5. On the Alkali Rocks of Almunge

A preliminary report on a new survey

By

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ABSTRACT.—The Almunge alkali complex is composed of nepheline-bearing sodic, and nepheline-free alkali syenites. The nepheline-bearing rocks (canadites) form a series of dike and sill intrusions starting with theralites and ranging through mesotype nepheline-amphibole rocks to leucocratic cancrinite-nepheline-biotite syenites. The nepheline-free syenites (umptekites) fail to disturb the pattern formed by the canadite intrusions. Powerful processes of assimilation and fenitisation were active during the formation of these rocks. Dike albitites and lestivarites are present in subordinate amounts and usually associate with zones of dislocation.

Contents

I. Introduction

Some 18 miles east of Uppsala a body of alkali rocks pierces the surrounding Archæan to form the Almunge alkali massif. Though reference in literature to the peculiar character of these rocks dates back to the sixties of the last century, they were not then considered to be other than a differentiated facies of Archæan granites and as such did not attract special attention. Thus it was not until 1912 that a systematic investigation of the alkali complex was begun. In his classic treatise of 1914, P. D. QUENSEL presents a rather detailed description of the chief alkali rock types as well as an account of their main structural features.[1] Basing his conclusions on the shape of the massif, its rock sequence and its structure plus an interpretation of the petrographic and tectonic pattern of the contact zones, QUENSEL suggests that the alkali district represents a deep-seated section through a volcanic neck of Late Archæan age. Citing QUENSEL: "The nepheline bearing rocks must be interpreted as older than the umptekite and can be explained as remains of the older magma which first filled the channel, but was followed by the intrusion of umptekite now enveloping some remains of the older rocks as great inclusions."

In spite of the brilliance of this first geological description much work remained to be done in the area.

Professor ERIK NORIN of Uppsala has, since 1945, conducted investigations into the geology of the alkali complex, resulting in a great number of significant new observations. The mapping work of that period was to a great extent carried out by student participants of the annual training-courses in geological field work. It was due to NORIN's suggestion that the present author in 1955 investigated some features of the western contact zone of the massif, this work later expanding to include all of the alkali rocks and their Archæan surroundings.

Thus, in 1957, a thorough revision of the geology of the Almunge area was launched, involving among other things a detailed remapping on a scale of 1 to 5000. Since the present investigation is far from complete, field and laboratory work are to continue for some time, before the area can be considered ready for conclusive treatment. It will thus be found that considerable parts of the alkali massif have not yet been the object of more than a superficial survey. Moreover, due to the timetable of the present work, a number of very important stages of the investigation have, as yet, barely been tackled, or are still unfit for publication.

Sincere thanks are due to Prof. E. NORIN, whose aid and suggestions greatly contributed to the progress of the work, and whose interest was a never failing source of inspiration.

I am also much indebted to Prof. QUENSEL, who placed at my disposal a map prepared during his investigation of the area, and to Dr. E. ÅHMAN for communicating several interesting field observations. Thanks are further due to Mr. O. WALLNER, who has been — and still is—preparing a steadily growing number of thin sections of Almunge rocks. For financial support the author is indebted to the trustees of the field research funds of this university.

[1] The story of the discovery of the massif and the previous surveys in the area is told by QUENSEL.

The new chemical analyses presented here have been executed at the Dept. of Analytical Chemistry of the University of Uppsala under the supervision of Prof. F. NYDAHL.

The optical data of the respective minerals have been obtained using a microscope equipped with a universal stage. The volumetric analyses have been carried out with a point-counter device; this, however, does not include examinations of contact rims and other smaller parts of slides, where a Leitz integration-table has been employed.

Niggli values for Q, L, M, π, γ, α and μ were calculated in accordance with BURRI and NIGGLI (1945).

II. Size, Rocks, and Main Structural Features of the Alkali Complex

The alkali rocks of Almunge form an irregularly rounded area (cf. Map, Pl. I) of some 15 sq. km, surrounded by Svecofennian Archæan supracrustals and plutonics. They can—with a certain degree of simplification—be divided into the following main types:

(1) Nepheline-bearing rocks and their associates, termed canadites by Quensel.

(2) Alkaline, nepheline-free and frequently somewhat quartz-bearing syenites constituting the umptekite group.

(3) Albite-rich, fine-grained rocks, characteristically concentrated in the peripheric parts of the massif.

In addition to this the list should include umptekite-canadite contact rocks (QUENSEL's white canadites), different kinds of pegmatite, quartz-bearing rocks petrographically ranging from syenites to alkali granites, and finally, the important and diversified assembly of fenitised Svecofennian surroundings.

The areal distribution of these constituting elements is of a by no means haphazard nature. The occurrences of nepheline-bearing rocks form a well-defined pattern, some of them joining in an obvious ring of comparatively small, mostly schistose en-echelon dikes, encompassing nearly all of the western, southern and northern peripheries of the alkali area. Whether or not there is a corresponding configuration in the east is as yet not definitely brought out by the mapping. In the eastern central part of the massif larger, multiple, lens-shaped bodies of the main canadite field display a conspicuous arrangement along a somewhat curved axis of north-northwesterly strike, running right through the alkali area from its northern to its south-eastern borders. In addition to this there is in the southern and central parts of the massif a set of canadite dikes, all of them striking in a north-easterly direction. Inside, or in the vicinity of, the outer contact zones of the alkali rock body the dip of the canadites is vertical to 70° toward the centre of the massif. Nepheline-bearing rocks situated more centrally display less definite tectonic relationship, this being due to a great amount of disruption and hybridization of the contacts. Subhorizontal parallel structures occur here, as do subhorizontal contacts between canadite and umptekite. A final evaluation of these observations has, however, been postponed, pending an investigation of some canadite bodies not yet mapped in sufficient detail. As pointed out by QUENSEL umptekites occupy the central parts of the alkali district and are in his opinion younger than the nepheline-bearing rocks. The shape of the area made up by them is rather irregular, its outlines projecting in places beyond the outer canadite ring, but more often failing to reach it, frequently missing it by a couple of hundred yards. Between the umptekites and the country-rock there is a broad belt of still macroscopically recognizable Svecofennian rocks in different stages of fenitisation. Moreover the umptekites, as contrasted with the canadites, include numerous and large slices of more or less fenitised Archæan rocks. The contacts toward these inclusions and the canadites are in part intrusive and brecciating (Gränby, Skallerbol, cf. Map, Pl. I.), but at least as often highly gradational, demonstrating step-by-step umptekitization processes including intense microcline-perthite and antiperthite porphyroblastese. The orientation and distribution of the different Archæan remnants is moreover by no means fortuitous; indeed, they easily allow of reconstruction of the prealkaline geology in substantial parts of the area now occupied by umptekitic rocks. The outer border of the alkali rocks roughly coincides with the peripheric ring of canadites, and is characterized by a zone of strongly schistose and leucocratic albite-rich aplitic rocks enveloping the alkali area. The environs of this roughly circular structure—bot in- and outside of it—are involved in different stages of fenitisation and pass gradually into often sodium-rich fine-grained marginal rocks and finally into umptekite. Having established this, there seems to be no point in further discussing the exact location of a "contact line", it being impossible to define such a line except in terms of a haphazardly fixed amount of alkalinisation of the surrounding rocks or of a certain amount of alkaline dikes. There is certainly nothing like a sharp contact separating a compact mass of syenites from the Svecofennian country-rocks, but instead a transitional zone 50 to 500 metres wide between the two.

In this connection some space must be allotted to what QUENSEL calls "a large amount of inclusions of dark rocks (which) have accumulated along the contact" and which he interpreted as "exogenous inclusions brought up from deeper levels by the rising umptekite magma" (QUENSEL, op. cit., p. 138–141, 196). The present detailed survey of the contacts confirmed these observations, but it also revealed the existence of a widespread supracrustal series including among other things basic volcanics, and of masses of inclusions, dikes and bodies of supracrustal, hypabyssic and plutonic basic rocks in the surrounding Archæan granite terrain. A correlation of these observations with the localities of dark inclusions along the margin of the alkali complex showed good agreement between the two. Due to the great diversity of the country rock, to variations in its power to resist alteration by the umptekites and to colour contrasts enhanced during the fenitisation, there seems to be, in places, an apparently abnormal accumulation of dark fragments in the contact zone of the alkali rocks. However, in every case investigated—and this includes most of the contact zone—there were found to exist corresponding occurrences of dark rocks outside the belt of fenitisation. Besides, there are numerous inclusions of all kinds of fine-grained, often dark, rocks troughout the alkali area, which in some cases still display strike directions joining them to supracrustal or dike rocks outside the alkali massif. This not only does not corroborate, but indeed contradicts the earlier conception involving a supply of dark fragments from the depths.

III. The Country Rocks

The rocks bordering the alkali massif range from early Svecofennian supracrustals to late Svecofennian granites. The oldest of these belong to what is known as the leptite series and include volcanics, limestone, and iron ores. They are exposed both east and west of the alkali complex, fragments of reddish and greyish leptites and grey porphyrites enclosed in granite touching upon its northern and eastern edge.

Some of the supracrustals bordering on and included in the syenites, belong, however, to a folded, steep-dipping sedimentary series chiefly composed of stratified quartz-oligoclase gneisses, quartzites, and micaceous shists concordantly interbedded with basic layers probably representing altered tuffites or lava beds. These sediments locally grade into garnet-sillimanite and/or cordierite gneisses. Incidentally the "cordierite-pseudoconglomerate" at L. Ellringe, which is mentioned by QUENSEL, is located in rocks belonging here.

Sizable areas of supracrustals invaded by granites are found just off the northern border of the alkali massif, where their strike runs in N and NE directions. From here they can be traced past and through the alkali complex to its southern parts, where they divide into two major belts interrupted in places by granites. One of these stretches past Gränby to the east, the other follows a SSW strike to the vicinity of Husby-Långhundra. Both eventually join the Widbo–Husby-Långhundra–Rånäs gneisses partly described by WIMAN (1930).

Middle Svecofennian infracrustals comprise generally strongly uralitised medium to coarse-grained basic and ultrabasic plutonics, diorites and granites. The basic rocks partly occur as small massifs of either pre- or postgranitic age. In other cases they form lenticular bodies which run parallel to the strike of the granites and then display very indefinite contact relations. Quartz-diorite, composed of andesine-labradorite, hornblende, quartz and essential amounts of biotite, chlorite, epidote, and sphene, brecciates the supracrustals to form a large body immediately south of Lake Södersjön.

The granite group includes penetrating grey tonalites and granodiorites of the Uppsala type, grey or reddish grey intermediate, and finally red acid granites, the last mentioned invariably being the youngest of the series. Basic grey tonaites and granodiorites compose much of the country rock. They often display parallel structures and/or schistosity, thereby changing into gneiss-granites. Xenolites of supracrustal rocks are here exceedingly common. The main constituents of the granodiorites and tonalites are partly sericitized andesine, quartz, common hornblende and biotite. Microcline is a constant constituent, but occurs in highly varying amounts. Sphene, chlorite, epidote, apatite, ores, and allanite are common accessories. The intermediate granites to the south-east and north of the alkali complex are usually medium- to coarse-grained and, as often as not, carry white or pink microcline porphyroblasts. They consist of microcline, plagioclase, quartz and biotite with fluorite as a rather constant accessory mineral. White fine- to coarse-grained, often porphyric granites are rather prominent in the northern and north-western parts of the area surveyed. Invariably they are intimately associated with and grade into rocks belonging to the supracrustal series. Acid red granites and gneiss-granites occupy large areas at the SW, W and NE limits of the alkali complex as well as in its western central parts. They consist of quartz and roughly equal amounts of somewhat sericitized albite or albite-oligoclase and slightly perthitic microcline. The dark minerals include biotite, chlorite, hornblende and sphene and usually do not exceed 3% in weight. West of Almunge railway station this rock grades into leptitic gneisses. Intrusive contacts are frequently displayed against the basic granite, gabbro, and rocks of the supracrustal series, more or less altered remains of all these occurring in the acid granite around Lake Fladen. At the contacts the attacked rocks often suffer a substantial increase their microcline and fluorite contents, the red granite invading the basic massifs losing in its turn most of its quartz and carrying up to 15 vol.% epidote. A selection of volumetric analyses of Svecofennian rocks of the Almunge district is tabulated on page 7.

Late Svecofennian magmatic activity resulted in the formation of a great number of amphibolite dikes, some of them conforming with the foliation of the gneiss-granites, others crosscutting it, but then in some cases displaying linear structures running parallel to the schistosity of the country rock. The tectonics and mineral composition indicate at least three different generations.

This was followed by a final migmatization locally implying potash-metasomatism of the older rocks, and by intrusions of red and grey granitic, aplitic and pegmatitic rocks of the Stockholm granite clan.

Broad shear zones are responsible for the subsequent formation of the Lake Södersjön and Kärven valleys. The early and middle Svecofennian rocks and the amphibolite dikes bordering these zones bear witness to intense deforma-

Table 1. Actual mineral composition of Archæan Almunge rocks (vol. %)

	1. Quartz	2. Plagioclase	Average An % of 2.	3. Alteration products of 2., mainly sericite	4. Microcline	5. Amphibole	6. Biotite	7. Chlorite	8. Epidote	9. Ores	10. Sphene	11. Apatite	12. Allanite	13. Zircon	14. Calcite	15. Fluorite
1. Plagioclase-porphyry; inclusion in basic gneiss-granite	10.3	36.7	35	3.0	0.7	20.3	24.9		0.1	0.0	2.7	1.3	—	0.0	—	—
2. Plagioclase-porphyry; inclusion in acid red granite	12.5	45.2	35 + ab	0.1	5.5	10.8	21.7	0.8	0.0	0.0	2.6	0.7	—	—	—	—
3. Supracrustal gneiss, slightly fenitised, St. Söderby	34.6	50.6	15	—	5.3	4.9	2.6		—	0.0	0.9	0.2	—	0.5	0.4	—
4. White acid granite, L. Ellringe	44.0	36.6	10	0.5	9.0	—	7.6	1.5	—	0.7	0.0	0.1	—	0.0	—	0.0
5. Red acid granite, Lövhagen	35.0	31.0	6	1.6	30.0	0.6	0.9	0.3	0.3	0.1	0.0	0.1	0.0	0.0	—	0.1
6. Basic gneiss-granite, mean composition of the rock S of the alkali area	21.8	40.9	35	3.7	10.9	6.8	12.9	0.4	0.1	0.2	1.8	0.3	0.1	0.0	0.1	0.0
7. Quartz-diorite, S of L. Södersjön	23.5	36.4	42	7.6	1.0	11.1	5.6	6.5	5.6	0.1	2.3	0.3	—	—	—	—
8. Hornblende-gabbro, Lövhagen	—	21.9	50	14.9	—	40.5	13.0	4.0	2.1	0.7	2.5	0.4	0.0	—	—	—
9. Acid vein in hornblende-gabbro	32.6	56.6	26	7.7	0.6	0.1	0.5	—	1.1	0.0	0.3	0.2	0.0	0.3	—	—
10. Dike amphibolite, Uddnäs-Lövhagen	—	28.2	41	—	0.8	64.2	1.0		1.0	0.1	3.3	1.5	—	—	0.0	—
11. Dike amphibolite, N of Lake Södersjön	—	26.9	40	—	—	64.7	7.1		0.1	—	1.1	0.1	—	—	—	—

tions accompanied by potash metasomatism and predetermining these tectonized belts to intrusions of dikes of Stockholm-granite conspicuously accumulated here. Post-Stockholm granite movements here produced faults and quartz-healed breccias. Curiously enough these inhomogenity zones are devoid of indisputable alkali rocks except for a couple of albite-aplite dikes. Another well discernible set of faults transverses the district in NS to NNE–SSW directions.

