GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN NO. 28

AN AUTORADIOGRAPHIC EXAMINATION OF ROCKS AND MINERALS FROM THE ILÍMAUSSAQ BATHOLITH, SOUTH WEST GREENLAND

BY

VAGN BUCHWALD AND HENNING SØRENSEN

WITH 3 FIGURES IN THE TEXT
AND 4 PLATES

Reprinted from
Meddelelser om Grønland Bd. 162, Nr. 11

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
1961

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Abstract.

Rocks and minerals from the lower part of the Ilímaussaq complex have been examined by means of the nuclear emulsion method. It was found that the radioactivity of the rocks increases from the early naujaite to the later lujavrite and hydrothermal veins.

The eudialyte is very weakly radioactive in the naujaite, naujaite pegmatites and in the kakortokites, but is more radioactive in the lujavrites which according to the field relations are the youngest nepheline syenites of the complex. The altered eudialyte may be strongly radioactive.

The radioactivities of lovozerite and rinkite are of the size of order of that of the eudialyte of the lujavrite. Isotropic parts of the grains of rinkite may be strongly radioactive.

The epistolite is very weakly radioactive, but flakes of a murmanite-like mineral in lujavrite were found to be fairly radioactive.

There are small strongly radioactive grains of thorianite in some vein steenstrupines.

Apatite is rare and very weakly radioactive; the rare earth-apatite, britholite is generally rather weakly radioactive.

The monazite of the lujavrites may, as mentioned in *8*, be very weakly radioactive, but strongly radioactive monazite has been found in a few rocks.

Several types of steenstrupine have been found in lujavrites and hydrothermal veins. The radioactivity varies from rather weak to strong; the weakly radioactive grains being anisotropic and the strongly radioactive ones isotropic. The crystals may be zoned with isotropic, strongly radioactive central parts and anisotropic, weakly radioactive marginal zones. The cause of this distribution is discussed.

The results of the autoradiographical and chemical examinations of steenstrupine are compared and the agreement is found to be satisfactory.

INTRODUCTION

In the autumn of 1956 an autoradiographic examination of rocks and minerals from the Ilímaussaq batholith in South West Greenland was commenced. Preliminary results of the examination have already been published (*1* and *16*). The examination comprises 94 nuclear preparations, which have been described in unpublished reports (*3* and *18*). The present paper brings the main results of the examination.

V. Buchwald has undertaken the preparation and the counting of the nuclear plates, H. Sørensen the mineralogic and petrographic work.

The geology and petrology of the Ilímaussaq area have been described by Ussing (*20*), Wegmann (*21*) and Sørensen (*17*). These papers should be consulted for details about the geology of the area in question.

Thanks are due Mr. J. Bondam, Mrs. Marianne Danø, Mr. J. Ferguson, Mr. Chr. Halkier, Dr. E. Hamilton, Miss Grethe Hansen, Dr. C. Jacobsen, Miss Me Mouritzen, Dr. H. Neumann, Oslo, Professor, dr. A. Noe-Nygaard, and Mr. E. Sørensen for help and discussions during the work.

April, 1960.

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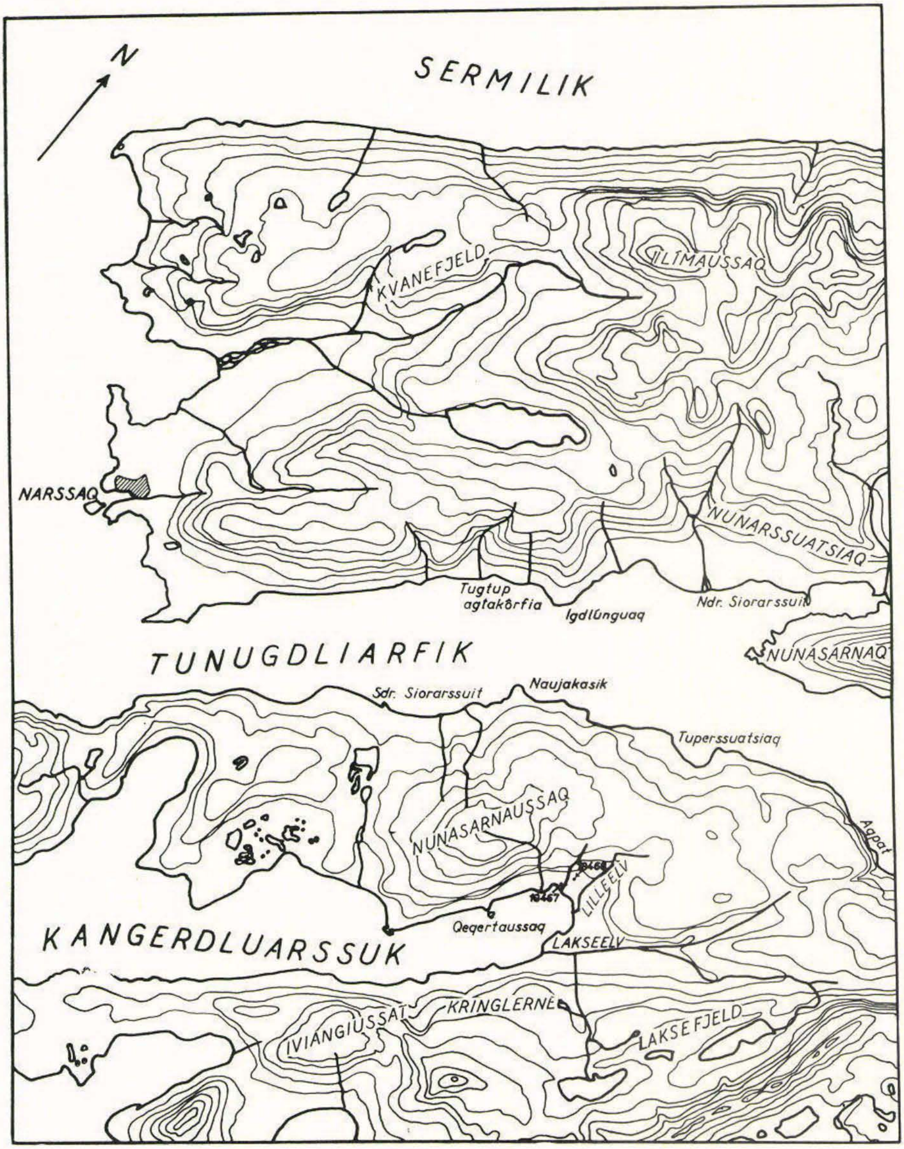

Fig. 1. Map showing the localities mentioned in the text. Scale 1:143.000, equidistances 100 m. The map is based on a preliminary map in 1:50.000 with the kind permission of the Geodetic Institute, Copenhagen (Copyright The Geodetic Institute, Copenhagen). Geological maps are published in *20* and *17*.

The Method.

The determination of the radioactivity of the minerals of Ilímaussaq was the primary subject of our study. We were less interested in the exact distribution of the radioactive elements in the various minerals of the rocks, in inter-crystal areas, etc. For this reason nuclear emulsions mounted on thin glass plates were found to be more convenient than liquid emulsions placed directly on the thin sections of rocks. The last-named method gives a perfect correlation of section and emulsion, the first-named method a less perfect correlation which was, however, found to be sufficiently exact for our purpose.

The nuclear plates used were of the same size as the slides of our thin sections (28 × 48 mm). The emulsion was Ilford's α-sensitive C. 2 as a 25 μ thick layer on top of the glass plate.

The Procedure: The thin sections (without cover glass) are kept in at least one month after cutting in order to re-establish the radioactive equilibrium in the section. The section is then carefully cleaned and two black crosses are marked on the glass of the thin section just outside the section of the rock. Black paper is pasted on the back of the slide with two small holes around the crosses.

In the dark room the nuclear plate is brought into close contact with the rock section and attached to the latter by means of adhesive tape. During the exposure the preparation is kept in a light-proof box, in most cases from 230 to 350 hours.

After exposure the preparation is placed (in the dark room) with the black paper downwards, in the small window of a light-box so that the position of the black crosses are marked on the nuclear plate.

The nuclear plate is developed $1^1/_2$–2 minutes at 20° C in a Kodak D–8, hydroquinone-NaOH-developer composed of: 180 g crystals of sodium sulfite, 45 g hydroquinone, 35 g caustic soda, and 30 g potassium bromide. Water is added so that the final volume is 1 liter. Before use the developer is diluted: 2 parts developer to 1 part of water (cf. *2*).

The development is stopped in a 2 $^0/_0$ solution of acetic acid. For fixation a solution of 30 $^0/_0$ sodiumthiosulfate is used in 30–45 minutes. The plate is rinsed in ca. 2 hours.

The preparative work, the exposure and the development took place at a temperature of 20° C.

After the development, the thin section, now with cover glass, and the nuclear plate are pasted together, back to back, using the black crosses as the first means of correlation, radioactive grains for the final correlation.

When the distribution of the radioactive elements in the rock is studied, the "double layer" has the emulsion side of the nuclear plate upwards. The cover glass side is turned upwards in order to study the minerals of the rock at high magnification. When the emulsion side is turned upwards, section and emulsion may be examined simultaneously by lowering and raising the objective of the microscope.

The number of alpha-tracks counted in a certain mineral is recalculated to give the number of alpha-tracks pr. cm^2 of the mineral pr. hour exposed: alpha/cm^2 hour.

The longest alpha-tracks are from ThC′ ($^{212}_{84}$Po). Their maximum-length is 47 μ in the emulsion. From other radioactive members of the uranium- and thorium-series there are emitted α-particles with energy corresponding to track–lengths of a few to 38 μ. Depending upon the position of the emitting atom in the thin section and the direction of the α–particle the part of the track which passes into the emulsion will vary considerably. Generally it may be stated that tracks shorter than 3 μ in the emulsion will not be observed. Whether the shortest tracks are counted or not depends on the quality of optics and emulsion and on the experience of the observer. The uncertainty of the counting is probably of the order of ± 5 $^0/_0$.

