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Preliminary account of the geology of the Kvanefjeld area of the Ilímaussaq intrusion, South Greenland

by

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PRELIMINARY ACCOUNT OF THE GEOLOGY OF THE KVANEFJELD AREA OF THE ILÍMAUSSAQ INTRUSION, SOUTH GREENLAND

Contribution to the mineralogy of Ilímaussaq, Nr. 14

by

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Abstract

The Kvanefjeld area is situated in the northernmost part of the Ilímaussaq intrusion. The area represents a section through the roof zone of this intrusion. The roof is composed of sandstone, basaltic lavas, sheets of gabbro and dykes of dolerite and trachyte. Large masses of anorthosite are also found in the roof zone.

The oldest members of the intrusion are augite syenite and alkali syenite which together with large masses of naujaite (poikilitic sodalite syenite) are enclosed in various types of fine-grained lujavrite. The lujavrite also intrudes the lavas of the roof. The bodies and veins of lujavrite are mainly located in zones of deformation in the rocks of the roof zone.

The lavas of the roof are strongly altered in contact with the lujavrite and are locally enriched in epistolite-murmanite minerals.

The latest member of the intrusion is a medium- to coarse-grained lujavrite which forms sheets and veins in most of the above-mentioned rocks. The earlier fine-grained lujavrites and the contact-metasomatized lavas have concentrations of steenstrupine, monazite and thorite (?) in contact with the medium- to coarse-grained lujavrite and may contain up to 0.3 % U and three to four times this amount of thorium. This mineralization has been studied by mineralogical, geochemical and radiometric methods and in a number of drill holes.

Analcime-rich veins rich in niobium and beryllium minerals are of widespread occurrence.

The present paper gives a preliminary account of the geology of this region with special reference to the structural geology. A detailed examination of the economic geology of the Kvanefjeld area is currently being undertaken.

CONTENTS

I INTRODUCTION

Detailed investigations on the Ilímaussaq alkaline massif were started in 1964 as a university research project following the publication of a new map of the intrusion (Ferguson, 1964). The new research, which is being carried out under the auspices of the Geological Survey of Greenland (GGU) and the Institute of Petrology of the University of Copenhagen, in close collaboration with the Danish Atomic Energy Commission's Research Establishment at Risø, comprises petrological, geochemical and mineralogical examinations. Some results of the studies have been published in a series of short papers entitled "Contributions to the Mineralogy of Ilímaussaq", most of which have appeared in Meddelelser om Grønland, Bd. 181 (see Sørensen, 1967).

So far the work has been concentrated on the north-western part of the intrusion in the Kvanefjeld area (fig. 1), because of the uranium-thorium mineralizations found there, and on the Taseq slope to the south-east, where there are beryllium and niobium mineralizations.

The first part of the detailed mapping of the Kvanefjeld area was completed in 1967. A summary of the preliminary results of this mapping are given here, even though the detailed examination of the petrology of the region is not yet complete.

The following have participated in the field work: S. Andersen, E. Bondesen, J. Engell, S. Funder, K. Færgemann, J. Hansen, K. Hansen, E. S. Jensen, J. M. Johansen, J. Gutzon Larsen, B. L. Nielsen, P. Nielsen, A. K. Pedersen, O. V. Petersen, H. Sørensen and T. V. Østergaard.

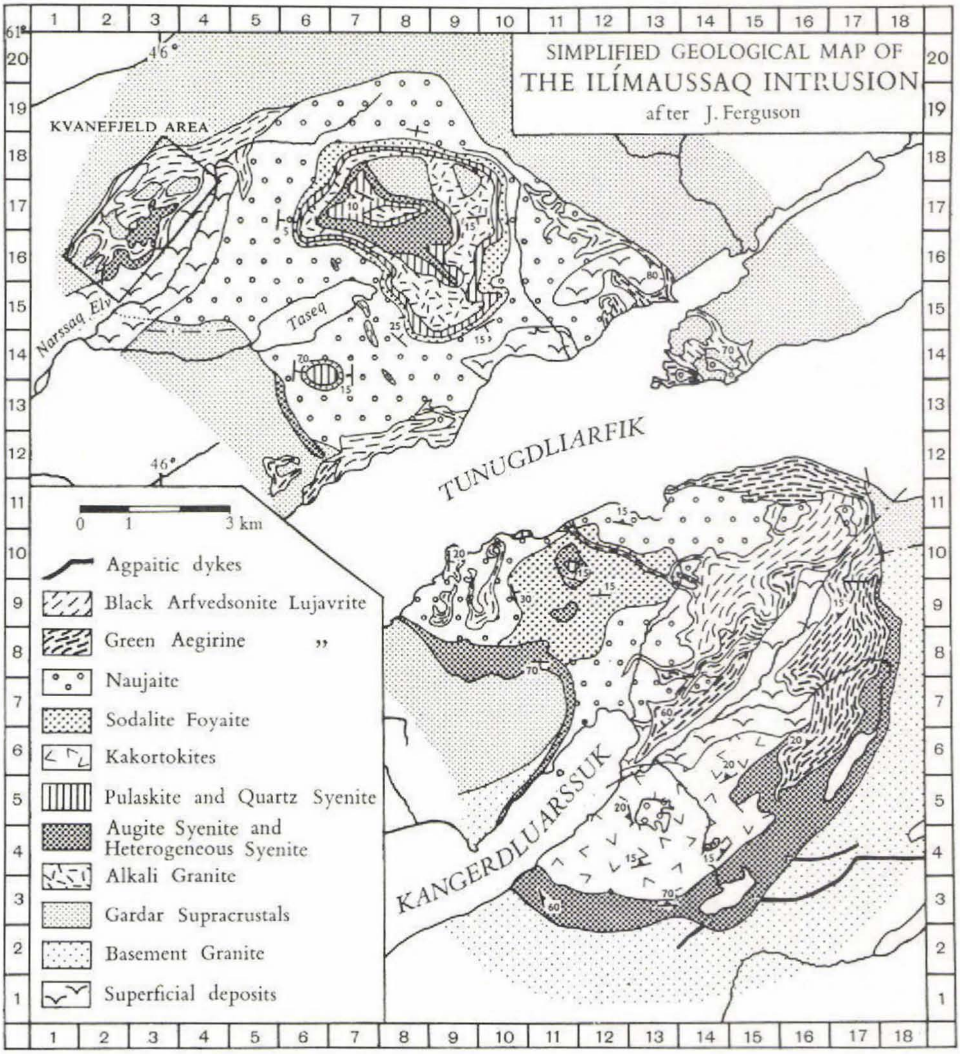

Fig. 1. Simplified geological map of the Ilímaussaq intrusion based on the map of Ferguson (1964).

II GENERAL DESCRIPTION; METHODS

The Kvanefjeld area is a hilly plateau between 500 and 700 m high on the north side of the Narssaq River (see fig. 1). The degree of exposure is fair, with small hills of well exposed, glacially smoothed rocks separated by lower ground covered with gravel and low scrubby vegetation and by many small lakes.

Kvanefjeld is situated at the north-western contact of the Ilímaussaq intrusion. The intrusion, which is 1030 ± 24 m.y. old (Bridgwater, 1965), cuts through basement granites of Sanerutian and Ketilidian age (Allaart, 1964), the sub-Gardar peneplain and Gardar sedimentary rocks and lavas (Poulsen, 1964, Stewart, 1964). The floor of the intrusion is below the present level of exposure, but the roof is seen at several localities, among them the Kvanefjeld area, where the marginal augite syenite of the intrusion and the volcanic country rocks have been broken up by agpaitic rocks, chiefly the late lujavrites.

The northern contact of the Ilímaussaq intrusion runs across the northernmost part of the Kvanefjeld plateau, which is bounded on the west, north and east by volcanic rocks belonging to the roof of the intrusion. As in other parts of the Ilímaussaq area the volcanic rocks dip gently towards the contact of the intrusion.

The Kvanefjeld plateau is formed of a complicated intrusion breccia, in which large and small blocks of volcanic country rocks, syenite, anorthosite, naujaite and foyaite are enclosed in various types of lujavrite.

The westernmost part of the plateau is composed mainly of volcanic rocks injected by fine-grained lujavrite, the central part mainly of syenites and anorthosite intruded by fine-grained lujavrite, and the easternmost part mainly of volcanic rocks underlain by fine-grained lujavrite and naujaite intruded by late medium- to coarse-grained lujavrite. In the northern part of the plateau naujaite forms the outermost part of the intrusion. South of this marginal naujaite there are numerous inclusions of naujaite and a few inclusions of foyaite in the fine-grained lujavrites. Naujaite and foyaite may occur together in one and the same inclusion.

On the slope facing the Narssaq River the lujavritic intrusion breccia is underlain by syenite and anorthosite which in turn are underlain by naujaite; all three are intruded by fine-grained lujavrite.

General accounts of the whole Ilímaussaq intrusion are presented by Ussing (1912), Sørensen (1958) and Ferguson (1964).

The geology of the Kvanefjeld region is so complicated that it has been necessary to make detailed outcrop maps on a scale of 1:2000 and locally of 1:500 as well. Key areas have been mapped on scales of 1: 10 and 1: 40, using both polaroid photos and a grid drawn on the rock surface. Air photos enlarged to a scale of 1: 2000 have also been used.

The radioactive rocks have been mapped radiometrically (Løvborg and Hansen, 1968; Løvborg, Kunzendorf and Hansen, 1968 a). Numerous rock samples have been analyzed for U, Th and Nb in the chemical laboratories at Risø.