IV. The Nepheline-Syenites

The nepheline-bearing rocks, denoted by QUENSEL as canadites include a variety of types ranging from theralites to rocks all but devoid of dark minerals. In order to facilitate their description the canadites will be divided in accordance with their mineralogical and structural characteristics as follows:

(1) Theralites and theralitic canadites. The line separating these rocks from the rest of the canadites is arbitrarily drawn at about 35–40 vol.% mafic minerals. As can be deduced from specimens in the possession of the Mineralogical

Museum at Uppsala, this will exclude some types of QUENSEL's theralitic canadites. Again, the above definition makes it possible to single out the group in the field, there being a hiatus in the structural development and areal distribution of the nepheline-bearing rocks at about this percentage of dark minerals.

(2) QUENSEL's normal canadites.

(3) Leucocratic canadites.

(4) Schistose nepheline-syenites of the border zones.

(5) Nepheline-syenite pegmatites.

(6) A somewhat problematic rock at the northern margin of the alkali complex.

Among the Almunge nepheline-syenites, the theralitic types are invariably the oldest. They often form fragments included in brecciating rocks belonging to groups 2 and 3 of the above list. This is the case for instance S and SW of Sågen and E of Skallerbol. Leucocratic nepheline-syenites are, with the possible exception of some pegmatites, the youngest of the series. Quantitatively they are rather subordinate, often appearing only as small veins.

1. *Theralitic canadites*

Though gradual transitions to "normal" canadites do occur in places, the rocks now referred to generally form a fairly well delimited group. They occupy the central parts of the main canadite field dominating an area which stretches southwards from a point some 200 m ENE of Byske to the path connecting Skallerbol and Sågen. Other outcrops are found S and SW of this line and also at Upptorp, NE of Byske and other places. Preliminary estimates based on maps of the present survey show that theralitic rocks occupy about half the area made up of nepheline-syenites.

As regards texture two main types of these blackish to dark grey, medium- or coarse-grained rocks can be discerned. One of them displays a well-developed trachytoid texture of automorphic and subautomorphic slender amphibole and plagioclase crystals surrounding spherical or short prismatic nepheline *augen* of a diameter usually ranging from 5 to 15 mm. This nepheline is spotted with small elongated automorphic amphiboles oriented at random and often concentrated to the periphery of the nepheline grains. The second type of texture is one of slender amphibole needles set in a xenomorphic groundmass of nepheline and plagioclase. This theralite variety is often encountered in small isolated or peripheric occurrences, as for instance at Upptorp, and possibly partly owes its development to a recrystallization of originally trachytoid types.

The main minerals are, in the order of abundance, amphibole, plagioclase and nepheline plus alteration products. Biotite is sometimes an essential constituent whereas pyroxene, sphene, ores, and apatite constitute the minor minerals. In unaltered rocks the percentage of potash feldspar was never ob-

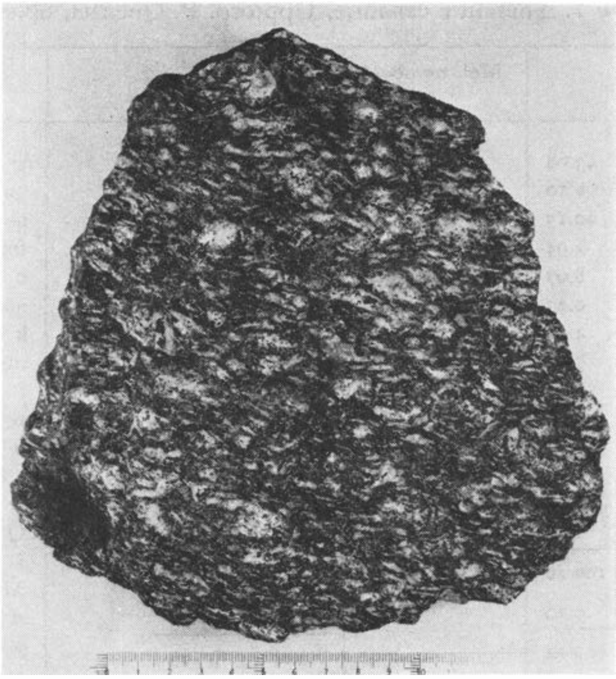


Fig. 1. Trachytoid theralitic canadite. 300 m NNE of Skallerbol. Photo G. Andersson.

served to exceed 0.2. Composite potash-sodium feldspar is at times encountered in what was described as the second textural type.

The plagioclase is an albite-oligoclase or, more often, an oligoclase-andesine, the An percentage of the latter varying between 25 and 35. As is the case in most other canadites closely-spaced polysynthetic twinning acc. to the albite law is extremely well developed. Although the plagioclase of non-marginal theralites has as a rule a fresh appearance, small grains of sericite and more seldom clinozoisite may frequently be encountered. The amount of nepheline and its alteration products is comparatively constant at about 25%. Well progressed alteration to sericite, analcite and fibrous zeolites is the rule, the pseudomorph minerals commonly also including small amounts of calcite, cancrinite and zoisite. Analcite, while usually found inside the nepheline pseudomorphs of forming rims around (altered) nepheline crystals sometimes also replaces the inner parts of plagioclase laths, occasionally forming patches limited by the (010) and (001) planes of the host crystal.

The amphibole is a brownish green one with rather low birefringence (about 0.012–15), $b = Y$, $c \wedge Z = 20$–$30°$ and $2V_x$ varying between 35 and 45°. Twinning on (100) is rare, diffusely zoned structures implying green borders around greenish brown cores studded with small sphene and ore crystals are, as a rule, well developed in most theralitic canadites. Absorption and pleochroism are:

Analysis No 1. Theralitic canadite, Upptorp. P. Quensel, op.cit., p. 182

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	43.68	73.73	or	11.74		si	99.0
TiO_2	1.10	1.38	ab	13.11		qz	−73.9
Al_2O_3	20.15	19.77	an	18.00		al	26.9
Fe_2O_3	2.94	1.84	ne	24.68		fm	37.2
FeO	8.97	12.49	hl	0.12		c	17.6
MnO	0.23	0.32	sal	67.65		alk	18.3
MgO	4.38	10.86				k	0.16
CaO	7.24	12.91	wo	3.50		mg	0.40
Na_2O	7.00	11.29	fs	1.86	di 6.97	f	1.43
K_2O	1.99	2.11	en	1.61		ti	1.88
P_2O_5	1.38	0.97	fa	8.33	ol 14.84	p	1.32
F	0.20	1.05	fo	6.51		c/fm	0.47
Cl	0.07	0.20	mt	4.26		w	0.14
H_2O	0.89		il	2.09		Q	16.2
Sum:	100.22		ap	3.26		L	55.5
			fr	0.16		M	28.3
− O for F, Cl	0.10		fem	31.58		π	0.19
	100.12		Sum:	99.23		γ	0.19
						α	−2.20
			+ H_2O	0.89		μ	0.32
				100.12			
CIPW classification II : 6(7) : 2 : 4			ne : or : ab : an		36.5 : 17.4 : 19.4 : 26.7		

Z = bluegreen > Y = green to brownish-green > X = greenish- or brownish-yellow.

Small light green crystals of aegirinic diopside ($c \wedge Z \geqslant 50°$) are present in subordinate amounts, as also is sphene. Most of that mineral and some of the biotite are alteration products of the amphibole. Shades of green dominate the pleochroic colours of the biotite, brownish hues were sometimes observed in mafic theralites. Numerous apatite prisms are found in all specimens of theralite and canadite. Calcite, epidote, chlorite, prehnite, and garnet are of a secondary or deuteric origin. The last three minerals along with accessorily occurring cancrinite cannot be traced in most of the slides examined.

The apparent order of crystallization in the theralitic canadites is:

Pyroxene ———
Amphibole ———————————————
Nepheline ————————————
Albite ——————————————
Biotite —————

Analysis No 2. Theralitic canadite, Skallerbol. General sample

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	44.44	73.99	or	10.35		si	106.0
TiO_2	1.48	1.85	ab	19.29		qz	−61.1
Al_2O_3	18.15	17.81	an	16.94		al	25.5
Fe_2O_3	2.78	1.74	ne	17.55		fm	36.2
FeO	9.23	12.85	sal	64.13		c	21.5
MnO	0.26	0.37				alk	16.8
MgO	3.44	8.53	wo	5.54	di 11.12	k	0.16
CaO	8.42	15.01	fs	3.32		mg	0.34
Na_2O	6.11	9.86	en	2.26		f	1.73
K_2O	1.75	1.86	fa	7.16	ol 11.58	ti	2.65
P_2O_5	1.33	0.94	fo	4.42		p	1.35
S (total)	0.05	0.16	mt	4.03		co_2	1.05
CO_2	0.32	0.73	il	2.81		c/fm	0.59
F	0.23	1.21	pr	0.10		w	0.21
$H_2O^{>105°}$	1.79		ap	3.16		Q	19.0
Sum:	99.78		cc	0.73		L	50.3
−O for F, S	0.12		fr	0.23		M	30.7
	99.66		fem	33.76		π	0.21
$H_2O^{<105°}$	0.10		Sum:	97.89		γ	0.26
			$+H_2O^{>105°}$	1.79		α	−1.50
				99.68		μ	0.25
CIPW classification II:6:2:4			ne : or : ab : an		27.4 : 16.1 : 30.1 : 26.4		

2. *Normal canadites*

The normal canadite is generally a medium grained rock grey in colour. Trachytoid textures are only seldom encountered, the minerals are mostly xenomorphic and the rock massive.

The amount of nepheline is usually somewhat higher than that of the theralitic rocks and varies within wide limits: ijolitic rocks with as much as 50–70 vol.% nepheline can thus be observed. The plagioclase is an all but pure albite, composite potash-sodium feldspars (soda-orthoclase) sometimes being present in fairly large amounts. Orthoclase and microcline do occur, but are not common, the latter mineral usually showing signs of a late origin. Its content increases markedly as the borders toward the umptekite are approached. Cancrinite can occasionally be found in great amounts, but its distribution is somewhat inhomogeneous, the mineral displaying a tendency to accumulate in streaks of more leucocratic rock. Nevertheless it can be said to be characteristic of most normal canadites.

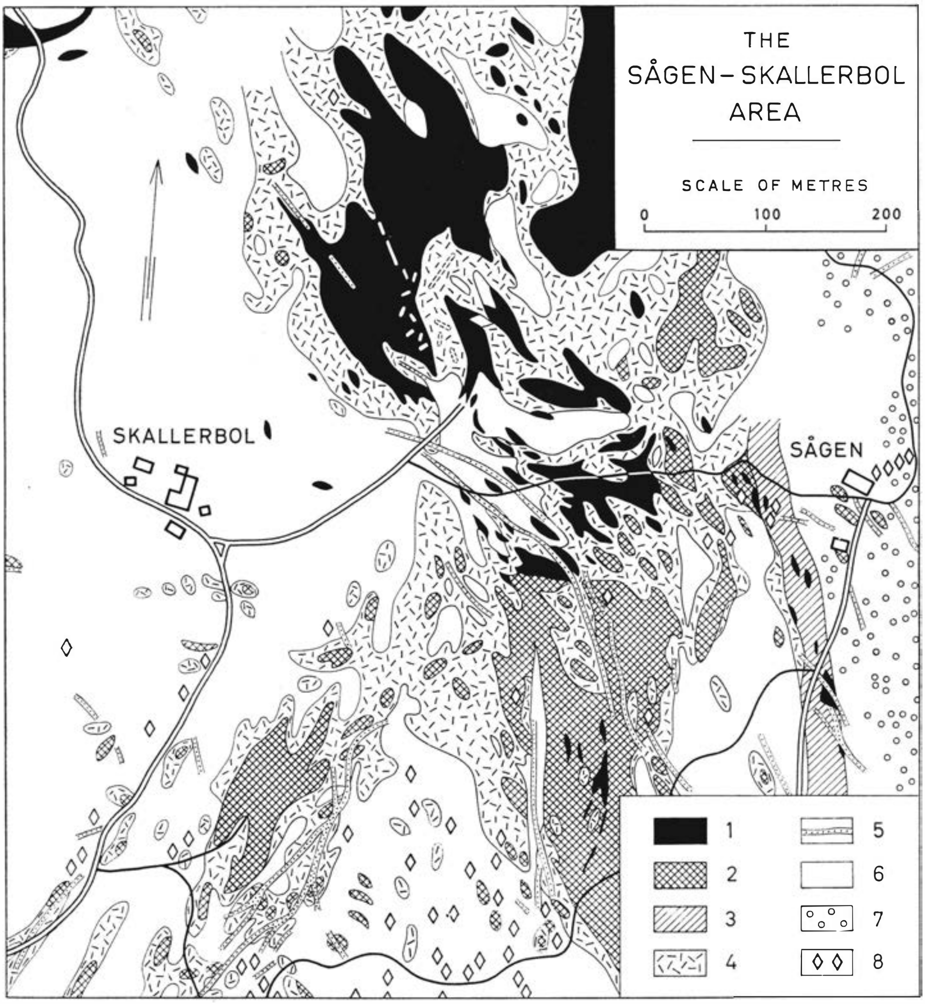


Fig. 2. Detail map of part of the main canadite field. Legend: 1 = theralitic canadite, 2 = normal canadite, 3 = leucocratic canadite, 4 = white syenite, 5 = lestivarite, albitite, aplites, 6 = umptekite, 7 = fenitised red granite, 8 = inclusions of supracrustals and metabasites.[1]

As to the dark minerals they are similar to the corresponding components of the theralites. Green biotite, however, holds a more prominent position. Both biotite and amphibole are commonly strongly corroded by the leucocratic minerals, especially albite. The original extent of the attacked amphibole grains is then often still traceable, being marked by rows of small sphene droplet-crystals which were left behind as the amphibole disintegrated (fig. 3 and 4). Bluish-green amphiboles and green borders in cases of zoning are rather

[1] In the area NW and W of Sågen new outcrops disclosed by forest-fire prove some of the canaditis here entered as isolated patches to form coherent N–S striking bodies.

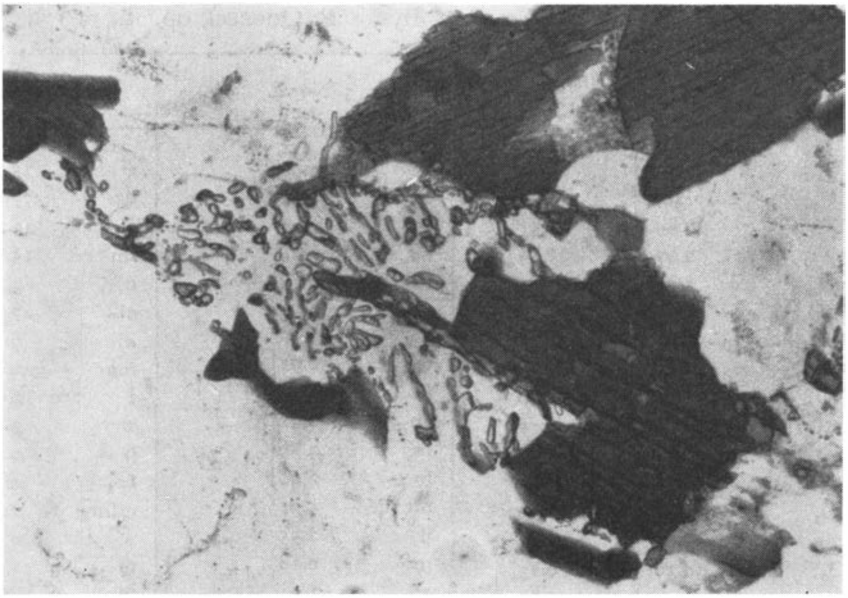


Fig. 3. Residual sphene droplet-crystals in albite corroding amphibole. Norrby farm. 1 nic., 220 ×.

more prominent than in the theralites. The mineral also displays purer green or blue-green hues and lower axial angles.