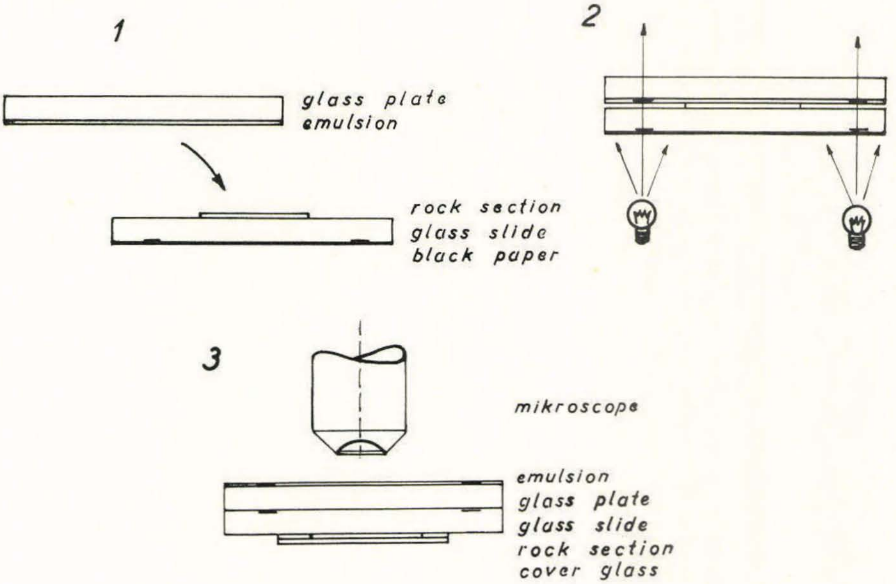

Fig. 2. The procedure of the examination. See the text for further explanation.

The average length of the tracks is about 25 μ. This means that the tracks from a radioactive grain of a diameter of 25 μ can easily be observed, counted and classified, while non-radioactive inclusions in radioactive minerals of this size will not be observed by means of the nuclear method. In other words it is only possible to give a more detailed description of the radiation from patches and zones of a heterogeneous mineral when the patches etc. are larger than 25 μ.

The background activity was about 1 alpha/cm^2. hour.

As to the sensitivity and uncertainty of the method reference is made to the standard texts, for instance, *2*, *4* and *7*.

On the Radioactivity of the Rocks of Ilímaussaq.

As described in the papers *20* and *17* the Ilímaussaq batholith is composed of an older unlayered complex of rocks and a younger layered complex.

The first named complex comprises augite syenite, essexite, nordmarkite and arfvedsonite granite. These rocks are according to the field examinations very weakly radioactive and they have not by us been examined by means of the autoradiographic method.

The younger layered complex comprises the agpaitic rocks: the transition series, sodalite foyaite, naujaite, kakortokite and lujavrite. The transition series and the sodalite foyaite are very weakly radioactive and have not been examined by us.

The naujaite and kakortokite are also very weakly radioactive. Their radioactivity is caused by the weakly radioactive eudialyte (see p. 9) and by small not-identified inclusions in the feldspars. These inclusions may be rather strongly radioactive, but they are scarce. The kakortokite may furthermore contain some rinkite (p. 12). The altered naujaite and kakortokite are more radioactive than the unaltered rocks, the radioactivity being attached to the alteration products of the eudialyte. Steenstrupine may occur in naujaites adjoining the veins mentioned below.

The youngest nepheline syenite of the complex, the lujavrite, is as mentioned in *1* the most radioactive rock in Ilímaussaq with in average 100–200 ppm U and three to four times that amount of Th. The radioactive minerals are: eudialyte (p. 11), steenstrupine (p. 14), monazite (p. 14), britholite (p. 13) and thorite? (p. 19).

The highest radioactivity in Ilímaussaq is found in late veins, of partly hydrothermal origin. Steenstrupine (p. 21), thorianite (p. 13) and britholite (p. 13) are the most radioactive minerals of these veins.

Eudialyte.

The eudialyte, which is a very common mineral in Ilímaussaq, was examined by means of nuclear plates in three of the eudialyte-bearing rock types, namely naujaite, kakortokite and lujavrite.

It was found that the eudialyte of naujaite, naujaite pegmatites and the three types of kakortokite from Kringlerne formed one weakly radioactive group with 10–35 α/cm^2. hour. No difference in the radioactivity of the eudialyte of the black, red and white kakortokite was noticed, but it should be emphasized that only one section of each type was examined by this method.

Table 1. Eudialyte.

Emulsion no.	Specimen no.	Rock type	Locality	α/cm² hour of eudialyte	
				fresh	altered
3	18462	naujaite pegmatite	Qeqertaussaq	60	..
4	18458	—	—	25	..
8	18506 b	ægirine vein	Igdlúnguaq	..	5500
13	18460	—	Qeqertaussaq	25–50	800–1000
22	18512 c	naujaite	Igdlúnguaq	25–140	150–1400
52	18508 a	—	—	20–35	1500
76	..	naujaite	Kangerdluarssuk	–25	..
78	..	red kakortokite	—	10–30	..
79	..	white kakortokite	—	20	1300
80	..	black kakortokite	—	15–18	2000–7000
30	18445 d	"kakortokite"	—	60–400	1800
31	18471 a	—	—	420–550	4000
16	18516 b	lujavrite	Igdlúnguaq	650	950
18	18496	—	—	550	..
19	18500 a	—	—	400–650	2100
20	18511 a	—	—	140	500–1000
21	18499 c	—	—	630	..
23	17023	—	Tuperssuatsiaq	..	40–4000
24	17007	—	—	..	280–1900
29	17027	—	—	..	500
41	G. 6	—	Sdr. Siorarssuit	..	250–400
42	G. 7	—	—	..	250
44	17064	—	Kvanefjeld	..	2000–8000
69	B. 100.4	—	—	..	–8000
87	425	—	—	650	1100–3000
88	540	—	—	..	2900–4100
95	1330. L. 15	—	—	..	500
63	17049	—	Igdlúnguaq	2100	..
			Tugtup agtakôrfia		
81	21098 a	—	—	1700–2000	..
82	21072	—	North coast	..	70–650
			Tunugdliarfik		
84	21114	—	—	..	500–2300
47	325	Green lujavrite	Kangerdluarssuk	260–640	..
77	..	—	—	100–300	1600
64	17059	lujavrite	Sdr. Siorarssuit	170–340	470–1300
			Tuperssuatsiaq		
65	Na. 3	—	Naujakasik	0–70	3800
67	D. 200. 5	—	Nunarssuatsiaq	..	5200
100	18467 c	vein	Kangerdluarssuk	270–330	..
102	21158	"kakortokite" vein	—	80–500	..
103	21159	—	—	350–590	..

The eudialyte of the rocks, which in *17*, p. 16 were interpreted as inclusions of deformed kakortokite in green lujavrite at the head of Kangerdluarssuk, was more radioactive than the eudialyte of the typical kakortokites and gave 60–550 α/cm^2. hour.

The eudialytes of the lujavrites were the most radioactive eudialytes examined in the Ilímaussaq region and gave 50–2100 α/cm^2. hour.

In *17* the naujaite and the kakortokites are believed to have been formed in the main phase of crystallization of the Ilímaussaq batholith, the naujaite being formed in the upper part of the batholith, the kakortokite in the lower part. The fact, that the radioactivity of the eudialyte is of the same size of order in all these rocks, is in agreement with this interpretation. According to the interpretation the above mentioned inclusions of deformed kakortokite enclosed in green lujavrite should be members of the transition series between naujaite and kakortokite. The eudialyte of these rocks is as radioactive as that of the enclosing lujavrite, a fact which is not in agreement with the interpretation. It is not yet possible to prove whether this deviation is caused by a partial recrystallization accompanying the deformation during which the enclosing lujavrite was formed, or whether the interpretation presented in the above-named paper is incorrect.

It is a conspicuous feature that the eudialyte of the naujaite pegmatites shows the same radioactivity as that of the naujaite. This proves that the pegmatites, as interpreted from the field relations, are conformable secretion pegmatites formed in fractures and cavities during the crystallization of the naujaite.

The lujavrites are, according to the field examinations, almost always the youngest nepheline syenites of the Ilímaussaq batholith and their eudialyte is, as should be expected, the most radioactive of the whole region.

The eudialyte of Ilímaussaq has, as the eudialytes of many other regions, irregular areas and zones of isotropic eudialyte (mesodialyte, *12*). In most cases examined the radioactivity of the anisotropic and isotropic parts of the grains was of the same size of order which speaks in favour of the idea, that the isotropicity is caused by the change from uniaxial positive (eudialyte) to uniaxial negative (eucolite) optical relations, a change which again is caused by variation in the chemical composition of the mineral (Na and Ca, rare earths and Nb). Only in one case (a green lujavrite from Kangerdluarssuk) a pronounced difference in radioactivity of anisotropic (ca. 100 α/cm^2. hour) and isotropic (300 α/cm^2. hour) eudialyte was noticed.

The eudialyte is as described in *6*, *8* and *19* very often altered. The alteration products are: katapleite, lovozerite, neptunite, monazite, britholite, colourless mica, schizolite, analcime, ægirine, iron oxides and unidentified dust and pigmentation. In many rocks, especially the lujavrites, fresh eudialyte is absent and the rocks are then rich in pseudomorphs of pigmentary material etc. which most probably replace the primary eudialyte. In other rocks, especially the naujaites (cf. *8*, p. *22*), there are patches in the fresh eudialyte of secondary products. The pseudomorphs and the secondary patches are generally more strongly radioactive than the unaltered mineral and often give 4000 or more α/cm^2. hour.

The alteration may also proceed along fractures in the eudialyte (fig. 1, plate 1). This is clearly illustrated in the eudialyte pegmatite of Qeqertaussaq (*20* and *8*). This pegmatite has a lower zone rich in eudialyte and in its central part an upper zone of felt-like ægirine. The pegmatite is conformable with the almost horizontal parting of the naujaite. The upper zone of ægirine is a zone of deformation and the underlying eudialyte is rich in fractures parallel to this upper zone. There may be felt-like ægirine in these fractures, especially in the matrix between the eudialyte crystals. The fractures within the eudialyte grains may contain tiny needles of ægirine in their outermost parts (in the thicker zones throughout the grains), but the thin fractures in the innermost parts of the eudialyte grains have little ægirine, much katapleite and brown and black pigmentary material. Steenstrupine and monazite may be associated with these fractures. The fresh eudialyte gives 25–50 α/cm^2. hour, in black zones (with katapleite) there are 800–1000, in the steenstrupine 4000–9000 and in the monazite 1100 α/cm^2. hour (plate 1, fig. 2). This observation proves clearly that the alteration products of the eudialyte may adsorb some of the migrating radioactive elements released during hydrothermal alteration processes.

