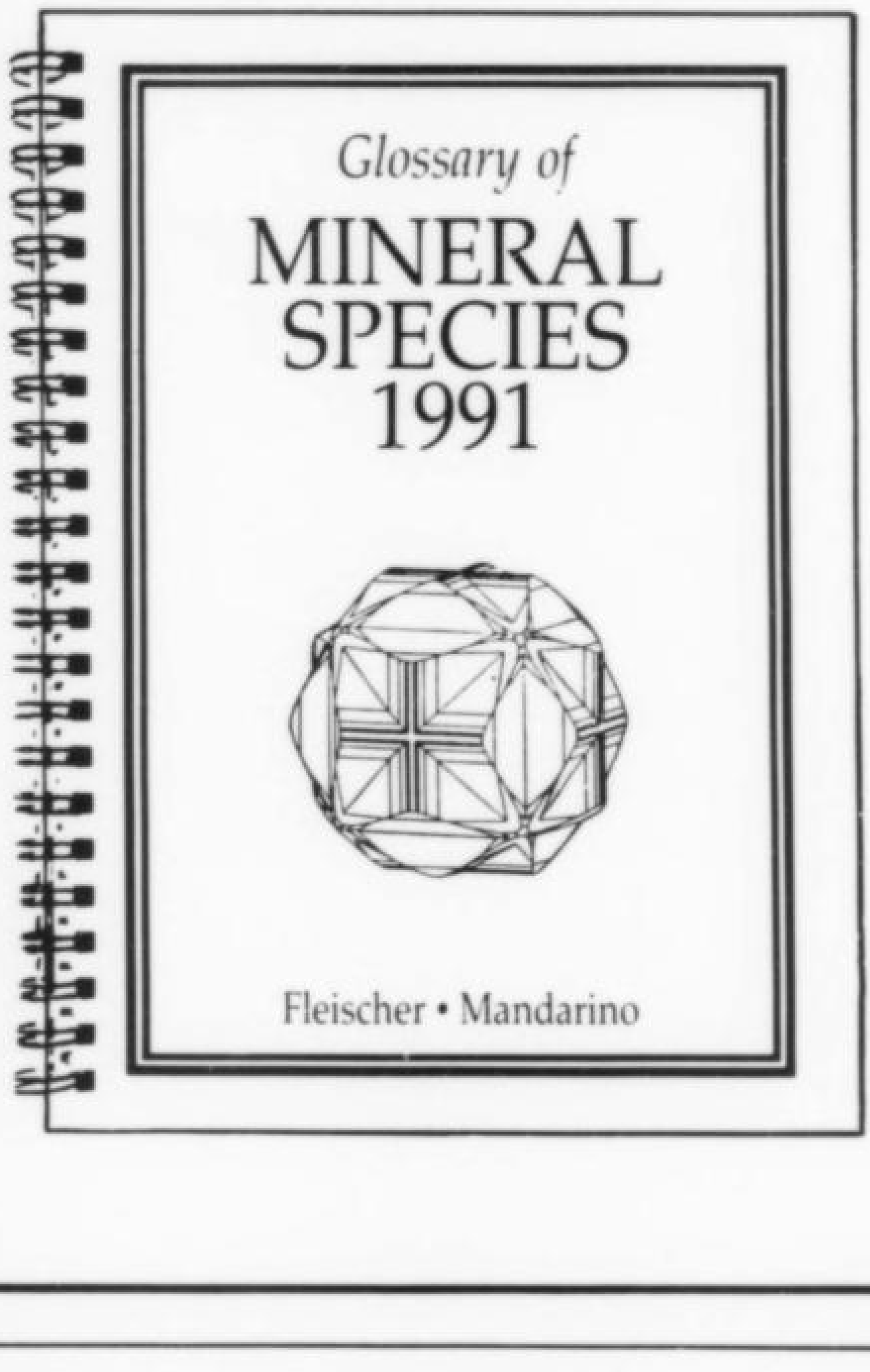

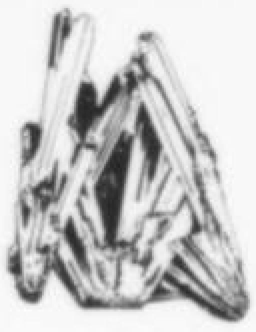

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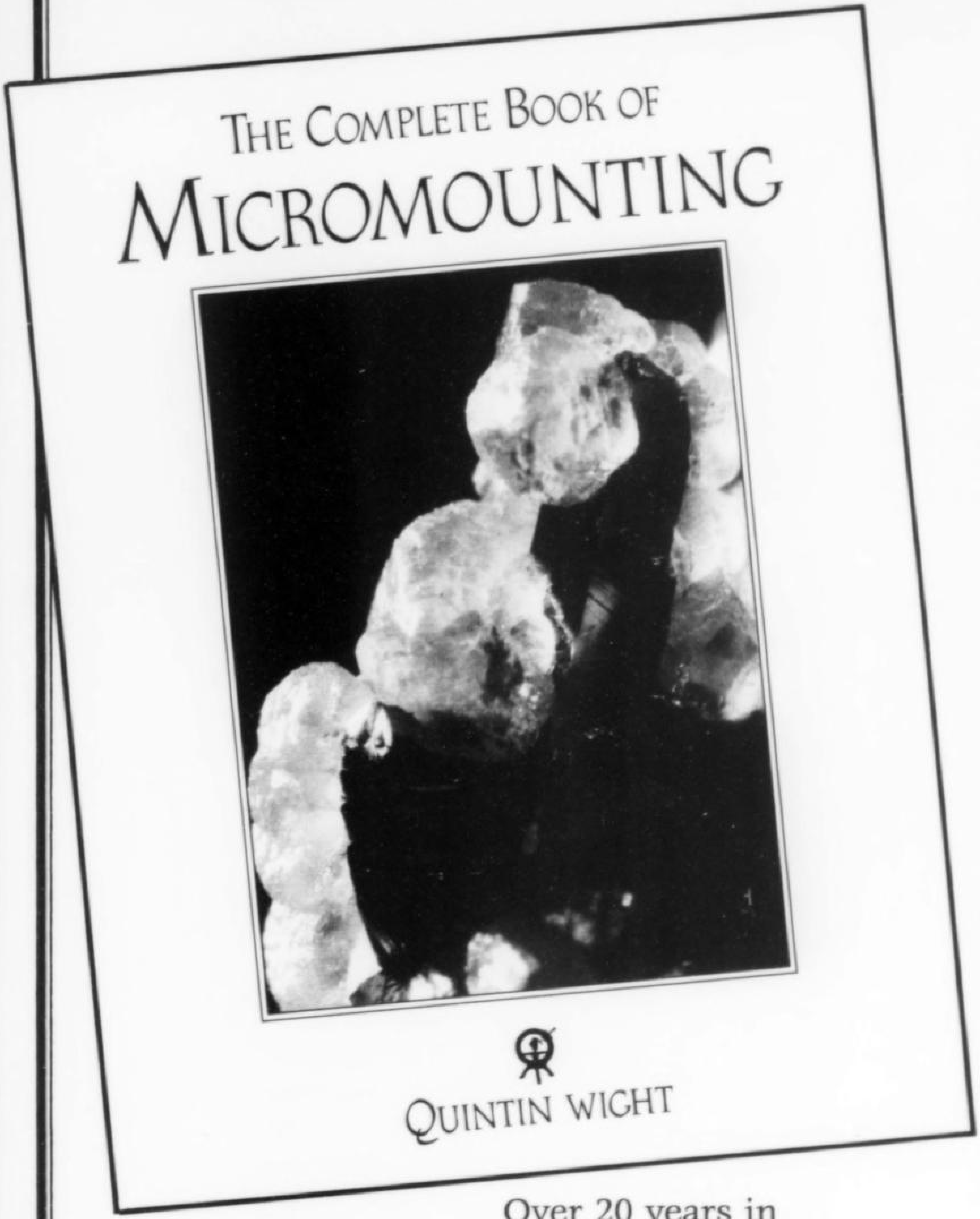

