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Beryllium mineralization in the Ilímaussaq intrusion, South Greenland,

with description of a field beryllometer and chemical methods

by

John Engell, John Hansen, Margrethe Jensen, Helmar Kunzendorf and Leif Lovborg

Contribution to the mineralogy
of Ilímaussaq no. 22

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GRØNLANDS GEOLOGISKE UNDERSØGELSE
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BERYLLIUM MINERALIZATION IN THE ILÍMAUSSAQ INTRUSION, SOUTH GREENLAND, WITH DESCRIPTION OF A FIELD BERYLLOMETER AND CHEMICAL METHODS

by
John Engell, John Hansen, Margrethe Jensen,
Helmar Kunzendorf and Leif Løvborg

Contribution to the mineralogy
of Ilímaussaq no. 22

With 10 figures, 5 tables
and 3 plates

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Abstract

In the peralkaline Ilímaussaq intrusion in South Greenland minor quantities of beryllium minerals are widespread in hydrothermal veins. Concentrations of veins rich in beryllium minerals are known from the Taseq slope and the Kvanefjeld area in the northern part of the intrusion. Up to now 10 beryllium minerals have been found, the most important being chkalovite. The hydrothermal veins range in width from about 1 mm to 2 m but are mostly a few cm thick. The most important minerals in the veins are analcime, sodalite, ussingite, natrolite, aegirine, arfvedsonite, epistolite and chkalovite. A field beryllometer based on the photoneutron method of determining beryllium is described. With a 100 mCi Sb^{124} activation source the instrument has a limit of detection of less than 10 ppm BeO. The effective measuring area is ca. 40 cm^2. Beryllium has a log-normal distribution in the rocks of the area.

CONTENTS

INTRODUCTION

At present, only two areas with considerable concentrations of beryllium minerals are known in the Ilímaussaq intrusion. These localities lie on opposite sides of the Narssaq Elv valley in the northern part of the intrusion. The one to be described here occurs on the Taseq slope with chkalovite as the principal beryllium mineral; the other occurs on the Kvanefjeld plateau in close spatial association with U and Th mineralization. The principal beryllium minerals at this occurrence are sorensenite and chkalovite (Sørensen *et al.*, 1969; Sørensen *et al.*, in press).

The mineralization on the Taseq slope was found in the summer of 1964 by E. I. Semenov. The investigation of the mineralization has been carried out under the auspices of the Geological Survey of Greenland and represents a collaboration between the Institute of Petrology, University of Copenhagen, (J. E. & J. H.), the Electronics Department (H. K. & L. L.) and the Chemical Department (M. J.) of the Danish Atomic Energy Commission's Research Establishment, Risø. The beryllometers are constructed by staff-members of the Electronics Department, Risø.

THE ILIMAUSSAQ INTRUSION

General

The Ilimaussaq intrusion (Rb/Sr age of polylithionite 1020 $\pm$ 24 m. y., Bridgwater, 1965) forms part of the Gardar magmatic province of South Greenland belonging to the gabbroic-alkaline association (Sørensen, 1965). The intrusion has been described by Ussing (1912), Sørensen (1958), Hamilton (1964), and Ferguson (1964 and 1970). It is situated a few kilometres east of the small settlement Narssaq on both sides of Tunugdliarfik fjord.

The intrusion as defined by Ferguson (1964) (fig. 1) covers an area of approximately 150 km^2 and is composed of a discontinuous margin of augite syenite chilled against the country rocks and a central stratified series of more or less saucer-shaped units of alkali granite, quartz syenite, pulaskite, heterogeneous syenite and an agpaitic

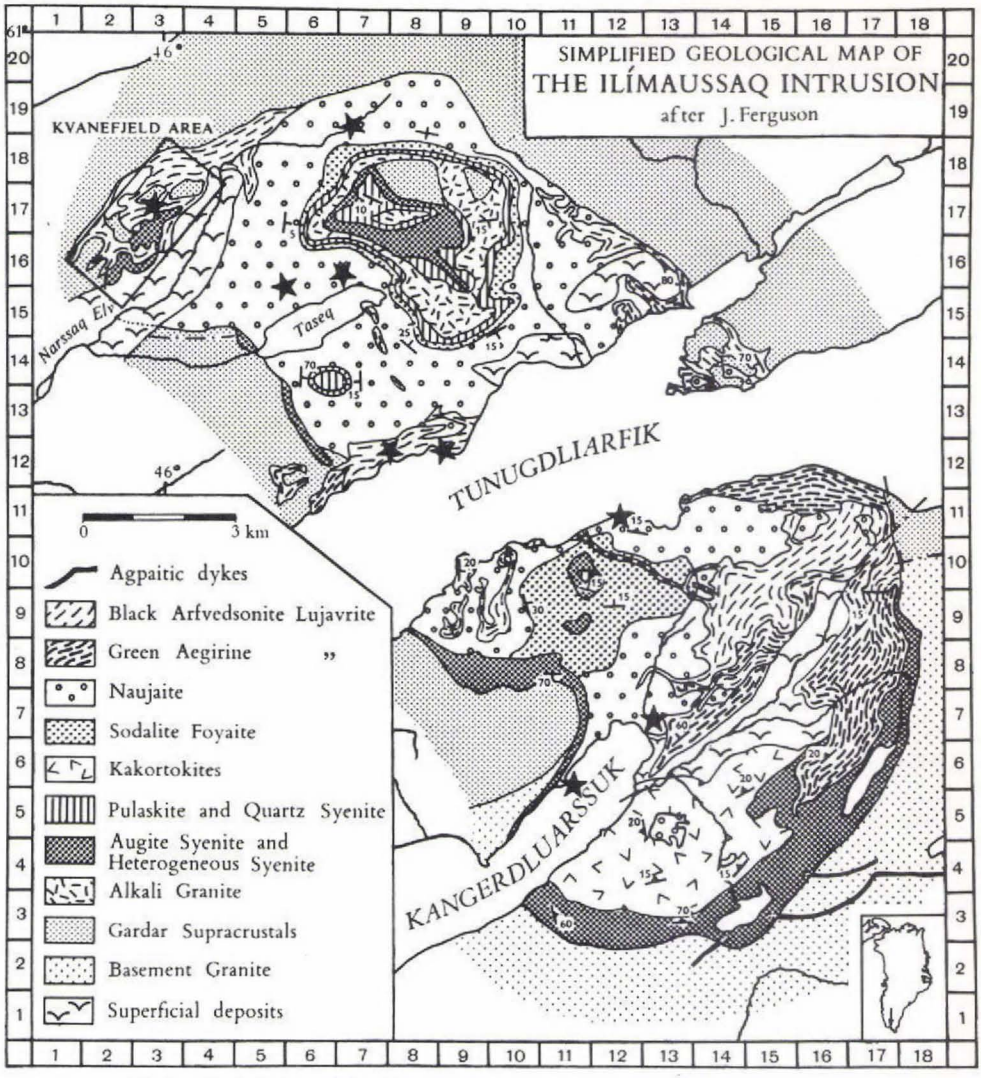

Fig. 1. Simplified geological map of the Ilímaussaq intrusion based on the map of Ferguson (1964) with smaller corrections. Localities where beryllium minerals have been found are marked with a star.

rock sequence, namely: sodalite foyaite, naujaite, lujavrite, and kakortokite, the whole series being named from the top downwards. The naujaite is strongly brecciated and interveined by lujavrite, especially in its lower parts.

The earliest rock is the augite syenite; it is thought that the heterogeneous syenite and agpaitic rocks are formed from an augite syenite magma by crystal differentiation in connection with volatile enrichment. The heterogeneous syenite, sodalite foyaite and naujaite are believed to have formed by crystallization from the roof downwards, while the kakortokite appears to have formed contemporaneously with

the naujaite by bottom accumulation. Finally, the lujavrite formed the last sheet of magma between the naujaite and the kakortokite.

In connection with the final consolidation of the lujavrite, parts of the earlier rocks, expecially the naujaite, and parts of the roof of the intrusion, were hydrothermally altered and cut by hydrothermal veins.

Beryllium minerals in the intrusion

Accessory amounts of beryllium minerals are widespread in the Ilímaussaq intrusion. In table 1 all beryllium minerals found in the intrusion until now are given together with references to the original descriptions. In fig. 1 localities of beryllium minerals have been indicated.

Table 1. Beryllium minerals found in the Ilímaussaq intrusion.

Mineral	Wt % BeO	Formula
bertrandite[1]	40-43	$Be_4(Si_2O_7)(OH)_2$
beryllite[1,7]	40	$Be_3SiO_4(OH)_2H_2O$
chkalovite[2]	11-13	$Na_2(BeSi_2O_6)$
epididymite[3,4]	11	$NaBeSi_3O_7(OH)$
eudidymite[4]	11	$NaBeSi_3O_7(OH)$
gelbertrandite[8]	ca. 34	$Be_4(Si_2O_7)(OH)_2 \cdot nH_2O$
genthelvine[5,4]	11-14	$Zn(BeSiO_4)_6S_2$
leucophane[6]	10-12	$NaCa(BeSi_2O_6)F$
sorensenite[7]	7-8	$Na_4SnBe_2Si_2O_{16}(OH)_4$
spherobertrandite[4]	40-43	$Be_5(Si_2O_7)(OH)_4$
tugtupite[2,8]	5	$Na_8Be_2Al_2Si_8O_{24}(Cl_2,S)$

[1]) Andersen (1967)
[2]) Sørensen (1960)
[3]) Hamilton (1964)
[4]) Semenov & Sørensen (1966)
[5]) Bollingberg & Petersen (1967)
[6]) Bøggild (1905)
[7]) Semenov *et al.* (1965)
[8]) Sørensen *et al.* (in press)

Leucophane occurs as an accessory in the naujaite, while epididymite has been found as an accessory in the alkali granite (Hamilton, 1964). All the other beryllium minerals occur in hydrothermal veins and alteration zones.

A chemical analysis of chkalovite, the most common beryllium mineral in the intrusion, is given in table 2.

Table 2. Chemical, spectrochemical and optical analyses of chkalovite.

	Chemical analyses		Spectrochemical analyses (semiquantitative)	
	Taseq slope (GGU 65925)	Tugtup agtakorfia (Sørensen, 1960)	Taseq slope (GGU 65925)	
	weight %	weight %		ppm
SiO_2	57.07	57.78	Li	10
MgO	*	0.16	Rb	<10**
CaO	*		Cs	<30**
Na_2O	30.56	29.20	Mg	≤100
K_2O	*	0.09	Sr	<10**
Cl	0.04	0.14	Ba	10–30
H_2O^+	0.06		Al	200***
H_2O^-	0.03	0.02	Ga	<10
BeO	12.20	12.56	Ti	<10
Fe_2O_3		tr	V	<10
S		0.17	Cr	<10**
Total	99.96	100.12	Ni	<10
$-O = Cl_2$	0.01	0.03	Cu	<10
			Zr	20
Total	99.95	100.09		
	Analyst: M. Mouritzen		Analyst: H. Bollingberg	

*) not detected
**) not detected, limit of detection indicated
***) Flint used as standard (Micheelsen, 1966)

Taseq slope		Tugtup agtakorfia
$2V_\gamma$: 77-82°	4 measurements	$2V_z$: 81°
$n\gamma$: 1.5528 ± 0.0003	3 measurements	$n\gamma$: 1.552 ± 0.001
$n\beta$: 1.5501 ± 0.0002	4 measurements	$n\beta$: 1.550 ± 0.001
$n\alpha$: 1.5489 ± 0.0001	4 measurements	$n\alpha$: 1.548 ± 0.001

THE GEOLOGY OF THE AREA BETWEEN TASEQ AND NARSSAQ ELV

General remarks

The area between Taseq and Narssaq Elv is rather badly exposed. The greater part of the Taseq slope (between the Taseq plateau and Narssaq Elv) up to 400-500 m has a cover of glacial sediments, often up to several metres thick, overgrown with grass. The rest of the slope is covered with extensive, semipermanent snow fields. Occasionally the slope may be snow-free at the end of July but more frequently the upper part of the slope remains covered throughout the summer (as it was in 1967). In addition, the upper part of the Taseq slope and the Taseq plateau is covered to the extent of about 50% by thin glacial sediments and weathered rocks. Large areas on the slope consist of metre-sized loose blocks, which seem to lie in situ.