III PETROGRAPHY AND DISTRIBUTION OF ROCK TYPES

1. The roof

Gardar supracrustal rocks found in the Kvanefjeld area comprise basaltic lavas, agglomerates, conglomerates and sandstones. All have been strongly altered near the contact with the agpaitic rocks; vesicles up to 2 cm across in the lavas are often filled with aegirine, albite and microcline.

The following stratigraphy has been established in the westernmost part of the plateau (E. Schou Jensen, pers. comm. ; see plate 1 and table 1).

1. The oldest unit is a lava flow more than 50 m thick which contains abundant star-shaped clusters of feldspar phenocrysts 1-5 mm long and up to 1 mm across in a dense, black to greenish-black

groundmass. It has been called "star basalt" in the field. The upper and lower parts of the flow are strongly vesicular and contain empty vesicles up to 2 cm, and rarely up to 5 cm, long.

2. A conglomerate 3 m thick with ellipsoidal pebbles up to 15 cm long in a coarse-grained matrix.

3. More than 20 m of fine-grained, banded sandstone which becomes coarse-grained upwards.

Table 1

Chronology established on the Kvanefjeld plateau

Rocks of the Ilímaussaq intrusion	Lamprophyric dykes	
	Pneumatolytic and hydrothermal veins	
	Medium- to coarse-grained lujavrite	
	Pneumatolytic and hydrothermal veins	
	Fine-grained lujavrite	
	Naujaite and foyaite	
	Trachytic dykes	
	Fine-grained alkali syenite	
	Augite syenite	
	? Quartz syenite	? Anorthosite
Country rocks	Basaltic dykes	
	Gabbro sheet II	
	Rectangle porphyry dykes	
	Gabbro sheet I	
	Basaltic lavas with agglomeratic horizons	
	Sandstone	
	Conglomerate	
	Basaltic lava	

4. Basalt with scattered feldspar phenocrysts 1-10 mm long and 1-2 mm across is the youngest unit found. It has layers of vesicles, especially in the upper part of the flow, and columnar jointing. Agglomerates and other pyroclastics have been found in this unit.

Two gabbro sheets, separated chronologically by a generation of "rectangle porphyry" dykes, intrude the lavas and are in contact with the agpaitic rocks. The older gabbro is a dark brown rock composed mainly of plagioclase laths up to 5 cm long and up to 1 cm across. The composition of the cores is about An_{50} and of the border zones about An_{35}. There is also augite in crystals up to 1 mm long, abundant apatite and iron oxide. Biotite and chlorite are secondary after the original ferro-magnesian minerals. The plagioclase phenocrysts are usually randomly oriented but locally have a preferred orientation that gives the rock a lamination. Vertical lamination is especially developed adjacent to the vertical contacts between gabbro and supracrustals. Very rarely the plagioclase laths give a lineation, the plunge of which is very variable.

The younger gabbro has only scattered plagioclase pheno-crysts, which may be up to 2 cm long. This rock is cut by many thin albititic veins (generally less than 1 mm), presumably indicating an earlier joint pattern. At one place columnar jointing is visible.

Both gabbro sheets have unusually high nepheline contents in the norm, 6.08 and 9.82 % respectively (table 2), a feature which in part may be attributed to metasomatism associated with the agpaitic rocks.

The "rectangle porphyry" dykes, which are up to 25 m thick, contain abundant box-shaped alkali feldspar phenocrysts up to 5 cm long. The groundmass is composed of biotite, chlorite and ore. The general strike of the dykes is NE-SW and they are vertical. The phenocrysts, which often are orientated parallel to the contacts of the dykes, become less abundant towards the contacts.

Younger than the rocks mentioned, but older than the rocks of the Ilímaussaq intrusion, are dykes which are dominantly of basaltic composition. Some are aphanitic and non-porphyritic, while others have phenocrysts of alkali feldspar up to 0.5 cm long. These dykes are from 0.5 to 10 m wide, vertical, and generally strike NE-SW. A few of them strike NW-SE. No intersections have been observed.

In the eastern part of the area all the rocks older than the naujaites are cut by dykes of quartz syenite, composed mainly of microcline perthite, ægirine/acmite and minor quartz.

Near lake 618 the fine-grained alkali syenite (see p. 12) is cut by trachytic dykes. These dykes are fine-grained, light grey to dark grey and contain a few white to reddish alkali feldspar phenocrysts up to 1 cm long. The matrix consists mainly of microcline perthite, arfvedsonite and ægirine/acmite. Adjacent to anorthosite the dykes may contain large white plagioclase grains presumably derived from the anorthosites.

2. Anorthosite

Anorthosite forms inclusions in the gabbro and the "rectangle porphyry" dykes and also forms masses up to 100 m across partly surrrounded by a fine-grained alkali syenite (Bridgwater and Harry, 1968; Nielsen, 1967). The feldspars of the anorthosite are usually randomly orientated, but occasionally give a lamination. In places the rock is composed of fragments of granular anorthosite. The plagioclase of the typical anorthosite (about An_{55}) forms subhedral to euhedral grains from 1 cm to more than 5 cm long. It is usually strongly saussuritized. The dimensional ratios are about 3 : 2 : 1. Dark minerals usually form less than 10 % by volume of the rock, but may exceed this amount in which case the rock should be called gabbro-anorthosite.

The margins of the anorthosite lenses are strongly deformed. The foliation in the zones of deformation, which are from a few cm to about 1 m wide, is often parallel to the margins. Lujavrite veins, from a few cm to about 1 m wide, are commonly found between the undeformed and the strongly deformed anorthosite. The deformed rocks have often been eroded away.

3. The rocks of the Ilímaussaq intrusion

a) The oldest lithological member of the Ilímaussaq intrusion itself is augite syenite, which forms a border zone up to several hundred metres thick four-fifths of the way around the intrusion. In the Kvanefjeld area this rock has been broken up by the lujavrites and occurs in the latter as inclusions up to 100 m across. (For further description see Ussing (1912) and Ferguson (1964)).

b) Younger than the augite syenite is a fine-grained alkali syenite of a type known only from the Kvanefjeld area and from the Narssaq River. It is widespread in the south-western part of the Kvanefjeld area, where it occurs as veins in the augite syenite and as areas up to 20 x 50 m across. The veins are not chilled against the augite syenite. While the agpaitic coefficient of the augite syenite is < 1, that of the fine-grained alkali syenite is higher than 1.2 (table 2). It is a fine- to medium-grained, black, bluish-green or green rock (depending on the arfvedsonite : aegirine ratio), and consists mainly of microcline perthite and arfvedsonite, with smaller amounts of aegirine, sodalite, analcime, natrolite and nepheline together with accessory neptunite and apatite and rarely ore minerals. The syenite may be porphyritic with reddish alkali feldspar grains 0.5 to 1 cm long that have white marginal zones. In places the rock has irregular pegmatitic patches. Where it is in contact with anorthosite it may contain large white plagioclase grains, presumably derived from the anorthosite.

There are several generations of this rock, which may intersect each other. Where sheared the rock may have a high content of pectolite and minerals of the murmanite-epistolite group (Hansen, 1966 and 1968).

c) Naujaite (poikilitic sodalite syenite) and foyaite are found mostly as large inclusions in the lujavrite, but also as closely-packed, small inclusions in thin veins of lujavrite intersecting the augite syenite. The inclusions have been carried up by the lujavrite magma from a thick horizon of naujaite below the augite syenite. The naujaite inclusions in the lujavrite are usually angular and may be fresh or strongly altered and bleached. In the latter case the dark minerals aegirine and arfvedsonite have been replaced by acmite (or have disappeared), and the eudialyte is partly replaced by katapleiite. Locally the naujaite contains veins consisting of albite, analcime, ussingite and/or natrolite; these veins may also contain lithium-mica and niobium and beryllium minerals (Semenov et al., 1968; Hansen, 1968; Sørensen et al., in press).

In the northernmost part of the Kvanefjeld area the agpaitic rocks are in direct contact with the lavas. In the contact zone the naujaite contains much pegmatite which locally has a high content of fluorite (colourless, blue and green), rinkite, britholite and lithium-mica (in flakes up to 5 cm across). Thin apophyses of naujaite with prominent poikilitic sodalite extend out into the lavas. Medium-grained patches have been found in the pegmatitic zone. They are unlayered but nevertheless recall the layered eudialyte-nepheline syenite (kakortokite) found in the southernmost part of the Ilímaussaq intrusion.

d) All the rocks described are cut by veins of felted aegirine (cf. Sørensen, 1962). These veins normally occur as fillings in the major joint systems, but locally are found in other directions. The lujavrite contains ellipsoidal inclusions of felted aegirine up to 10 x 3 cm across which presumably come from these veins.

e) The youngest rocks of the intrusion are the lujavrites which have broken up all the earlier rocks in the Kvanefjeld area and have brought inclusions of many different rock types together.

There are two main types of lujavrite : i) fine-grained lujavrite, which occurs in several generations, and ii) medium- to coarse-grained lujavrite, which forms the youngest intrusive phase in the Ilímaussaq intrusion.

i) The following types of fine-grained lujavrite have been distinguished: arfvedsonite lujavrite, in which arfvedsonite is the predominant dark mineral and aegirine is subordinate; aegirine lujavrite, in which aegirine is the predominant dark mineral; naujakasite lujavrite, which contains up to 75 % naujakasite (Petersen, 1965), and brown lujavrite, in which acmite is the predominant dark mineral.

The arfvedsonite lujavrite is the most widespread type of lujavrite in the area. It usually has a pronounced lamination due to planar orientation of the feldspar laths. Locally the arfvedsonite lujavrite contains many ellipsoidal brown patches rich in acmite (cf. Sørensen, 1962, p. 57).