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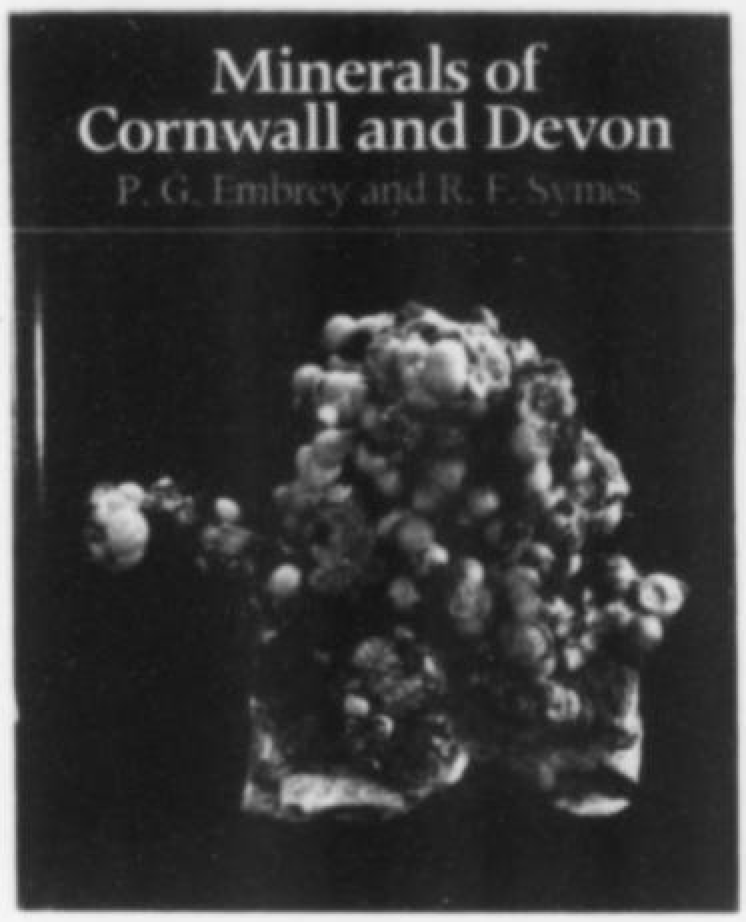

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