The mapped area covers the greater part of the Taseq plateau north of the lake, from the western contact of the intrusion to the foot of Nâkâlâq, fig. 2. Parts of the Taseq slope down to altitudes of 400-500 m have also been mapped. The greater part of this area was mapped on a scale of 1:4000 using aerial photographs (plate 1), while a smaller area on the slope, that with the richest beryllium mineralization, was mapped with a plane table on a scale of 1:500 (plate 2). In the area not included in plate 2 and shown without boundaries to the individual rock exposures on plate 1 only reconnaissance has been made.

The mapped area consists of layered naujaite with a concordant horizon of syenite. These rocks are veined by arfvedsonite lujavrite, metasomatic rocks associated with these and different types of hydrothermal veins and alteration zones formed from fluids expelled from the consolidating lujavrite. A late lamprophyric dyke also cuts the naujaite.

At the western contact of the intrusion there is a zone of syenite with inclusions of gabbro and anorthosite between the lava series and the naujaite. This zone and the lava series are veined by thin, irregular, dense dykes of black, reddish or greenish colour. Ferguson (1964) and Hamilton (1964) disagreed as to the existence of a zone of augite syenite at the western border of the intrusion in the investigated area. The present observations are in accordance with those of Hamilton.

The naujaite and the concordant band of syenite

According to Ferguson (1964), the naujaite occurs in a 800-1000 m thick unit occupying the greatest area of the exposed rocks in the intrusion. It is assumed that the naujaite consolidated from the roof of the magma chamber downwards. The

Fig. 2. The Taseq slope seen from the Kvanefjeld area. The area with strongest beryllium mineralization is indicated.

mapped area represents a section through the naujaite about 200 m under the contact between the naujaite and the overlying sodalite foyaite (extrapolated from the contact at the north-west part of Nâkâlâq mountain).

Petrographic descriptions of the naujaite have been given by Ussing (1912) and Ferguson (1964 and 1970). The rock-forming minerals are sodalite, perthite, nepheline, aegirine, arfvedsonite, eudialyte, and aenigmatite. Structurally the naujaite is very coarse-grained and characterized by numerous euhedral crystals of sodalite, a few mm in diameter, poikilitically enclosed in crystals of pegmatitic dimensions of all the other rock-forming minerals except nepheline. The nepheline occurs as about 1 cm large rectangular crystals included in all minerals except sodalite.

In the naujaite good layering is developed (Sørensen, 1958; Ferguson, 1964; Hamilton, 1964), and in the investigated area strikes and dips varying between 20-24° and 10-36° E respectively, are found. Minor discordances are present. In one horizon 2-3 m long schlieren-like layers are included in "average naujaite". Generally, however, the layers are assumed to be continuous over long distances; a few layers have been shown to be continuous for more than 250 m. The individual layers are from a few cm to about 2 m thick and occur in sequences or singly, separated by zones of "average naujaite". The individual layers display knife-sharp and mostly plain contacts, but wavy contacts have been observed.

The layering may be due to variations in the size of one or more of the rock-forming minerals, to their proportions and to their textures or to a combination of these features. Rhythmic layering with alternating light-coloured feldspar-rich and dark-coloured aegirine-rich layers is the most common.

At an altitude of 550-570 m there exists on the Taseq slope a 20 m thick, sharply defined, concordant layered syenite. This unit wedges out in the investigated area (plate 2) and disappears about 500 m from the contact between the naujaite and the border zone of the intrusion. The unit is fully developed just north of plate 2 and has been followed for more than one km to the north without diminishing.

Pegmatites

Pegmatites occur in the naujaite and syenite unit in several discrete horizons. In general the pegmatites occur as thin concordant sheet-like bodies; in one horizon they are differentiated. Schlieren-like pegmatites of variable orientation and irregular pegmatites with rounded outlines occur in a few horizons; these are undifferentiated and unzoned. The pegmatites are composed of the same minerals as the surrounding rocks but in different proportions. No beryllium minerals have been observed. The pegmatites have not been studied in detail, but it is believed that they all are facies or phase-facies pegmatites (Vlasov *et al.*, 1966, p. 67).

The differentiated pegmatites have some resemblance to the pegmatites from Qeqertaussaq at the head of Kangerdluarssuk described by Sørensen (1962).

The lujavrite and its relation to the beryllium mineralization

The layered series is intruded by arfvedsonite lujavrite. The largest body of lujavrite in the investigated area is a sheet-like intrusion, occurring at an altitude of about 400 m on the Taseq slope. The sheet is about 10 m thick and can be followed more than 300 m thinning out to the south and branching in the northern end. A concentration of dyke-like intrusions of lujavrite occurs on the Taseq slope east and north-east of this body, i.e. overlying it (plate 1 is incomplete in this area). On the Taseq plateau a few irregular dyke-like intrusions of lujavrite occur.

On the Taseq slope the most mineralized area is found in close connection with the NW-SE striking vertical zone of steenstrupine-arfvedsonite-lujavrite which intersects plate 2 diagonally. This zone is composed of an irregular branching main vein, 2-10 m thick, of variable strike being vertical or nearly so. This vein is interrupted east of point 16 (plate 2) and it is assumed that the magma has been unable to reach the present level of erosion here, although it is probably continuous at a lower level.

At the top of the lower part of the lujavrite vein some of the biggest hydrothermal veins in the area occur (p. 17). These originate from crystal cavities in the lujavrite vein, with which they are continuous. They are composed mainly of ussingite.

To the north-west the main lujavrite vein branches out to a number of thin veins of arfvedsonite and acmite lujavrite, zones of aegirinitized naujaite and veins mainly composed of felted aegirine and feldspar. Associated with this, a number of hydrothermal veins occur which are rich in analcime and often contain chkalovite and ussingite.

Having reached its greatest thickness in the upper part of the slope the main lujavrite vein dies out to the south-east on the plateau. In this area an E-W striking zone of thin arfvedsonite lujavrite dykes, dipping 20° S, unites with it. The last thin offshoot of the main vein can be followed to the large zone of the albitized naujaite just east of plate 2, where it is albitized. An apophysis of this albitized zone dies out on the edge of the plateau just north of the main vein. Only a few hydrothermal veins occur in this area and beryllium minerals are scarce.

At an altitude of 530-550 m a large number of thin veins of felted arfvedsonite, zones of aegirinitized naujaite, veins of felted aegirine and analcime and albite veins penetrate the naujaite. These radiate from the southern side of the main lujavrite vein. In this area the greatest concentration of beryllium minerals is found (plate 2 and 3).

An albitized, arfvedsonite-rich offshoot from the northern side of the main lujavrite vein (where it swells up, the outer one shown on plate 2 and plate 3) should be mentioned because it contains a great number of beryllium minerals, reflecting the complex history of the offshoot. The first formed beryllium mineral chkalovite is later altered to tugtupite which again is altered to eudidymite and epididymite (Semenov & Sørensen, 1966).

Where the main lujavrite vein is thick, it forms an intrusive breccia with angular

to rounded inclusions of macroscopically fresh to altered rocks from the layered series. The inclusions are up to a few metres in diameter. The lujavrite magma has in places reacted with the inclusions in which case they are surrounded by alternating light and dark schlieren.

The lujavrite of the NW-SE striking zone is a fine- to medium-grained sometimes porphyritic rock (phenocrysts of analcime) without pronounced schistosity. In general it is a steenstrupine-bearing arfvedsonite lujavrite, resembling that described by Sørensen (1962). The rock forming minerals are arfvedsonite, aegirine/acmite, analcime, sodalite, microcline and steenstrupine. Locally it contains naujakasite in appreciable amounts. Minor constituents are pectolite, epistolite, neptunite, white mica and natrolite. In cavities earth-like aggregates of natrolite and clay minerals are found. In one area, just below the large ussingite veins near point 16 (plate 2), the lujavrite contains impressions after a dissolved mineral (villiaumite?). These are up to 1 cm in diameter and formed like Maya-pyramids. No sign of nepheline and eudialyte, either fresh or altered, has been found, thus strictly speaking the rock is not a lujavrite. However, it resembles lujavrite so closely that the name has been retained.

The steenstrupine- and naujakasite-bearing lujavrite is believed to represent late differentiates of the lujavrite magma (Sørensen, 1962; Petersen, 1965; Engell, 1968). In this connection, a lujavrite vein, a few m thick, occurring about 40 m below the NW corner of plate 2 is worth mentioning because it contains pegmatitic zones resembling the medium- to coarse-grained lujavrite on Kvanefjeld (Sørensen, Hansen & Bondesen, 1969).

The hydrothermal veins and alteration zones

The hydrothermal veins and alteration zones may be divided into two main groups according to their distribution. A concentration of different types of hydrothermal veins and alteration zones, mostly containing beryllium minerals, is found in close association with the concentration of lujavrite veins on the Taseq slope. Most of these veins are thought to have formed from fluids expelled from the locally injected lujavrite magma (Engell, 1968). These veins constitute the first main group. On the Taseq plateau no concentration of veins is found around the lujavrite bodies.

The most prominent members of the second main group are zones with regional extension of albitized and natrolitized naujaite with blue fluorite. Beryllium minerals have not been found in these zones. The zones cut, alter and locally displace the lujavrite veins by a few metres. It should be noted that none of the lujavrite veins in the area have trends approximating to the main directions of these zones.

One of the albitized zones occurs in the naujaite along the contact with the syenitic border zone of the intrusion. Others have a general strike of about ENE-WSW and a vertical or steep dip. The largest of these is about 20 m wide and seems to be contiguous with an old regional fault-zone in the area, along which movements took place

prior to the formation of the Ilímaussaq intrusion. No movement has been detected along this zone in the intrusion. This second group of veins owes its formation to hydrothermal fluids of regional extension, probably formed by the consolidation of the main lujavrite magma.

A complete distinction between veins in relation to the two main groups has not yet been possible. The group two veins seem to have formed later than the group one veins.

Sørensen (1962) has described several different types of veins from the lower part of the naujaite unit in the "breccia zone" (Ussing, 1912). Some of the vein types occurring in the Taseq area show close similarity to these. Semenov *et al.* (1967) have stressed the difference in mineralogy between the veins in the "breccia zone", at the level of the Taseq slope and at the level of the Taseq plateau. They put forward the hypothesis that the difference is caused by the differences in level between the three areas. However, the albitized zones of the "Taseq plateau" level can be followed down the Taseq slope to a point well below the concentration of veins in the "Taseq slope" level. It is also found that the main difference between the two lower levels, as also stressed by Semenov *et al.* (1967), is more in quantity of certain minerals than in mineralogy. Therefore the present authors cannot agree with this hypothesis.