The aegirine lujavrite is most commonly found as more or less parallel zones in the arfvedsonite lujavrite or as areas in the arfvedsonite lujavrite where the latter is rich in inclusions of naujaite and foyaite. The aegirine lujavrite may have a lamination parallel to that of the arfvedsonite lujavrite, but is often unlaminated. It is commonly cut by many thin albite veins.

In the naujakasite lujavrites the dark material is predominantly acmite. They are often layered, the layers containing varying amounts of naujakasite.

The brown lujavrite, which has the same appearance as brown nodules in the naujakasite lujavrite - acmite being the predominant dark mineral, may represent naujakasite-free parts of the "naujakasite lujavrite".

The lamination in the dykes and sheets of lujavrites is always parallel to the contacts and wraps conformably around inclusions. The lujavrites contain bands a few millimetres to about 1 m thick which are alternately grey and black; alternating black, light-grey and reddish bands have also been seen.

As mentioned above, the lujavrites often contain inclusions of other rocks, especially basalt, naujaite and syenite, which may be so abundant that the rock becomes an intrusion breccia. This is especially so on the slopes in the south-western part of the map. The contact zones between these inclusions and the lujavrite are often albitized. Detailed descriptions of the above-mentioned types of lujavrite have been given by Ussing (1912), Sørensen (1962), Ferguson (1964) and Petersen (1965).

ii) The youngest generation of lujavrite is a medium- to coarse-grained lujavrite which so far has only been found in the Kvanefjeld region. It forms flat, sheet-like bodies or veins intersecting all the other rocks. It is a dark rock composed of 50-60 % light-coloured minerals - mainly microcline, nepheline and analcime - and 40 %-50 % arfvedsonite. Minor amounts of acmite are common. The most abundant type is composed of laths of microcline up to two cm long haphazardly arranged in a matrix of aggregates of fine-grained arfvedsonite; the texture is thus "doleritic". As in the other types of lujavrite, the microcline is non-perthitic (cf. Ussing, 1912, p. 160). Locally the medium- to coarse-grained lujavrite contains layers with a more massive appearance composed mainly of nepheline and arfvedsonite. In both types of coarse-grained lujavrite late analcime has commonly replaced the other light-coloured minerals, often to such an extent that all microcline and nepheline has disappeared. Natrolite and sodalite may also occur. Minor components are eudialyte, monazite, aegirine, acmite, steenstrupine, neptunite, etc. The agpaitic coefficient is 1.67 (Gerassimovsky and Kuznetsova, 1967). Østergaard (1964) has described the igneous layering developed in this type of lujavrite.

As seen in table 2, the chemical composition of the medium- to coarse-grained lujavrite is close to that of the fine-grained arfvedsonite lujavrite which is widespread in Ilímaussaq. At present the coarse-grained rock is regarded as a variety of the common lujavrite and for that reason has not been given a special name.

The medium- to coarse-grained lujavrite is rich in thin veins of pegmatite which have border zones of microcline, arfvedsonite and steenstrupine, and cores of analcime, sodalite, natrolite, pyrochlore, chkalovite, sorensenite, beryllite, blue apatite, monazite, etc. (Semenov et al., 1965; Semenov et al., 1968; Hansen, 1968). There are also veins composed mainly of analcime that vary in size from thin, short veins to lenses several metres long, and veins with albite-rich centres that contain abundant streaks of pyrochlore, neptunite and igdloite. Along the contact between the medium- to coarse-grained lujavrite and the volcanic rocks of the roof there is a pegmatitic zone, up to a few metres thick, composed of the same minerals as the pegmatites and analcime veins.

The lujavrite is especially radioactive near the margins of inclusions of the older rocks.

The coarse-grained lujavrites and their metasomatic aureole (the mixed zone and the zone of banding, cf. pp. 20 - 22) have been traced towards the north-east beyond the edge of the Kvanefjeld plateau to the foot of Steenstrups Fjeld.

4. Pneumatolytic and hydrothermal veins

The syenites and naujaites are cut by hydrothermal veins from a few mm to about 1 m thick. These consist mainly of albite, analcime and/or natrolite, and are locally rich in beryllium and niobium minerals such as tugtupite, chkalovite, beryllite, epistolite, pyrochlore and igdloite (Hansen, 1966; Hansen, 1968; Sørensen et al., in press). The veins are most probably genetically associated with the fine-grained lujavrites (Sørensen, 1962). In cracks in the volcanic rocks there are thin veins of albite rich in aggregates of pectolite needles up to 5 cm long.

5. Late lamprophyric dykes

A few thin lamprophyric dykes, which strike about NE, are later than the hydrothermal veins. They are generally vertical, but locally have a low dip. They vary in width from a few cm to about 1.5 m, and often wedge out and continue in en echelon fashion. The rocks of the dykes are fine- to medium-grained, brown to black and are composed of prismatic grains of brown amphibole up to 5 mm long, strongly zoned titaniferous augite and alkali feldspar in a dense groundmass. The amphibole needles are arranged parallel to the contacts of the dykes. There are vesicles filled with calcite or zeolites.

IV THE STRUCTURES AND THE ALTERATION OF THE PRE-AGPAITIC ROCKS CAUSED BY THE LUJAVRITES

In the preceding sections the petrography and the field relations of the rock types have been treated, but the structures have not been discribed. These will be dealt with in this chapter together with the alteration of the pre-agpaitic rocks, as the structures are considered to be related mainly to the intrusion of the lujavrites and as the alteration zones are found to be spatially connected with areas of lujavrites.

The large-scale structure of the Kvanefjeld area is characterized by wide zones of deformation, which trend dominantly NE-SW but also NW-SE. Intrusions of lujavrite are especially common in the NE-SW zones in which various rocks adjacent to the lujavrites are strongly altered and deformed.

There appears to have been intense initial shearing in the zones of deformation; this may be deduced from the presence of relic mylonitic rocks. Fine-grained arfvedsonite lujavrite was then intruded along the shear zones to form elongate or lensoid bodies in a breccia-like pattern. These were further intruded by the medium- to coarse-grained lujavrite and deformed and altered in various ways.

The deformation of the pre-agpaitic rocks (gabbro, porphyries, anorthosites) resulted in stretching in which the feldspars were drawn out into rods up to 20 cm long and a few mm wide, and a weakly developed, nearly vertical foliation was formed. Where the deformation was stronger, dense grey or black, often banded rocks were formed. Near contacts with the fine-grained arfvedsonite lujavrite the deformed rocks are often rich in small rectangular plates of niobium minerals belonging to the epistolite-murmanite-lomonosovite group. These altered rocks may contain up to 10 % by volume of "murmanite" or up to 0.6 % Nb_2O_5; they have very low contents of uranium and thorium (Hansen, 1968).

The descriptions of the structural relations in the alteration zones are based on investigations of key-areas and mapping on scales of 1 : 10, 1 : 40 and 1 : 500. The relations between the roof rocks of the Kvanefjeld plateau itself and the large homogeneous body of medium- to coarse-grained lujavrite west of Kvanefjeld are described according to the following division into zones:

1) The unaltered and undeformed roof rocks.
2) The alteration and deformation of the roof rocks.
3) The zone of mixed rocks.
4) Border relations between the zone of mixed rocks and the main body of medium- to coarse-grained lujavrite.
5) The medium- to coarse-grained lujavrite.

In addition to these zones the relations between the main medium- to coarse-grained lujavrite body and the surroundings to the west and north and the relations between the anorthosite and the fine-grained lujavrite will be described under the headings:

6) The alteration and deformation of the fine-grained alkali syenite.

7) The alteration and deformation of the anorthosite.

The localities of the various key-areas and the position of the maps shown in the figures is indicated in plate 6.

1. The unaltered and undeformed roof rocks

The roof rocks making up Kvanefjeld itself are strongly fissured, dense, blackish green lavas and various intrusive rocks ("rectangle porphyry", gabbro I and gabbro II). The characteristic porphyritic textures of these rocks are valuable when tracing the single members into the zones of alteration and deformation. In addition to the rocks mentioned above there are pre-agpaitic basic dykes.

All contacts between the rock types are vertical or sub-vertical and this is also the case with the internal primary structures (orientation of phenocryst, flow layering etc.).

2. The alteration and deformation of the roof rocks

The deformation and alteration of the pre-agpaitic roof rocks are best studied near lake 587 and near the excavation made in the southern part of the plateau. The rocks can be traced into a wide zone of alteration, strongly veined by lujavrite, in which they occur as lenticular bodies fairly well preserved in the centres but foliated around the borders and surrounded by lujavrite. The trend of the "rectangle porphyry" and gabbro dykes can be followed across the lenticular pattern of the altered zone, showing that there has been very little relative displacement. However, traces of movement are found in small scale plastic deformation and flattening of the textures of gabbro I and the porphyry.

The porphyritic dykes are generally strongly altered near albitite veins from less than 1 mm to about 0.5 m thick that are common in the zones of deformation. In the less altered rocks only the smaller feldspar phenocrysts have been replaced, but near the contacts with the veins the larger feldspar grains have disappeared as well, and the most altered rocks are dense to fine-grained and greenish-grey to green. Where the albite is most abundant an albitite breccia containing sharp-edged fragments of country rocks has been formed.

Within the altered country rocks of the roof the fine-grained lujavrite occurs mainly as lenticular bodies and veins in NE-SW-trending deformation zones. The lamination of the lujavrite is parallel to the contacts of the bodies and generally trends NE-SW. There are numerous xenoliths of altered lava, gabbro, anorthosite, syenite, naujaite, etc.