"Lovozerite".

As mentioned in *8*, lovozerite-like small grains have been observed in a few places in Ilímaussaq. Five sections containing this mineral were examined by means of nuclear plates. The lovozerite occurs in one vein as independent small crystals and in some lujavrites as a secondary mineral in eudialyte. The lovozerite is almost always cloudy of brown and black dust. The unaltered mineral gave 300–850, the cloudy grains 750–2500 α/cm^2. hour.

Rinkite.

In the rinkite-eudialyte pegmatite of Qeqertaussaq (*20* and *8*) the rinkite occurs as prismatic crystals which are generally very fresh. They are in thin section clear, twinned and birefringent. Isotropic alteration products are rare in this locality. 350–1180 α/cm^2. hour has been counted in this rinkite.

As mentioned by Ussing (*20*) the kakortokites of Kringlerne contain small rinkite-looking grains which in thin section are seen to be dark brown and cloudy and they have isotropic areas. The optical properties of the anisotropic parts of the grains show good agreement with those of rinkite. The freshest parts of the grains give 1400, the dark and isotropic parts as much as 9200 α/cm^2. hour.

The isotropic rinkite of the kakortokites recalls the rinkolite, lovchorrite and vudyavrite of the Kola Peninsula. The vudyavrite contains 0.90 to 2.06 $^0/_0$,the rinkolite 0.45 $^0/_0$ and the lovchorrite 0.65 to 0.94 $^0/_0$ ThO_2 according to the tables in *10*. A trace of uranium has been found in lovchorrite.

Epistolite.

The epistolite of the albitic veins at Tugtup agtakôrfia is practically non-radioactive. Flakes of epistolite in some lujavrites from Kvanefjeld were found to be weakly radioactive with 135 α/cm^2. hour.

In a lujavrite from Nordre Siorarssuit an epistolite-like mineral (perhaps murmanite, cf. *8*) was found. It gave 4000 to 8000 α/cm^2. hour. (Plate 3, fig. 2).

Thorianite.

Small black or brown equidimensional inclusions have been observed in steenstrupine from Igdlúnguaq and other localities, they give as much as 120.000 α/cm^2. hour. A powder diffraction diagram of a metamict steenstrupine with such inclusions showed reflexes corresponding to those of thorianite. (Plate 2, figs. 1 and 2).

Apatite.

Apatite is very rare in the nepheline syenites of Ilímaussaq and is weakly radioactive. The apatite of a breccia zone in the border of the batholith at Agpat gave 40 α/cm^2. hour.

Britholite.

As mentioned in *8* britholite has been found in a number of lujavrites, especially in rocks rich in analcime. The radioactivity of the mineral varies from almost inactive to strongly radioactive with 5000 α/cm^2. hour. The britholite may in the late veins be associated with steenstrupine and thorianite.

Table 2. Monazite and Britholite.

Emulsion no.	Specimen no.	Rock type	Locality	α/cm^2 hour	
				monazite	britholite
2	Geox. 18	lujavrite	Kangerdluarssuk	0–80	..
9	18467 b	vein	—	..	250–500
11	18448 b	inclusion in kakortokite	Kangerdluarssuk	0–350	..
12	18465	vein	Qeqertaussaq	–1900	weakly RA.
13	18460	—	—	–1100	..
19	18500 a	recryst. naujaite	Igdlúnguaq	..	–5000
21	18499 a	—	—	..	–4000
22	18512 c	—	—	..	weakly RA.
42	G. 7	lujavrite	Sdr. Siorarssuit	–1000	..
47	325	green lujavrite	Kangerdluarssuk	..	300–1400
67	D. 200. 5	lujavrite	Nunarssuatsiaq	–140	..
71	B. 100. 6	—	Kvanefjeld	–14.000	..
87	425	—	—	100–3300	..
88	540	—	—	290–500	..
89	1310. K. 25	—	—	–8000	..
90	1314. I. 20	—	—	..	500
91	1315. I. 05	—	—	7700	..
92	1315. I. 05	—	—	3900–4200	..
93	1325. I. 25	—	—	3600	..
104	21228	—	—	30–400*)	..

*) This monazite has been analyzed for uranium and thorium by Mr. E. SØRENSEN who found 138 ppm U and 585 ppm Th.

Monazite.

The lujavrites may, as mentioned in *8*, contain clusters of small angular grains of monazite. They are often weakly radioactive (less than 100 α/cm^2. hour) for which reason the X-ray diffraction patterns have for monazite unusually sharp reflections (see *8*, p. 15). In some rocks these monazites give as much as 2500 α/cm^2. hour, the maximum value counted so far was 14.000 in monazite from Kvanefjeld.

Steenstrupine.

Steenstrupine has formerly been described from veins and pegmatites in the nepheline syenites of Ilímaussaq. The mineral was first found by K. J. V. STEENSTRUP in 1876 and was described and named by LORENZEN in 1881. It has later been examined by MOBERG, BØGGILD, and others (see *6*).

During the last few years steenstrupine has been found to be of much more wide spread occurrence in Ilímaussaq than formerly known and it has also been found as a constituent of lujavrite in many localities. The cause of these new discoveries is the radiometric survey of the greater part of the Ilímaussaq complex which has resulted in the localization of the occurrences of radioactive minerals.

The occurrence of steenstrupine is as mentioned in *1* associated with three main rock types:

1. lujavrites,
2. recrystallized inclusions of naujaite in lujavrite
3. veins in naujaite:
   a. veins of felt-like ægirine
   b. veins of albitite,
   c. veins rich in analcime.

In the present paper five types of steenstrupine will be distinguished:

1. steenstrupine in lujavrites,
2. steenstrupine in recrystallized inclusions of naujaite and veins of felt-like ægirine and analcime,
3. steenstrupine in albitic veins,
4. a reddish-brown, steenstrupine-like mineral,
5. less well-defined steenstrupine.

The first three types are closely related. The steenstrupine is in thin section clear, yellowish, isotropic and often with darker-coloured marginal zones which may be anisotropic. In type 4. the grains are in thin section reddish-brown with the strongest colour in the central parts of the grains.

1. Steenstrupine in Lujavrites.

During the last few years steenstrupine has been found in lujavrites from many localities in Ilímaussaq, although often in an altered state. Three of these occurrences were briefly mentioned in *1*, namely Tuperssuatsiaq, Søndre Siorarssuit and Kvanefjeld. Other localities studied by means of autoradiographic methods are: the area around Tugtup agtakôrfia and Igdlúnguaq, the mountains north of Nunarssuatsiaq and Nordre Siorarssuit, and a single sample from Naujakasik.

In general it may be said that the steenstrupine from lujavrites is clear, colourless to yellowish grey in thin section, when unaltered. There may be narrow dark marginal zones. The major part of the grains are metamict.

Examples of steenstrupine-bearing lujavrites from different localities will be briefly described in the following:

A. Tuperssuatsiaq: The lujavrites of this locality are generally very fresh and the main minerals are: arfvedsonite, nepheline, albite, microcline and sometimes large crystals of sodalite. Naujakasite is a common constituent and ussingite may partially replace the microcline in some rocks. Accessories are: sphalerite, schizolite, lithium-mica, and neptunite.

Unaltered eudialyte has not been found in the examined samples from this locality, but there are tiny remnants of eudialyte in small pseudomorphs which have the shape of eudialyte crystals. These pseudomorphs are of two types: 1) small grains (up to 0.3 mm in diameter) of lovozerite-like type and crowded with pigmentation (cf. *8*), 2) larger grains (up to 0.8 mm in diameter) composed of a scaly aggregate of an unidentified mineral with high birefringence and often of greenish tinge. The small grains give 400–2000 α/cm^2. hour, the larger grains 180–500 α/cm^2. hour.

Steenstrupine occurs in small, often flat, crystals of a diameter of 0.1–0.3 mm and in larger, more irregular grains, up to 0.6 mm across. They often have inclusions of arfvedsonite, lovozerite, and pigmentary material. They are interstitial between the laths of feldspar and are particularly associated with the intersertal network of arfvedsonite. Small crystals of steenstrupine are often enclosed in the flakes of naujakasite.

Table 3. Steenstrupine in Lujavrite.

Emulsion no.	Specimen no.	Locality	α/cm^2 hour of Steenstrupine	
			anisotropic	isotropic
24	17007	Tuperssuatsiaq	1400–2700	6000
25	17014	—	2100–4200	..
27	17011	—	3800	6700–7200
28	17030	—	2600	5600–6700
29	17027	—	..	2600–7800
69	B. 100. 4	Kvanefjeld	1300	4700
71	B. 100. 6	—	3600–3800	..
89	1310. K. 25	—	..	7500
91	1315. I. 05	—	..	6000–10.000
92	1315. I. 05	—	..	10.000
94	1329. I. 94	—	..	6000
95	1330. L. 15	—	..	9000–12.000
81	21098 a	Tugtup agtakôrfia	..	12.000
82	21072	North coast, Tunugdliarfik	..	4200
83	21102	—	3550–4000	7900–11.400
85	21087	—	..	5400–10.300
86	21113	—	..	6000

The central parts of the steenstrupine crystals are generally clear and colourless or yellow when studied under the microscope. The margins of the grains may be of darker colour, brown or black. The grains are almost always isotropic, but the marginal zones may be anisotropic. The central parts of the grains are generally most radioactive with 7000 or more α/cm^2. hour, while the marginal zones give about 2500 α/cm^2. hour. The α-track intensity over the steenstrupine has been seen varying from 1400–10.000 α/cm^2. hour (see further p. 27).