Hansen (1968 b) describes different types of veins cutting the country rock east of the intrusion. A group of albite veins occurring there may possibly be correlated with the albitized zones of regional extension found in the area considered here. In the following, only the veins and alteration zones occurring in connection with the beryllium-mineralization will be discussed.

ALTERATION OF COUNTRY ROCKS

Lujavritized syenite

The eastern part of the area included on plate 2 (see also plate 1) is intersected by a N-S striking vertical lujavrite dyke 2-5 m wide which dies out to the south. The northern mapped part of this vein consists of strongly metasomatized syenite. Both north and south of this area the vein is composed of normal arfvedsonite lujavrite.

The lujavritized rock has lost all its primary structures and is an inhomogeneous medium-grained rock. It is composed of alternating feldspar-rich and arfvedsonite-rich streaks which are more or less vertical.

Locally, similar, but more fine scale horizontal banding occurs. The banding may be folded. The zone contains rounded inclusions of albitized syenite in which the original structure can still be seen. Further inclusions are found of a 10 cm thick boudinated arfvedsonite lujavrite vein.

The lujavritized rock contains beryllium minerals (plate 3).

Aegirinitized naujaite

In the investigated area zones of aegirinitized naujaite only occur on the southwest side of the NW-SE striking zone of arfvedsonite lujavrite or in veins associated with this zone. Along the strike the zones of aegirinitized naujaite may either die out or pass continuously into veins of felted aegirine rich in feldspar. The zones are composed of altered naujaite with numerous angular or rounded inclusions of macroscopically unaltered naujaite. The aegirinitized naujaite contains chkalovite as scattered, centimetre-sized, subhedral crystals. Below a height of about 520 m ussingite mineralization may be connected with these zones.

Analcimitized rocks of the layered series

Below the 530 m contour analcimitized naujaite occurs in a number of elongated and rounded areas a few square metres in extent. The rock is composed of sub- to euhedral analcime crystals, 2-5 cm in size, and centimetre-long aegirine prisms, arranged in bunches partly enclosed in the analcime. The rock is very porous and crystal cavities up to one decimetre occur. Chkalovite, epistolite and lithium mica are abundant accessories. Some areas are cut by veins of felted aegirine, clearly formed before the analcimitization.

Where the main lujavrite vein of the NW-SE striking zone swells up in the upper part of the slope an elongated zone of dense analcimitized naujaite and syenite occurs as a continuation of an albitized zone. A little chkalovite occurs in the lower part of the zone.

Natrolitized syenite unit

In the lowermost part of the syenite unit scattered "natrolite suns" with a diameter of 5 to 30 cm occur; these clearly replace the syenite. Beryllium minerals have not been observed.

HYDROTHERMAL VEINS

Veins of felted aegirine

This group embraces a number of thin, fine-grained veins consisting dominantly of felted aegirine; other constituents are microcline, steenstrupine and analcime. They contain no beryllium minerals. The veins are at most only a few cm thick; some have been followed for more than 100 m along the strike.

As far as it can be established from the field relations there exists a continuous transition from aegirinitized naujaite through veins of felted aegirine rich in microcline, to veins consisting almost entirely of aegirine (95 vol. % or more (determined by point counter)) and further on to the unzoned aegirine-analcime veins.

All veins of felted aegirine which are seen in intersections with the lujavrite veins, are of the feldspar-rich type containing less than 80 vol. % aegirine (macroscopic determination).

In one case a vein of felted aegirine cuts an arfvedsonite lujavrite vein and contains inclusions of this. In other cases the reverse has been observed. The above-mentioned zone of lujavritized syenite (p. 14) slightly offsets a vein of felted aegirine.

The veins of this group clearly belong to an early phase as the earliest zone of many other vein types is composed of felted aegirine. In fact veins which in their whole length are composed of felted aegirine are comparatively rare. More often parts of a vein are unzoned and parts zoned composed of one or two zones of felted aegirine and one zone mainly composed of either analcime or albite.

Veins of felted arfvedsonite

This group comprises all veins composed dominantly of felted arfvedsonite. They occur in a very restricted area around points 22 and 23 (plate 2). The veins are 2-5 cm thick and occur in two principal directions, namely 170/64 W and 88/82 N. They are rather closely spaced and only a few are marked on the map merely to show the extension of the area in which they occur. The veins are composed of felted arfvedsonite (80-100 vol. %) and may contain a limited amount of albite. No beryllium minerals have been found in these veins.

Unzoned aegirine-analcime veins

Veins of this group are dominantly composed of analcime and aegirine. They occur between the 530 and 560 m contours on the Taseq slope north of the NW-SE striking zone of arfvedsonite lujavrite. The greater part of these veins strike 160-180° and dip 70-88° E or W.

The veins are up to about two decimetres thick and can be followed for some tens of metres. They are composed of very small aegirine needles partly enclosed in 1-2 mm large euhedral analcime crystals. The proportion between these minerals varies between wide limits, in fact there is a gradual transition from veins of felted aegirine on the one side to veins or parts of veins containing more than 80 vol. % analcime on the other. Especially where analcime dominates, the veins contain crystal cavities with subhedral to euhedral analcime crystals up to 1 cm in size, chkalovite (up to 10 vol. %) in half-centimetre sized grains and centimetre long flakes of epistolite.

Veins dominated by analcime, sodalite and natrolite

These veins are characterized by a zone mainly composed of analcime, sodalite and natrolite, of which the natrolite is the youngest. In addition, chkalovite, epistolite, and lithium mica occur.

Only a few scattered thin veins have this assemblage. These veins have marginal zones of sodalite.

Most of the veins included in this group are composite, with an analcime zone and one or two zones of felted aegirine. They can be symmetric with border-zones of felted aegirine or asymmetric with the aegirine zone along one side of the vein. This aegirine zone can change abruptly from one side of the vein to the other.

Chkalovite occurs in crystals up to a few centimetres across. They may be rather numerous. Locally analcime and sodalite may be partly replaced along cleavages by natrolite, probably in the tetragonal form recently described from Ilímaussaq (Andersen *et al.*, 1969). In one case a still later albitization has been observed, the albite occurring in dense masses.

Chkalovite-natrolite mineralized joints

In the most intensively mineralized area south of the NW-SE striking zone of arfvedsonite lujavrite, mineralized joints with chkalovite and "natrolite" cut the naujaite. The chkalovite occurs in subhedral crystals up to a few cm in size, and "natrolite" occurs as thin coatings on the joint planes. According to Hansen (1968 a) these joints may also contain appreciable amounts of epistolite. In some joints a coating of epistolite without other minerals has been observed.

Veins containing ussingite

The most interesting veins in the area, both mineralogically and chronologically, are the ussingite-bearing veins. These, especially those just north of point 16, plate 2, have been described briefly by Semenov *et al.* (1967) while a more detailed description has been given by Engell (1968). Fig. 3 shows a sketch map of the big veins just north of point 16.

Veins carrying macroscopic ussingite have only been found below the 535 m contour in the mapped area; a lower limit has not been established. The veins are very closely associated with lujavrite veins and aegirinitized naujaite. They may originate from crystal cavities in the lujavrite veins or they may occur at the contact between these and the naujaite. The crystal cavities in the lujavrite vein, from which the largest ussingite veins originate, are composed of analcime, chkalovite and epistolite. The structure of the lujavrite veins indicates that the ussingite veins were formed from

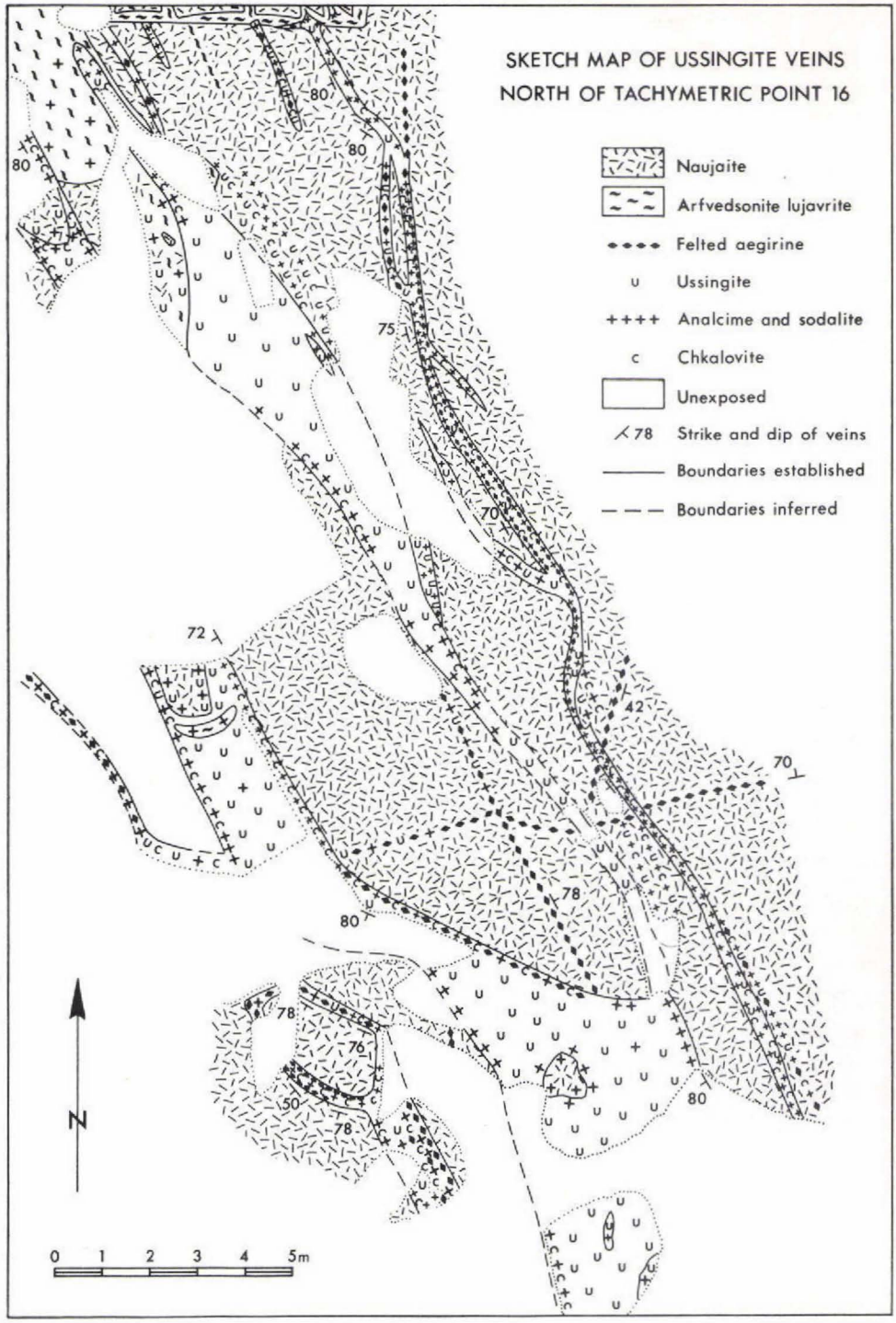

Fig. 3. Sketch map of the ussingite veins north of tachymetric point 16.

the residual liquids squeezed out from the lujavrite magma (Engell, 1968). They never cut the lujavrite but may cut veins of felted aegirine.