The volcanic rocks of the roof are strongly recrystallized in contact with the fine-grained lujavrites and may acquire a lujavritic appearance and mineral composition.

To the south-west of Kvanefjeld itself (plate 1) the two gabbros, the "rectangle porphyry" and other porphyritic dykes occur in direct contact with a zone of medium- to coarse-grained lujavrite mixed with other rock types (see the next sub-section).

When tracing these roof rocks towards the medium- to coarse-grained lujavrite the first change noticable is an indistinct, sub-vertical foliation which is best seen in the "rectangle porphyry" because of the flattening and parallel orientation of the feldspar phenocrysts. This flattening has in places more than doubled the length of the phenocrysts. In the other rocks the flattening deformation has produced a faint schistosity which usually strikes NE-SW. The basalts are transformed into strongly fissile, dense, black rocks or are crushed.

In a zone adjacent to the zone of mixed rocks the strike of the steep schistosity turns abruptly towards north-west, and attains dips towards the north-east at a low angle. The fine-grained dykes have usually been more resistant to bending and alteration than the coarse-grained ones. A tectonic pinch-and-swell structure is frequently developed and may be caused by competence differences between the various rocks.

The original nature of the strongly deformed and altered rocks can be recognized in some small areas. Thus there may be boudins of "rectangle porphyry", characterized by rounded aggregates of sodalite and analcime in a dense black groundmass. In the most strongly altered rocks these aggregates are "rolled out" into white rods. The basaltic rocks also show boudinage phenomena. The differences in competence have caused complicated structural patterns in this hinge zone, which may be a result of a drag towards NE in the rocks underlying the volcanic roof pendant which forms the Kvanefjeld mountain.

3. The zone of mixed rocks

A zone of roof rocks and fine-grained lujavrite mixed with and veined by the medium- to coarse-grained lujavrite occurs between the zone of altered roof rocks (especially the hinge zone west of Kvanefjeld) and the main body of medium- to coarse-grained lujavrite. This is a sort of "migmatite zone" surrounding the intrusion of the medium- to coarse-grained lujavrite. In addition to the veins of medium- to coarse-grained lujavrite there are also numerous thin analcime veins and pegmatites. The rocks often display a banded structure and are in places strongly folded.

The banded rocks are associated with a homogeneous grey rock which is more fine-grained than the medium- to coarse-grained lujavrite but which has a similar "doleritic" texture. It is drawn out and foliated in the fold hinges. The same lithological unit also forms dyke-shaped bodies, and small apophyses from the "dykes" into the reticulate rock (see further p. 23) suggest intrusive relations. However, the dykes are folded in places.

Locally the medium- to coarse-grained lujavrite is so abundant that an intrusion breccia or "agmatite" is formed.

Although the rocks are well exposed in this mixed zone it is extremely difficult to trace individual horizons and structural units because of the very strong variation in texture, grain size, colour and structural pattern. A general preferred orientation of linear and planar elements appears nevertheless to be present.

The variation in the orientation of linear structures appears to reflect the shape of the sheet-like body of medium- to coarse-grained lujavrite which has been established by drilling.

The detailed structures of the mixed zone can best be illustrated by means of small scale maps made by laying out a grid on the rock surface and drawing accurately the trend of the structures.

Plate 2 shows such a locality, 10 m^2 in area, in which a well defined sequence of alternating light grey, darker grey, and black bands are folded disharmonically. The thicknesses of the individual bands in the central part of the drawing seem to remain constant and the bands have been folded either in accordian folds with sharp hinges or concentrically. The fold axes have a very constant trend and a fairly constant angle of plunge, except in the westernmost part of the area, where variation in plunge is interpreted as a result of conjugate folding (Ramsay, 1962). The style of folding shown in the middle of the plate is very common in the zone of mixed rocks (see also fig. 2). On either side there are similar folds, probably flow folds, the axes of which are parallel to the axes of the folds in the middle zone. Mafic and other less well defined bands are characteristic of the similar folds.

In addition to the banded rocks there are inclusions of a dark dense rocks in the medium- to coarse-grained lujavrite shown in plate 2. The shapes of these inclusions show that they may originally have been angular inclusions, while structures in the north-eastern corner of the drawing show that the inclusions have been deformed plastically in similar folds and have acquired a fine axial plane foliation.

The whole area shown in plate 2 is enclosed in a homogeneous, medium- to coarse-grained lujavrite. Sometimes the doleritic texture of this rock is also visible between the bands, and there are bands grading into patches displaying this texture. The banded rocks continue into a banded zone in the homogeneous medium- to coarse-grained lujavrite in the south-western part of the drawing.

Plate 3 shows a zone of banded and folded rocks with relations similar to those found in plate 2. The characteristic accordian and contentric styles of folding are conspicuous, passing into a similar fold style towards the south-east. It should be noted that this figure shows a double fold pattern and also that the lineations measured fall into two groups in the Wulff-net diagram. Also plates 2 and 3 show a definite symmetry around the middle banded zone. If double folding is present, and it looks very much as if it is, the first folds must have been isoclinal and probably of similar type and the second folds of concentric type.

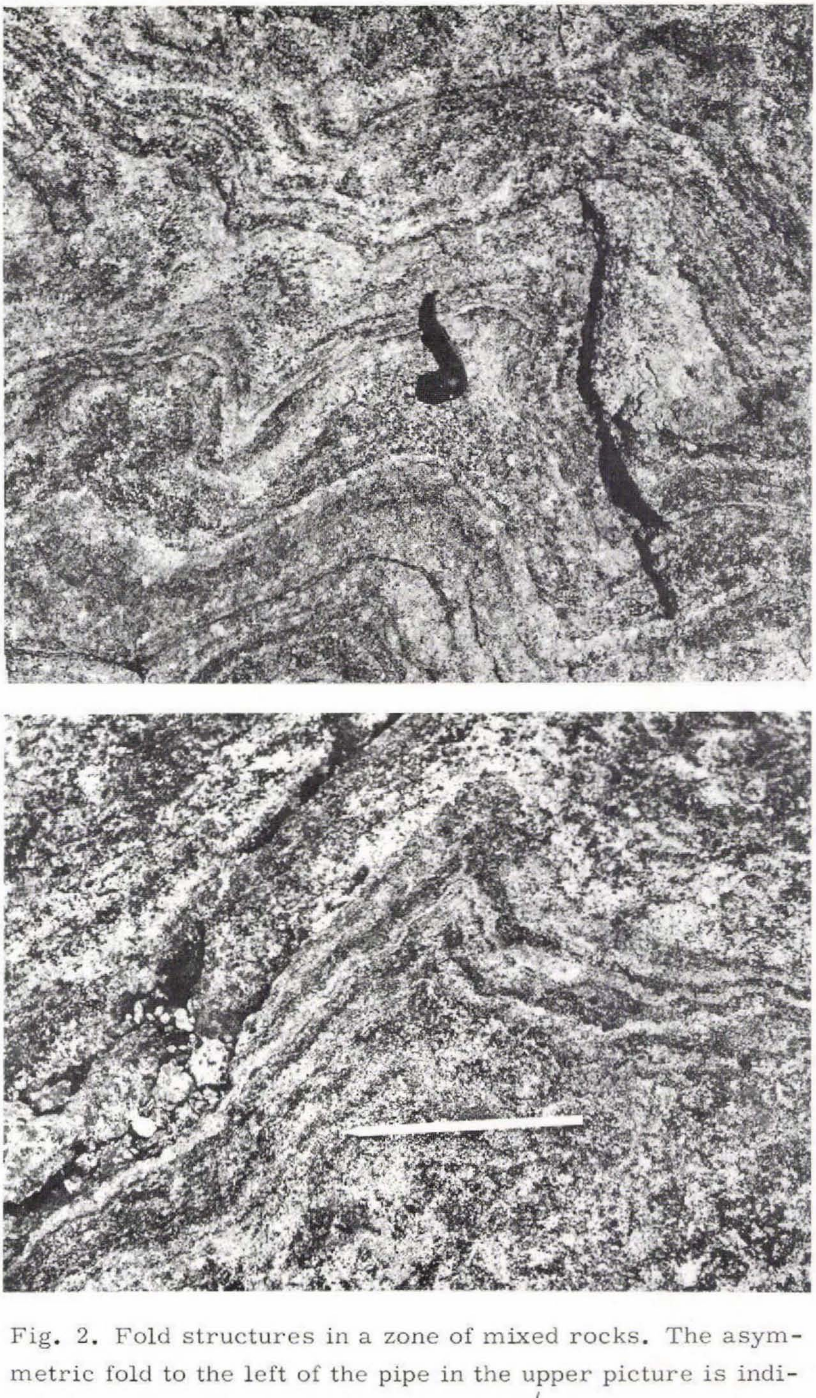

Fig. 2. Fold structures in a zone of mixed rocks. The asymmetric fold to the left of the pipe in the upper picture is indicated on plate 3 by the fold axis symbol ↗ 32.

Inclusions of dense dark rocks which grade into homogeneous rocks with the doleritic texture are present in the area shown in plate 4. In one part of this figure the rocks grade from a dark type into a light type.

Characteristic both of the areas shown in plates 2 and 3 and of the zone of mixed rocks as a whole are patches with small elongated clusters of arfvedsonite. This mineral lineation has been measured and is parallel to the axes of the "first" folds. Mineral orientations are also found in the south-western part of the area along a small structural discontinuity. This orientation is rather common in the zone of mixed rocks and is interpreted as caused by minor thrusting.