The other constituents are as listed under the previous heading, in addition to some garnet, allanite, and vesuvianite not to be encountered in most slides. As the occurrence of the last mentioned mineral has previously been the subject of much discussion, exceptional attention was paid to its position in the area. In the course of the present investigation all the vesuvianite localities mentioned by QUENSEL have been relocated, in addition to the discovery of a great number of other vesuvianite-bearing rocks. The results thus obtained show that vesuvianite is not restricted to the canadites only, but also occurs in remnants of basic Archæan rocks enclosed in the umptekite. Concerning its presence in the canadites the mineral can, as mentioned by QUENSEL, be found at localities as far apart as one can go without leaving the alkali complex. Still, there is a very pronounced degree of order governing its distribution. The canadite rocks most abundant in vesuvianite were found to be transitional or border types, viz. fragments of theralite enclosed in normal canadite, border zones between normal and theralitic canadite and finally the white syenites which form contact aureoles separating canadite and umptekite, and which are to be described later. In contrast to this the central parts of larger normal or theralitic canadite bodies are devoid of vesuvianite. The metabasite remnants carrying the mineral are either supracrustal rocks or belong to bodies of altered uralite-gabbro. The last type of vesuvianite occurrence is important, contradicting as it is a possible

Analysis No 3. Normal canadite, Byske. P. Quensel, op.cit., p. 179

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	48.60	80.92	or	13.36		si	135.3
TiO_2	1.34	1.68	ab	34.92		qz	−75.0
Al_2O_3	19.89	19.51	an	9.23		al	33.2
Fe_2O_3	2.97	1.86	ne	20.76		fm	25.9
FeO	5.76	8.02	th	0.18		c	13.3
MnO	0.36	0.51	sal	78.45		alk	27.6
MgO	1.32	3.27				k	0.15
BaO	0.05	0.03	wo	0.91	di 1.84	mg	0.21
CaO	4.43	7.90	fs	0.62		f	0.53
Na_2O	8.74	14.10	en	0.31		ti	2.81
K_2O	2.26	2.40	fa	4.59	ol 6.67	p	0.65
Ce_2O_3	0.59	0.18	fo	2.08		co_2	4.18
P_2O_5	0.56	0.39	mt	4.31		c/fm	0.51
S	0.01	0.03	il	2.55		w	0.30
SO_3	0.10	0.13	pr	0.18		Q	21.4
CO_2	1.10	2.50	ap	1.31		L	61.6
F	0.06	0.32	cc	2.50		M	17.0
H_2O	1.73		fr	0.23		π	0.09
Sum:	99.87		fem	19.59		γ	0.23
− O for F, S	0.03		Sum:	98.04		a	−3.47
	99.84		$+ H_2O$	1.73		μ	0.16
				99.77			
CIPW classification II : 6 : 2 : 4			ne : or : ab : an		26.5 : 17.1 : 44.6 : 11.8		

influence of calcareous sediments on the genesis of the mineral. No vesuvianite has been found in the basic rocks and gneisses encompassing the alkali massif. The nearest occurrence is a limestone-skarn more than 10 km to the south (WIMAN op. cit.), which, of course, is a rather natural place for vesuvianite to occur and which does not seem to have any direct bearing on the presence of the mineral in the Almunge rocks.

T. INOUE and A. MIYASHIRO (1951) compare a number of vesuvianite analyses and conclude that vesuvianites from nepheline-syenitic rocks are characterized by higher contents of Al and Ti and lower of Ca and Mg than those from metamorphosed calcareous rocks. While the number of analyzed specimens from nepheline-syenites is too low to permit statistical treatment, their chemical composition is, in most respects, well outside the field of metamorphic-calcareous-rock vesuvianite.

The minerals commonly associated with vesuvianite in the Almunge rocks are albite, biotite, diopside and chlorite. Garnet occurs in the same type of rock

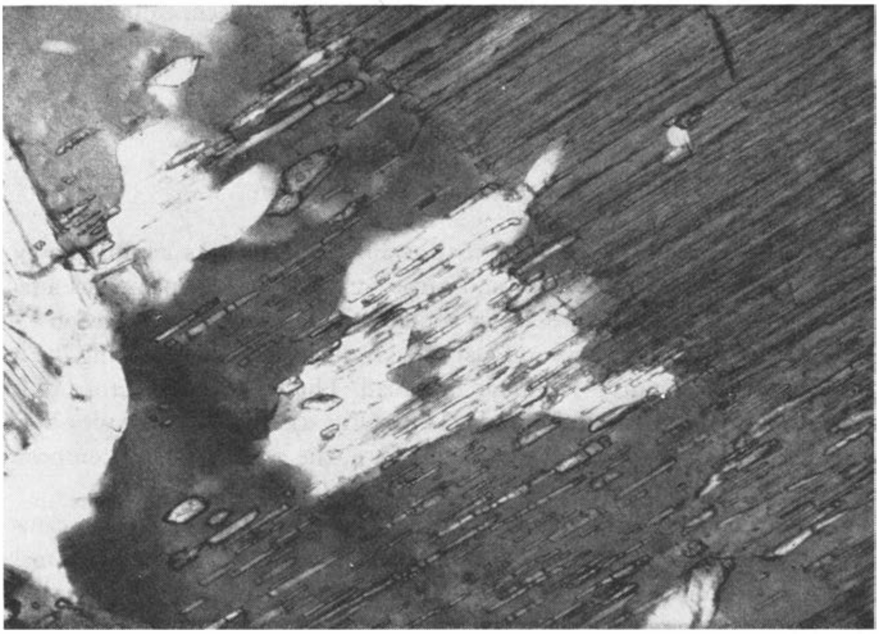


Fig. 4. Amphibole (upper right) replaced by albite and biotite. The sphene droplets here still retain their original orientation parallel to the c-axis of the amphibole. SW of Sågen. 1 nic., 130 ×.

but not strictly together with vesuvianite. Instead they seem to take each others place. The vesuvianite paragenesis is further characteristically low in amphibole, which gives place to biotite. When occurring in schistose rocks (deformed inclusions etc.) vesuvianite generally displays a manifest preferred orientation of the crystallographic c-axis parallel to the foliation. The crystals of the mineral here, as in other cases, occur either as single subautomorphic ones or in large radiating clusters frequently enclosing biotite, diopside, albite a. o. in a helicitic manner. While a detailed elucidation of the chemical and physical conditions of the formation of vesuvianite in the Almunge rocks requires more chemical data, and still more studies of the petrographic setting of the mineral, the facts presented above are considered to indicate an origin by contact influence and the action of metasomatizing alkaline solutions on rocks relatively richer in calcium. This origin is evidently similar to that proposed for the vesuvianites of Afrikanda and the Kola Peninsula alkali granites (CHUMAKOV et al., 1948). The optical data of vesuvianite are given by QUENSEL (op. cit., p. 173), the formula unit of the mineral (cf. WARREN and MODELL 1931) calculated to numbers of atoms on the basis of 72 anione valencies being:

$$\underbrace{Ca_{8.6}Na_{0.4}K_{0.0}Mg_{0.3}Mn_{0.1}}_{9.4},\ \underbrace{Fe^{3+}_{0.7}Fe^{2+}_{0.4}Ti_{0.4}Al_{0.5}}_{2.0},\ Al_{4.0},\ \underbrace{Al_{0.4}Si_{8.6}}_{9.0}O_{34}$$

plus 4 anione valencies for (OH, F, etc). Now this may seem to be rather poor correspondence with the ideal formula, but does fit the mean actual composition of the mineral (MACHATSCHKI 1932).

3. *The leucocratic canadites*

With the exception of some pegmatite dikes, these rocks are the youngest members of the canadite series, and crosscut the other nehpeline-syenites to form a number of veins and dikes of comparatively restricted dimensions. The best exposures are found by, and just east of, the car-track connecting the farm of Sågen with the Knutby–Almunge highroad. The rock here outcrops to form a 20 to 30 m wide NS striking elongated dike (Fig. 2). A general sample obtained in this locality is represented by analysis No. 4, the actual mineral composition of the central parts of the dike being given in Tab. 2 (No. 15).

In the exposures S of Sågen there is in addition to the leucocratic canadite a subordinate amount of theralitic rock partly occurring along the eastern margin of the dike and in part forming a breccia of angular fragments and contorted slices inside the younger rock.

Macroscopically the leucocratic canadite is of a white colour spotted with black biotite and a few blue sodalite grains. The texture is fine- to medium-grained and pronouncedly trachytoid, subparallel acicular crystals of feldspar 2–4 mm long being readily recognized by the naked eye. Under the microscope this feldspar is seen to be an albite-microcline antiperthite, with a rather low percentage of potash feldspar. The antiperthite is of a string character, locally passing into a type intermediar between string and patch structure. Remnants of homogeneous Na-K felspar may also occasionally be found here. The groundmass chiefly consits of nepheline, cancrinite, subordinate amounts of albite and interstitial microcline. Nepheline can now and then be seen to form most beautiful hexagonal prisms, displaying a succession of zones alternately poorer and richer in secondary sericitic mica. On the whole, however, all the minerals of the rock are of a remarkably fresh appearance. The cancrinite is one of the last minerals to have crystallized, since it fills the interstices between, and many of the cracks and cleavages inside, feldspar, biotite and nepheline. Corrosion of these minerals by cancrinite is common, and there are also a few grains of symplectitically intergrown cancrinite and albite. The remaining salic mineral, viz. sodalite is comparatively sparse, but occurs evenly distributed throughout the central parts of the rock. Its textural position is equivalent that of cancrinite.

Biotite is the sole Fe-Mg mineral found in amounts warranting the position of an essential constituent. It is either of the green type common in the area or of a darker brownish shade. The leucocratic rock, as contrasted with most other types of canadite, is conspicuously poor in apatite; in addition to this mineral

Analysis No 4. Leucocratic canadite, Sågen. General sample

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	55.58	92.54	or	19.14		si	181.2
TiO_2	0.11	0.14	ab	47.97		qz	−80.4
Al_2O_3	21.59	21.18	ne	21.93		al	41.5
Fe_2O_3	1.65	1.03	c	0.89		fm	12.5
FeO	2.39	3.33	hl	0.08		c	5.6
MnO	0.09	0.13	nc	0.28		alk	40.4
MgO	0.35	0.87	sal	90.29		k	0.17
CaO	1.60	2.85				mg	0.14
Na_2O	10.66	17.20	fa	2.30	ol 2.91	f	0.31
K_2O	3.24	3.44	fo	0.61		ti	0.27
P_2O_5	0.06	0.04	mt	2.38		p	0.08
S	0.02	0.06	il	0.21		co_2	5.70
CO_2	1.28	2.91	pr	0.04		c/fm	0.45
F	0.03	0.16	ap	0.13		w	0.37
Cl	0.05	0.14	cc	2.65		Q	25.3
$H_2O^{>105°}$	1.16		fr	0.05		L	67.7
Sum:	99.86		fem	8.37		M	7.0
			Sum:	98.66		π	0.01
− O for S, Cl, F	0.03					γ	0.27
			$+ H_2O^{>105°}$	1.16		α	−8.44
	99.83			99.82		μ	0.10
$H_2O^{<105°}$	0.05						
CIPW classification	I:6:1:4		or:ab:ne	21.5:53.9:24.6			

the only other accessories are a few grains of magnetite, natrolite, a secondary zeolite, and chlorite plus calcite of a very late crystallization.

Chemically and mineralogically the leucocratic canadite is a logical member of the canadite series, for the tendencies of evolution found when comparing theralites with members of the normal canadite group here reach their height. There is thus a gradual fall in Ca, P, Mg and Fe, a continued rise of the Fe/Mg ratio and an utter enrichment in volatiles leading to the appearance of sodalite, the suppression of nepheline by cancrinite and the prevalence of biotite over amphibole.

These rocks have consequently many features in common with some of the schistose canadites (cf. Ch. IV, heading 5) of the marginal ring. These similarities appear still more marked when the secondary alteration of the schistose rocks—involving among other things a rise in K and possibly also in Si—is given due consideration.

The remaining (vein-)occurrences of leucocratic canadite appear to have a composition similar to that described here. The texture, however, is aplitic, i.e. xenomorphic throughout and more or less massive. By gradual changes in

Table 2. Actual mineral composition of canaditic rocks (vol. %)

	1. Plagioclase	An % of 1.	2. Potash feldspar	3. Nepheline	4. Nepheline pseudomorphs	5. Cancrinite	6. Analcite (A) Sodalite (S)	7. Pyroxene	8. Amphibole	9. Biotite	10. Calcite	11. Sphene	12. Ores	13. Epidote	14. Apatite	15. Fluorite	16. Muscovite not included in 4.	17. Alia
12. Theralitic canadite, Upptorp	27.1	15	0.1	15.4	10.0[2]	—	—	1.7	40.7	1.8	—	0.5	0.4	—	2.0	—	—	0.3[6]
13. Theralitic canadite, Skallerbol	36.6	30	0.0	22.1		—	—	—	29.1	8.1	0.4	0.7	0.2	—	2.8	—	—	—
14. Normal canadite, Byske	37.6	5	0.7	21.5		13.1	—	0.0	19.1	5.4	0.0	0.5	0.4	0.7	0.9	—	0.1	—
15. Leucocratic canadite, Sågen[1]	49.0	< 5	11.7	13.1		21.0	0.7(S)	—	—	3.0	0.4	—	0.9	—	0.1	—	0.1	—
16. Dike canadite, S of Seglinge	38.2	4	6.1	17.4		14.2	—	—	14.5	7.9	—	—	0.6	0.4	0.7	—	—	—
17. Dike canadite, Gränby school[1]	43.2	5	1.6	10.1	24.7[3]	—	—	—	15.2	2.2	1.8	0.2	0.0	0.0	1.0	—	—	—
18. Border zone of 17	58.0	5	3.1	8.4		0.0	—	—	—	28.5	0.1	—	0.1	—	0.2	0.0	1.6	—
19. Dike canadite, St. Ellringe	45.3	6	6.0	14.9		—	—	0.0	28.3	1.6	0.0	1.0	0.1	0.1	1.7	—	—	1.0[6]
20. Dike canadite, St. Ellringe, altered rock	50.8	< 5	4.9	12.2		—	—	—	10.9	12.7[7]	0.0	1.3	0.3	2.8	1.1	—	—	3.0[6]
21. Schistose canadite, Uddnäs[1]	43.8	< 5	24.5	19.8		0.0	—	—	2.5	8.2	0.1	0.0	0.9	0.0	0.1	0.0	—	0.0
22. Schistose canadite, Oppgården[1]	46.5	< 5	24.4	20.2		0.0	—	—	0.6	6.2	0.1	0.0	1.3	0.4	0.1	0.0	—	0.2
23. Schistose cancrinite-canadite, Lilla Ellringe	51.6	5	16.7	12.6		5.6	—	—	1.1	10.8	0.0	0.0	1.3	—	0.1	0.1	—	0.1
24. White vein in schistose canadite, Uddnäs	26.7	< 5	39.1	5.2		6.2	18.0(A)	—	—	9.6	—	—	0.4	—	0.0	0.0	—	—
25. Mylonitized schistose canadite, Uddnäs	48.1	< 5	17.3	1.3		—	—	—	—	10.1[4]	0.5	0.0	4.9	0.1	0.1	0.2	17.4[5]	—
26. Problematic rock, Norrby	44.1	40	—	—		—	—	—	42.7	0.8	0.1	2.1	0.7	0.1	2.6	—	6.8	—

1 Central parts of dike.
2 Including 2.0 analcite.
3 Including 8.6 analcite.
4 Including chlorite.
5 Including zeolites.
6 Prehnite.
7 Including some chlorite, garnet, and vesuvianite.

grain size the rock of the light veins passes into canadite-pegmatites, thus underlining the intimate relationship between and the similar PTx conditions governing the formation of both rocks.