Where fully developed, the ussingite veins are symmetrical, with an outer contact zone of felted aegirine about 5 cm thick. This is followed by an analcime zone, up to 20 cm thick, composed of analcime, sodalite, chkalovite (up to 20 vol. %) and epistolite (20 vol. %). The ussingite zone lies at the centre and can be nearly 2 m thick. Besides ussingite it contains scattered euhedral crystals of chkalovite and analcime up to 2 decimetres in size. Numerous elongated, angular cavities indicate the presence of an easily soluble mineral. Sphalerite and galena are frequent accessories.

A network of late tetragonal natrolite penetrates the other minerals along cleavages. Associated with this or forming independent irregular veins are scaly grains of lithium mica.

Table 3. Minerals found in the ussingite veins.

aegirine/acmite	a, (b)
analcime	b, c, (a)
arfvedsonite	a
beryllite	(replacing chkalovite)
chalcothallite	c
chkalovite	b, c
cuprostibite	*)
epistolite	b, c
galena	c
gerassimovskite	(replacing epistolite)
ilimaussite	
Li-mica	
natrolite (tetragonal and probably orthorhombic)	
nenadkevichite	
niobophyllite	c
microcline	a
molybdenite	
pectolite	a, b
sodalite	b, (a)
sphalerite	c
steenstrupine	a, b
tugtupite	(replacing chkalovite)
ussingite	c, (b)

clay minerals, and a number of yet unidentified minerals occur in small quantities.

a. Felted aegirine zone
b. Analcime zone
c. Ussingite zone

*) reported by Sørensen, Semenov, Bezsmertnaya & Khalezova (1969).

Microscopic evidence indicates that a) ussingite has replaced the analcime zone, b) sodalite is replaced by analcime and at least the outer part of the analcime zone was originally composed of sodalite, chkalovite and epistolite, c) there was possible re-solution of chkalovite during the formation of analcime, d) ussingite does not seem to replace chkalovite.

In places chkalovite crystals are cut by veins of analcime which are more or less completely replaced by ussingite. Sodalite and analcime (including the big crystals in the ussingite zone) are partly replaced by ussingite.

Where the ussingite is in direct contact with the naujaite, the latter is replaced by ussingite.

The later natrolite-mica mineralization is very unevenly distributed; some of the largest veins are totally devoid of it, whereas some of the small veins are very rich in it. Associated with this later mineralization, light brown aggregates of natrolite and clay minerals of the montmorillionite-chlorite group occur in cavities.

A list of minerals found in the ussingite-bearing veins is given in table 3. Of these chalcothallite, cuprostibite and ilimaussite are unique to the Ilímaussaq intrusion.

Veins dominated by albite

This group comprises all veins with a zone dominated by albite. They may be composite with marginal zones of felted aegirine. Chkalovite is a scarce constituent.

Just south of point 21 (plate 2), in the most highly mineralized area, there occur a number of veins composed of fine-grained albite, analcime, chkalovite, tugtupite, sphalerite and galena. Veins of this type cut the lujavrite.

Miscellaneous veins

A few veins have a structure which differs from those of all other veins in the area. They occur in the offshoot of albitized naujaite at the south-east corner of the mapped area (plate 2). The veins are composed mainly of a medium- to fine-grained matrix of acicular aegirine crystals and rounded feldspar grains, in which up to 5 cm long platy microcline crystals occur arranged perpendicular to the contact. In some of these veins centimetre-long prisms of either arfvedsonite or acmite may occur, similarly arranged perpendicular to the contact. They contain no beryllium minerals.

BERYLLOMETER PROSPECTING

In 1950 Gaudin *et al.* described an apparatus in which use was made of the nuclear reaction ^{9}Be (γ, n) ^{8}Be to determine the concentration of beryl in ores (Gaudin *et al.*, 1950). With the advent of transistorized electronics in the mid-fifties it became possible to design field instruments working on the same principle (Brownell, 1959, Bowie *et al.*, 1960). For the sake of simplicity, such instruments are usually called beryllometers among exploration geologists, a designation which has been adopted in this paper.

Two types of beryllometers have been used in the prospecting in the Ilímaussaq intrusion. Most of the measurements were performed with an instrument designed to measure the beryllium content over a circular area of about 40 cm^2 and with a limit of detection of about 10 ppm beryllium. This instrument is described below. The other beryllometer used, which was designed to scan veins, has a measurement area of about 10 $\times$ 25 cm and a limit of detection of about 100 ppm beryllium (Løvborg *et al.*, 1968).

Description of the field beryllometer

Fig. 4 is a photograph of this beryllometer. In general it is similar to the instrument described by Bowie *et al.* (1960). The essential feature of the instrument is a specially designed radiation shield which prevents the operators from receiving undue radiation doses when handling and using the instrument. This shield is shown in fig. 5. The shield is made of lead and consists of a cylindrical housing and a pivotally mounted disc in the housing. The γ-source is inserted in the hole shown in the periphery of the disc. By means of a key the disc may be turned 180° from the position indicated in fig. 5 to a position where the γ-source is located at the centre of the combined shield formed by the housing and the disc. In the former position the source irradiates the support for the beryllometer, while in the latter position the source is surrounded by 8 cm lead on all sides (stand-by position).

The γ-source is ^{124}Sb ($E\gamma = 1.69$ MeV, $T_{1/2} = 60$ days) placed in a sealed aluminium capsule and made by irradiation of pure antimony metal with thermal neutrons in the Danish research reactor DR3. At the time of mounting in the instrument the source has strength of 100 mCi, and the same source is normally used for a period of 2-3 months. With a fresh source in the stand-by position in the shield the maximum γ-dose rate on the surface of the carrying case amounts to about 100 mR/h. This figure is quite high, but experience has shown that responsible persons are able to handle the beryl-

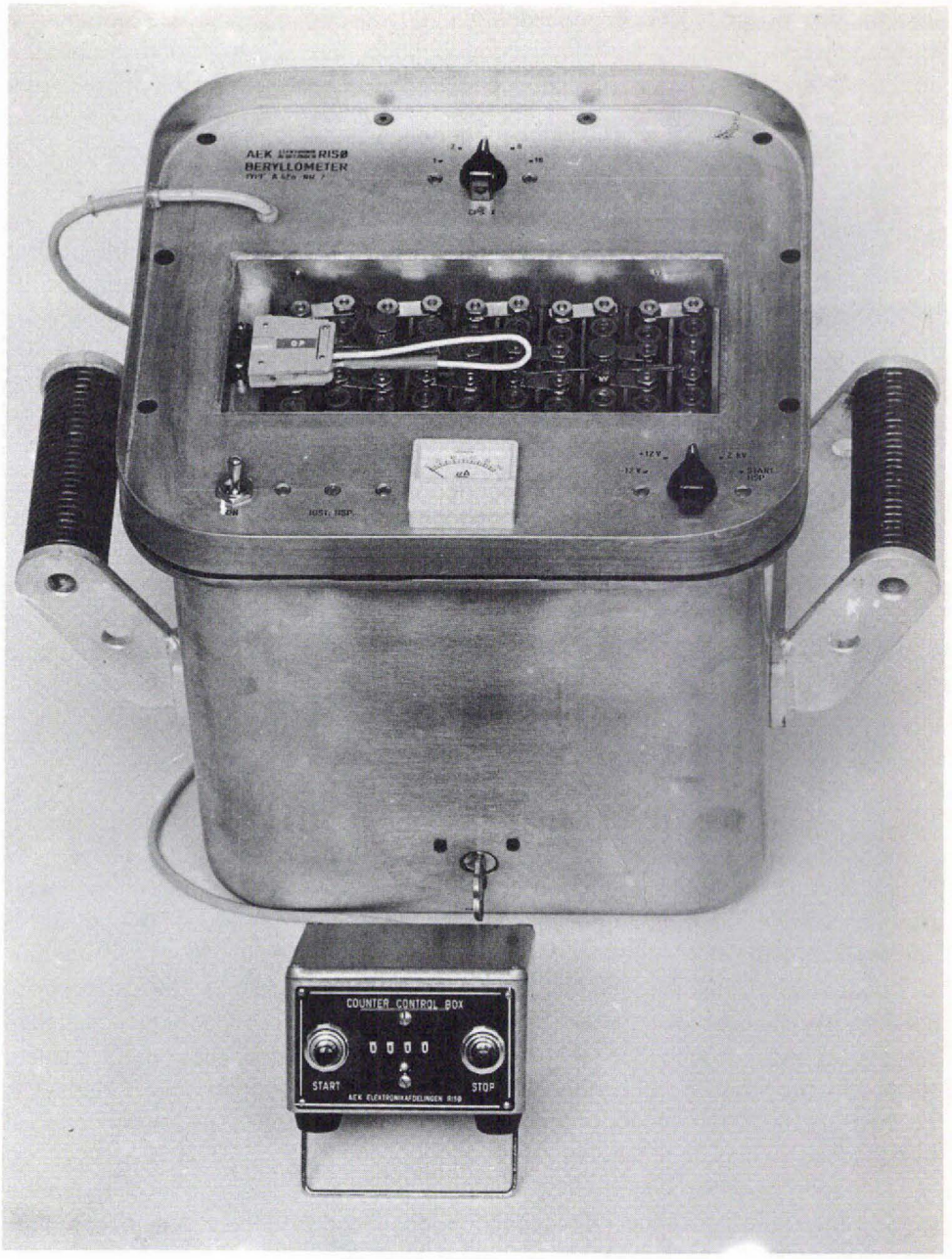

Fig. 4. The field beryllometer.

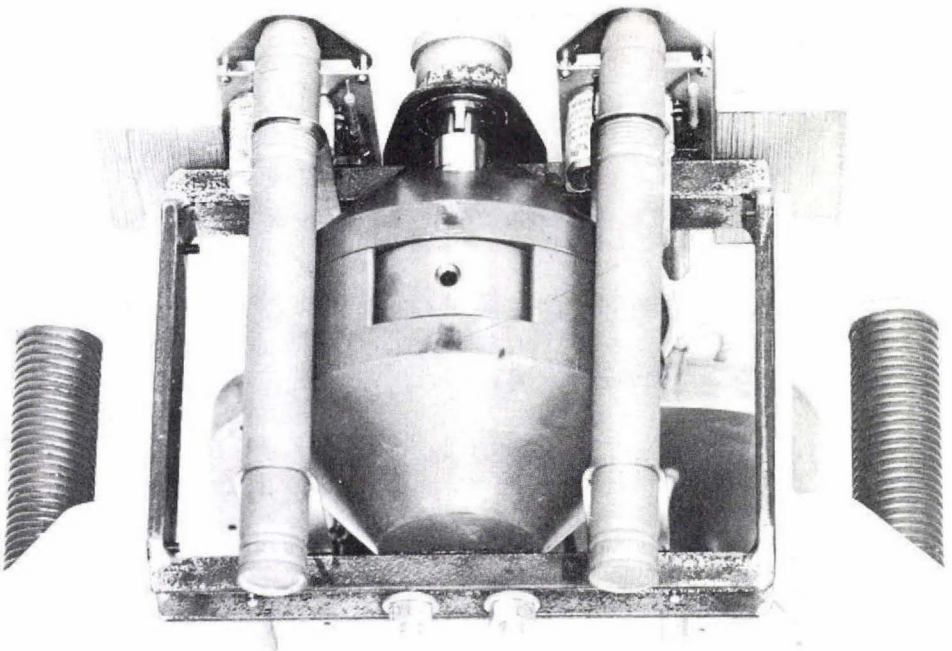

Fig. 5. The field beryllometer showing the lead shield. The γ-source is inserted in the hole shown in the periphery of the disk. When not in use the source is turned into the centre of the shield by means of the key.

lometer in the field without receiving more than a fraction of the acceptable tolerance dose at the end of a field season. As an extra precaution, two 1 m long carrying rods are normally used to transport the instrument from one field locality to another. When the beryllometer is used in the laboratory an additional shield consisting of bags filled with steel-balls is always set around the instrument, in which case the instrument is absolutely safe.