The altered grains of steenstrupine often show a zonal structure. They are of darker colour than the unaltered mineral and are often crowded with pigmentation. The outer zones are most strongly altered and may enclose entirely unaltered steenstrupine. The altered mineral may show a weak aggregate extinction. The altered steenstrupine is generally more radioactive than the unaltered mineral. In one rock with 2000–5000 α/cm^2. hour in the unaltered steenstrupine, the altered grains showed as much as 8000 α/cm^2. hour. The highest values observed in altered steenstrupine in this locality are 12.000 (and in small spots 20.000) α/cm^2. hour.

B. Søndre Siorarssuit: The lujavrites are strongly altered with very large amounts of analcime which forms the groundmass in most examined samples. Arfvedsonite is the predominant mafic mineral occuring in prisms and needles which may be arranged in stellate groups. There are laths of microcline, perhaps two generations, and in some rocks also of albite. Corroded remnants of nepheline and structural relics of sodalite may be found. Acmite is rare and is often surrounded by arfvedsonite. It is most common in the albite-bearing rocks. Eudialyte has not been found but lovozerite-like grains occur. They give 250–400 α/cm^2. hour.

Unaltered steenstrupine of the same appearance as in Tuperssuatsiaq has only been observed in a few cases, but rusty-coloured pseudomorphs after steenstrupine are quite common. They are composed of rusty pigmentation and of a brown micaceous mineral. The smallest pseudomorphs have the outlines of crystals of steenstrupine, the larger ones have irregular outlines. The pseudomorphs give 1000–10.000 (and in small spots 20.000) α/cm^2. hour (see further p. 27).

Accessories in the lujavrite are: schizolite, sphalerite, "britholite" (cf. *8*, p. 18), astrophyllite, "perovskite" (*8*, p. 25), neptunite, epistolite, and ore. Monazite has also been observed.

C. Kvanefjeld: The lujavrites are medium- to coarse-grained rocks very rich in arfvedsonite and most often with a groundmass of analcime. The arfvedsonite is often present in stellate groups of prisms, but it may also occur in large aggregates composed of numerous small grains. These aggregates have the appearance of pseudomorphs after some primary mineral, perhaps a pyroxene. There are probably at least two generations of arfvedsonite.

Microcline is always present, either in large plates or in small laths enclosed in the analcime. Small laths of albite may be present, and natrolite occurs in some rocks.

There are lujavrites with albite, microcline, nepheline and sodalite which resemble the lujavrite of Tuperssuatsiaq.

Small grains of unaltered eudialyte occur in some rocks, they may be associated with katapleite and monazite and give about 650 α/cm^2. hour. Pseudomorphs after eudialyte are much more common. They are composed of pigmentary material, katapleite, lovozerite and neptunite in a matrix of analcime. They give 500–1100 (and more rarely 8000) α/cm^2. hour.

Acmite is rare and is most often partially surrounded by the arfvedsonite. It is most common in the albite-bearing rocks which may have large grains of acmite with small inclusions of arfvedsonite. These large grains, or aggregates of grains, are in turn surrounded by arfvedsonite. It appears as if pseudomorphs of acmite after arfvedsonite (of the type found in the altered naujaites) are enclosed in the arfvedsonite lujavrite. One of the examined samples contained no arfvedsonite, only large grains of acmite which have green ægirine-like patches.

Accessories are: schizolite, neptunite, epistolite, ramsayite?, sphalerite, lithium-mica, "perovskite" and britholite.

Steenstrupine is present in some of the samples. The albite-bearing rocks have small crystals of the type found in Tuperssuatsiaq. They give 3600–4700 α/cm^2. hour. The analcime-rich rocks may contain larger, more irregular grains of steenstrupine, a few millimetres across. They are isotropic, colourless or brown, the colour is often irregularly distributed. The grains are often surrounded by radiating fractures in the analcime and microcline, and they give 6000–12.000 α/cm^2. hour. The steenstrupine has poikilitic inclusions of arfvedsonite, monazite and the yellowish-green mineral mentioned below.

The rocks with large crystals of steenstrupine have large plates of microcline in the groundmass of analcime and they are often rich in pseudomorphs after eudialyte. These rocks have small prisms of arfvedsonite. When the stellate groups of arfvedsonite are found in these rocks they may enclose steenstrupine.

Some rocks in Kvanefjeld contain, as mentioned in *1*, large "pseudomorphs" composed of spindle-shaped small grains of monazite and a strongly radioactive mineral which is isotropic, yellowish-green, and sometimes with black cores and spots. it has not yet been identified, but has some resemblance to thorite. Further constituents of the pseudomorphs are: neptunite, mica, schizolite, epistolite, katapleite, britholite, black ore and pigmentation. The monazite gives 100–3600, the yellow mineral more than 50.000 α/cm^2. hour.

The pseudomorphs are penetrated by an irregular network of a brown, isotropic substance. A similar network has been found in the altered grains of steenstrupine in the veins of analcime in naujaite, which will be described below. Steenstrupine is often associated with the pseudomorphs, which are of the same size as the large grains of steenstrupine mentioned above. The pseudomorphs may therefore be strongly altered grains of steenstrupine, and not as proposed in *1* altered eudialyte. This interpretation is in accordance with the fact that the metamict steenstrupine when heated to ca. 700° C recrystallizes into a mixture of a $(Th,Ce)O_2$-compound and monazite (cf. *16*). NEUMANN, SVERDRUP and SÆBØ (*15*, p. 16) write that steenstrupine in the same way as tritomite recrystallizes into a mixture of a thorianite-compound and apatite. Dr. H. NEUMANN, Oslo, has in a personal communication informed us that it has been mistakingly printed that steenstrupine behaves as tritomite when heated, and that he also found that monazite was formed during the heating of steenstrupine. As mentioned on p. 13 small grains of thorianite have been observed in some vein steenstrupines. It has not been possible to identify thorianite in the pseudomorphs discussed here, instead the thorite-like mineral occurs. This will be further discussed on p. 30.

D. Only a few samples of steenstrupine-bearing lujavrites from Naujakasik, and the mountains north of Nunarssuatsiaq and Nordre Siorarssuit have been examined by means of the autoradiographic method. Steenstrupine is present in small grains of the type found in Tuperssuatsiaq, but most often altered. The most fresh steenstrupine, which is clear, yellowish-grey and isotropic, gives 800–3200, the altered mineral as much as 8000 α/cm^2. hour (see further p. 28). The rocks have groundmasses rich in analcime and/or natrolite. Arfvedsonite is the predominant mafic mineral. Acmite is very scarce, and there may be a few needles of ægirine. Microcline is the predominant light-coloured mineral (apart from the groundmass minerals analcime and natrolite), but albite, nepheline, and sodalite may be present in subordinate amounts. Eudialyte, pseudomorphs after eudialyte, and the unknown green aggregate mineral mentioned on p. 16 also occur. The rocks north of Nordre Siorarssuit contain the murmanite-like mineral mentioned on p. 13.

E. As mentioned in *8*, p. 30 steenstrupine has been observed as an alteration product in eudialyte in the green lujavrite north of Lakseelv. It is associated with lovozerite. The eudialyte in these rocks gives 260–640, the lovozerite 300–700, the steenstrupine 950–1540 α/cm^2. hour.

F. On the north coast of Tunugdliarfik steenstrupine has been found in three horizons in the lujavrites occurring on the steep cliff facing the fjord.

The lowermost horizon is found on the shore of the easternmost point of Tugtup agtakôrfia. The lujavrite is very rich in nepheline and eudialyte; it is from this locality in the Ilímaussaq complex that the latter mineral shows its maximum radioactivity. It gives 1700–2100 α/cm^2. hour. Arfvedsonite is the predominant mafic mineral, but some patches of the rock contain grains of ægirine with inclusions of arfvedsonite. There are, however, also small grains of arfvedsonite growing on the ægirine. Microcline, analcime, natrolite and sphalerite are further constituents.

The lujavrite in this locality has very scattered crystals of steenstrupine. But in white veins in the lujavrite there are poikilitic grains of steenstrupine, a centimetre or more in diameter. They enclose nepheline, a few altered grains of eudialyte, microcline, albite, arfvedsonite and acmite. The grains of steenstrupine are clear, yellowish-grey to brown with the strongest colours along the margins and in the border zones on inclusions. The mineral is isotropic. It gives about 12.000 α/cm^2. hour. The white parts of the veins are composed of corroded crystals of nepheline in a matrix of analcime. Eudialyte, arfvedsonite and feldspars are very rare.

In altitudes from 110 til 150 metres steenstrupine-bearing lujavrites occur in the mountain wall behind and to the west of Tugtup agtakôrfia. The lujavrites are green, brown and black and they contain very scattered grains of steenstrupine. In thin horizons, see for instance *1*, fig. 4, there are very high concentrations of steenstrupine.

Ægirine is the predominant mafic mineral in these rocks and arfvedsonite may be entirely lacking. The ægirine occurs in prismatic crystals, a few millimetres long, the mineral may be intergrown with acmite. Arfvedsonite is present in smaller needles which often grow along the prisms of ægirine and enclose the latter, so that it appears that the arfvedsonite is the youngest of the two minerals. Further constituents are microcline, analcime and natrolite. Nepheline and eudialyte are rare. The place of the latter is taken by pseudomorphs giving 500–2100 α/cm^2.

hour. Schizolite is always present, accessories are: lithium-mica, neptunite, sphalerite, iron ore and astrophyllite.

Steenstrupine is present as large poikilitic grains with inclusions of ægirine, arfvedsonite, microcline, and altered eudialyte. The grains are isotropic, clear to yellowish-grey in the central parts and brown along the margins. The range in α-track intensity is from 4200–10.000 α/cm^2. hour. In one rock the central parts of the grains gave 10.000, the brown marginal parts 5000 α/cm^2. hour. The larger grains are irregular, the smaller ones may have developed crystallographical outlines. The steenstrupine is by all stages of transition connected with poikilitic areas of pigmentation which give about 3000 α/cm^2. hour.