4. *Canadite pegmatites*

Pegmatitic dikes and veins are found in most canadite varieties which form the large field of that rock in the eastern parts of the alkali complex. As is to be expected they are frequent in felsic and rather uncommon in theralitic varieties of nepheline-syenite. Compositionally they range from rocks farily rich in dark minerals (hastingsite and biotite) to types made up of nepheline, cancrinite and feldspars only. The former kind is often beautifully zoned; rims rich in large slender amphibole crystals oriented at right angles to the strike of the vein surround cores of white albite and nepheline. Since the main object of the early stages of the present investigation was an elucidation of the basic features of the geology of the district, no scanning of the pegmatites for rare minerals has yet been made. QUENSEL mentions malacone and orangite, and the list still has this appearance. The pegmatites of the present heading are, at a superficial glance, easy to confuse with, but should be kept apart from, pegmatitically developed rocks generated at the contacts between canadite and umptekite.

Two isolated parallel canadite pegmatite dikes of about 150 by 1 meters are to be found by the eastern shore of Lake Fladen, roughly halfway between Seglinge and Gränby. These pegmatites are white feldspar rocks ablaze with pink (decomposed) nepheline crystals and bearing a limited amount of biotite in addition to which there are a few shreds of fine-grained distorted biotite rock specked with large white albite *augen* enclosed inside the dikes. Incidentally, this pegmatite is one of the occurrences of nepheline-syenite dikes, where the younger age of the surrounding umptekite—here a coarse pegmatitic rock—is not immediately obvious. This means that the contacts are entirely transitional. As the locality, discovered in the autumn of 1959, has not yet been the object of microscopic and microtectonic examination no premature speculations should, however, be invited here.

5. *Dike canadites and schistose nepheline-syenites*

As intimated above a number of steeply dipping canadite dikes exist in the southern, central and northwestern parts of the alkali massif. The width of these bodies is between 1 and 10 metres and, even when considerably altered, embayed and occasionally interrupted by umptekite, some of them can be followed over a distance of several hundred metres. Mineralogically and chemically these rocks are comparable with the normal canadites, the differences, including higher K and sometimes fairly large contents of fluorite, being such as can

Analysis No 5. Dike canadite, Gränby

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	50.74	84.48	or	16.14		si	150.5
TiO_2	0.35	0.44	ab	44.59		qz	−48.3
Al_2O_3	21.17	20.77	an	9.73		al	37.0
Fe_2O_3	3.15	1.97	ne	7.00		fm	26.0
FeO	5.28	7.35	c	3.47		c	12.3
MnO	0.27	0.38	sal	80.93		alk	24.7
MgO	1.18	2.93				k	0.21
BaO	0.10	0.07	fa	5.42	ol 7.48	mg	0.20
CaO	3.82	6.81	fo	2.06		f	0.75
Na_2O	6.80	10.97	mt	4.56		ti	0.78
K_2O	2.73	2.90	il	0.67		p	0.37
P_2O_5	0.28	0.20	ap	0.67		co_2	4.58
CO_2	1.13	2.57	cc	2.57		c/fm	0.47
F	0.08	0.42	fr	0.11		w	0.34
$H_2O^{>105°}$	2.54		fem	16.06		Q	28.2
Sum:	99.62		Sum:	96.99		L	59.3
						M	12.5
− O for F	0.03		$+H_2O^{>105°}$	2.54		π	0.20
	99.59			99.53		γ	0
$H_2O^{<105°}$	0.30					α	−2.72
						μ	0.20
CIPW classification II : 5 : 2 : 4			or : ab : an : ne		20.84 : 57.57 : 12.56 : 9.04		

easily be explained by interaction with the surrounding umptekite. Though never essentially richer in femic minerals than most of the normal canadites the dike rocks, due to the fineness of the grain (0.5–3 mm) are usually of a much darker blackish colour.

Other features distinguishing the dike rocks from the "normal" massive type are the lack of composite alkali feldspars and the occasional abundance of microcline, this mineral, however, always being of a late nature. Cancrinite may or may not appear as an important primary constituent.

The nepheline is, as a rule, completely altered into brick-red pseudomorphs made up of flaky sericitic mica set in a groundmass of analcite. In many cases the alteration has proceeded still farther, the only remnants of the original mineral being streaks and patches of muscovite interlaced with sparse veins of analcite. At this stage there usually is a pronounced increase in biotite replacing amphibole. Chlorite, garnet, and vesuvianite now also enter the paragenesis.

In thin-slides the amphibole is seen to belong to a bright blue-green variety, among the greenest found in canadite rocks. As to its optical properties there are pronounced resemblances with the Almunge hastingsite (very low 2V, high angles of extinction).

Analysis No 6. Dike canadite, Gränby; dike margin

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	49.16	81.85	or	21.09		si	137.5
TiO_2	0.73	0.91	ab	32.22		qz	−48.6
Al_2O_3	20.24	19.86	an	12.74		al	33.4
Fe_2O_3	1.31	0.82	ne	8.17		fm	30.3
FeO	8.14	11.33	c	2.52		c	14.8
MnO	0.28	0.40	sal	76.74		alk	21.5
MgO	1.88	4.66				k	0.30
CaO	4.94	8.81	fa	10.19	ol 13.47	mg	0.26
Na_2O	5.59	9.02	fo	3.28		ti	1.53
K_2O	3.57	3.79	mt	1.90		p	0.79
P_2O_5	0.66	0.47	il	1.38		co_2	4.50
CO_2	1.18	2.68	ap	1.58		c/fm	0.49
$H_2O^{>105°}$	1.54		cc	2.68		w	0.13
Sum:	99.22		fem	21.01		Q	26.6
$H_2O^{<105°}$	0.11		Sum:	97.75		L	57.3
			$+H_2O^{>105°}$	1.54		M	17.1
						π	0.22
				99.29		γ	0.09
						α	−1.92
						μ	0.24
CIPW classification II:5:2:4			or : ab : an : ne	28.4:43.4:17.2:11.0			

Texturally the dike canadites are most frequently trachytoid, long tabular crystals of albite and short prisms of nepheline then spotting the rock. In the vicinity of the contacts toward umptekite this texture often changes into a granular one, involving interstitial and porphyroblastic microcline(-perthite) in a mass of albite and biotite. This facies is devoid of lenads, the alteration of nepheline proceeding as described above. By the action of shearing stress schistosity is often produced. The rock thus affected is apt to lose some of its salic components leaving the residue rich in biotite, The chemical effects of this tectonization, combined with the results of some umptekitization are demonstrated by the analysis (No. 6) of the marginal schistose parts of dike canadite from Gränby school.

An essentially similar petrographic character is displayed by the canadite of Stora Elringe. This rock forms a couple of parallel dikes or lenses, which follow a somewhat curved course relating them to the outer canadite ring. The main minerals are the usual ones, viz. albite, nepheline, amphibole, and some biotite. The Stora Ellringe canadite, in addition is particularly rich in secondary epidote and prehnite forming large bow-tie clusters. Garnet and vesuvianite can also be found here. Zones of deformation following directions parallel to the strike of the dikes, and thus also parallel to the outer margins of the alkali complex,

Fig. 5. Schistose nepheline-syenite. 500 m WNW of Uddnäs.

produce a gneissose granular texture in places relating the rock to the schistose rest of the canadite ring to be described next.[1]

These rocks are fine-grained (average grain diameter 0.3–1.5 mm) granular and form a number of branching curved dikes 5 to 30 metres wide. The dikes run all the way from Oppgården past Uddnäs, Lake Fladen and Ellringe to the northern parts of the massif, where the rock group is represented by some strongly altered remnants well inside the umptekite field.

Albite, microcline and considerably altered nepheline form the bulk of the rock. Green biotite is constantly present in amounts of between 5 and 10%, magnetite, apatite, epidote and fluorite constituting the accessory minerals. Amphibole contents are invariably low. A great deal of the potash-feldspar is metasomatic, being introduced by interaction with the surrounding fenites. This fact is clearly demonstrated by manifest accumulations of the mineral in marginal and altered portions of the rock. The albite is of a very sodic composition and practically devoid of polysynthetic twinning. It has generally undergone little decomposition. In many sections there are several distinct generations of feldspar mirroring the history of the rock from its emplacement to the final stages of fenitising activity.

[1] The same is the case also at Andersberg, where the schistose canadite is in direct continuation of the main canadite body stretching down from Skallerbol, and not a separate occurrence as shown in QUENSEL's (op. cit.) map. As the investigation of the area in question was completed subsequent to the preparation of the map (Pl. I), this canadite and some other dikes parallel to it, could not be entered there.

Macroscopically greyish-white nepheline crystals acquire light green hues as the content of secondary sericite flakes becomes prominent. Brick-red pseudomorphs, of a type recorded above, consist of sericitic mica set in analcite. This composition is confirmed by X-ray analysis, indicating analcite, muscovite and some calcite, only the strongest reflections of the latter mineral being visible on the film. The 3.34 Å line of muscovite is very weak in both recordings made. The flakes of pseudomorphous mica are usually orientated either parallel to or at right angles to the *c*-axis of the disintegrating host. Additional minerals entering the nepheline pseudomorphs are epidote, cancrinite, natrolite, a zeolite of thompsonitic affinities and, rarely, some hematite pigmentation. Very often there are rims of analcite round the decomposed nepheline crystals. This analcite also strongly corrodes the surrounding feldspar grains, penetrating them by the way of cracks and intergranular boundaries.

The sparse amphibole is of a hastingsitic character. The central parts of the dikes are the preferred habitat of this mineral, its contents rapidly diminishing to the point of complete suppression, as the neighbourhood of strongly schistose zones, contacts and areas rich in microcline is approached. Cancrinite ($n_w = 1.524$) may or may not be present in essential amounts. The first is, for instance, the case at Lilla Ellringe and the southernmost outcrops at Uddnäs.

The schistosity of the rock is, as mentioned by QUENSEL chiefly due to the subparallel arrangement of the mafic minerals in addition to which the granular nepheline is accumulated in streaks. Veins of younger rocks (lestivarites etc), as a rule, also follow the directions of foliation.

The mineral proportions, as determined in a great number of thin-slides (mean compositions given in Tab. 2), are, in spite of this, fairly consistent. The existent banding is, consequently, largely due to differences in size of grain, fine-grained layers appearing dark in comparison with coarser rock of the same composition. Actual differences are, moreover, largely compensated within sections represented by slides cut at right angles to the direction of strike.

White comparatively coarse schlieren of a composition different from that of the bulk of the schistose nepheline-syenite, do nevertheless occur in many of the outcrops. The volumetric analysis included in Tab. 2 represents one of these white veins from a locality 300 m S of Lake Fladen. The slides here examined include shreds and border-zones of normal schistose rock, which produces higher biotite and albite values than those warranted by the actual composition of the white vein. Apart from this, the vein rock appears to be rich in microcline, cancrinite and analcite. The borders toward the surroundings are rather diffuse and marked by minute veinlets of analcite and corroding intergranular rims of this mineral. When best developed this mode of occurrence results in a groundmass of analcite enclosing replacement remnants of the original feldspars. The biotite of the attacked rock is often broken and crenulated, thus giving the impression of dynamic alterations accompanying the emplacement of the

Analysis No 7. Schistose nepheline-syenite, L. Ellringe. P. Quensel, op.cit., p. 190

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	56.44	93.97	or	28.38		si	179.3
TiO_2	0.12	0.15	ab	37.46		qz	−70.5
Al_2O_3	20.52	20.13	an	1.42		al	38.4
Fe_2O_3	2.72	1.70	ne	20.95		fm	20.0
FeO	4.51	6.28	hl	0.11		c	4.2
MnO	0.06	0.09	sal	88.32		alk	37.4
MgO	0.28	0.69				k	0.26
CaO	1.23	2.19	wo	1.68	di 3.53	mg	0.07
Na_2O	9.01	14.53	fs	1.65		ti	0.29
K_2O	4.80	5.10	en	0.20		p	0.13
P_2O_5	0.10	0.07	fa	3.22	ol 3.56	c/fm	0.21
S	0.07	0.22	fo	0.34		w	0.35
Cl	0.06	0.09	mt	3.94		Q	26.1
H_2O	0.75		il	0.23		L	64.1
Sum:	100.67		pr	0.13		M	9.8
			ap	0.23		π	0.01
−O for S, Cl	0.05		fem	11.62		γ	0.14
	100.62		Sum:	99.94		α	−5.08
			$+H_2O$	0.75		μ	0.06
				100.69			
CIPW classification I:6:1:4			or : ab : an : ne			33.2 : 42.5 : 1.6 : 23.7	

white veins. The analcite veinlets are often bordered by 0.1–0.2 mm wide zones of symplectitically intergrown analcite, albite and/or a very fine-grained scaly mass of sericite, probably secondary after nepheline. Symplectites are also typical of the "white veins" proper, and here imply analcite-feldspar and cancrinite-feldspar intergrowths. Large crystals of cancrinite, analcite and microcline are further prominent.

Locally analcite and calcite also fill younger shear-zones parallel to, and tension-cracks intersecting the schistose nepheline-syenite obliquely to its strike.