The photo-neutrons released from beryllium in a sample being irradiated by the γ-source are detected with the aid of two boron-trifluoride proportional counters (20th Century type 12 EB 40) mounted on each side of the radiation shield (fig. 5). In order to achieve a high detection efficiency a combined moderator and reflector consisting of a layer of paraffin wax surrounds each neutron detector (this layer was not yet cast when the photograph in fig. 5 was taken). A 2 kV high-voltage is produced in a stabilized saturated-core converter and applied to each detector. The signal-pulses from the detectors are mixed and amplified, after which they are passed to a trigger-circuit which discriminates against γ-background and noise.

The pulses are finally applied to a binary scaling circuit with adjustable scale-factor followed by an electromechanical register. The latter is mounted in a separate small metal box together with two pushbuttons which respectively are used to initiate and interrupt the counting of pulses (fig. 4). It is thus possible to stay at a safe distance (2 m) from the beryllometer while a field determination of beryllium is being made.

The beryllometer is powered by a 2 × 12 V rechargeable nickel-cadmium battery which can be inserted in a cavity in the top cover of the instrument (fig. 4.). A fully charged battery lasts several working days. Recharging is usually carried out overnight with the aid of a special charging unit which may be powered from a small motor generator in the field.

The beryllometer described weighs 40 kg, mainly due to the heavy radiation shield. It is therefore hard to handle in the field, but a reasonably safe radiation protection was considered to be an urgent need in the design of the instrument.

In order to make an estimate of the effective sample volume obtained when the beryllometer is placed on an outcrop of rock with a homogeneous distribution of beryllium, we have measured the count rate of neutrons from a small glasscontainer filled with BeO for different positions of this container with respect to the bottom surface of the instrument. For both specimens of the instrument we found that the neutron count rate n decreased almost exponentially with increasing distance r between the container and the centre of the bottom surface:

$$n = n_o e^{-r/\lambda} \qquad (1)$$

In each case the value of the relaxation length λ was approximately equal to 2 cm, independent of the orientation of radius vector $\vec{r}$. This experiment did not account for the scattering and absorption of γ-photons and neutrons occurring in a rock layer, but these phenomena are not so important compared with the effect of distance. It may thus be stated that the sensitivity of the instrument to beryllium is almost constant along the surface of any hemisphere with centre at the centre of the instrument bottom.

On the basis of equation (1) it is estimated that 90% of the neutron count rate obtained from a homogeneous and infinite rock layer is due to the beryllium content in the volume delineated by a hemisphere with a radius of ca. 10 cm. For a rock layer with density 2.7 g/cm^3 (naujaite and lujavrite) this volume corresponds to a mass of ca. 6 kg.

One important consequence of the strong dependence between count rate and distance as expressed by equation (1) is that field readings are strongly influenced by surface irregularities in the outcrops of rock, and also that even a thin layer of overburden cannot be accepted. We have thus found that the count rate decreases by ca. 15% for each cm of elevation of the instrument above a plane rock surface (cf. Bowie *et al.* 1960). The precision obtained in a single field determination of beryllium is therefore normally rather poor. The true value of the beryllometer in field-

work lies in its speed, permitting hundreds of field determinations to be made in the course of a field season. The information regarding the average concentration of beryllium derived from such a large amount of data must be assumed to be quite reliable, as the random experimental errors will tend to cancel.

The absolute sensitivity of the beryllometer is ca. 10 cpm/% BeO mCi^{124}Sb. This figure means that the net count rate of neutrons observed with the instrument placed in contact with a homogeneous rock layer containing 100 ppm BeO amounts to ca. 10 counts per minute for a source strength of 100 mCi. The background count rate of the instrument can be assumed to be exclusively due to neutrons produced by cosmic radiation. At sea level in south Greenland, the background is 1-2 cpm. This figure rises to 2-3 cpm when the instrument is used at an altitude of about 500 m.

The figures given for the sensitivity and the background count rate of the beryllometer may be used to estimate an approximate limit of detection. Hence, if one requires a net count exceeding twice the standard deviation of the background count for a counting time of 10 min, the concentration of beryllium in the rock layer must be ca. 10 ppm BeO or more. The actual limit of detection depends of course on the relief of the rock surface and the distribution of the beryllium minerals in the rock layer. Based on the results presented later in this report it is probably safe to assume that the practical limit of detection that can be obtained in a single field measurement of 10 minutes' duration is lower than 10 ppm BeO (cf. Bowie *et al.* 1960).

The use of the beryllometer, in the field or in the laboratory, is based on the validity of the formula

$$\% \text{ BeO of sample} = \frac{\text{net count rate from sample}}{\text{net count rate from standard}} \times K \qquad (2)$$

If the physical and geometrical properties of the standard are identical to those of the sample, the factor K is equal to the weight percentage BeO of the standard. This condition is easy to fulfil in the laboratory where the instrument normally is used to determine beryllium in crushed rock samples. In this case the standard may simply be prepared by filling a sample container with a homogenized powder of known BeO concentration.

In the field the standard would be very impractical to handle if it had to represent an essentially infinite rock layer. We instead make use of a standard yielding about 60% of the count rate that would be obtained from an infinite layer with the same concentration of beryllium. This standard has the dimensions 20 × 20 × 5 cm and contains 2% BeO by weight. It was prepared by the dissolution of $Be_4O(CH_3COO)_6$ in styrene and an unsaturated polyester which was cured in an iron frame. Originally mixtures of cement and BeO were tried and used for some time as standard materials, but these were found to be too fragile.

The correction factor to be applied to the count rate obtained with the beryllometer placed on the standard described above was measured in the following way: A plastic vessel with dimensions 35 × 30 × 15 cm was completely filled with a fine-

grained mineral concentrate containing ca. 0.1% BeO. With the beryllometer placed on the surface of this powder, which could be assumed to represent a homogeneous and infinite medium, we determined the corresponding net count rate n_1. Next, a wooden case with inner dimensions equal to the dimensions of the standard was filled with a portion of the same powder, and the net count rate n_2 obtained with the beryllometer placed on the top of this reduced amount of powder was determined.

On the basis of several repeated experiments we found an average value of 1.6 for the ratio n_1/n_2. The value of the factor K in equation (2) to be applied when calibrating the beryllometer against the 2% BeO standard in field work was therefore equal to $2/1.6 = 1.25$.

Field measurements

Fig. 6 gives an indication as to how the instrument is used. Since the exact calibration of the beryllometer depends on several electronic parameters (high-voltage, gain and discriminator level) which vary slightly with the battery voltage and the ambient temperature, the instruments were calibrated against the reference standard about every two hours. Measurements of the background count rate were also carried out several times a day. This was done with the beryllometer placed on the top of the wooden box used for transport and storage of each instrument. The time spent on a

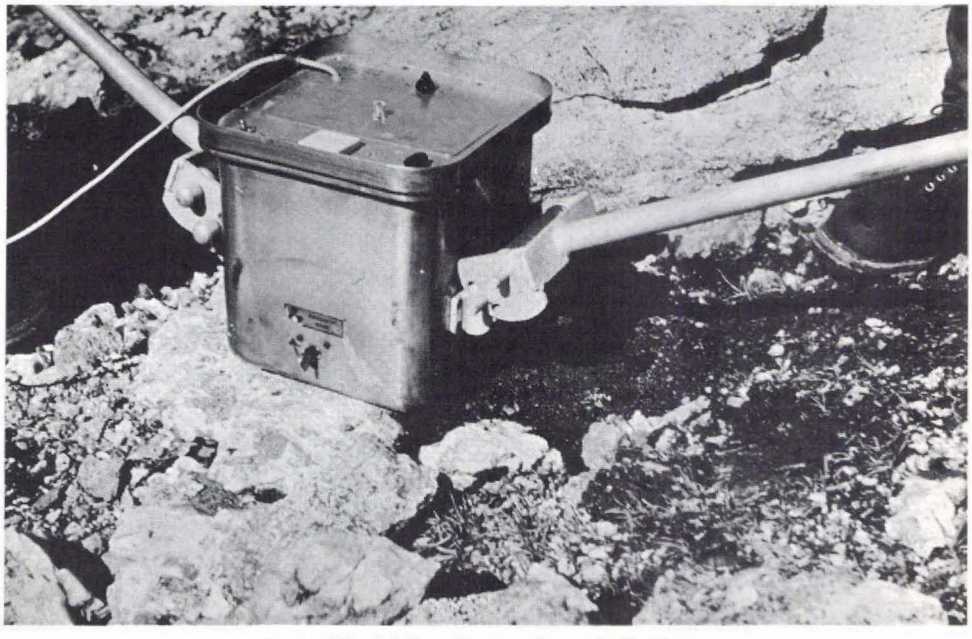

Fig. 6. The field beryllometer in use in the field.

single field determination was normally chosen so as to obtain a count significantly higher than the background count in the same time. For a beryllium content of more than 25-40 ppm BeO this condition could normally be fulfilled with a counting time of 4 min. or less.

The measurements have mostly been carried out at grid intersections placed at representative localities of the different rock types.

Laboratory measurements

The field readings with beryllometers, as mentioned on p. 26, are strongly influenced by surface irregularities, giving a reduction in count rates of ca. 15% for each centimetre of average spacing between rock surface and the instrument. At each measurement locality for beryllometers such compensation has been carried out. In order to evaluate any correction necessary due to effects of weathering within the upper 40 cm of the rock we measured in the laboratory the dust produced by drilling from some of the localities. For this purpose both beryllometer and wet chemical analysis were carried out.

The beryllometer measurements were undertaken on 20 cm^3 material crushed to -50 mesh/$inch^2$ and placed in a box filled with paraffin wax in order to achieve a high detection efficiency (cf. p. 23).

Chemical analyses have been carried out in order to calibrate the beryllometer measurements.

METHOD OF CHEMICAL ANALYSIS

The chemical analytical method used is a modification of that given by Adam *et al.* (1952). The following procedure has been used:

To 25 cc of the solution (containing up to 10 μg beryllium) add 25 cc 0.02 M NaCl and 2 drops methyl red. Adjust pH to 0.5-1 and add 2.0 cc 10% complexone, adjust pH to 7-8 with 0.1 M NaOH. Add 5 cc 5% aqueous acetylacetone and adjust pH to 7-8. Wait 5 min. and extract with 3 $\times$ 10 cc chloroform. Cover the chloroform extract with 15 cc water, 2.0 cc 16 M HNO_3 and 2.0 cc 60% perchloric acid in a Pt-bowl. Evaporate off the chloroform and continue the evaporation slowly on a hot plate to dryness. Repeat the evaporation after addition of 2.0 cc HNO_3 and 2.0 cc perchloric acid until no organic material remains.