In an altitude of about 200 metres there is behind Tugtup agtakôrfia a horizon in the dark lujavrite which has scattered grains of steenstrupine. The rock is composed of ægirine, arfvedsonite (often along the borders of the ægirine), microcline, corroded crystals of nepheline, pseudomorphs after eudialyte, analcime, natrolite, sphalerite and iron ore. The steenstrupine is present in small crystals and in larger irregular poikilitic grains which have numerous inclusions of ægirine, arfvedsonite, microcline, nepheline, and altered eudialyte. The arfvedsonite is especially found in the marginal parts of the grains. The steenstrupine is clear, light-coloured and isotropic in the central parts of the grains, brown and sometimes anisotropic in the marginal parts. It gives 8000–11.000 α/cm^2. hour; the red-brown margins may give as little as 4000 α/cm^2. hour.

2. Steenstrupine in Recrystallized Inclusions of Naujaite, in Veins of Felt-like Ægirine and in Analcime-rich Veins.

The steenstrupines of these occurrences are according to the results gathered so far of the same type. The occurrences will be described in a paper under preparation and only a few remarks will be given here.

The steenstrupine often forms flat, trigonal crystals which may be a few centimetres across. The crystals are in thin section colourless to brown in their central parts and often strongly coloured along the margins. The coloured rims may send "apophyses" into the interior of the crystals (cf. BØGGILD, 5, p. 208). The central parts of the crystals are almost isotropic, the marginal parts may be anisotropic, but many crystals are isotropic throughout. In some crystals there is a strongly developed zoning with thin marginal zones parallel to the outlines of the crystals. The normal case is then that there are one or two thin outer zones which may be distinguished from the main part of the crystal by being anisotropic. In some cases they may be of a stronger colour than the central isotropic steenstrupine, but in many crystals there is no difference in colour between the different zones. The outermost zone is sometimes rich in short fractures perpendicular to the crystal faces. The fractures may continue in radiating fractures around the crystals. The zones are generally less than 0.05 mm thick.

In some crystals there is an increase in anisotropicity from centre outwards, in others recurrence takes place with a very thin isotropic zone between the outermost strongly anisotropic zone and an inner less anisotropic zone. There may be a gradual transition from the isotropic to the anisotropic parts of the crystals, but there may also be rather sharp borders. This is in accordance with the observations of BØGGILD (op. cit. p. 208). In most cases it is not possible to demonstrate any difference in refractive indices of the different zones, but in a few cases there is a slight difference. It has been planned to treat this problem later in another connection.

In addition to the zoned distribution of isotropic and anisotropic steenstrupine a few other types of distribution should be mentioned. Some crystals of steenstrupine may have small spots with irregular and weak extinction. Such an extinction is always observed in small patches rich in pseudoparallel fractures. These patches may have a darker colour than the main parts of the crystals and they may be connected with the anisotropic marginal zones. They often occur in the border zone between two adjacent crystals of steenstrupine and the fractures are then perpendicular to the border. These patches have gradual transition to the isotropic steenstrupine.

In some crystals there is a weak extinction along irregular cracks.

3500–7800 α/cm^2. hour have been counted in the predominantly anisotropic parts of the crystals, the number of tracks in the isotropic steenstrupine has been found to vary from 5000 to 13.600 α/cm^2. hour. There is most often a fairly even distribution of the radioactivity of the grains.

In a few rocks the zoned crystals have an outer zone of a strongly red, anisotropic mineral with higher refractive indices than the steenstrupine. There may also be independent small crystals of the red mineral which will be further dicussed on p. 25.

The steenstrupine of these occurrences is associated with analcime, ægirine, natrolite (partly in large crystals), yellow sodalite, schizolite, neptunite, and pseudomorphs after eudialyte. The latter are composed of: katapleite, ægirine, mica, neptunite, britholite, pigmentation, etc. They may be associated with steenstrupine which apparently "grow around" the pseudomorphs. This steenstrupine may then in the interior, isotropic parts of the crystals have small patches, up to 0.6 mm across, of darker colour and showing a weak aggregate extinction. This aggregate structure corresponds to the structure of the pseudomorphs.

The steenstrupine may have small inclusions of brownish-black small crystals of thorianite (plate 2, fig. 1). They may be associated with britholite and astrophyllite.

The steenstrupine is often altered into a brown micaceous mineral, black and brown dust, and into a network of a brown to black isotropic substance. The matrix of these pseudomorphs is composed of analcime. If altered and unaltered steenstrupine are present in the same rock, the altered one is generally the most radioactive. As much as 35.000 α/cm^2. hour have been counted in altered steenstrupine. The radioactive elements are no doubt partly adsorbed on the pigmentary material of the pseudomorphs.

The steenstrupine of this type has been especially studied in Igdlúnguaq, but is has been found in many localities in Ilímaussaq.

The naujaite adjacent to the veins and the lujavrite adjacent to the recrystallized inclusions of naujaite may have large poikilitic grains of steenstrupine of the type mentioned above.

Table 4. Steenstrupine in Veins, etc.

Emulsion no.	specimen no.	Rock type	Locality	α/cm^2 hour of steenstrupine	
				anisotropic	isotropic
6	18468 c	vein	Kangerdluarssuk	3000–3250	6000–8000
7	18468 d	vein	—	. .	6000–7000
8	18506 b	ægirine vein	Igdlúnguaq	3500–7600	8400–9700
13	18460	vein	Qeqertaussaq	4000	9000
15	18491g	albite vein	Tugtup agtakôrfia	1000–2400	4400–5400
50	. .	—	—	1300–1900	11.400
16	18516 b	lujavrite adjacent to vein	Igdlúnguaq	3850	8000–8300
17	18518	analcime vein	—	> 3900	10.000
49	. .	—	—	5300–6800	11.400–13.600
19	18500 a	recryst. naujaite	—	5400–6200	7000–10.000
20	18511 a	lujavrite adjacent to vein	—	5600–7800	7800–8000
21	18499 c	recryst. naujaite	—	. .	8400–9600
18	18496	—	—	6000	5000–8000
51	9051	vein	Naujakasik	. .	9000
52	18508	recryst. naujaite	Igdlúnguaq	. .	4800–7000
103	21159	vein	Kangerdluarssuk	. .	4000–5900

3. Steenstrupine in Albititic Veins in Naujaite.

The types of steenstrupine mentioned in the preceding chapters are mainly metamict; while the steenstrupine in the veins of albitite at Tugtup agtakôrfia is generally non metamict and it gives X-ray diffraction patterns.

The smallest grains of steenstrupine in the mentioned locality are generally well-developed crystals with the colour varying from faintly yellow to strongly brown. The crystals are generally anisotropic throughout. The larger grains are of a more irregular shape. They are clear, colourless and isotropic in their central parts, brown and anisotropic in the marginal parts. The transition from the isotropic to the anisotropic parts is gradual.

There often is a concentration of pseudoparallel fractures in the outer anisotropic parts of the grains. These fractures are in some crystals parallel to the basal faces of the crystals, indicating a weak cleavage parallel to that direction. These fractures are restricted to the anisotropic steenstrupine, the interior parts of the grains have few and more irregular fractures (plate 3, fig. 1).

It is seen that the brown colour of the steenstrupine is especially connected with fractures in the crystals. The marginal parts of the crystals are often colourless between the fractures and the brown colour may penetrate into the interior parts of the crystals along irregular fractures.

The isotropic steenstrupine gives 4400–11.400, the anisotropic steenstrupine 1000–2400 α/cm^2. hour. The distribution of α-tracks over the crystals is fairly even, except for the difference between isotropic and anisotropic areas.

In a few small anisotropic grains there is a very narrow dark zone just inside the margins of the crystals.

The steenstrupine in these occurrences is associated with albite (in part cleavelandite), microcline, yellow sodalite, analcime, acmitized arfvedsonite, schizolite, lithium-mica, sphalerite and epistolite. The steenstrupine has inclusions of arfvedsonite and acmite.

In a vein in the naujaite at the head of Kangerdluarssuk (no. 18468) the groundmass is composed of microcline, ussingite, small laths of albite, and prisms of ægirine. The vein contains crystals of steenstrupine which may form small aggregates. The crystals may reach a size of 0.5 cm. They are metamict but with thin anisotropic rims. A few of the smaller crystals are anisotropic throughout. The rims may be developed as regular zones parallel to the margins of the grains, and there may be a few zones of varying anisotropicity, sometimes with thin isotropic zones between the anisotropic ones. There may be gradual transition between the zones or sharp borders. The zones are generally less than 0.1 mm thick.

The crystals are clear and yellowish brown with darker colours along the margins and around inclusions of lovozerite and ægirine. The lovozerite is often in a stage of dissolution in the steenstrupine.

The anisotropic border zones may have higher refractive indices than the metamict steenstrupine.

In some crystals there are short and closely spaced fractures in the anisotropic border zones, these fractures may be arranged perpendicular to the crystal faces. In other crystals there are pseudoparallel, less closely spaced fractures which penetrate the metamict steenstrupine.

The isotropic steenstrupine gives 6000–8000, and the anisotropic zones 3000–3500 α/cm^2. hour.

4. Red, Steenstrupine-like Mineral.

This mineral has first of all been found in a small vein (no. 18467) north of Lilleelv at the head of Kangerdluarssuk. The occurrence will be described in the paper referred to above and only information of importance for the present study will be given here.

The vein is a "composite" one with kakortokitic, lujavritic, and analcititic components. The red mineral has especially been found in the lujavritic parts of the vein and in streaks of arfvedsonite and ægirine/acmite in an analcititic matrix. These rocks are composed of arfvedsonite, ægirine/acmite, analcime, microcline, remnants of nepheline, pseudomorphs after eudialyte (and in a few thin sections also fresh eudialyte), schizolite, britholite and neptunite. Arfvedsonite is at least partly formed later than the ægirine/acmite.

The red mineral is reddish brown in the handspecimen, in thin section it is brown, in thick sections deep red. It is most often present in aggregates of crystals, the thin section study indicates that the mineral is trigonal as steenstrupine and it is also uniaxial negative as the anisotropic steenstrupine. The crystals are 0.2–1.5 mm large.