Still later than these are zones of crushing conforming with the borders of the alkali complex and mylonitizing the rock immediately south of Lake Fladen. The nepheline pseudomorphs are here distorted into streaks of muscovite. Biotite also suffers disintegration and is pseudomorphosed into chlorite and muscovite spotted with blebs of iron ore. Calcite is prominent, as are fluorite and ochreous hydrated iron oxides. This mineral composition indicates crushing stress at low temperatures, plus an influx of volatiles. By comparison with the

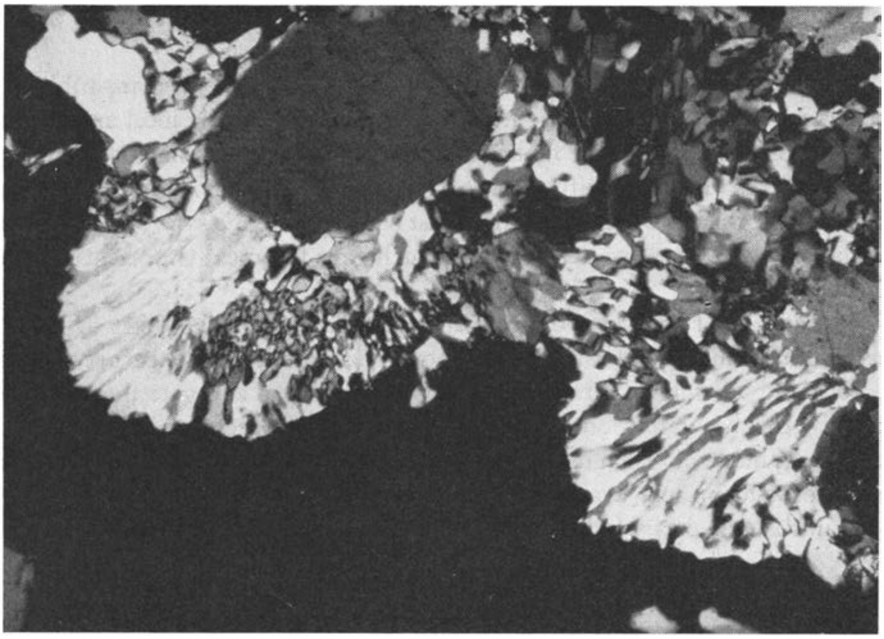


Fig. 6. Symplectitically intergrown albite and cancrinite in a light vein corroding schistose nepheline-syenite. Black: analcite. 300 m S of Lake Fladen. 2 nic., 130×.

structures of the surrounding fenites, the alteration is found to have taken place at a late stage in the history of the alkali complex, but still before the final cessation of the activities responsible for its formation. A more complete elucidation of the tectonic features of the contact zones of the massif, accompanied by detailed maps is now in preparation and will be published later.

The schistosity of the rocks described above has, time and again, induced geologists visiting the area, to suggest an origin by nephelinisation of paragneiss, i.e. a process similar to that described from the Bancroft, Ont. area (GUMMER and BURR 1946). This mode of origin is, however, strongly contradicted by the ring configuration of the schistose nepheline-syenites, forming well-defined dikes, with strikes often at high angles to the foliation of the supracrustals found in the surrounding terrain. This *per se* conclusive evidence is further supported by the petrographic character of the nepheline-bearing rocks, which differs profoundly from that of any of the fenitised gneisses in the area.

The texture which was considered by QUENSEL to be of a protoclastic nature, is, by analogy with conditions prevailing in the surrounding fenites, and by reasons of compositional and PT-facies differences found within the dikes, assumed to be a result of post-magmatic recrystallization.

Remnants of tabular feldspar found in the central amphibole-rich parts of the schistose canadite at L. Ellringe are suggestive of an original trachytoid texture, and thus liable to strengthen the conclusions arrived at by the present author.

There are also drag-folds and other tectonic features not very compatible with a magmatic origin of the texture now existing. Except for the local areas of late deformation described above no bent, broken, contorted or otherwise deformed crystals of the main constituent minerals can be detected. The texture and mineral composition which now exist must consequently be syn- or posttectonic in relation to the phase of deformation which gave the rock its present granular schistose dress.

The absence of any signs of gradual nephelinisation in the dikes or in their surroundings and the absence of compositional interdependence between the bedrock and the schistose nepheline-syenite is liable to abrogate the case of an origin by the mineralization of shear zones. Thus there seems to be no reason to introduce a mode of origin different from that of the rest of the canadites, which, on evidence at present available, is thought to be one of a succession of magmatic intrusions, partly followed by alterations at pegmatitic and lower temperature conditions.

6. *Problematic rocks*

By the pond on the hillock between the Old and New Norrby farms there are exposures of a "diorite" of peculiar character and still unsettled genetic relations.

This is a medium-grained dark grey rock, which displays a texture of slender amphibole prisms, enveloped by a mass of large feldspar crystals. In hand specimens the rock cannot readily be distinguished from theralite of what has been described as the second textural type. The main constituents are andesine and amphibole occurring together with subordinate amounts of biotite, sphene, and apatite. The amphibole displays pleochroic colours and absorption characteristic of its counterparts in the mafic theralitic canadites (cf. p. 10). The extinction $c \wedge Z$ varies between 18 and 28 degrees, with $b = Y$ and 2V usually about 38–40°, but occasionally as high as 55–60°. As is the case with the amphibole of the canadites the mineral fails to extinguish in sections cut at low and medium angles to the c-axis. This and rather strong absorption put difficulties in the way of an exact determination of the optical data. Brown-green zoning and corrosion by the plagioclase with subsequent formation of residual sphene droplets are quite common.

The plagioclase is generally only moderately altered. There are nevertheless clusters of large flakes of sericitic mica, which may or may not represent disintegrated pseudomorphs of originally present nepheline, althought no traces of this mineral entering the norm to an amount of 8% can be discovered.

The chemical composition of a specimen from the central parts of the occurrence is represented by analysis No. 8. In comparison with data obtained by planimetric analysis of a number of thin-slides (Tab. 2) the chemically determined P_2O_5 value seems to be rather too low.

Analysis No 8. Problematic theralite, Norrby

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	46.11	76.77	or	7.90		si	111.1
TiO_2	1.87	2.34	ab	26.45		qz	−43.1
Al_2O_3	16.48	16.17	an	18.94		al	23.4
Fe_2O_3	3.97	2.49	ne	8.22		fm	40.5
FeO	9.55	13.29	sal	61.51		c	22.6
MnO	0.27	0.38				alk	13.5
MgO	3.76	9.33	wo	7.34		k	0.15
BaO	0.09	0.c6	fs	4.05	di 14.65	mg	0.33
CaO	8.72	15.55	en	3.26		f	1.61
Na_2O	4.92	7.94	fa	5.88	ol 10.16	ti	3.39
K_2O	1.34	1.42	fo	4.28		p	0.77
P_2O_5	0.75	0.53	mt	5.76		co_2	0.62
CO_2	0.19	0.43	il	3.55		c/fm	0.56
F	0.21	1.11	ap	1.78		w	0.27
$H_2O^{>105°}$	1.48		cc	0.43		Q	23.1
			fr	0.36		L	44.7
Sum:	99.71		fem	36.69		M	32.2
−O for F	0.09					π	0.27
			Sum:	98.20		γ	0.24
	99.62		$+H_2O^{>105°}$	1.48		α	−0.62
$H_2O^{<105°}$	0.11			99.68		μ	0.45
CIPW classification	II (III) : 6 (5) : 3 : 4		or : ab : an : ne			12.8 : 43.0 : 30.8 : 13.4	

Umptekite and fenites surround the problematic "diorite", its marginal parts being hybridized into a kind of migmatitic gneiss composed of dark fine-grained biotite-amphibole-diopside and red albite-microcline-perthite schlieren. Eventually the migmatite grades into umptekite unusually rich in dark minerals. This marginal zone incidentally includes a type locality of QUENSEL's "dark fragments" (QUENSEL, op. cit., p. 140 and Pl. II, Fig. 1). In varieties of "diorite" less permeated by umptekitization single microcline-perthite porphyroblasts and secondary schistosity are exceedingly common. The central parts of the problematic rock-body are however massive and quite devoid of potash-feldspar.

Two possible modes of origin must be considered in classifying the rock here described: either it belongs to the canadite family or else it represents a very thoroughly fenitised Archæan diorite or gabbro. The texture of even the most central parts may be—and probably is—secondary and thus not very helpful. Large bodies of Archæan basic rocks are present in the vicinity and may be taken to support the latter mode of origin. The mineralogical and chemical compositions, the latter fitting the characteristics of a theralite, seem however to speak in favour of the alternate genetic possibility: e.g. the low K_2O value strongly counterindicates fenitisation. So also do some of the field features, as, for instance, the following: The intermediary Archæan granite bordering the "diorite" in the north and separated from it by only a few metres of nordmarkitic umptekite is rather weakly fenitised. If the problematic rock be an altered member of the bedrock, this fact must be said to be rather unexpected, since experience in other parts of the alkali complex proves basic rocks to be considerably more resistant against fenitisation than granites in comparable position. A fully satisfactory solution of the problems here proposed, however, requires considerably more work in the investigation of the, as yet, incompletely surveyed northern border of the alkali massif.

Small occurrences of rocks similar to that considered here are found NNW of Ryggestalund and by the path connecting Hällen and Sågen.

7. *Contact relations of the canadites*

a. *Archæan rocks*

Most of the canadite is situated well inside the umptekite area and thus, naturally, does not come into direct contact with unaltered Archæan bedrock. Still, there are localities along the borders of the complex where schistose nepheline-syenites would be expected to border on Svecofennian granites and supracrustals.

Even at these localities, however, there always are zones of umptekite or aplitic lestivarite separating the canadites from the Archæan. These interposited rocks are clearly younger than the canadites, and consequently cannot be considered a simple unaltered result of contact fenitisation. In view of the tectonically disturbed character of the areas surrounding the marginal canadite, this fact is of course not directly surprising: later intrusions and metasomatising solutions naturally did follow the avenues of ascent once opened by the canadites and by the accompanying tectonic action.

This means however that the contact alterations and possible fenitisation, accompanying the intrusion of the canadites, are clouded by the results of later petrogenetic activities.

Among the phenomena located in Archæan rock, which can be assigned to the contact influence of canadite with a reasonable degree of probability, are porphyroblastic calcite-cancrinite lenses in fragments of metabasite 0.5 to 5 m from the contact of a 10 m broad canadite dike at Gränby school. The metabasite fragments rest in umptekite, which also carries remnants of quartzite and other sedimentary and igneous Archæan rocks. The umptekite causes alterations in the contact facies of the canadite and some 50 m farther off, though in a zone of tectonic disturbance, disrupts that rock, thus probably being the younger. The absence of features comparable to the occurrence of cancrinite mentioned here, elsewhere in the umptekite area, as well as the areal interdependence between canadite and the cancrinite porphyroblasts strongly suggests a causal relationship between the two.

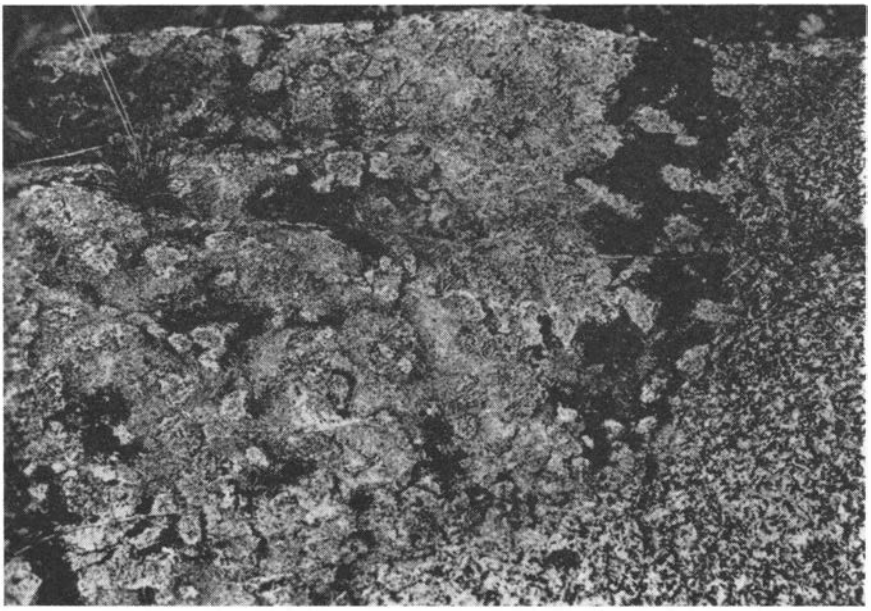


Fig. 7. Altered inclusion in normal canadite. ESE of Skallerbol. Photo B. Bohlin.

Inclusions of foreign rocks in the canadites are rather rare: there are a couple of contorted remnants of biotite-amphibole-andesine metabasite partly transformed into aegirine-albite hornfels in the schistose canadite S of Lake Fladen, and a similar fragment NE of Skallerbol, as well as some inclusions of doubtful affiliation in the normal canadite of the Skallerbol–Sågen area. The latter rock fragments are basic and completely transformed into a nepheline-syenite showing long amphibole needles poikilitically enclosed within large fields of albite and nepheline (Fig. 7). Some vesuvianite appears here. These altered inclusions are possibly derived from Archæan rock, but may represent fragments of theralitic canadite as well.

b. *Umptekite-contacts*

The contacts between umptekite and rocks of the canadite group are of two commonly occurring types. One of these involves transitional white syenites, the other is either abrupt or characterized by the occurrence of gradual mineralogical changes.

The white nepheline-syenites, so called by QUENSEL, are developed along the margins of a decided majority of canadite bodies, and also appear as isolated patches inside the umptekite terrain. The adjoining canadites, especially the leucocrate and normal ones, are very frequently of a pegmatitic development passing by degrees into the white rock. In other cases the zone of transition between the two is one of minute diffuse white feldspar *schlieren* and porphyro-

Fig. 8. White transitional syenite in normal canadite. Note the basic rim around the lens of white syenite. ESE of Skallerbol. Photo B. Bohlin.

blasts infesting the canadite. The dark minerals of the canadite then recrystallize, and accumulate in patches to be corroded by the growing feldspars as the rock gradually turns into white syenite. Poikilitic intergrowth is hereby produced. In addition rims of dark minerals frequently accumulate around clusters of feldspar porphyroblasts in the canadite, or at the borders between that rock and more compact patches of white syenite (Fig. 8).

In several places, so for instance around Byske and in the Sågen–Skallerbol area, the marginal parts of canadite dikes carry abundant angular fragments of white transitional syenite as well as umptekite in part surrounded by the white rock. There are also localities where these remnants are deformed and pass into pegmatitic veins criss-crossing the umptekite-canadite contacts. Also in the Hällen area the trachytoid umptekite found there is cut by dikes of hybridic pegmatites passing into canadite-pegmatites and canadite. These observations—though sometimes admittedly interpretable in more than one way—together with the dike-shaped configuration and other features of most canadite bodies, suggest some of the umptekites to be older than the nepheline-syenite intrusions. Again, the details of the contacts between umptekite and canadite prove a very intense hybridization and secondary alteration of the latter rock, the surrounding umptekites and white syenites in development of textures and mineral alterations very often being the attacking rock. Furthermore there is the indisputable fact of umptekite and especially lestivarite dikes traversing the canadites. The umptekites of these dikes are, however, very often of a sodic fine-grained lestivaritic type or belong to the quartz-bearing kind of dike rock described below (Ch. VI: 2), and form dikes in the umptekites as well.

A final answer to the problem of umptekite-canadite age relations is thus depending on the results of the still very incomplete investigation of the white transitional syenites.

As far as can be ascertained now, the umptekite-canadite relations are of a more complicated character than hithero assumed and involve several phases of intrusion, plastic deformation and metasomatic alteration. The white transitional rocks are thus, at the present stage of investigation, assumed to be the result both of canadite contact influence on its surrounding rock, whether this be umptekite or Archæan rocks later umptekitized, and of subsequent hybridization during what might be termed the final development of the umptekites and the emplacement of lestivarites and mostly fine-grained leucocratic dike umptekites.