4. Border relations between the zone of mixed rocks and the main body of medium- to coarse-grained lujavrite

The border relations characteristic of the contact between the homogeneous medium- to coarse-grained lujavrite and the zone of mixed rocks is shown in plate 4. Here the mixed zone is composed of rocks of very different textures and structures.

The rock which appears to be the oldest is light grey and has a curious reticulate structure in which concentrations of steenstrupine and arfvedsonite form a thin, branching network between "nodules" of the dense grey rock 1-2 cm across. The network may be an impregnation of steenstrupine and arfvedsonite in zones of crushing. Adjacent to the medium- to coarse-grained lujavrite the reticulate rock is weakly foliated and may show drag folds.

The reticulate rock, which is strongly radioactive, grades away from the contact into a banded and foliated sequence displaying concentric folding. There is also a tight isoclinal folding in which the thicknesses of the layers are the same in the hinges as on the limbs of the folds.

The banded rocks are associated with a homogeneous grey rock which has a "doleritic" texture similar to that of the medium- to coarse-grained lujavrite, but is much more fine-grained than that rock.

This fine-grained rock is drawn out and then shows axial plane foliation in the fold hinges. Similar fine-grained "doleritic" rocks also form dyke-shaped bodies. Small apophyses into the reticulate rock suggest intrusive relations, but the "dykes" are folded locally.

Still later are bodies of a black arfvedsonite-rich rock which form "en echelon" dykes almost completely enclosed in pegmatite (central part of plate 4). These dykes are foliated parallel to the contacts and are boudinaged. Except for one small apophysis they are unfolded.

The mixed zone also contains zoned pegmatites which appear to be genetically associated with the medium- to coarse-grained lujavrite. They have marginal zones rich in microcline, arfvedsonite and steenstrupine and cores rich in analcime, pyrochlore, etc. (see p. 15).

5. The medium- to coarse-grained lujavrite

The late medium- to coarse-grained lujavrite forms large sheet-like bodies which are gently curved and dome-shaped. This shape is well reflected in the topography and, as mentioned above, can also be established from the drillings.

It is uncertain whether the area indicated on plates 4 and 5 as medium- to coarse-grained lujavrite represents one large sheet or is composed of several sheet-like bodies separated by zones of banded structures. The banding may be folded in a concentric manner, frequently as fan-shaped folds. In the banded parts "graded" bedding caused by varying proportions of light and dark minerals has been observed.

The late, medium- to coarse-grained lujavrite also shows clear intrusive features (plate 5), especially along the south-western, western and north-western sides of the larger homogeneous bodies i.e. along their foot walls. Towards the west the medium- to coarse-grained lujavrite forms dykes, most of which trend north-east, in fine-grained lujavrite and naujaite. In the south-western part of the area a large-scale breccia has been formed with inclusions of fine-grained syenite, naujaite and lujavrite in medium- to coarse-grained lujavrite.

6. The alteration and deformation of the fine-grained alkali syenite

To the north of the main body of medium- to coarse-grained lujavrite near lake 587 m this rock is in contact with fine-grained lujavrite as well as with fine-grained alkali syenite. The contact with the fine-grained syenite is shown on plate 6. The structural features of the fine-grained syenite and a wide zone rich in rocks related to the medium- to coarse-grained lujavrite have been recorded. The more detailed structures are shown in plate 6 and fig. 3; the positions of figs. 3 and 4 are shown in plate 6.

In the south-western part of plate 6 macroscopically unaltered, fine-grained alkali syenite, locally with rhomb-shaped phenocrysts, occurs. The phenocrysts and the relic jointing can be followed into a zone of altered rocks 3-4 m wide which must therefore be derived from the fine-grained syenite. The altered rocks are dense and greenish black, and have a pronounced fissility which is associated with numerous parallel and folded fissures (tension gashes). Fig. 4 shows details of these fissures. The pattern is that of zones of tension associated with the shearing couple indicated by the arrows. With further movement the earliest formed parts of the fissures tend to become folded with a drag-like pattern. Small inclusions of the surrounding rock can be found in the larger fissures. Fig. 5 shows a further development where many small inclusions of the surrounding rock are found in fissures which, however, show a more irregular pattern and were probably produced by injection forces rather than by a shearing couple.

Some of the tension gashes are filled with a velvet-black, fine-grained rock with a "doleritic" texture produced by tiny laths of microcline. This rock may have graded bedding folded concordantly with the surrounding rocks. Fig. 3 shows graded bedding in a small part of the area seen in plate 6.

Larger veins of medium- to coarse-grained lujavrite are related to the fissures and increase in frequency towards the south-east in plate 6.

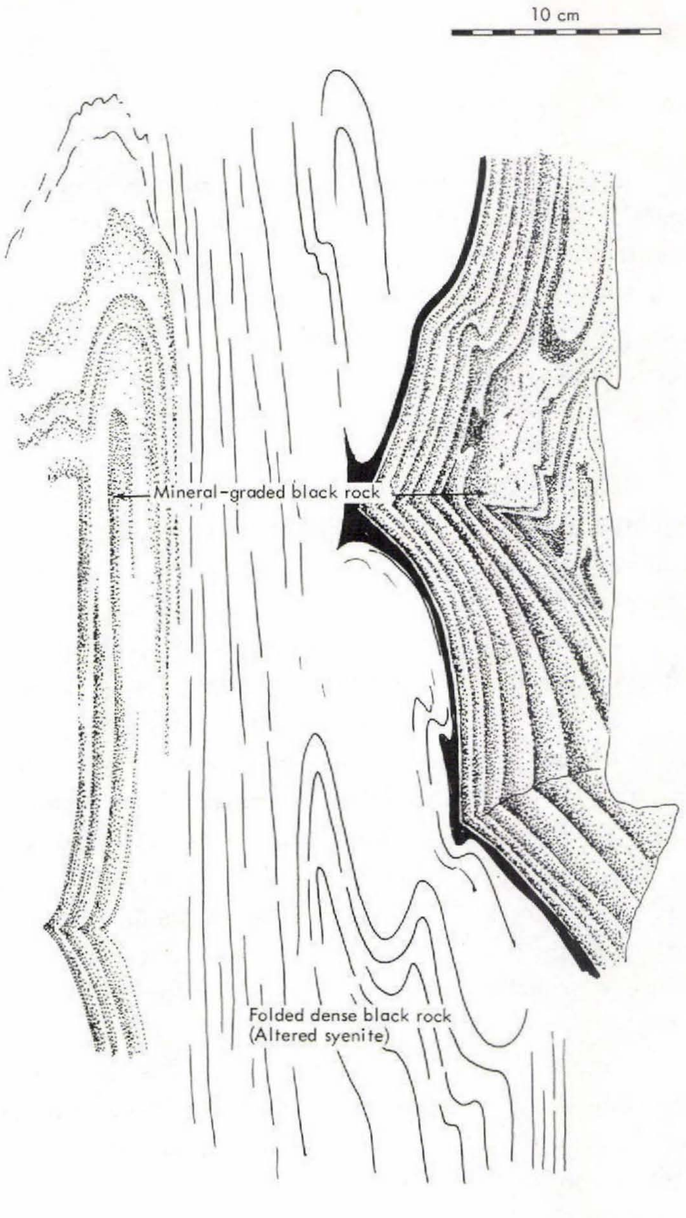

Fig. 3. Detail from the alteration zone between medium- to coarse-grained lujavrite and fine-grained alkali syenite.

Fig. 4. Folded tension gashes in fine-grained alkali syenite. For locality see plate 6.

Fig. 5. Tensional pattern in altered fine-grained alkali syenite. Location 10 m NW of plate 6.

The lujavrite in the veins is rich in nepheline or analcime and contains pegmatitic microcline-rich patches.

Lineations and the axes of small-scale folds all have the same general trend as the strike of the veins and fissures in the altered rocks. They are horizontal or have a low plunge in the banded vein material but plunge steeply in the folds thought to have been produced by injection forces.

7. The alteration and deformation of the anorthosite

The deformation of the anorthosite is best studied at the northern contact of the largest body of that rock. During the first stage of deformation the plagioclase recrystallized into a mixture of sodalite, nepheline and albite. Small needles of arfvedsonite are enclosed in these minerals. The rock is weakly banded with bands of different shades of grey reflecting the varying contents of arfvedsonite. Very little murmanite and pectolite is present.

With stronger deformation the rock became streaky and thinly banded, the different bands being one to a few mm thick. Arfvedsonite is found partly disseminated in the bands, partly as aggregates of small arfvedsonite needles up to 2 cm long and a few mm thick. The content of murmanite and pectolite may exceed 10 % by volume. The murmanite occurs as platy grains up to 1 cm across orientated parallel to the banding and as aggregates of small grains.

With still stronger deformation the rock was altered into a dark grey, dense rock, identical in appearance to the altered dykes and resembling the arfvedsonite lujavrite. The mineralogical composition is the same as that of the lujavrites except for the content of murmanite.

Veins of lujavrite have intruded the zones of deformation wrapping the bodies of anorthosite. They are generally concordant with the banding of the deformed rocks, but may be discordant in places. The zones of deformation are also cut by thin veins of fine-grained alkali syenite which indicates that some of the deformation was considerably older than the intrusion of lujavrite.

V DISCUSSION

The Kvanefjeld area is the only part of the Ilímaussaq intrusion where lujavritic rocks have been found in contact with the volcanic roof. The medium- to coarse-grained lujavrites may be interpreted as products of crystallization of the upper parts of a body of lujavritic magma from which the gases have been prevented from escaping by the impermeable roof of volcanic rocks. Elsewhere the emplacement of the lujavrite took place during a period of deformation so that the volatile components were squeezed out during the crystallization.