In thin section it is seen that the mineral most often occurs in a mosaic-like aggregate of crystals of hexagonal shape (plate 4, fig. 1). Isolated crystals of the same shape are found in thin streaks of arfvedsonite and ægirine/acmite. The crystals are generally most dark-coloured in their central parts and almost colourless along the margins. In some cases there is again a dark-coloured zone outside the coulourless zone. This is especially the case in the aggregates of crystals in which the mutual border zones of the crystals are of darker colour than the central parts of the crystals. This outer, dark-coloured zone may be cut by closely spaced short fractures arranged perpendicular to the border zone.

Table 5. The Red Type of Steenstrupine.

Emulsion no.	Specimen no.	Rock type	Locality	α/cm^2 hour of steenstrupine	
				anisotropic	isotropic
9	18467 b	vein	Kangerdluarssuk	4300–4700	7600
14	18480	ægirine vein	Naujakasik	3800	5000
20	18511 a	lujavrite adjacent to vein	Igdlúnguaq	1200	..
97	18467 a	vein	Kangerdluarssuk	3000	4300–4750
98	18467 b	—	—	2780	5000
99	18467 b,1	—	—	3100–5300	6200–8300
100	18467 c	—	—	..	4800–5600
101	18467 d	—	—	3000	3900–5900

When seen under crossed nicols some crystals are anisotropic throughout, but generally the central parts of the crystals are isotropic and the marginal parts anisotropic. The crystals are then zoned with thin zones parallel to the outlines of the crystals. The transition between zones may be gradual or sharp. 0.02 to 0.08 mm from the margins of the crystals there often is a ca. 0.01 mm thick isotropic zone between the anisotropic zones. The zone is parallel to the crystal faces, but is mostly situated in different distances from the various faces of a crystal. The closely spaced fractures of the border zone of the crystals are in many cases confined to the anisotropic, dark-coloured zone outside the isotropic zone. In case there are steps or other irregularities on the crystal faces, this irregularity is reflected in the zoning which is still parallel to the faces of the crystals (fig. 3 and plate 4, fig. 2).

The crystals of the red mineral have inclusions of arfvedsonite, ægirine/acmite and analcime.

In a few rocks may be seen that the red mineral is associated with eudialyte.

The mineral is weakly radioactive with 3900–8300 α/cm^2. hour in the central parts of the grains and 2800–4000 α/cm^2. hour in the marginal zones.

This mineral will be treated from a mineralogical point of view in a later publication.

The mineral has been found in a few other places. A boulder found at Naujakasik is composed of ægirine, microcline, sodalite, arfvedsonite, analcime and schizolite. It contains large rusty pseudomorphs with patches of steenstrupine in the light-coloured parts of the boulder, small crystals of the red mineral in the green rock of felt-like ægirine. The red mineral is identical with the mineral mentioned above. It gives 3800–5000 α/cm^2. hour.

At Igdlúnguaq the mineral has been found in two samples of coarse-grained arfvedsonite-analcime rocks associated with recrystallized naujaite. The mineral may be present as thin zones, less than 0,04 mm thick, around small crystals of normal steenstrupine, but it is also present as individual small crystals. The mineral gives 1260, the steenstrupine 5600–7800 α/cm^2. hour.

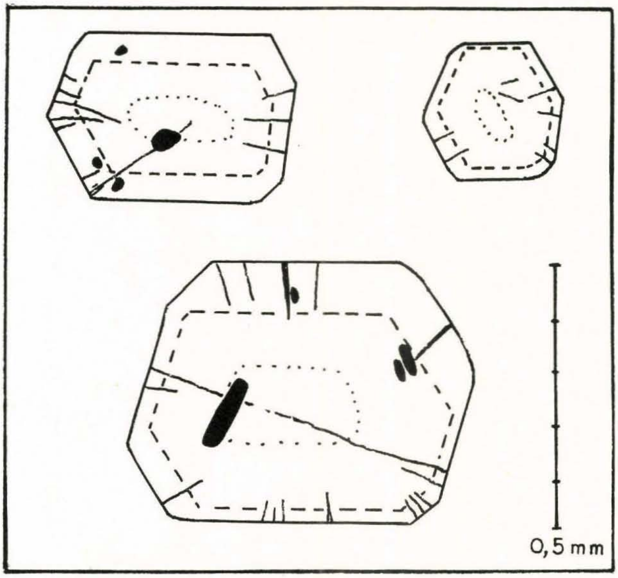

Fig. 3. Sketches of zoned crystals of the red steenstrupine–like mineral. Broken line: thin isotropic zone, dotted line: border between isotropic core and anisotropic margin. The fractures are indicated, but not the colouration. (No. 18467 b, 1, Kangerdluarssuk).

In the lujavrites from Tuperssuatsiaq mentioned on p. 16 two types of steenstrupine may be distinguished. Some of the grains are colourless in their central parts and darker coloured along the margins. The other type has the opposite colour distribution, its colour is yellowish-brown and there is weak birefringence with aggregate extinction. This type gives 800–3000, the first type of grains 3800–7200 α/cm^2. hour. The weakly radioactive type is mainly found in rocks rich in acmite and it may be the red mineral mentioned in this chapter.

At Søndre Siorarssuit the lujavrite contains more or less altered grains of the appearance of the red mineral. They are faintly radioactive with 1800–4100 α/cm^2. hour. In most cases they are so altered that it is impossible to distinguish between altered grains of the red mineral and altered steenstrupine.

Small grains of the red mineral have also been found in a sample of lujavrite from the mountain north of Nunarssuatsiaq. They give 4000 α/cm^2. hour.

5. Steenstrupine of Uncertain Type.

Some of the grains of steenstrupine found cannot be placed in any of the groups discussed above.

In an eudialyte-rich "kakortokitic" part of the vein (no. 18467) discussed on p. 25 there are irregular grains of a steenstrupine-looking mineral. It is brown with colour spotting of irregular distribution and in addition it has irregular extinction. Some grains have red, anisotropic patches and these grains may then represent an alteration stage of the above-mentioned red mineral.

The mineral is often associated with eudialyte, either as an alteration product in that mineral or also growing along the margins of the eudialyte crystals. This growth is very irregular and the mineral does not enclose the eudialyte.

The eudialyte gives 350–590, the steenstrupine-mineral 4000–5900 α/cm^2. hour.

The associated minerals are: microcline, arfvedsonite, ægirine, nepheline, analcime, natrolite, neptunite and monazite.

A similar mineral has been found in the altered part of the eudialyte pegmatite of Qeqertaussaq (cf. *20* and *8*). The mineral is in crystals and in irregular grains with irregularly distributed brown and black colour. The extinction is weak and irregular. The marginal parts of the grains are sometimes of the darkest colour. The mineral is associated with strongly altered eudialyte and with monazite. The α-track intensity of the mineral varies from 2600–35.000 α/cm^2. hour. The highest intensity was found in the darkest parts of the grains.

The mineral is accompanied by analcime, ægirine, microcline, albite, natrolite, lithium-mica, sphalerite, neptunite, schizolite and britholite.

A similar mineral has also been observed in the fractures in eudialyte in the same pegmatite (see p. 12). It gives 4000-9000 α/cm^2. hour.

The mineral may be an alteration product (or perhaps an early stage ?) of the steenstrupine of the other types mentioned.

6. Comparison of the Observed and Calculated Number of $\tilde{\alpha}$-Tracks in Steenstrupine.

There are a few rather old chemical analyses of steenstrupine (*5* and *6*) and the contents of uranium and thorium of some steenstrupines have recently been determined by Miss Me Mouritzen and by Mr. E. Sørensen. It was therefore considered to be of some interest to calculate the

α-track intensity from analyzed steenstrupines and to compare the results with the actual countings. The procedure described by Coppens (*7*) was used:

$$N = (8{,}58 \cdot C_U + 1{,}92 \cdot C_{Th}) \cdot K' \cdot 3600 \ \alpha/\text{cm}^2. \text{ hour},$$

where N is the number of α-tracks and K' is a constant, the absorption coefficient, which is determined by the chemical composition of the mineral:

$$K' = \frac{0{,}85}{\sum \frac{c_i \cdot s_i}{A_i}}$$

where c_i is the concentration of the element with the atomic number A_i and s_i is the absorption for α-particles of the element.

The constant K' was calculated for two of the steenstrupines analyzed (*5*, p. 229, nos. 4 and 5) and was found to be 16,5 and 16,9 respectively. An average of 16,7 was used in the further calculations. The results are brought in table 6.

Table 6

Locality	Chemical analysis		$\frac{C_{Th}}{C_U}$	N	
	C_U %	C_{Th} %		calculated	counted
Tugtup agtakôrfia	0,21	1,66	7,9	3000	2400–11.400
Tuperssuatsiaq	0,78	5,62	7,2	10.500	9200
Igdlúnguaq	0,40	3,99	10,0	6700	5000–8000
Naujakasik	0,30	2,65	8,8	4600	3800–5000

The coincidence between the two sets of results is fairly satisfactory, especially taking into consideration that different crystals were examined by the two methods.

The Th/U-ratio of the steenstrupine varies from 7,2 to 10,0. The ratio in the lujavrites mentioned in *1* varies from 1,5 to 3,0. If the steenstrupine of these rocks has the same Th/U-ratio as the vein steenstrupines in table 6 a considerable amount of uranium is contained in other minerals than steenstrupine in the lujavrites. Some of this uranium is without doubt adsorbed on pigmentary material.

7. Discussion.

The mineralogy of steenstrupine and the petrology of the steenstrupine-bearing rocks will be discussed in future papers, but a few concluding remarks may be based on the material presented in this paper.

First of all it appears that steenstrupine is especially found in rocks in which the eudialyte is either strongly altered or also totally lacking. Steenstrupine has been found together with fresh eudialyte in a few rocks, but it is then either present in the altered parts of the crystals of eudialyte or also associated with the most altered grains of eudialyte. Inclusions of altered grains of eudialyte are, however, common in steenstrupine from many occurrences.

The eudialyte is a primary mineral in the nepheline syenites of Ilímaussaq. As discussed in *20* and *17* and also on p. 11 of the present paper the lujavrites are the latest nepheline syenites of the complex. They have recrystallized inclusions of naujaite and undoubtedly assimilate or replace the naujaite.