The contacts of the white rock toward umptekite are, as a rule, wholly transitional, the only exception to this being found S of Sågen. There a coarse-grained pinkish-white transitional rock—the product of a very gradual change from canadite—is seen to border sharply upon a very sodic albitized umptekite of a rather similar composition, but finer grain-size and pronounced parallel structure crosscut by the whitish rock.

The umptekite bordering on white syenite is often unusually rich in sodium-feldspar, this characteristic persisting for a surprisingly long distance into seemingly normal umptekite.

While the white rock, taken as whole, obviously is a transitional facies between canadite and umptekite these areas may also harbour pegmatitic late differentiates of the canadites, rocks formed by fenitising solutions advancing along the compositional and structural inhomogenities, represented by the borders between the canadites and their surroundings, as well as other genetically inhomogeneous elements. As the investigation of the white syenites is still in an embryonic stage, it would be premature to discuss now the problems belonging here. The same is also true of a systematic petrographic description of the rock group. All detail which cannot yet be evaluated in its context will therefore be withheld for the time being. In addition to the characteristics given by QUENSEL, viz. richness in albite, relative abundance of microcline and the gradual disappearance of nepheline etc., the regular presence of various mineral facies, reflecting an orderly gradual change of the conditions of rock formation should however be noted. As to the dark minerals, these groupings include e.g. chlorite-ore-vesuvianite, epidote, biotite-garnet, biotite-amphibole, aegirinaugite and other parageneses. Zones of intense feldspars hydration are prominent in places and macroscopically appear as belts of salmon-red rock. None of the original amphibole of the canadites escapes destruction during the alteration of the rock. As indicated by the abundant presence of fluorite, zircon, calcite etc, volatiles and mineralizers were prominent during the formation of the white

Analysis No 9. White canadite. P. Quensel, op.cit., p. 185

Weight %		Mol. numbers × 100	Norm		Niggli values	
SiO_2	52.04	86.65	or	14.02	si	156.9
TiO_2	0.26	0.33	ab	46.77	qz	−59.1
Al_2O_3	23.92	23.47	an	6.45	al	42.5
Fe_2O_3	1.46	0.91	ne	12.98	fm	20.8
FeO	4.18	5.82	c	5.24	c	7.7
MnO	0.11	0.16	sal	85.46	alk	29.0
MgO	1.50	3.72			k	0.16
CaO	2.38	4.24	fa	4.83 } ol 7.45	mg	0.32
Na_2O	8.36	13.49	fo	2.62	ti	0.60
K_2O	2.37	2.52	mt	2.11	p	0.33
P_2O_5	0.26	0.18	il	0.50	co_2	2.39
CO_2	0.58	1.32	ap	0.61	c/fm	0.37
H_2O	2.21		cc	1.32	w	0.23
Sum:	99.63		fem	11.99	Q	27.8
			Sum:	97.45	L	60.0
					M	12.2
			$+H_2O$	2.21	π	0.12
				99.66	γ	0
					α	−2.99
					μ	0.32
CIPW classification I:6:2:4			or : ab : an : ne		17.5 : 58.3 : 8.0 : 16.2	

rock. This conclusion is also supported by the dominant position of rock-types displaying pegmatitic size of grain. Regarding analysis No. 9, recalculated from Quensel's paper, nothing is known about the field relations or the mineralogical position of the rock. Its presence in this paper however serves to illustrate the trends of hybridization, among which the rise of the k and mg values of the canadite should be especially noted. Parallels to these features in the outer contact zone of the massif will be given later (Ch. VI).

Umptekite-canadite contacts not involving white syenites are in places (e.g. NW and S of Skallerbol) of a breccia-like character, numerous veins of (pegmatitic) umptekite intersecting the older rock. The canadite fragments of the breccias are strongly altered and locally deformed, in which case they appear as slices arranged parallel to the strike of the rather sodic umptekite forming dikes in the canadite. This type of contact gives the impression of considerable movement inside the younger rock.

In other cases the canadite very gradually becomes enriched in microcline, which, together with the decomposition of nepheline and the locally occurring hydration of the original plagioclase contributes to give the rock a brick-red colour. The texture is not perceptibly affected in the early stages of alteration, but granulation of the feldspars takes place as the "umptekitization" proceeds. The amphibole of the canadite gradually changes character, but still retains the acicular habitus so characteristic of that mineral. This feature and an unusually high content of dark minerals and plagioclase persist far into otherwise normal-looking mostly fine-grained umptekite.

Contacts of the type last described are found between Byske and Eneby and also E of Seglinge, at Upptorp and other places.

V. The Umptekite Group

As has been stated previously this group is, quantitatively, the most important of the alkali rocks found at the present erosion surface. There is, however, very little uniformity governing its development, a wide range of textural and compositional varieties being represented in the area. This inhomogenity has been remarked upon by Prof. QUENSEL, who holds that the typical umptekites are confined to the outcrops between Hällen, Gränby and Eneby i.e. only about one sixth of the total "umptekite field". As a matter of fact, even in these parts, there is scarcely an area of more than a couple of hundred square meters presenting a homogeneous appearance.

A selection of character minerals—microcline-perthite, albite and hastingsite can be made, but their proportions and textural development are the subject of considerable disagreement.

No new analyses of umptekite being available, the following summarising division into a number of main types lacks, alas, the check of chemical examination. In order to conform with the features observed in the field, the general coarse-grainedness of the rock necessitates a modification of the normal deliminations of grain-size terminology. Umptekites of the fine-grained group are thus understood to have an average grain diameter of less than 3 mm, "normal" rock ranges between 3 and 20 mm while the rest is referred to as coarse. As can be inferred from this, the usual size of grain is between 3 and 20 mm, coarser types however being exceedingly common.

The fine-grained umptekite of the central parts of the complex is a rock of 10–20 % dark minerals and, in places where the age relations can be ascertained, appears older than the rest of the group. Microscopic and field investigation readily reveals most of this rock to possess mineralogical and structural features branding it as a relatively well recognizable granulated fenite or altered canadite. There is, however, still another type of fine-grained "umptekite", predominantly found in the marginal zones of the massif and thus further considered in the next chapter. Anticipating the description given there, it can be said to be considerably more salic, and and in part more sodic, than the umptekites proper.

The medium-grained umptekite is of a number of colour- and compositional types. Usually the rock is brown or reddish-brown, pink types being more subordinate and sometimes transitional to fenitised red granite. Green and greenish-red patchy, and often fine-grained, rock is found when the margin of the complex, or inclusions of country-rock, are approached. The greenish coloring is due to an opaque pigmentation of the feldspars, interstitially present and impregnating, partly hydrated, oxides of iron being responsible for the red patches. The percentage of dark minerals in the normal umptekite is usually about 10 to 15 by weight, more leucocratic varieties of the brown rock commonly occurring as a younger facies displaying pegmatitic size of grain.

As is apparent from the above, there are a number of generations of umptekite; these rocks of different age however do not form independent intrusions, but occur in the shape of patches and crisscrossing veins. On the whole the tendency is for the younger rocks to be more leucocratic and to divide into two groups: the one red and quartz-bearing, the other yellowish or greyish-brown and quartz-free. As can be deduced from the thin slides available, the first of these late elements is comparatively rich in potash, while the second displays a high Na/K ratio, relating it to the fine-grained rocks of the border zones.

Umptekites with as much as 30 and more per cent dark minerals can be found in many parts of the massif. These mafic varieties in most cases show so close a relationship to occurrences of metabasites and basic plutonics, as to indicate a genetic interdependence between the two. This assumption is confirmed by an examination of the amphiboles of the dark rock, which not infrequently show similarities to types found in the Archæan metabasites. The clusters of dark minerals frequently occurring in the umptekite often have a similar origin. According to Quensel (op. cit., p. 150) "these patches are chiefly composed of hornblende, biotite, the usual feldspars and sphene, the feldspars in the most basic places, however, appearing in considerably reduced quantities... These dark basic rocks are however nothing else than accumulations of the mafic minerals of the umptekite." While this certainly is the case, a closer investigation of the dark clusters often proves them to be nothing but re-crystallized inclusions of older basic rocks. Perfect transitions from moderately fenitised metabasites to "dark clusters" can thus be seen at Gränby, St. Söderby, Seglinge, etc. etc.

The exposures in low-lying areas, until recently covered by water, are apt to illustrate strikingly the irregularity of the umptekites: weathering here emphasizes the compositional and textural differences not so easily perceived in the glacier-polished outcrops of more weakly weathered localities.

This review of umptekite types should also include rocks "with large tabular perthitic carlsbad-twinned feldspar, showing a subparallel arrangement causing a beautiful flow structure in the rock" (Quensel, page 154). In places, as for instance at Hällen and SW of Seglinge, these rocks form comparatively extensive compact areas and often display clearly intrusive relations toward their surroundings. The structure might thus indeed be a fluidal one. Again in other localities the parallel arrangement of the large perthites follows the foliation of incompletely altered older rocks, recognizable as fenites, and thus owes its origin to the directing influence of preexisting structure.

The composition of the pegmatitic schlieren, so characteristic of the umptekite district, corresponds either to the normal brown variety of the rock, then showing a paragenesis of microcline-perthite, antiperthite, hastingsite and biotite, or to the two rock types referred to above as younger leucocratic members of the umptekite group. The latter two are characteristically abundant in quartz and magnetite respectively, the quartz-carrying varieties often also containing some pyrite. Zircon is abundant in many of the umptekite-pegmatites and other vein rocks found in the umptekites.

In his paper QUENSEL gives an excellent description of the mineral composition of the umptekites. For the sake of completeness, a recapitulation of the main features will be given here. As mentioned above, most umptekites are characterised mineralogically by the predominance of hastingsite and alkali feldspar. The feldspars, especially those of the centrally situated rock-types considered in this chapter, are generally perthitic, microcline-albite intergrowths being by far the most common. The non-perthitic feldspar is albite, only very insignificant amounts of microcline locally forming interstitial grains. There are also, in some marginal and partly fine-grained dike rocks, feldspars showing the optical properties and characteristic twinning of anorthoclase, these grains successively grading into crypto- and microperthites (or antiperthites) of the film-, braid- or string-types. Much of the perthite found in the central umptekite is, however, of a rather coarse vein or patch type, this, along with the other varieties, being frequently surrounded by broad marginal rims of albite. Interstitial albite as well as discrete albite grains enclosed in the large perthite crystals are of common occurrence. The proportions between potash- and sodium-feldspar inside the perthites are highly variable, grading through the whole scale between microcline with moderate amounts of albite films, to almost pure sodium feldspar. Grains of very different composition can be found side by side in the same slide.

While a great amount of the perthite seems to have formed by unmixing, the distribution of albite gives the impression of a considerable mobility of the sodic material in the late stages of umptekite formation, in places actually leading to the generation of replacement perthites. This conclusion is also in accordance with the appearance of the late sodic veins and dikes to which reference has been made above.

In studying the petrographic relationships of perthite, GATES (1953) concludes that sodic feldspar unmixed from potassic feldspar is in a condition to migrate under structural control, to form local accumulations leading to the formation of (patch-)perthite. EMMONS (1953) even tentatively suggests that concentrations of unmixed sodic feldspar in shear-zones are responsible for the formation of the nepheline-syenites of the Wausau, Wisc. area.

According to GATES, the types of perthite formed are dependent mainly on

Analysis No 10. Pinkish umptekite, Seglinge. P. Quensel, op.cit., p. 154–55

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	62.57	104.18	or	35.45		si	231.4
TiO_2	0.22	0.28	ab	50.44		qz	− 14.5
Al_2O_3	16.72	16.40	ne	1.16		al	36.4
Fe_2O_3	1.32	0.83	sal	87.05		fm	19.9
FeO	4.25	5.92				c	7.0
MnO	0.07	0.10	fs	2.81	di 6.52	alk	36.6
MgO	0.52	1.29	en	0.57		k	0.39
BaO	0.05	0.03	wo	3.14		mg	0.14
CaO	1.76	3.14	fa	2.71	ol 3.22	ti	0.62
Na_2O	6.27	10.11	fo	0.51		p	0.31
K_2O	6.00	6.37	ac	0.37		c/fm	0.35
P_2O_5	0.20	0.14	mt	1.74		w	0.22
S	0.13	0.41	il	0.42		Q	35.8
H_2O	0.37		pr	0.24		L	54.1
			ap	0.47		M	10.1
Sum;	100.45		fem	12.98		π	0
− O for S	0.06					γ	0.26
			Sum:	100.03		α	− 0.c6
	100.39		+ H_2O	0.37		μ	0.10
				100.40			
CIPW classification II : 5 : 1 : 3			or : ab : ne	40.7 : 58.0 : 1.3			

the concentration of the sodic material. While certainly there is often an interdependence between perthite-type and the Na-K proportions, the observations on Almunge perthites indicates the type to be controlled less by the concentration of sodic material than by the behavior and mobility of this material in the late stages of umptekite formation. It is also suggested that the bulk of the sodium partaking in the recrystallization of the umptekite minerals is derived less by unmixing than by a continuous supply of solutions from an external source, which might be a crystallizing highly sodic magma.

The conditions of unmixing in the supersolvus alkali feldspars in the presence of water vapour have been the subject of highly important experimental study by Tuttle and Bowen (1958), who conclude that a dry environment is a prerequisite for the existence in nature of fine perthitic intergrowths and homogeneous composite feldspars.

Considering the irregularity of the umptekites, which is due to the great part played by pegmatites, fenitisation and replacement processes, all indicative of a richness in volatiles, the frequent occurrence of microperthite must indeed be said to be surprising—a feature which the Almunge rocks share with the fenites of Alnö, Fen, Spitskop and other alkali districts. In principle, however,

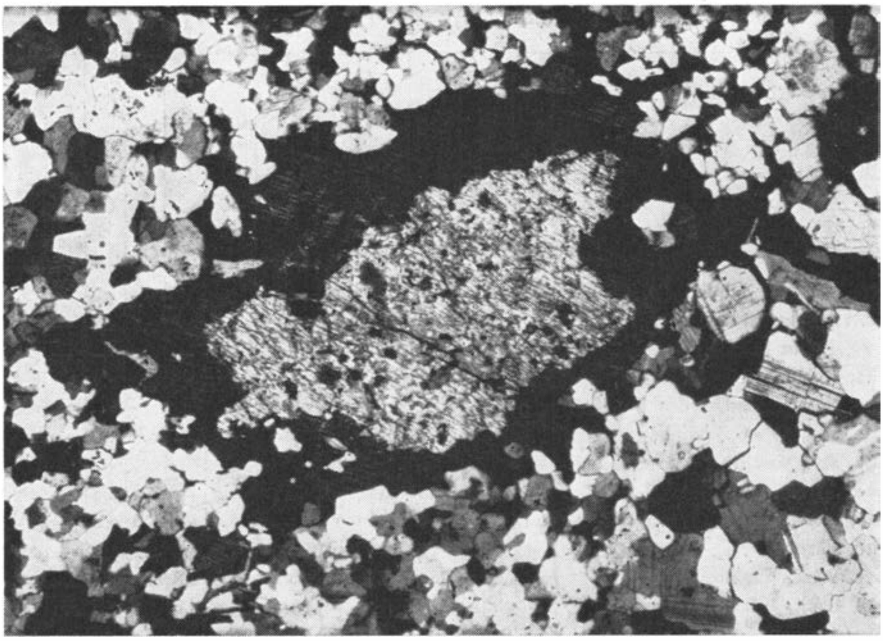


Fig. 9. Aegirine-augite surrounded by rim of ferrohastingsite. Umptekitic fenite, 550 m SSW of Seglinge. 2 nic., 35 ×.

the experimental data are in good agreement with the distribution of the homogeneous mixed alkali feldspars in the Almunge rocks, the canadite hosts of these minerals for petrographic and magmatectonic reasons being taken to represent a formation milieu considerably poorer in water than that from which the umptekites originated. This preliminary report is, however, not the place to indulge in a consideration of the details of perthite relationships in the Almunge rocks, a problem-complex to which the author hopes to return in a subsequent paper.