Dissolve in 15 cc 0.1 M HNO_3 – if necessary by boiling and place the solution in a 100 cc separation funnel. Add 2 drops bromothymol blue and 1 cc 10% complexone reagent. Make up to pH 7 with 0.1 M NaOH – add 2 ml 1% aqueous acetyl

acetone and adjust to pH 7-8. Wait 5 min., extract with 3 × 8 cc chloroform, collect in a 25 cc measuring flask. Adjust to 25 cc with chloroform and place in a separating funnel with 50 cc 0.1 M Na(OH).

Shake vigorously for 30-60 sec., allow the two layers to separate and repeat the alkali extraction with 50 cc 0.1 M NaOH. Run the chloroform through a small filter paper into a 1 cm quartz cell and measure the extinction of the solution at 2950 Å against a blank of pure chloroform. Use a calibration curve made as follows: 50 cc portions each containing 25 cc 0.02 M NaCl and known amounts of Be (e.g. 1 μg, 2 μg, ... 10 μg) are treated as described above after no organic material remains. The minerals are dissolved by heating 100 mg with 10 cc HF in a small Pt bowl and fuming with 3-4 drops concentrated H_2SO_4 to remove excess HF. The dry residue is dissolved in 6 M HCl and the necessary dilutions made.

The importance of other elements in the beryllium minerals is shown in table 4. According to Adams *et al.* (1952) aluminium and magnesium may have influence on the analysis but not with the amounts of complexone used. It was shown, however, that the amounts of complexone must be increased by a factor of five for this to be valid. The amount of NaCl used in the calibration was similar to that found in the analyzed minerals. Particular attention should be paid to the wet destruction of the chloroform which should be carried out very slowly and carefully. When these modifications were observed slightly better results than the 5% reported by Adam *et al.* (1952) were obtained (see table 4).

Table 4. Influence of impurities on beryllium analyses.

Solution nr.	Impurities in μg/μg Be					μg Be theoretical	μg Be found	Deviation in % from theoretical value
	Na	Mg	Al	K	Fe			
1	5760	0.12	4.0	5.6	0	2.03	1.98	–2.5
2	3770	0.08	0	0	0	3.05	2.95	–3.3
3	11500	0	8.1	11.3	0	1.02	1.06	3.9
28	2270	0	2.0	0	0	5.08	4.98	–2.0
29	2270	0	4.0	0	0	5.08	5.24	3.1
30	2270	0	0	0	0.4	5.08	5.18	3.9
31	2270	0.04	0	0	0	5.08	5.02	–1.2
32	2270	0.01	0	0	0	5.08	4.93	–2.9
33	2270	0	0	0.02	0	5.08	5.00	–1.6
34	2270	0.04	4.0	0.02	0.4	5.08	5.21	2.6

RESULTS OF THE BERYLLOMETER SURVEY

In order to determine the average concentration and the distribution of beryllium in the mineralized area, more than 2000 measurements were performed with beryllometers in the field and more than 1000 in the laboratory on dust from drillings to 30-40 cm depth at the same localities. The results are given in plate 3. At least 10 measurements have been performed at each locality.

Generally there is a good agreement between the average of field and laboratory determinations from the same locality. Field and laboratory measurements from one and the same spot, however, often gave different results.

The good correlation shows that though the surface of chkalovite weathers easily the content is nearly the same within the upper 40 cm. No important chemical weathering has occurred or the same chemical weathering of the beryllium minerals has occurred within the upper 40 cm. It is well known that other beryllium minerals like beryl, crysoberyl and phenacite are highly insoluble in solutions formed during chemical weathering.

The beryllometer survey confirms the field observations that the beryllium mineralization is restricted to the hydrothermal veins and alteration zone. The wall rocks – naujaite and lujavrite – show no general increase in the beryllium content compared with other parts of the intrusion (Table 5).

The large number of beryllium analyses made with the beryllometer on the country rock of the mineralized area make a numerical treatment of the data possible. Data exist for the naujaite and the lujavrite on the Taseq slope and on Kvanefjeld, and for the syenite unit on the Taseq slope.

A histogram representing the frequency distribution of 513 field determinations of beryllium in naujaite from the Taseq area is given in fig. 7. Two characteristic features of this distribution are conspicuous:

1) The dispersion of the beryllium concentration about the arithmetic mean value of all single observations is very large.
2) The distribution exhibits a marked positive skewness.

These features were found to dominate the distribution of beryllium in all the rock types treated here.

The positive skewness has the effect that the arithmetic mean value tends to be very susceptible to the actual population of single observations in the »tail« of each experimental distribution, particularly when the observations are few in number. A direct comparison between the arithmetic mean contents of beryllium in the different rocks might therefore lead to erroneous conclusions.

An estimate less influenced by accidental, large observations in each set of experi-

Table 5. Beryllium content in rocks from the Ilímaussaq and Lovozero intrusions.

	Ilímaussaq					Ilímaussaq Gerassimovskii (1969)			Ilímaussaq Hamilton (1964)		Ilímaussaq Ferguson (1964)			Lovozero Gerassimovskii *et al.* (1965)
	Locality*	No.of obs.	Means Be ppm			Be ppm			Be ppm		Be ppm			Be ppm
			Arith.	Geom.	Arith./Geom.	No.of obs.		Mean	No.of obs.	Mean	No.of obs.		Mean	
Syenite unit	T	40	12	12	1.0									
Naujaite	T	513	18	16	1.1	4	10-25	17						
Naujaite	K	60	27	27	1.0				4	23	5	7–27	15	
Fine-grained arfvedsonite lujavrite	K	18	14	14	1.0	5	26-42	35	3	35				
Fine-grained arfvedsonite lujavrite	T	291	28	24	1.1						5	15-43	26	10
Medium- to coarse-grained lujavrite	K	17	11	8.7	1.3	1		44						
Naujaite albitized and analcimitized to a dense compact rock	T	298	17	15	1.1									

* T = Taseq slope K = Kvanefjeld area

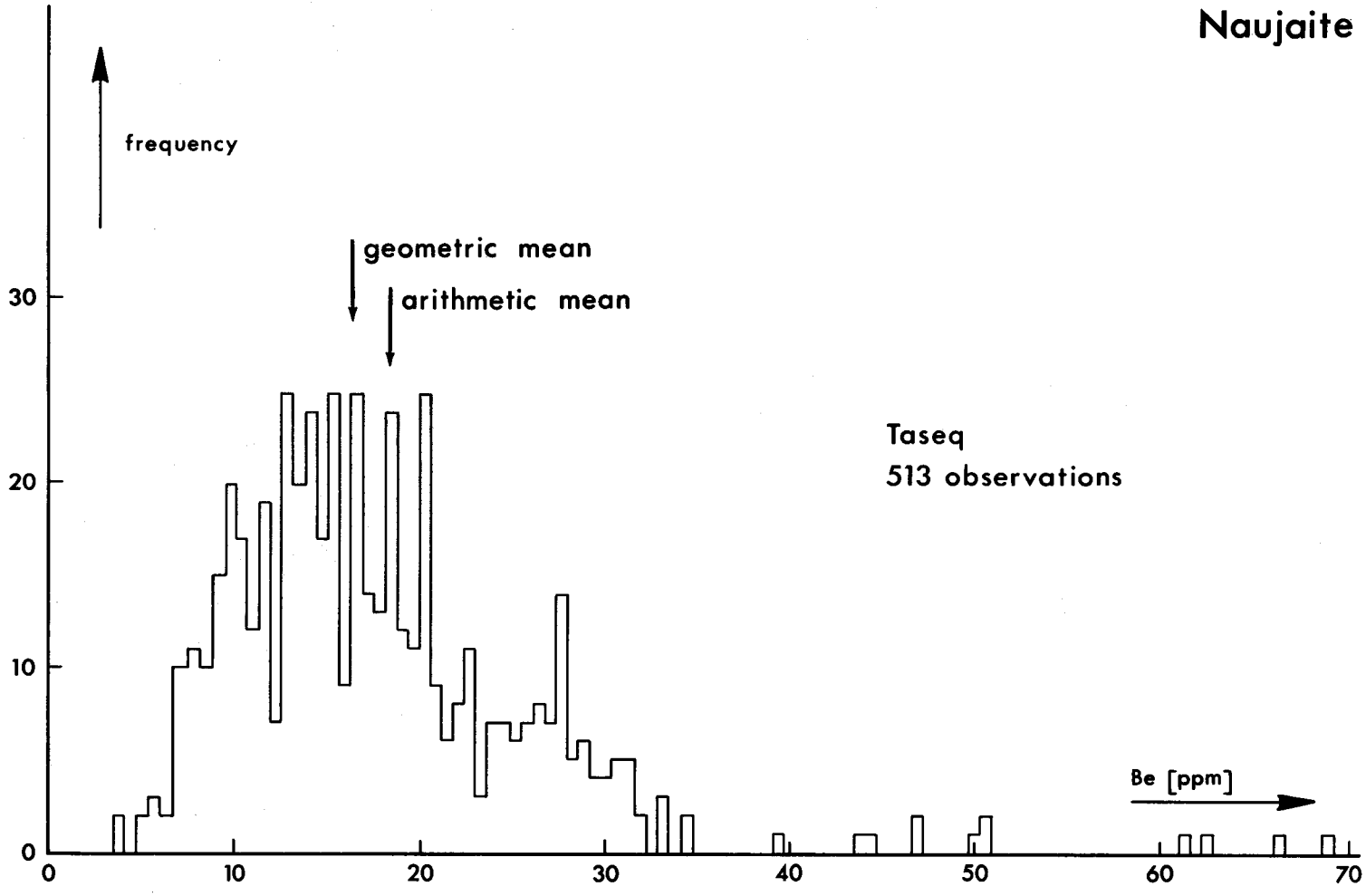

Fig. 7. Histogram representing the frequency distribution of 513 field determinations of beryllium in naujaite from the Taseq slope.