This may explain the fact that the fine-grained lujavrites are laminated and the coarse-grained lujavrites are massive.

A second possible interpretation of the coarse-grained rocks is that they were formed by mobilization of rocks of the roof zone (volcanics, naujaite, lujavrite) which had been permeated by gases. Coarse-grained rocks associated with partly assimilated inclusions of naujaite in lujavrite occurring elsewhere in Ilímaussaq have been interpreted in this way (Sørensen, 1962).

The intrusion breccia comprising volcanic rocks injected by fine-grained arfvedsonite lujavrite is folded in contact with the medium- to coarse-grained lujavrite. This folding is interpreted as a plastic deformation of rocks softened because of heating and gas permeation during the emplacement of the coarse-grained lujavrite. They are intersected by so many thin veins of medium-grained lujavrite and analcime that a second generation of intrusion breccia has been formed. The folded rocks are heavily metasomatized and are enriched in analcime, steenstrupine, thorite (?) and monazite. It is the uranium mineralization of this zone which is currently being studied.

There are thus several generations of lujavrite in the Kvanefjeld area. The arfvedsonite and aegirine lujavrites are the oldest and are intruded by naujakasite lujavrite. Still later are the bodies and veins of medium- to coarse-grained lujavrite.

The medium- to coarse-grained lujavrite, which may be regarded as a special type of pegmatoid lujavrite, is confined to the

Kvanefjeld area, where it forms several sheet-like bodies located in a horizon between the volcanic roof and the underlying naujaite, syenite, lujavrite and lava-lujavrite migmatite. Most of the veins of coarse-grained rocks appear to wedge out downwards.

As mentioned above, the volcanic rocks are strongly deformed and metasomatically altered in contact with all types of lujavrite. The deformation of the anorthosite appears to be earlier than the emplacement of the fine-grained syenite (Nielsen, 1967). This indicates that there were several periods of deformation which were most probably connected with various stages of intrusion, especially with the intrusion of the fine-grained alkali syenite and that of the fine-grained lujavrites.

The niobium mineralization in the sheared anorthosite, "rectangle porphyry", and gabbro is most probably genetically associated with the intrusion of the fine-grained lujavrite.

VI ECONOMIC GEOLOGY

The uranium and thorium mineralization of the Kvanefjeld area was discovered in 1956 and a preliminary description was given by Bondam and Sørensen (1959). A radiometric survey of the whole plateau has been made and a number of drill holes put down. Radiometric logging of the drill holes has been undertaken and numerous chemical determinations of U and Th in drill cores and surface samples have been made. A gamma spectrometric examination is in progress (Løvborg and Hansen, 1968; Løvborg, Kunzendorf and Hansen 1968 a). 1379 single determinations of the count rates observed with a γ-sensitive geiger counter in the joints of a 5 m grid are given in plate 7. In the same plate chemical determinations of U and Th in samples of surface rocks are given. The hatched areas in the figure indicate that the geiger count rate exceeded a level corresponding to 70 % of the logarithmic mean of all geiger count rates. These areas do not form any regular pattern. The cumulative frequency distribution of the γ-flux neither corresponds to a normal nor a log normal distribution (Løvborg et al., 1968 a).

The average contents of U and Th are 575 ppm and 1920 ppm respectively. The maximum values determined so far are 0.3 % U and 1.3 % Th. The radioactive minerals are steenstrupine, monazite and thorite (?). On the basis of the drilling program in 1958 it was estimated that there are at least 4000 tons of uranium in the plateau. Later examinations have shown that the strongly radioactive rocks extend farther to the north-east but this part of the deposit has not yet been investigated by drilling.

Niobium minerals occur in analcime veins associated with the medium- to coarse-grained lujavrite, and also in the metasomatized anorthosites and volcanics. In the first type of deposit the minerals are pyrochlore and epistolite, and in the second type they are of the epistolite-murmanite group (Hansen, 1968, Semenov et al., 1968). The analcime veins may contain up to 10 % by volume of pyrochlore, equivalent to more than 5 % Nb_2O_5.

The contents of niobium and tantalum in the metasomatized rocks reach values of 0.6 % and 0.015 % respectively. The ratio Nb/Ta varies from 13 to 511 and is highest in the rocks with the highest contents of niobium (Hansen, 1968).

Beryllium minerals occur in the analcime veins associated with the medium- to coarse-grained lujavrite and also in albite-analcime veins which are most probably genetically associated with the fine-grained lujavrites.

Beryllometres have been used in the beryllium survey (Hansen and Løvborg, 1966; Løvborg and Hansen, 1968; Løvborg, Kunzendorf and Hansen 1968 b; Engell, Hansen, Kunzendorf and Løvborg, in prep.) but no larger deposits of beryllium minerals have been found so far.

Sphalerite is a subordinate component of all types of lujavrite and also occurs in the radioactive rocks. The content of Zn varies from 0.1 to 0.7 %. Zinc could be produced as a by-product in the extraction of uranium from the radioactive rocks.

APPENDIX

Table 2

Table 2

Chemical analyses
weight %

Spec. No.	Rock type	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	F
65093	Gabbro I	46.99	2.99	18.17	2.60	8.59	0.16	3.83	7.91	4.58	2.18	1.36		
64484	Rect. porph.	51.57	1.17	21.12	1.56	3.82	0.04	1.40	7.81	6.08	2.32	0.50		
64486	Gabbro II	44.99	3.48	15.72	2.90	10.49	0.20	4.85	7.39	4.41	2.85	1.39		
65001	Fin. gr. alk. sy.	63.22	0.36	14.33	3.73	2.22	0.18	0.16	1.37	8.20	5.78	0.13		
64786	"	61.48	0.75	14.08	3.61	2.69	0.20	0.29	2.02	8.06	5.18	0.23		
65094	Trachyte	60.50	0.95	15.05	3.15	4.26	0.25	0.70	2.32	6.30	5.70	0.27		
65698	Black luj.	50.51	0.32	12.14	4.00	8.63	0.69	0.43	1.66	11.20	2.53	0.11		
77019	Njk. luj. +	50.58	0.33	14.97	4.42	9.03	1.04	0.08	0.31	14.04	2.10	0.18	0.23	0.14
77100	Med.-c. luj.	53.28	0.55	10.78	5.89	10.05	0.70	0.48	0.22	7.39	5.51	0.22	0.26	0.18
*a	"	53.87	0.42	12.04	4.02	9.11	0.59	0.06	0.80	6.70	7.40	0.42		
*b	"	54.35	0.41	11.29	5.90	7.45	0.60	0.09	0.71	7.60	6.43	0.69		
*c	"	52.70	0.30	14.58	5.23	5.44	0.49	0.03	0.93	10.10	4.71	0.54		
77102	Lamp.	42.85	4.15	14.33	1.85	8.01	0.07	7.69	8.87	4.50	4.12	0.98		
65382	"	41.95	2.39	14.91	1.70	7.55	0.30	5.53	9.96	5.80	3.28	0.66		
65699	"	52.81	2.41	13.04	2.53	10.74	0.22	0.19	4.94	5.10	4.33	0.88		
65319	"	57.34	0.18	11.80	4.82	6.30	0.63	0.34	0.96	6.25	6.40	0.07		
65322	"	40.73	2.65	13.84	3.15	7.26	0.04	5.01	6.64	9.40	4.05	0.40		
64689	"	41.23	2.73	13.21	2.29	8.41	0.00	6.18	6.99	6.18	4.92	0.58		

* Drill core no. 23 a: 31.60 - 31.90 m; b: 85.90 - 86.10 m; c: 88.32 - 88.68 m. Analyses taken from Østergaard (1964)

\+ Naujakasite lujavrite

Chemical analyses by Ib Sørensen, GGU chemical laboratory

CaO in chemical analysis includes SrO

Table 2 (continued)

X-ray fluorescence analyses
weight %

Spec. No.	Rock type	SrO	Cr_2O_3	ZnO	"Ce"	"Y"	Rb_2O	Li_2O	ZrO_2	Nb_2O_5
65093	Gabbro I	0.19	tr	tr	tr	tr	tr		0.07	tr
64484	Rect. porph.	0.32	tr	tr	tr	tr	tr		0.04	tr
64486	Gabbro II	0.14	tr	tr	tr	tr	0.01		0.04	tr
65001	Fin. gr. alk. sy.	tr	tr	tr	tr	tr	0.1		0.35	0.05
64786	"	0.03	0.2	0.05	tr	tr	0.1		0.16	0.05
65094	Trachyte	tr	tr	tr	tr	tr	0.02		0.09	tr
65698	Black luj.	0.02	tr	0.08	tr	0.21	0.07		1.99	0.13
77019	Njk. luj. [+]								0.34	
77100	Med. -c. luj.						0.17	0.27	0.19	
*a	"								0.02	
*b	"								0.07	
*c	"								0.15	
77102	Lamp.	0.23	0.04	tr	tr		0.05		0.1	0.03
65382	"	0.06	0.02	tr	tr		0.07		0.06	0.01
65699	"	0.04	tr	tr	tr		tr		0.05	0.01
65319	"	0.01	0.05	0.04	tr	0.15	0.15		0.52	0.5
65322	"	0.12	0.03	tr	tr	0.04	0.19		0.08	0.05
64689	"	0.10	0.06	tr	tr	0.02	0.5		0.08	tr

* Drill core no. 23 a: 31.60 - 31.90 m; b: 85.90 - 86.10 m; c: 88.32 - 88.68 m. Analyses taken from Østergaard (1964)

\+ Naujakasite lujavrite

Calculations based on table 2

CIPW weight norm+

Spec. No.	Or	Ab	An	Ne	Ap	Di	Ol	Mt	Il
65093	12.89	27.50	22.54	6.08	3.22	6.48	11.28	3.77	5.68
64484	13.72	32.67	23.44	10.14	1.18	10.01	1.76	2.26	2.22
64486	16.86	19.16	14.64	9.82	3.29	10.70	13.46	4.20	6.61

+ Norms calculated by means of an Algol III programme based on the principle set out by C. H. Kelsey (1965) Miner. Mag. vol. 34, 276-282. Only results from wet chemical analyses are used for the calculation. The CIPW norm is not valid for the peralkaline rocks; a norm for these rocks is in preparation.