Steenstrupine is found in Ilímaussaq in recrystallized inclusions of naujaite with strongly altered eudialyte and in veins in naujaite, also with altered eudialyte. It is further found in lujavrites with altered eudialyte. This means that eudialyte was a stable mineral of the nepheline syenites until the first stages of formation of lujavrite. In later stages steenstrupine was formed, in part under hydrothermal conditions. These rather complicated processes will be discussed in one of the papers referred to above.

Two types of steenstrupine have been observed in lujavrite, namely small crystals (which as pointed out on p. 27 may be divided into a clear and red type) and large grains which are especially found in the black lujavrites of Kvanefjeld and in some green lujavrites on the north coast of Tunugdliarfik. The small crystals of steenstrupine are often poikilitic and are most probably formed during the "lujavritization".

The large grains from Kvanefjeld may have another origin. They have inclusions of a thorite-looking mineral and of monazite. The steenstrupine of the recrystallized naujaite and the veins in naujaite may have inclusions of thorianite and britholite. If inclusions of naujaite containing these grains of steenstrupine are "assimilated" in the lujavrite, the original inclusions of thorianite and britholite may react and also react with the steenstrupine under the formation of thorite and monazite. This means in reality that the silica of the britholite to a large extent has been expelled and that the thorianite has absorbed some silica:

$$\underset{\text{britholite}}{(Ca,Ce,Na)_5[(Si,P)O_4]_3(OH,F)} + \underset{\text{thorianite}}{(Th,Ce)O_2} \rightarrow \underset{\text{monazite}}{Ce[(P,Si)O_4]} + \underset{\text{thorite}}{(Th,Ce)SiO_4} + Ca^{2+} + Na^{+} + H_2O$$

The acmite found in patches in many lujavrites may in accordance with this interpretation be regarded as another naujaitic "relic" since the arfvedsonite of the naujaite in the first stages of transformation is replaced by acmite.

It is a remarkable fact that the most fresh steenstrupine in lujavrites and veins is found in rocks carrying albite (and ussingite). The steenstrupine of the analcime-bearing rocks is often more altered and also occurs in corroded crystals in many cases.

The crystallization of albite instead of analcime may indicate a higher temperature of formation, but the two minerals may also have been formed at similar temperatures since a high water pressure may have stabilized analcime at temperatures where it under normal pressure conditions should have dissociated. The fact that the analcime often appears to have crystallized later than the albite may then indicate either a lowering of temperature or an increase in water pressure. The alteration of the steenstrupine may then be associated with a decrease in temperature or an increase in water pressure.

Non-metamict steenstrupine is especially found in the albite-bearing veins, but it is always associated with metamict steenstrupine. Non-metamict steenstrupine in analcime-bearing veins is restricted to very thin marginal zones around crystals of metamict steenstrupine. The steenstrupine of lujavrites are generally in metamict, unzoned grains which only show zoning in the first stages of alteration.

The autoradiographic examination showed that the metamict steenstrupine is more radioactive than the non-metamict steenstrupine. The steenstrupine may on the basis of the degree of metamictization and the α-track intensity be divided into three groups:

1. metamict steenstrupine with 5000–14.000 α/cm^2. hour,
2. steenstrupine with weak and irregular extinction with 4000–7800 α/cm^2. hour,
3. anisotropic steenstrupine with less than 4000 α/cm^2. hour. This intensity corresponds according to the calculation on p. 29 to 2,2 $^0/_0$ Th and 0,3 $^0/_0$ U. Only grains of this group gave X-ray diffraction patterns.

This data shows clearly that there is a distinct relationship between radioactivity and degree of metamictization, that is: the crystal lattice of steenstrupine may contain a small amount of radioactive elements without being destroyed, this in spite of the fairly complex crystal structure with possibilities of substitution in many lattice positions.

This relationship is in accordance with the results obtained on zircons (*13,14*), Thus it is stated in *13*, p. 718: "For a given set of specimens (of zircon) of a given age, the lattice disruption increases directly as the alpha activity providing the age is not too great".

The writers have examined allanites from Greenland in the same way, but in this case no such relationship has been observed. The most radioactive allanite was anisotropic and gave weak X-ray reflections, while slightly radioactive allanites were entirely metamict. It should, however, be emphasized that the ages of the samples have not been determined.

As to the monazites of Ilímaussaq the weakly radioactive ones give very sharp X-ray reflections, but the most strongly radioactive ones with 14,000 α/cm^2. hour are also non-metamict.

The zoning observed in some of the steenstrupines with central metamict and marginal anisotropic zones may be explained in two ways:

1. The difference in radioactivity of the zones is primary and reflects a varying content of radioactive elements in the magmatic or hydrothermal "solutions",
2. The zoning is secondary and caused by leaching of the radioactive elements.

In support of the first-named interpretation may be stated that the most anisotropic steenstrupine occurs in albite-bearing rocks. It might then be assumed that in the albite stage (with higher temperature or lower water pressure than in the analcime stage) a smaller amount of radioactive elements was present in the late-magmatic solutions than in the later analcime stage. This interpretation is in accordance with the general rule that the amount of "rest-elements" in the late-magmatic solutions increases as the crystallization progresses. But this interpretation is not in accordance with the zoning of the crystals which shows a decrease in radioactivity as crystallization progresses, not an increase at it should be expected. If the zoning is taken as growth stages it must be admitted that there was a decrease in the content of radioactive elements in the late-magmatic solutions during the crystallization of steenstrupine.

According to the second way of explanation radioactive elements have been leached from the marginal parts of the larger grains and also from the interior parts of the smaller grains. This explanation is favoured by the fact that the parts of the crystals with the most closely spaced fractures are generally anisotropic, that is: fractures have facilitated the leaching.

The marginal fractures were most probably formed as a results of expansion during the metamictization of the interior parts of the crystals. In some cases the fractures form short radially arranged fissures in the outer, anisotropic parts of the crystals. These fissures may continue in radiating fissures around the crystals. In other cases a faint basal cleavage is developed in the anisotropic parts of the crystals.

The anisotropic parts of the crystals are generally of darker colour than the metamict parts. The colouration may be taken as evidence of oxidation which favours the leaching of uranium as UO_2^{++}. This is in accordance with the observations of ELLSWORTH (*9*, p. 242) who states that in an altered uraninite from Villeneuve mine in Quebec the proportion of UO_3 and Th increases with increasing alteration while total U and UO_2 and rare earth metals decrease. That is: uranium is leached faster than thorium. The repeated zoning observed in some crystals of steenstrupine and the occasional thin isotropic zone present in the marginal anisotropic part of the crystals may then be explained by different leaching velocities of uranium and thorium. A partial removal of uranium from the marginal zones of the crystals may explain the observed decrease in radioactivity towards the margins, since uranium has larger alpha activity than thorium. One gram of uranium emits according to HEINRICH (*11*, p. 11) $6 \cdot 10^6$ α/minute, one gram of thorium $1.5 \cdot 10^6$ α/minute.

The fact that the leached outer zones are anisotropic may be explained in at least two ways.

1. The fractures in the outer parts of the crystals formed during the metamictization have facilitated the leaching from the outer parts of the grains and the leaching has here been so fast that these parts of the crystals have preserved their crystal structure;
2. The leaching took place during hydrothermal alteration of the crystals and was accompanied by heating which allowed the outer parts of the crystals to re-crystallize.

In conclusion may be stated that a part of the observed zoning may be primary but that leaching may also have played a role, especially in the most fractured parts of the crystals.

Finally should be stated that the red mineral mentioned on p. 25 in many respects resembles steenstrupine. It shows the same type of zoning and the anisotropic zones of the crystals are least radioactive.

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Færdig fra trykkeriet den 13. marts 1961.

Plate 1.

Fig. 1. No. 13: 18460, 45 ×, 1 nic. Black fractures in the eudialyte of the pegmatite at Qeqertaussaq.

Fig. 2. Nuclear film of the same, 281 hours exposure. The shadows of the black zones are seen and the highest concentration of α–tracks are found over these zones. The film is somewhat scratched.

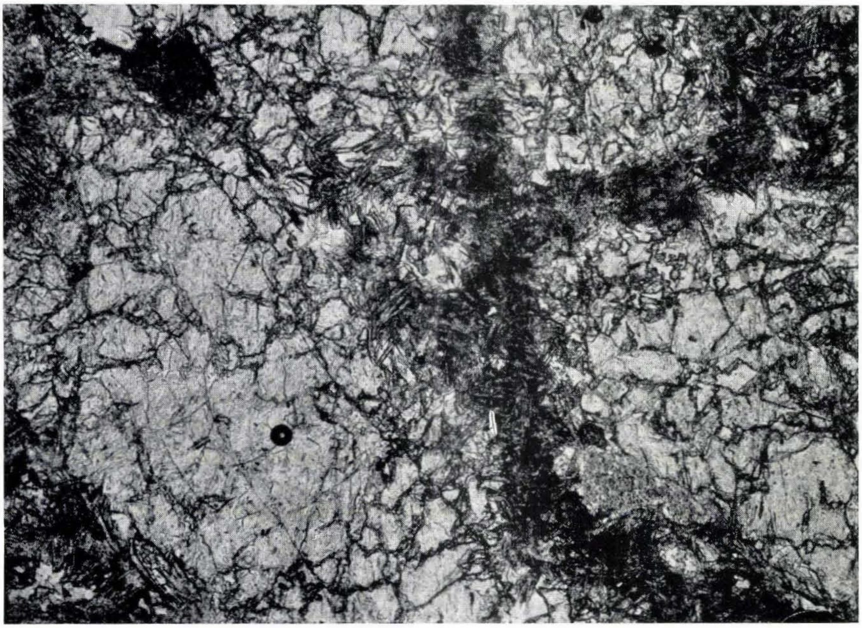

Fig. 1.