The predominant amphibole of the umptekites is a hastingsite very high in bivalent iron. This is proved by QUENSEL's analysis of the mineral, as well as by a later one (S. LJUNGGREN 1952) from which the formulas reproduced here are calculated:

$$Ca_{1.7}Na_{0.7}K_{0.4}Fe^{2+}_{3.4}Mg_{0.3}Mn_{0.1}Ti_{0.1}Fe^{3+}_{0.9}Al_{0.2}[Si_{6.1}Al_{1.9}O_{22}]+2(OH) \qquad \text{(QUENSEL)}$$

$$Ca_{1.8}Na_{0.6}K_{0.4}Fe^{2+}_{3.4}Mg_{0.4}Mn_{0.1}Ti_{0.1}Fe^{3+}_{0.9}[Si_{6.3}Al_{1.7}O_{22}|(OH_{2.1}F_{0.2})] \qquad \text{(LJUNGGREN)}$$

The optical properties are $b = Z$, $2V_x$ 10–15° (about 10° according to LJUNGGREN) dispersion $\varrho > v$ and extinction 35–42° ($c \wedge Y$ 37° in LJUNGGREN's specimen). Absorption $Y \geqslant Z > X$, pleochroism X = greenish-yellow, Y = bluish-green, Z = bluish-green or green.

The biotite is of two generations, one of them—occurring in some rocks only

Table 3. Actual mineral composition of umptekites (vol. %)

	1. Quartz	2. Potash feldspar	3. Albite and oligoclase	4. Sericite etc.	5. Aegirine, aegirine-augite	6. Ferrohastingsite	7. Biotite	8. Chlorite	9. Ores	10. Sphene	11. Epidote	12. Calcite	13. Apatite	14. Zircon	15. Fluorite
27. Umptekite, typical, Hällen (P. Quensel's spec. and classification)	—	34.7	57.6	—	0.0	2.2	3.8	0.2	0.1	0.2	—	0.9	0.3	—	—
28. Umptekite, Näset headland	0.0	27.8	59.2	0.4	—	6.2	2.4	—	4.0	—	—	0.0	0.0	—	—
29. Umptekite, reddish, Upptorp	0.0	32.2	58.6	0.3	0.3	4.0	2.9	0.3	0.1	0.3	0.3	0.5	0.2	0.0	—
30. Umptekite, fine-grained, Uddnäs	1.9	33.8	52.5	0.0	—	7.0	2.1	0.1	1.9	—	—	0.0	0.5	0.0	0.2
31. Umptekite, red, W of Seglinge	2.0	33.7	49.1	0.1	0.3	7.0	5.9	—	0.7	0.6	—	0.4	0.1	0.1	0.0
32. Umptekite, Ryggestalund (veins in basic umptekite)	—	17.9	66.8	0.3	—	8.1	4.2	—	0.2	0.3	—	1.2	1.1	—	—
33. Umptekite, fine-grained, Gränby	0.1	34.5	57.6	—	7.1	—	0.1	—	0.6	0.0	—	—	0.0	0.0	—
34. Umptekite, Sågen	—	35.8	56.1	—	4.6	0.5[1]	1.7	0.6	0.2	0.1	—	0.4	0.0	—	—
35. Umptekite, basic, Sågen	—	7.3	68.3	1.0	0.1	6.2	10.0	0.8	0.9	0.9	0.2	3.8	0.5	—	0.0
36. Umptekite, basic, Näset headland	—	5.4	65.9	0.5	—	21.3	3.2	0.0	0.7	0.9	0.2	1.0	0.8	0.1	—
37. Umptekite, greyish, SE of Skallerbol	—	0.4	88.9	1.0	0.0	2.4	4.0	—	0.4	0.1	0.1	2.4	0.3	—	—

[1] Riebeckite.

—earlier or roughly contemporaneous, the other later than the ferrohastingsite. Both generations are either green or have $Z = Y$ dark brown or brownish-green, X = light yellow. The latter type of pleochroism is, by the way, characteristic of some of the biotites found in the marginal "umptekites". Both biotite varieties further display considerable corrosion by the feldspars, shreds, but also small flakes of late formation following the cleavages occurring inside the antiperthite crystals.

Light apple-green aegirine-diopside ($c \wedge Z \sim 50°$) grading into emerald-green aegirine ($c \wedge X$ 5°, $2V_x \sim 70°$) is prominent in many umptekites, as for instance those occurring by Lake Fladen, S of Gränby, NE of Byske, around Ryggestalund, Sågen etc. Very frequently the pyroxene is intergrown with, or surrounded by, rims of hastingsite, the *c*-axes of the two minerals usually coinciding (Fig. 9). Except for the case of a few fenites, pegmatites and aplites of late formation, the pyroxene is always the older mineral. Small crystals of sphene, along with some magnetite and possibly also a little rutile, crowd the interior of most hastingsite grains. Sphene is also present in the shape of larger crystals, pleochroic in hues of reddish brown and occurring either independently or in the company of biotite secondary after hastingsite.

Apatite, calcite, zircon and magnetite are the common accessories, the latter two minerals together with some monazite(?) frequently concentrating in pegmatitic and other younger veins.

Quartz may or may not enter the composition of the umptekites, slightly quartziferous types being rather in excess of rocks free of that mineral.

Molybdenite is a prominent minor constituent of a rather fine-grained rock found SE of Lilla Ellringe by the shore of Lake Fladen.

The actual mineral composition of some umptekite rocks is given in Tab. 3. The perthitic feldspar has there been resolved into its components as far as practicable by a magnification of 200 ×. A comparison between the data thus obtained and the mode of the rock as calculated from QUENSEL's analysis proves a satisfactory agreement.

The texture of the umptekites is either xenomorphic-granular or hypautomorphic-granular depending for type on the proportions between perthites and granulated groundmass as well as on the development of the perthites, which may or may not be hypautomorphic. Porphyric, porphyroblastic and granoblastic textures are further of common occurrence.

VI. Fenites and the Border Zones of the Alkali Complex

1. *General statement on the character of the contact zones*

In Chapter III I have already remarked upon the gradual and transitional character, of the contact zones of the alkali complex. The rocks found here are generally of a medium- to fine-grained granular character and exhibit in part strong schistosity running nearly parallel to the general trend of the borders of the massif. The dips are vertical or slightly convergent; well developed linear structures plunging steeply toward the central parts of the alkaline rock-body are also encountered. In the fenites bordering upon this zone of what can be called maximal foliation and also in the neighbouring weakly fenitised Archæan rocks, there are numerous crushing-zones and signs of cataclase, folding and plastic deformation, the granites generally behaving as mechanically the least rigid members of the country rock, commonly showing "flowage" structures around more resistant fractured chunks of e.g. amphibolite and quartzite.

Inside the alkali complex there is generally no correspondence to this concentric schistosity, the remnants of Svecofennian rocks and the fenites being more or less massive, or reverting to their original strikes found outside the alkali complex.

The structural development of the rocks thus creates the impression of a limited ring of tectonic disturbance encircling the central parts of the Almunge massif.

As to the development of the contacts, there seems to be a certain interdependence between the structural character and the grade of coincidence of their directions of strike with those of the surrounding country-rock. Where the two are of a similar orientation the different petrographic elements are all arranged in subparallel streaks, the contact belt also being rather well-defined, and attaining its most striking appearance. The amount of contact "dike-rocks"

—e.g. the lestivarites and allies—is at its peak, these rocks are here also best developed, thus evidently depending for development on the presence of marked zones of structural weakness.

This is the case e.g. along the SW and W sectors of the contact zones, where the ring structure also includes the greatest amount of schistose marginal canadites treated in Chapter IV.

Along parts of the N and NE delimitation of the alkali complex and also S and SE of Oppgården, where the strikes of the Archæan rocks are markedly different from those of the contact belt, dikes of alkali aplites and diffuse zones of fenitisation are seen to finger out into the surrounding terrain, evidently following the parallel structures of preexisting rock. In the S and SE the boundary of the alkali rocks is also less conspicuous and rather irregular and is marked by a series of dislocations, along which the Archæan rocks retreat stepwise eastward to be replaced by umptekite and fenite. This last-mentioned part of the contact belt requires, however, much more mapping to elucidate the details of its structure.

In all sectors of the border zones so far investigated in detail, there were found streaks of crushing and mylonitisation carrying the ring of schistosity practically all around the massif, although the site of this ring in places is outside the central aureole of fenites (St. Ellringe–Broängen) or overridden and masked by umptekite formation.

Regarding the relative age of this structure, the petrographic and tectonic data now available indicate a very early origin. Subsequently these areas have repeatedly been the site of tectonic movement and material supply, thus being active from the earliest to the latest stage of the formtion of the massif. There are e.g. healed streaks of cataclastic deformation, earlier than most of the fenitisation, and there are also crush-zones younger than the latest rocks reshaped or formed by this process or by magmatic intrusion. Similarly, the lestivarite dikes can be seen to be of both pre- and postumptekite formation.

The concentric type of tectonic deformation was finally succeeded by (or well outside the massif was possibly partly contemporaneous with the formation of) a set of joints radially pointing toward the central parts of the alkali-rock body. These joints, mostly of a tension-fracture (ac-) character, are in part occupied by hypabyssically textured umptekite (Norrby) or carry veins of quartz of post-umptekite and post-fenitisation age (Uddnäs *int. al.*).

2. *Dike-rocks predominantly found in the contact zones of the alkali complex*

A. *Lestivarites and albitites*

The lestivarites and albitites are fine-grained (0.1–0.3 mm) rocks of a characteristically leucocratic and, in comparison with the umptekites, sodic composition. Texturally they are xenomorphic-granular with pronouncedly rectilinear

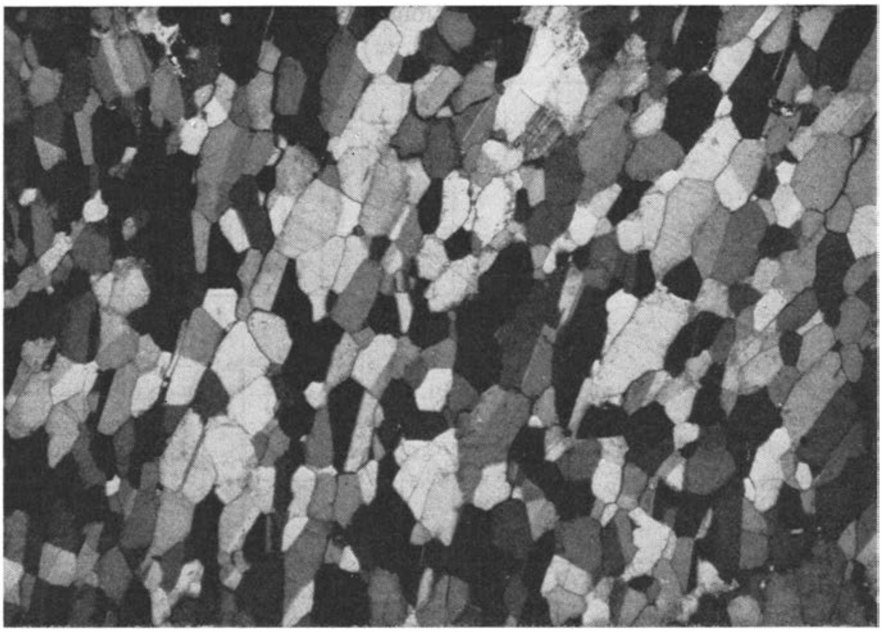


Fig. 10. Lestivarite, W of Uddnäs. 2 nic., 35 ×.

grain-boundaries, lending them the appearance of a mosaic of either equidimensional or slightly elongated grains of polygonal albite. The colour is usually white or yellow, interstitial films of iron oxides often causing the appearance of crimson-red patches and streaks.

Very sodic albite constitutes between 68 and 98% of the volume, thus strongly dominating the mineral composition. It is usually characteristically untwinned or develops only a few comparatively broad lamellae of albite twins. The rest of the rock is made up of microcline, generally occurring in the shape of interstitial serpents or blebs, magnetite, aegirine and sporadic grains of apatite, biotite, or chlorite. The magnetite commonly forms large blue-black crystals often measuring 5, 10 or more millimetres across, now and then surrounded by reaction rims of epidote and sphene.

One variety of rock belonging to this group carries large, partly subautomorphic crystals of microcline or microcline-perthite giving the lestivarite a porphyric over-all pattern. These potash-feldspars have usually a size of between 1 and 2 cm. There are however instances of perthites as big as a brick, in which large units there may occasionally be found inclusions of groundmass albite. Besides occurring as single large crystals microcline may also be enriched to form discrete veins of a pegmatitic appearance.

The lestivarites and albitites are generally conspicuously bound to zones of mechanical failure, and while predominantly found in the schistose border areas of the complex, they also appear inside the central umptekites and cana-

Table 4. Actual mineral composition of lestivarites, albitites and aplites (vol. %)

	1. Quartz	2. Microcline	3. Plagioclase, mainly albite	4. Sericite	5. Aegirine	6. Hastingsite	7. Riebeckite	8. Biotite	9. Chlorite	10. Ores	11. Epidote	12. Sphene	13. Calcite	14. Zircon	15. Fluorite
38. Lestivarite, Uddnäs	—	26.8	69.0	0.0	—	—	—	—	—	3.6	—	—	—	—	0.6
39. Lestivarite, Uddnäs	—	23.4	70.8	0.0	—	—	—	0.6	—	5.2	—	—	—	—	—
40. Lestivarite, Uddnäs	0.0	24.5	71.1	—	—	—	—	0.6	—	3.6	—	—	—	0.0	0.2
41. Lestivarite, Uddnäs	—	20.8	69.7	—	—	0.7	—	8.6	—	0.0	—	—	0.2	0.0	0.0
42. Lestivarite, Gränby	—	31.4	68.0	—	—	—	—	—	0.5	0.0	—	0.0	0.1	0.0	—
43. Albitite, Uddnäs	—	0.8	98.5	—	—	—	—	—	0.7	0.0	—	—	—	—	—
44. Groundmass of lesivarite-porphyry, Hällen	—	9.0	89.3	—	0.4	—	—	—	—	1.3	—	—	—	—	—
45. Alkali-syenite-aplite, Uddnäs	9.9	40.8	39.6	—	2.5	1.0	0.3	5.2	—	—	—	0.1	0.0	0.6	—
46. Alkali-syenite-aplite, Uddnäs	15.7	49.4	29.6	—	0.9	3.2	0.1	—	—	0.6	—	0.0	—	0.1	0.4
47. Alkali-granite-aplite, Uddnäs	19.7	38.0	38.2	—	1.3	0.3	—	2.3	—	0.1	—	0.0	0.0	0.1	—
48. Alkali-granite-aplite, Uddnäs	22.2	42.0	30.7	—	1.4	1.2	0.5	1.3	—	0.2	—	0.0	0.3	0.2	0.0
49. Red aplite, Oppgården	0.9	41.1	55.9	0.0	—	0.5	—	—	1.2	0.3	0.0	—	—	0.1	—
50. Red aplite, Oppgården	27.5	21.6	47.8	0.1	—	0.2	—	2.6	—	0.0	0.2	—	—	0.0	—
51. Red aplite, Lövhagen	30.0	5.8	59.6	—	—	—	3.4	0.0	0.0	1.2	—	—	—	—	—
52. Aplite of unsettled age, filling shear-zone N of Lake Södersjön	0.4	32.9	59.8	—	—	—	—	0.0	0.7	1.2	5.0	—	—	—	0.0

dites. This applies to the dike described by QUENSEL (op. cit., p. 192) from the area between Hällen and Sågen, where about half a dozen exponents of the rock-group were located during the present survey (cf. Map, Fig. 2).