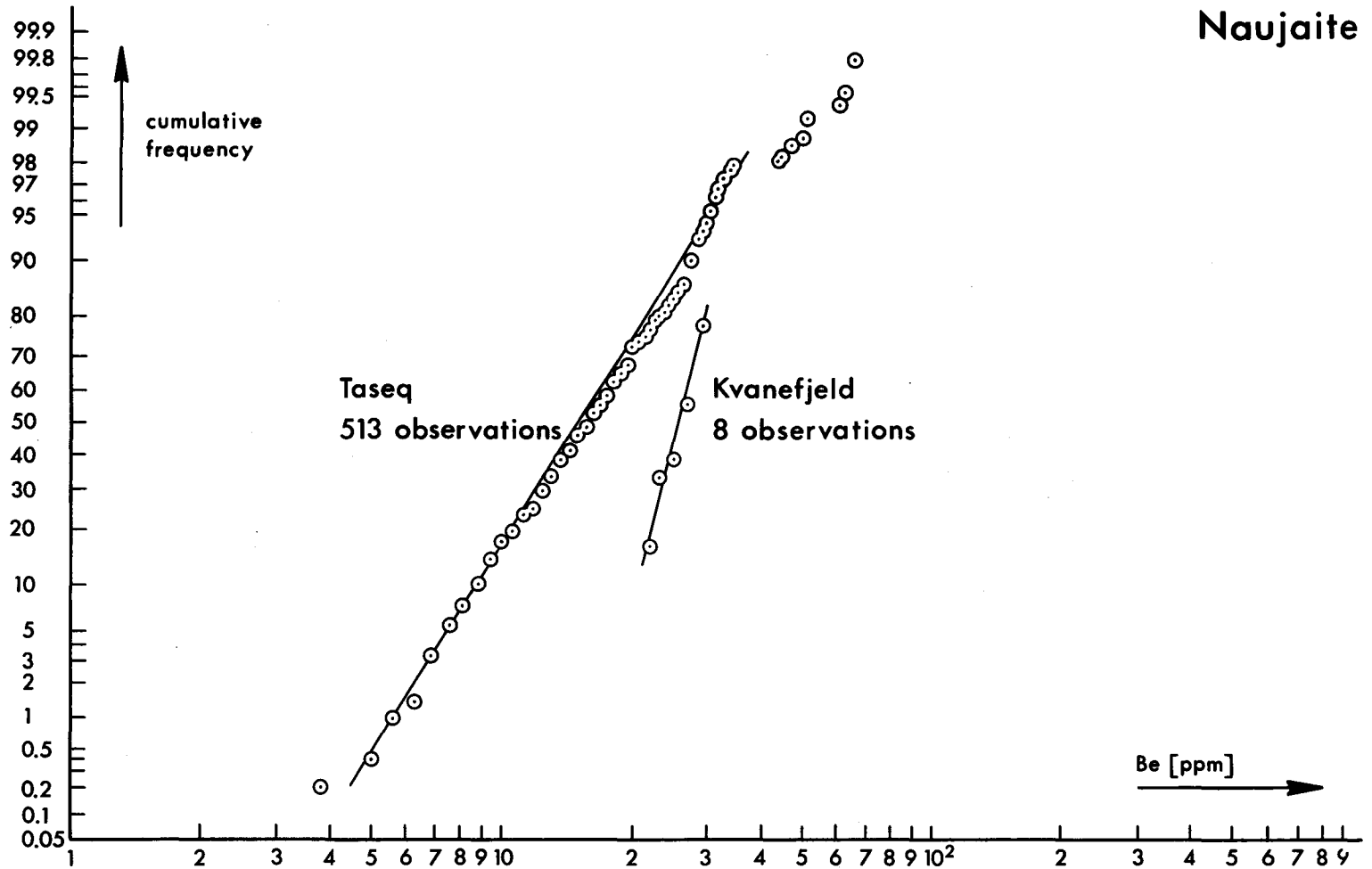

Fig. 8. Cumulative frequency distribution of beryllium in naujaite from the Taseq slope and the Kvanefjeld area.

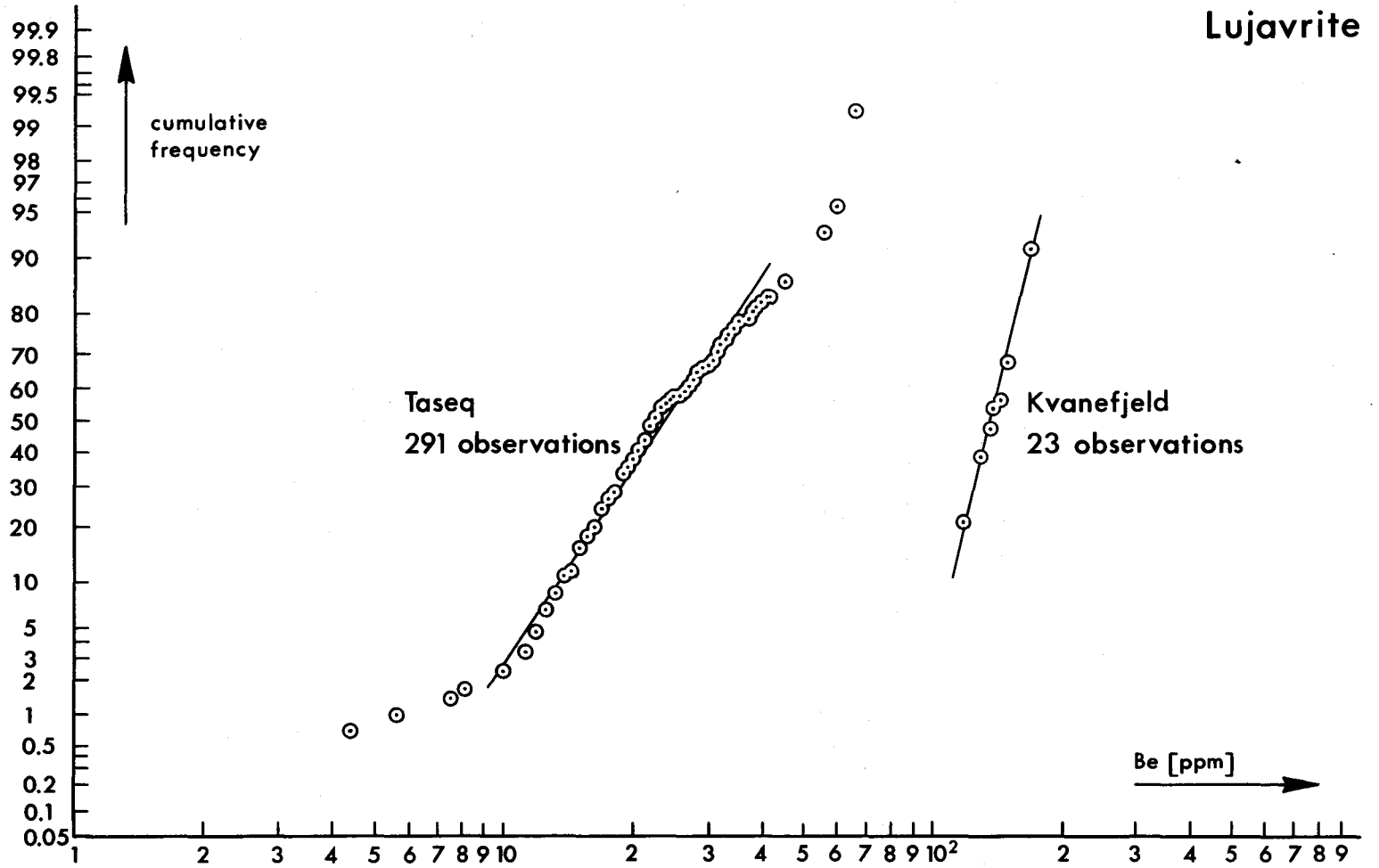

Fig. 9. Cumulative frequency distribution of beryllium in fine-grained lujavrite from the Taseq slope and the Kvanefjeld area.

mental data can be obtained by taking the geometric mean as a measure for the prevalent content of beryllium in the rocks. Table 5 lists both the arithmetic and the geometric mean for each of the rock types investigated here. In table 5 is also given data from Gerassimovskii, Hamilton and Ferguson for rocks from other places in the intrusion and from Lovozero, Kola peninsula, USSR. From the data in table 5 it appears that:

1) The fresh and the albitized and analcimitized naujaite from the Taseq slope have a similar beryllium content. The naujaite from the Kvanefjeld area is richer in beryllium than naujaite from Taseq.
2) The steenstrupine lujavrites from the Taseq slope are richer in beryllium than the lujavrites from the Kvanefjeld area.
3) There is a good agreement between the present and the earlier observations on the beryllium content in the naujaite and in the lujavrite from other places in the intrusion.
4) The lujavrite from Lovozero has a beryllium content similar to that of the fine-grained lujavrite from the Kvanefjeld area.

The cumulative frequency distributions of beryllium in naujaite and in fine-grained lujavrite from the Taseq slope and the Kvanefjeld area are given in fig. 8 and fig. 9, respectively. It is seen from the figures that beryllium has a log-normal distribution. The beryllium content in all the rock types mentioned has a log-normal distribution, as first suggested by Ahrens (1954).

The distribution of beryllium has been studied further in the ussingite veins and in an arfvedsonite-rich vein containing a large number of beryllium minerals.

Field work has shown that in the ussingite veins beryllium is predominantly concentrated in the analcime-sodalite zone which forms the border zones of the veins. The veins generally are too coarse-grained to show this with beryllometers by traverse profiles. At some localities beryllometer measurements have, however, confirmed the field work.

A treatment of all the measurements (fig. 10) indicates two log-normal distributions, probably referring to the zones without beryllium minerals and to those where beryllium minerals are concentrated.

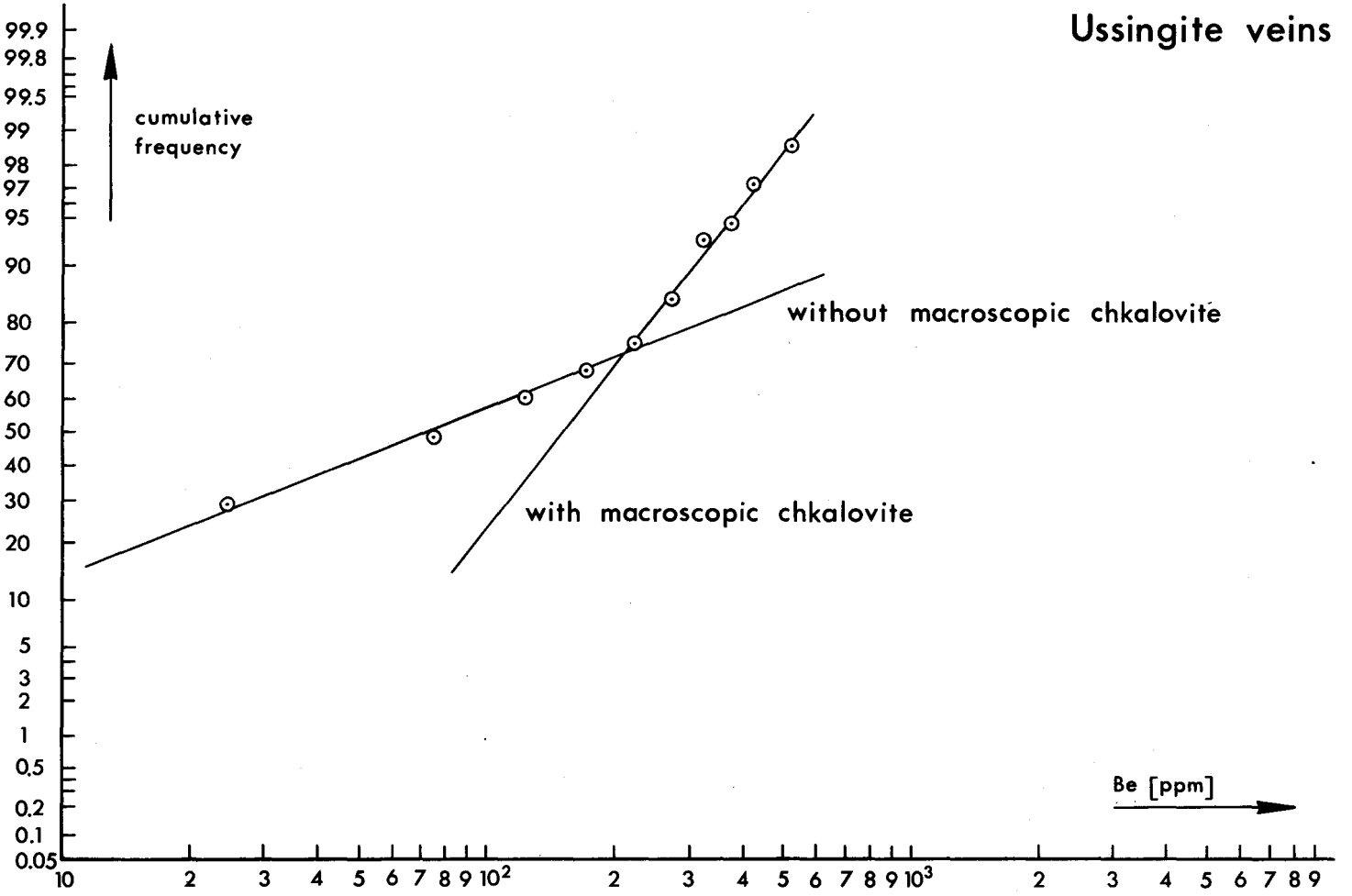

Fig. 10. Cumulative frequency distribution of beryllium in ussingite veins with and without macroscopic chkalovite.