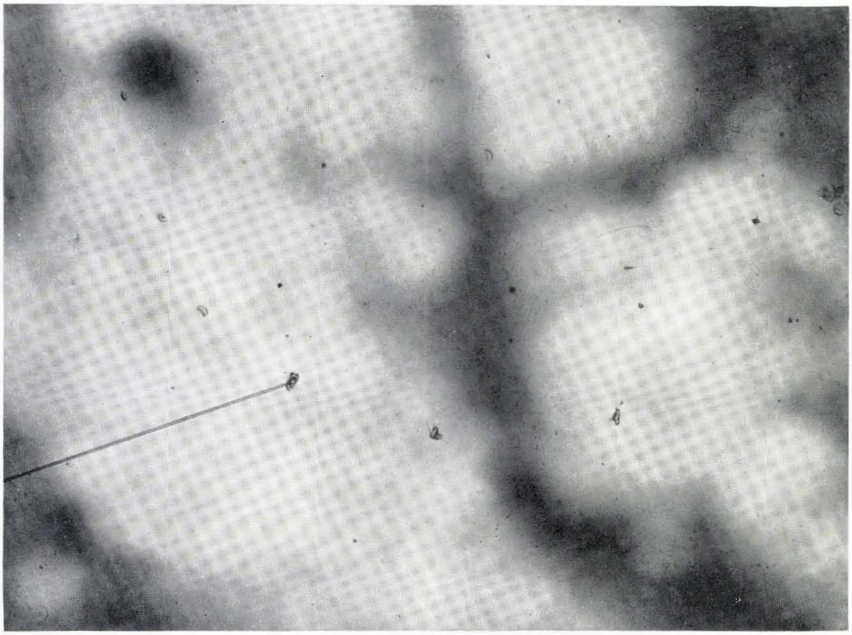

Fig. 2.

Plate 2.

Fig. 1. No. 17: 18518, 45 ×, 1 nic. Small inclusions of thorianite (black) in steenstrupine from an analcime vein at Igdlúnguaq.

Fig. 2. Nuclear film of the same, 336 hours exposure. The strong concentration of α–tracks over the thorianite is seen in the upper part of the photo. The α-track intensity has been counted to be 120.000 α/cm^2. hour in another emulsion exposed for $17^1/_2$ hours. The dark patches in the steenstrupine give shadows in the emulsion. The emulsion is heavily scratched.

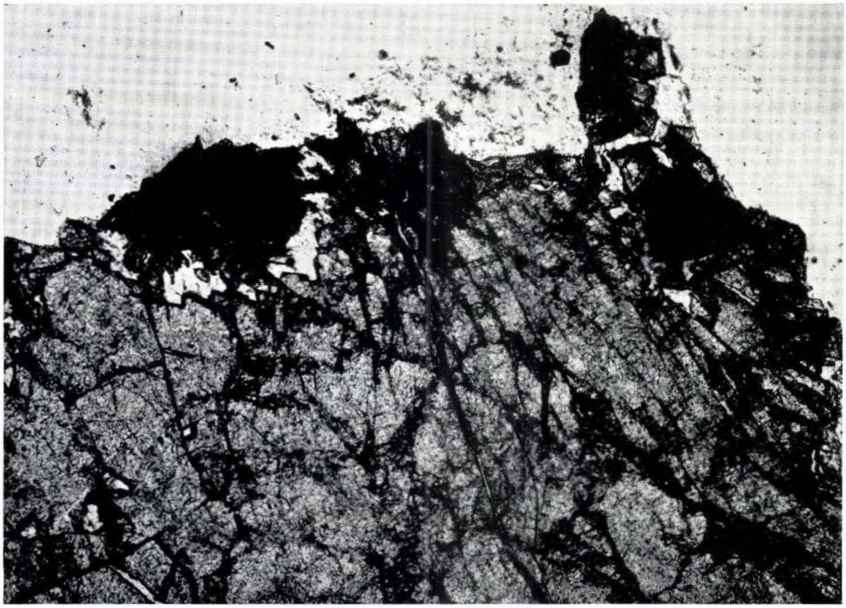

Fig. 1.

Fig. 2.

Plate 3.

Fig. 1. No. 50: 45 ×, 1 nic. Crystal of steenstrupine from the albitite at Tugtup agtakôrfia. The light–coloured core is isotropic, the dark–coloured margin anisotropic and rich in fractures parallel to the basal face of the crystal. There are in addition a few radiating fractures in the outer zone.

Fig. 2. No. 45: 17086,1, 1 nic., 45 ×. Flakes of "murmanite" (centre top) in arfvedsonite lujavrite from Nordre Siorarssuit.

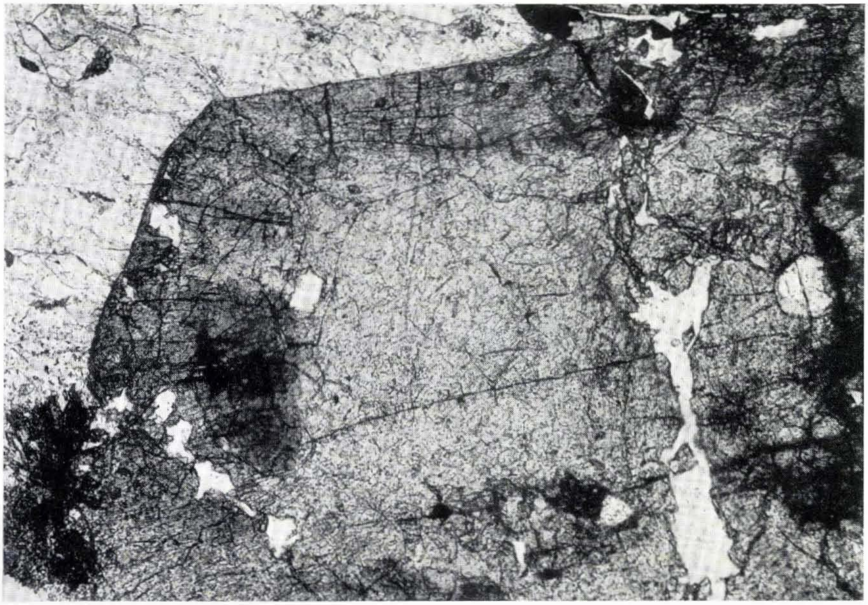

Fig. 1.

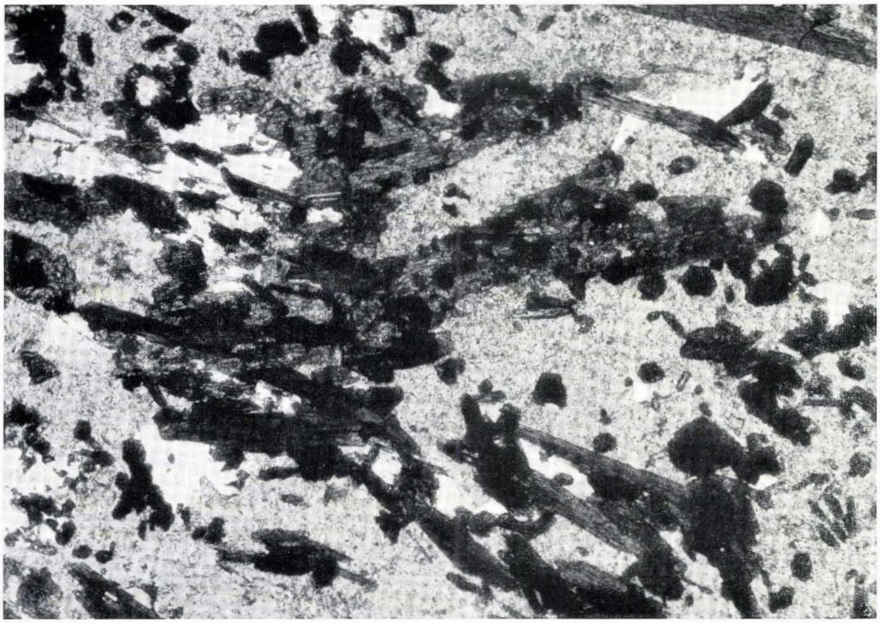

Fig. 2.

Plate 4.

Fig. 1. 18467 d, 35 ×, 1 nic. Polygonal aggregate of red type of steenstrupine with short marginal fractures in a matrix of arfvedsonite, ægirine and analcime. Vein in Kangerdluarssuk.

Fig. 2. 18467 b, 35 ×, 1 nic. Zoned crystals of the red steenstrupine mineral in a matrix of arfvedsonite, ægirine and analcime. The same locality as plate 4, fig. 1, see the map fig. 1 and compare text fig. 3.

Microphotos by CHR. HALKIER.

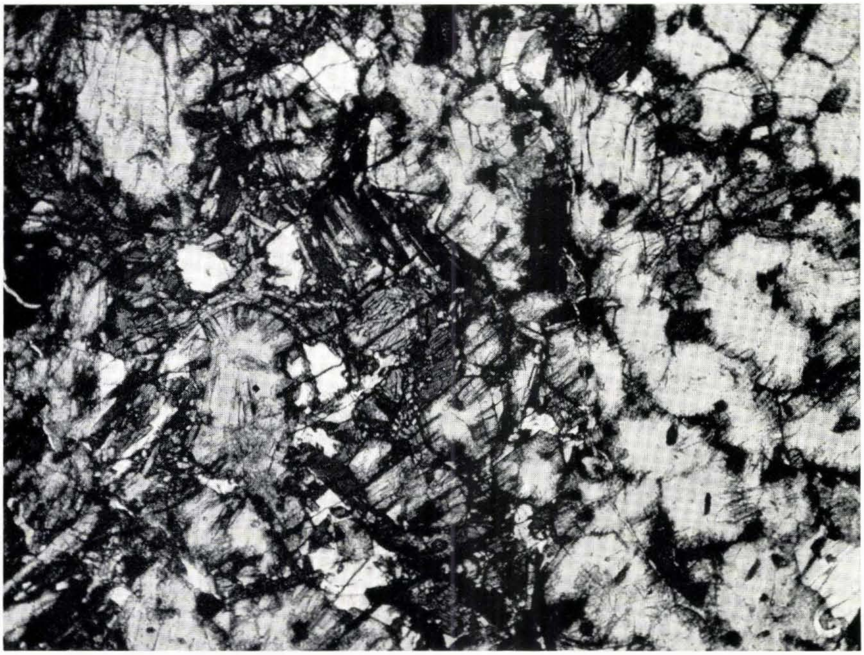

Fig. 1.

Fig. 2.