Agpaitic coefficient

Spec. No.	65093	64484	64486	65001	64786	65094	65698	77019	77100
Agp. coeff.	0.54	0.59	0.66	1.38	1.10	1.70	1.74	1.70	1.68

Spec. No.	*a	*b	*c	77102	65382	65699	65319	65322	64689
Agp. coeff.	1.68	1.73	1.49	0.83	0.88	1.00	1.46	1.43	1.17

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Plate 1. Geological map of part of the Kvanefjeld area.

Plate 2. Fold pattern in the zone of mixed rocks in contact with the medium- to coarse-grained lujavrite. Locality ca. 10 m SE of drill hole 15.

Plate 3. Folded banded rocks from the zone of mixed rocks. Locality ca. 25 m NW of drill hole 15.

Plate 4. Border relations between medium- to coarse-grained lujavrite and the zone of mixed rocks. Locality ca. 30 m SW of drill hole 26.

Plate 5. Relations of fine-grained lujavrite and naujaite with medium- to coarse-grained lujavrite. Locality ca. 25 m S of drill hole 27.

Plate 6. Zone of alteration between medium- to coarse-grained lujavrite and fine-grained alkali syenite. Locality ca. 40 m WNW of drill hole 29.

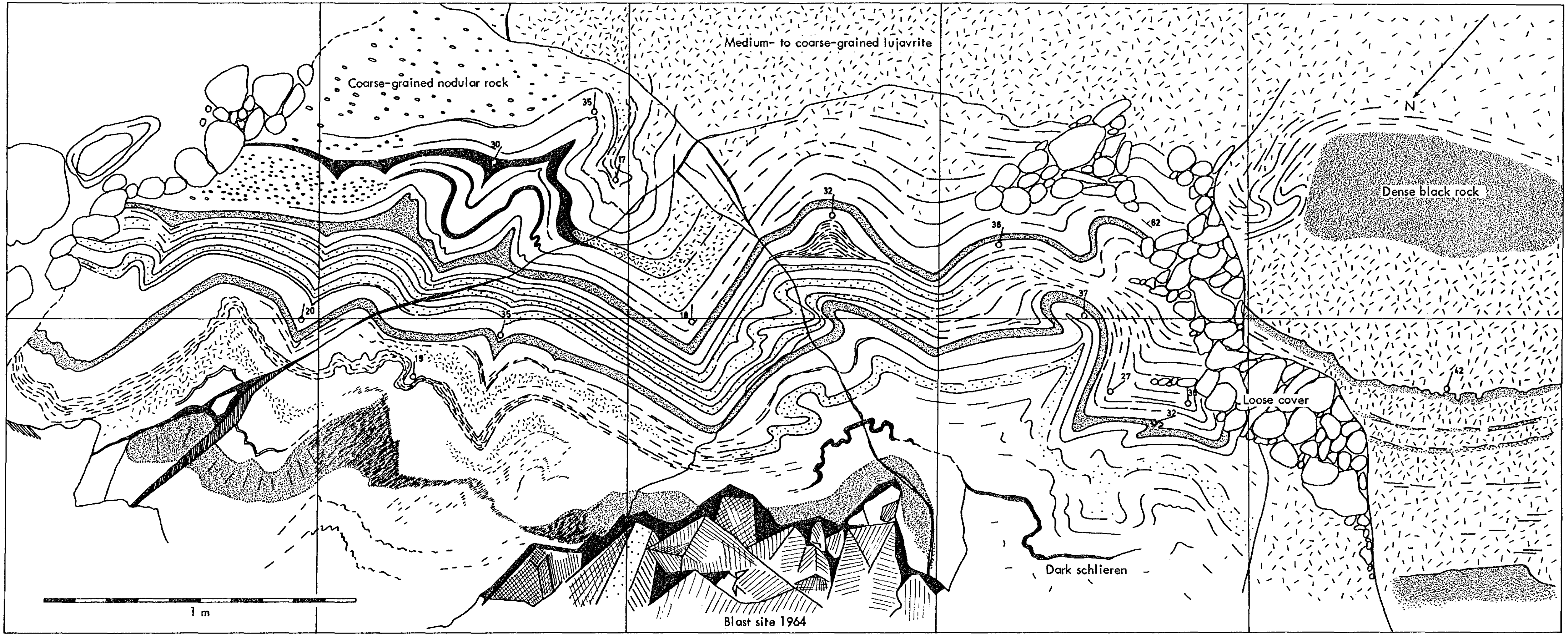
Plate 7. Radiometric map of the area near the trial excavation.

GRØNLANDS GEOLOGISKE UNDERSØGELSE

THE GEOLOGICAL SURVEY OF GREENLAND

PLATE 1

Plate 2


Medium- to coarse-grained lujavrite
Coarse-grained nodular rock
Dense black rock
N
Loose cover
Dark schlieren
Blast site 1964
1 m

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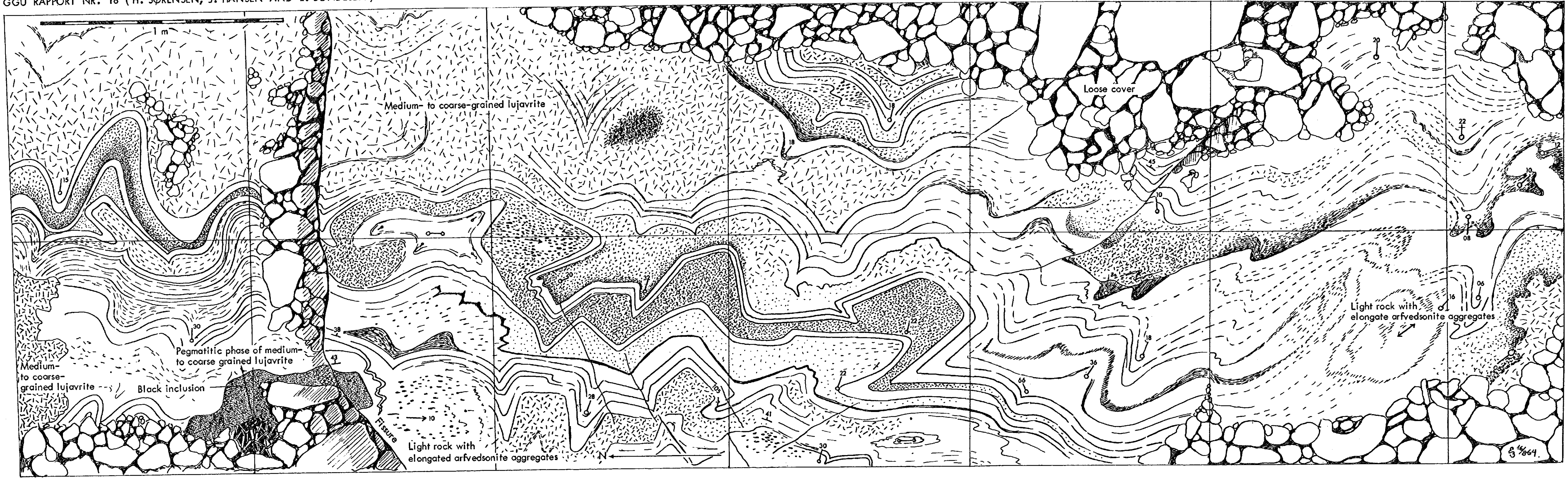