ECONOMIC APPRAISAL

The highest concentration of beryllium known from the Ilímaussaq intrusion is found on the Taseq slope. The predominant beryllium mineral is chkalovite (table 2.)

Beryllium minerals occur in several types of hydrothermal veins and in metasomatic rocks. The greatest concentration of these veins so far known is found in the area shown on plate 2. Outside this area, but still on the slope, a limited number of veins carrying beryllium minerals exist. In contrast veins with beryllium minerals appear to be very rare on the plateau.

The beryllium mineralization on the Taseq slope is about 500 m long and up to about 200 m wide. It occurs at altitudes from about 460 m to about 560 m centering around the area investigated in detail (plate 2). The greatest concentrations are found in close connection with the NW-SE striking vertical zone of arfvedsonite lujavrite which intersects the area of plate 2 diagonally, and in the lower half of the mineralized area. The veins and zones containing beryllium minerals are thin, in general only a few centimetres wide, ranging from about 1 mm to about 2 m. In general they have a length of a few tenths of a metre. The veins are so thin, irregular, and unevenly distributed that selective mining would be difficult. We have therefore tried to estimate the average content in wall rocks and veins based on beryllometer measurements on the surface and on drill dust down to 40 cm. The results are given in plate 3.

The beryllometer measurements indicate an average concentration of less than 0.1% BeO in most of the mineralized area.

An average concentration of 0.1% BeO or more is only found in smaller areas in the lower half of the mineralized area. Due to relatively bad exposure it is at present not possible to determine the exact area having this concentration, but it is believed to be approximately 3000 m^2 with a difference in altitude of approximately 80 m, giving 72000 m^3 ore or ca. 180.000 tons with an average of 0.1% BeO.

BERYLLIUM MINERALS OTHER PLACES IN THE INTRUSION

The beryllium minerals on the Taseq slope are found in hydrothermal veins in naujaite near lujavrite. A survey of places with these relations has been undertaken in the intrusion, but only scattered veins with accessory amounts of beryllium minerals (predominantly chkalovite) have been found. The localities where beryllium minerals have been found are indicated in fig. 1.

The only beryllium mineralization outside the Taseq slope is found on the Kvanefjeld area on the northern side of Narssaq Elv. It is associated with a U-Th mineralization (Sørensen, Hansen & Bondesen, 1969).

The Kvanefjeld area which forms the northern contact of the intrusion is made up of a complicated intrusion breccia in which large and small blocks of volcanic country rocks are enclosed in various types of lujavrite. In the Kvanefjeld area there are at least two generations of hydrothermal veins with beryllium minerals: veins genetically associated with the fine-grained lujavrite and veins genetically associated with a later medium- to coarse-grained lujavrite only known from this area.

The veins associated with the fine-grained lujavrite mainly consist of albite and natrolite. Further constituents are natrolite, the beryllium minerals chkalovite, tugtupite, beryllite and bertrandite, and the niobium minerals epistolite and pyrochlore (Sørensen, Hansen & Bondesen, 1969, and Sørensen *et al.*, in press). Generally the content of beryllium and niobium minerals is very low, but locally these minerals form up to a few percent of the rocks. The veins are from a few mm to ca. 0.5 m thick; most often they are less than 1 cm thick. Generally they can be followed for some metres. The veins cut the pre-agpaitic rocks, augite syenite, fine-grained alkali syenite and naujaite.

The veins associated with the medium- to coarse-grained lujavrite consist mainly of analcime. The bodies often are zoned with a border zone of microcline, arfvedsonite and steenstrupine and a core composed of analcime, sodalite and natrolite with pyrochlore, neptunite, blue apatite, igdloite, monazite, chkalovite and beryllite (Semenov *et al.*, 1965). Sorensenite is the most common beryllium mineral in these veins and is found in aggregates from a few mm up to 20 cm i size. Chkalovite may be found in contact with the sorensenite but only in one place is it found in bigger than accessory amounts.

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THE NW PART OF THE TASEQ AREA

GEUS
Report File no.
22355
Enclosure (1/3)

Contour interval 5m

0 100 200 300 400m

- Lava and gabbro
- Albitized gabbro
- Anorthosite
- Augite syenite
- Naujaite
- " with pegmatite
- " albitized
- " sheared
- " natrolitized
- Syenite unit
- Lujavrite
- Unexposed
- Dense dykes
- Lamprophyric dykes
- Albite
- Analcime
- n Natrolite
- u Ussingite
- F Fluorite
- c Chkalovite
- t Tugtupite
- e Eudidymite and epididymite
- /73 Strike and dip of veins
- ⊙ Tachymetric point
- Boundaries established
- Boundaries inferred

The rectangle marks the area mapped in detail in plate 2

TASEQ

505.2

109.000 108.500 108.000 107.500

109.250 109.500 110.000 110.400

OUTCROP MAP OF A DETAIL OF THE TASEQ SLOPE

GEUS
Report File no.
22355
Enclosure (2/3)

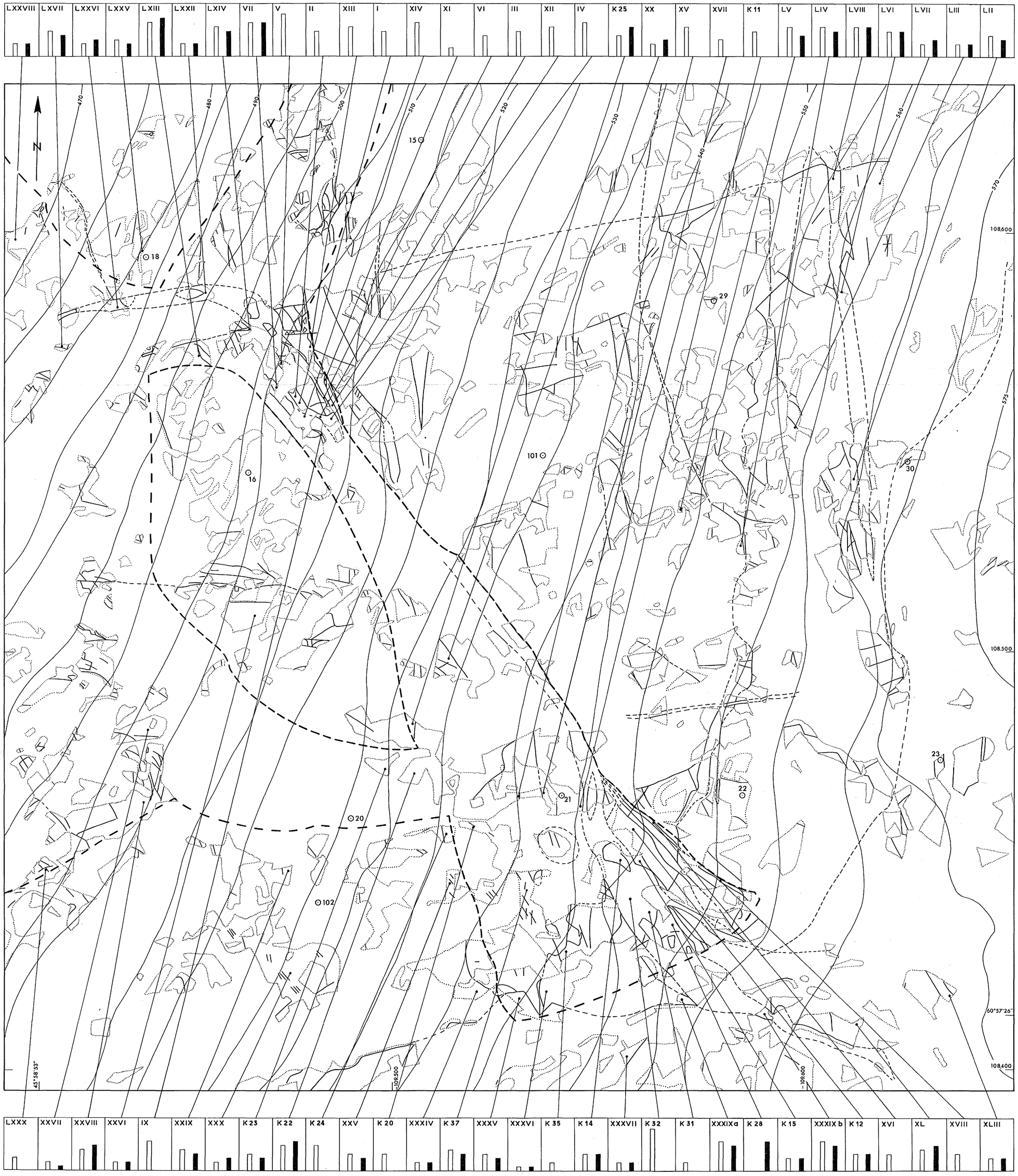
Contour interval 5m

0 10 20 30 40 50m

- Naujaite
- " lujavritized
- " albitized
- " analcimitized
- Syenite unit
- " " lujavritized
- " " albitized
- " " analcimitized
- Arfvedsonite lujavrite / with naujakasite
- Unexposed
- Aegirine – rich veins
- Arfvedsonite – rich veins
- Unzoned aegirine – analcime veins
- Albite
- Analcime
- Natrolite
- Sodalite
- Ussingite – bearing veins
- Chkalovite
- Eudidymite and epididymite
- Tugtupite
- Deformation zone
- Igneous layering
- Pegmatite
- Strike and dip of igneous layering
- Strike, dip and thickness of veins, thickness in cm
- Tachymetric point
- Boundaries established
- Boundaries inferred

GEUS
Report File no.
22355
Enclosure (3/3)

MAP SHOWING THE RESULTS OF FIELD AND LABORATORY BERYLLOMETER MEASUREMENTS ON A DETAIL OF THE TASEQ SLOPE



Contour interval 5m

0 10 20 30 40 50m

Field locality no. — XL

Laboratory measurement

Field measurement

%BeO
>0.50
0.50
0.30
0.10
0.06
≤0.02

——— Established boundaries. Veins

– – – – Inferred boundaries

..... Boundaries of exposure

— — — Boundary of mineralized zone

⊙23 Tachymetric point