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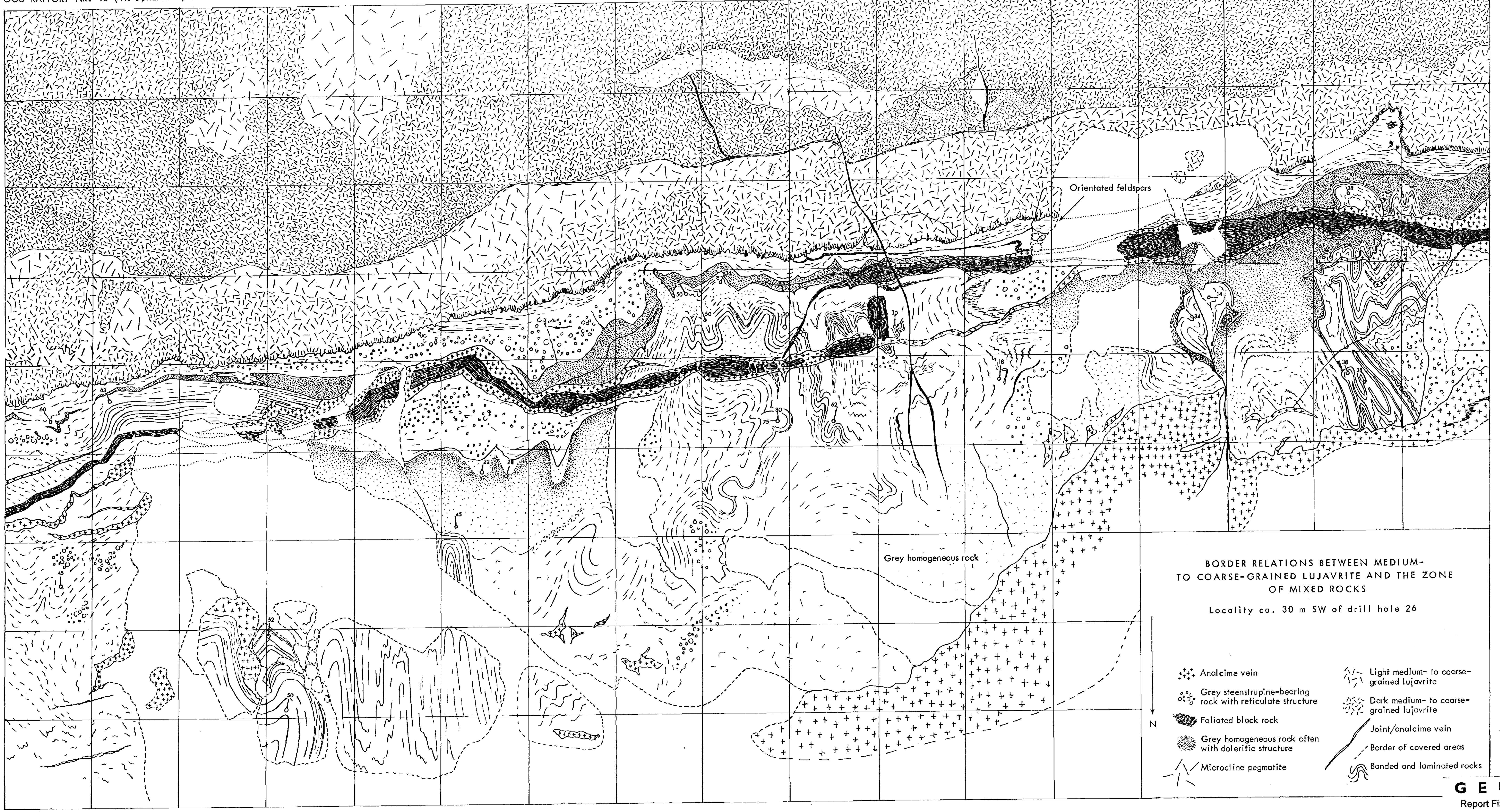

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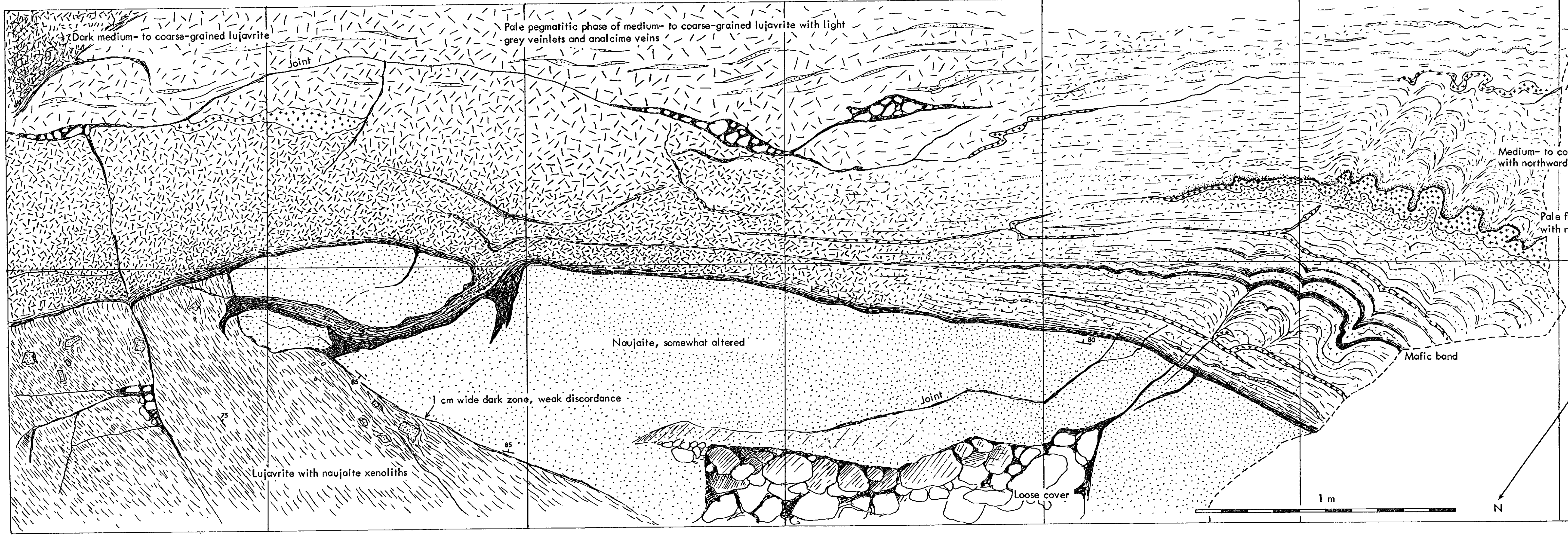

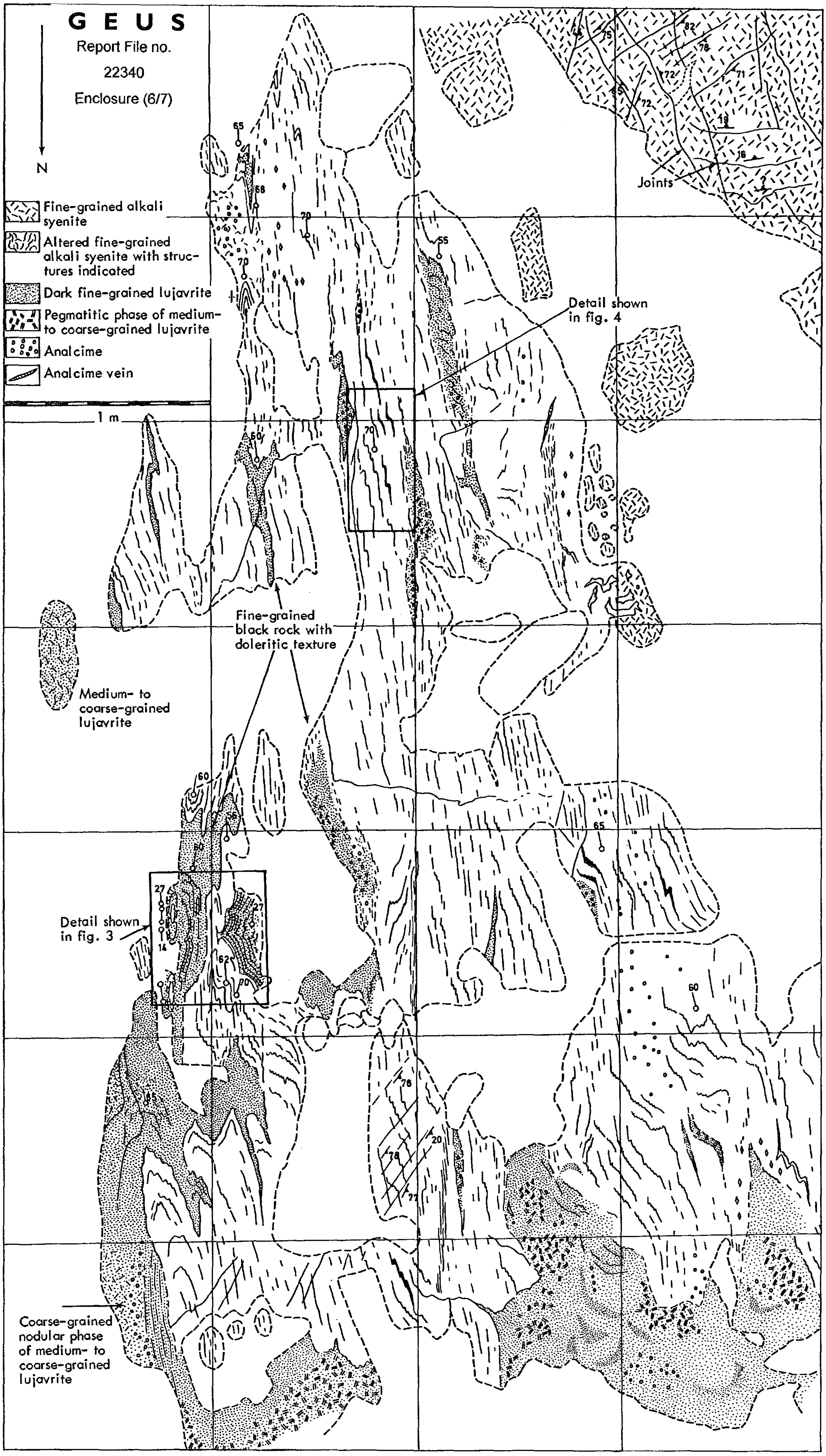
N
Fine-grained alkali syenite
Altered fine-grained alkali syenite with structures indicated
Dark fine-grained lujavrite
Pegmatitic phase of medium- to coarse-grained lujavrite
Analcime
Analcime vein
1 m
Joints
Detail shown in fig. 4
Fine-grained black rock with doleritic texture
Medium- to coarse-grained lujavrite
Detail shown in fig. 3
Coarse-grained nodular phase of medium- to coarse-grained lujavrite

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GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

PLATE 7

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No. 5 The Precambrian geology of the Sârdloq area, South Greenland. 1966 by B. F. Windley. D.kr. 7.00.

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No. 19 Report of activities, 1968. 1969. D.kr. 6.00.

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