In marginal sectors not falling within the ring of schistosity, and consequently relatively poor in zones of mechanical failure, the lestivarites mostly fail to form coherent streaks, and appear instead in the shape of small winding veinlets and diffuse accumulations of fine-grained albite infesting large areas of the marginal umptekites and fenite. This is the case e.g. in the woods E and N of Ryggestalund in the NE corner of the map, Pl. I.

Elsewhere, the lestivarites and albitites are of a markedly parallel structure often displaying a streaky distribution of white, red and yellow colour. Here there are also schlieren of rock rich in biotite, the colour then ranging with the content of this mineral from dirty yellow to grey. Microscopic investigation proves these dark streaks to be contaminated with recrystallized "rolled-out" metabasite and nepheline-syenite, granitic remnants also occurring in comparable positions forming distorted schlieren of sericitized granulated plagioclase and biotite surrounded by rims of large microcline crystals. As the absorption of these inclusions proceeds, the plagioclase yields granular albite, the sericitic flakes coalesce to form muscovite, the biotite finally altering into iron ore or aegirine.

Analysis No. 11 gives the chemical composition of a white lestivarite found in umptekitic fenite (fenitised red granite) S of Lake Fladen. Analysis No. 12 represents a general sample of streaky lestivarite from a dike surrounded by red fenitised granite with inclusions of metabasites. There is abundant evidence of contamination of this lestivarite by the contiguous rocks.

B. *Quartz-bearing aplites*

This provisional term was devised to cover a very irregular group of red leucocratic aplitic rocks containing various amounts of quartz. Sometimes there may be noticeable compositional semblance to the lestivarites, the quartz-rich rocks in the overwhelming majority of cases, however, being much richer in silica and potash. The texture is a typically aplitic one of xenomorphic granular small feldspar-grains with suturated boundaries. Recrystallized mortar textures were also noticed in some cases.

The main minerals are microcline, albite or albite-oligoclase, and quartz, which occur together with lesser amounts of biotite, chlorite, epidote, ores, apatite, zircone, and fluorite. Polysynthetic albite twinning and weak sericitization of the plagioclase are often present. The sum of mafic constituents may also include small amounts of aegirine-augite, ferrohastingsite, or riebeckite. When these colored minerals are found in dikes cutting the granites outside the zone of fenitisation, the alkaline affinities of the aplites are evident enough; in other cases it may be rather difficult to decide on the genetic position of the rocks which greatly resemble the several generation of Archæan aplites veining the granite terrain. Often there are no contacts exposed between the problematic aplites and undoubtedly alkaline rocks, the only indication of age then being the concentration of the former in the vicinity of the marginal zone of the alkali complex. There are cases when even this indirect proof is lacking. A system of quartz-bearing aplite dikes at Oppgården was thus previously supposed to be of pre-alkaline age (cf. QUENSEL, p. 137), but the recent discovery of fragments of magnetite-porphyric lestivarite inside this rock revealed the contrary.

Closely associated with the quartz-bearing aplites are pegmatitic rocks of a similar composition and characterized by the occurrence of lenses and cores of compact cherty-looking quartz, one of these lenses, measuring 3×0.75 m, being planted in a dike of schistose nepheline-syenite S of Lake Fladen.

C. *Alkali-quartz-syenites and alkali-granites*

With the sole exception of vein-quartz, the alkali-quartz-syenites are the youngest rocks of the complex, and form branching irregular dikes and veins inside the fenites of the marginal belt, a schistose type of the rock also occurring

Analysis No 11. Lestivarite, S. of L. Fladen

Weight %		Mol. numbers × 100	Norm		Niggli values	
SiO_2	67.82	112.92	q	2.38	si	302.3
TiO_2	0.06	0.08	or	27.83	qz	11.6
Al_2O_3	18.13	17.79	ab	67.06	al	47.6
Fe_2O_3	0.34	0.21	hl	0.01	fm	4.4
FeO	0.78	1.09	sal	97.28	c	0.2
MnO	0.01	0.01			alk	47.8
MgO	0.05	0.12	fs	1.13 } hy 1.25	k	0.28
BaO	0.01	0.01	en	0.12	mg	0.07
CaO	0.03	0.05	di	0.02	ti	0.2
Na_2O	7.97	12.86	ac	0.28	p	0.03
K_2O	4.71	5.00	mt	0.35	co_2	0.05
P_2O_5	0.01	0.01	il	0.12	c/fm	0.04
CO_2	0.01	0.02	cc	0.02	w	0.28
F	< 0.01	—	ap	0.03	Q	41.1
Cl	0.006	0.02	fem	2.07	L	57.4
$H_2O^{>105°}$	0.15		Sum:	99.35	M	1.5
Sum:	100.09		$+H_2O^{>105°}$	0.15	π	0
$H_2O^{<105°}$	0.05			99.50	γ	0.04
					α	5.71
					μ	0.07
CIPW classification I : 5 : 1 : 4			or : ab	29.3 : 70.7		

in dislocation zones e.g. by the farm-buildings of Ryggestalund and in the canadites SW of Sågen. The veins of this rock found S of Lake Fladen are, however, much less foliated than the surrounding fenites and lestivarites, indicating an age later than the main phase of tectonic deformation. Incidentally the alkali-granite is the only rock of the alkali complex which exhibits distinct chilled borders. Its colour is brownish-red to pink, usually shifting on the margins to a peculiar brownish-violet tint. The size of grain is about 0.5–1.5 mm, the texture xenomorphic-granular, the composition, though showing some diversity, is always much more constant than that of the "quartz-bearing-aplite" of the preceding paragraph. Quartz usually amounts to between 10 and 25 %, coloured components, which include brown biotite, aegirine, riebeckite ($b = Y$, $c \wedge X\ 5°$) and hastingsitic amphibole comprising an additional 5 to 10 per cent of the volume. The main constituents of the rock are moderately perthitic microcline and albite, the amount of the potash-feldspar almost always exceeding that of the total (granular plus perthite-lamella-) albite. Fluorite, calcite and zircon are the normal accessories.

The total area of the above rock is very small; a microscopically not yet investigated and genetically unclassified rather similar fine-grained granite appears, however, in quantity in the southern parts of the alkali complex.

Analysis No 12. Lestivarite, S. of L. Fladen. General sample

Weight %		Mol. numbers × 100	Norm		Niggli values	
SiO_2	63.51	105.74	q	0.21	si	245.5
TiO_2	0.06	0.08	or	18.70	qz	−13.3
Al_2O_3	18.99	18.63	ab	71.96	al	43.2
Fe_2O_3	2.47	1.55	an	1.85	fm	14.6
FeO	1.75	2.44	c	0.89	c	2.5
MnO	0.06	0.09	hl	0.09	alk	39.7
MgO	0.26	0.65	sal	93.70	k	0.20
CaO	0.60	1.07			mg	0.10
Na_2O	8.52	13.74	fs	1.19 } hy 1.85	ti	0.2
K_2O	3.16	3.36	en	0.66 }	p	0.05
P_2O_5	0.03	0.02	mt	3.59	co_2	0.49
CO_2	0.09	0.21	il	0.12	c/fm	0.17
F	0.05	0.26	cc	0.21	w	0.55
Cl	0.01	0.03	ap	0.07	Q	37.2
$H_2O^{>105°}$	0.32		fr	0.10	L	57.3
Sum:	99.88		fem	5.94	M	5.5
− O for F, Cl	0.02		Sum:	99.64	π	0.03
					γ	0
	99.86		+ $H_2O^{>105°}$	0.32	α	−0.56
$H_2O^{<105°}$	0.05			99.96	μ	0.10
CIPW classification	I:5:1:4		or : ab : an	20.2 : 77.8 : 2.0		

3. *Fenitisation processes*

On the map, Pl. I, will be found a division into (moderately fenitised) Archæan plutonics and supracrustals, mostly fine-grained marginal umptekitic rock (roughly corresponding to the fenite-gneisses and fenite-migmatites of Norin and Gorbatschev 1960), and granitic or quartz-bearing umptekites, all these groups being to a very great extent what is covered by the term fenite, viz. products of alteration *in situ.* These marginal and transitional groups, however, also include diffuse streaks, small dikes, and other concentrations of lestivaritic and homogeneous umptekitic material, as well as rocks which, although microscopically seen to be derived by processes of fenitisation, have the bulk composition and macroscopic appearance of umptekite. There are no definite boundaries separating these "umptekitic fenites" from "typical umptekites" and it was consequently felt that the use on the map of both the terms "fenite" and "umptekite" would create a misleading impression of the field relations and might be taken to imply a genetic division into fenites and nonfenites, undesirable at the present stage of investigation.

This consideration is further strengthened by the requirements imposed both by the scale of the map and by the necessity of a division of the unhomogeneous marginal rocks into a limited number of types, readily recognizable without microscopic examination.

The alterations effected by the process of fenitisation depend both on the composition of the attacked rock, and on its location within the complex. Generally speaking there may be said to exist broad aureoles of regional fenitisation, and more limited belts of alteration surrounding the lestivarites and allied dikes, or occurring along zones of mechanical failure. These two types are often superimposed upon each other, their character being further complicated by the local prominence of dynamic action. Moreover there seem in places to have been several successive surges of fenitisation, causing a repeated recurrence of similar parageneses.

Turning first to the belts of alteration surrounding the (schistose) lestivarites, these may be said to imply spatially limited, but very intense metasomatism, granular albite and aegirine (or occasionally riebeckite) rims around quartz being the most prominent newly-formed minerals. This local metasomatism along with the alterations characteristic of the belt of schistosity are of a noticeably more sodic character than the fenitisation leading to the formation of the umptekites proper.

Several hundred metres off the borders of the alkali complex there are limited zones of mechanical failure and albite formation, forming the forerunners of the schistosity belt. On a more regional scale, there is first an accentuation of the wavy extinction of quartz, which nearer to the umptekites is followed by the granulation of all the minerals of the Archæan rocks, the original quartz and feldspar grains here disintegrating into groups of grains still exhibiting subparallel extinction.

In the red acid granite S of Lake Fladen, the sector of the contact zone studied in greatest detail, the new minerals first to appear are pyroxenes marginally replacing the original quartz of the granite. The pyroxene starts with almost pure diopside, then gradually alters into aegirine-diopside as the alkali complex is approached. Decalcification of plagioclase is also inaugurated at a very early stage in the history of fenitisation. This process is naturally not very marked in the oligoclase and albite of the red granite. In the basic fragments enclosed in this rock there is, however, an intense formation of clinozoisite or calcite.

Next, and partly coinciding with the formation of pyroxene rims, follows a belt of increasing, though usually not very pronounced, plagioclase sericitisation and turbidity. This is usually just outside the zone of maximum granulation. Simultaneously the pyroxene rims formed around the quartz crystals become unstable, and are replaced by ochreous masses of iron oxides, studded with small chlorite flakes, and interwoven with calcite. The ochreous material also dissipates along intergranular boundaries and cracks, giving each of the disintegrating pyroxenes and amphiboles a macroscopically red aureole of interstitial

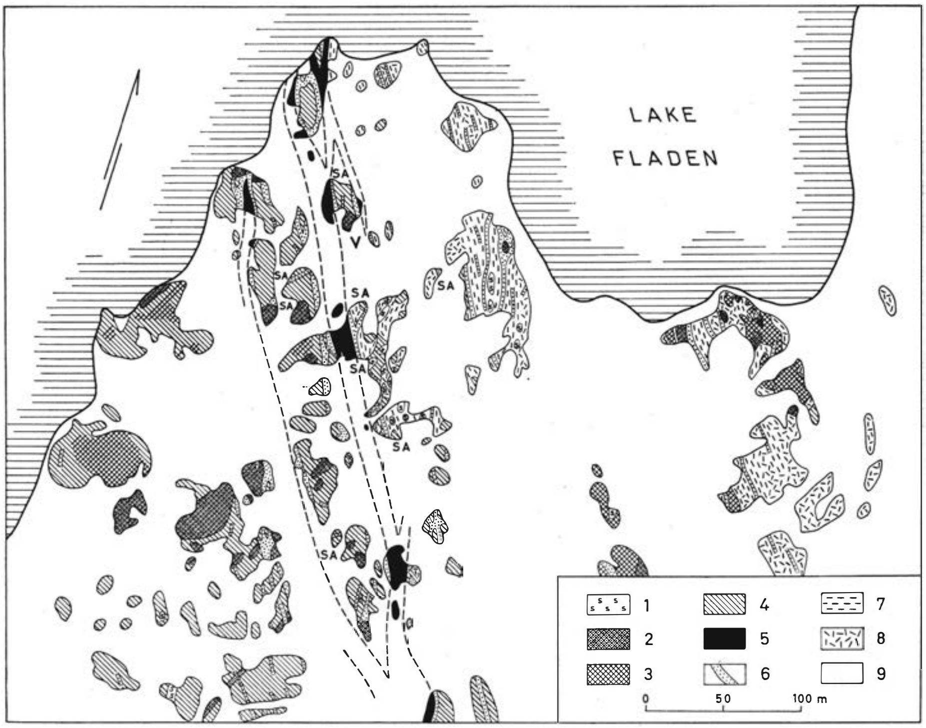


Fig. 11. Sketch-map of the border zone of the alkali complex W of Uddnäs. Legend: 1 = Archæan supracrustals, 2 = amphibolite, diorite, 3 = granodiorite and grey granite, 4 = red acid granite, 5 = schistose nepheline-syenite, 6 = lestivarite and albitite, 7 = schistose fenite, 8 = umptekite and umptekitic fenite, 9 = covered ground, SA = alkali-syenite- and alkali-granite-aplites. V = vesuvianite-bearing fenitised amphibolite.

iron oxides. This process is very similar to the one described by STRAUSS and TRUTER (1950) from the Spitskop umptekites.

At this stage of fenitisation there also appear large crystals of calcite and considerable amounts of fluorite, the latter mineral locally accumulating in amounts so large as to give the rock a violet colour. New microcline begins to form along intergranular boundaries, and also in the cores of sericitised plagioclase, replacing that mineral to form a kind of patch-perthite. There are often small rims and blebs of fluorite inside these perthitic crystals. The formation of microcline continues through the succeeding stages of fenitisation, the mineral becoming increasingly more perthitic, and showing a manifest tendency to develop large porphyroblastic grains. The sericitised turbid granular plagioclase alters into small grains of fresh albite, albite also forming at the expense of quartz, the content of which mineral steadily decreases throughout the whole process of fenitisation. The ochreous iron oxides finally recrystallize into biotite, forming stellate rosettes emanating from the intergranular boundaries formerly lined with ochreous material.

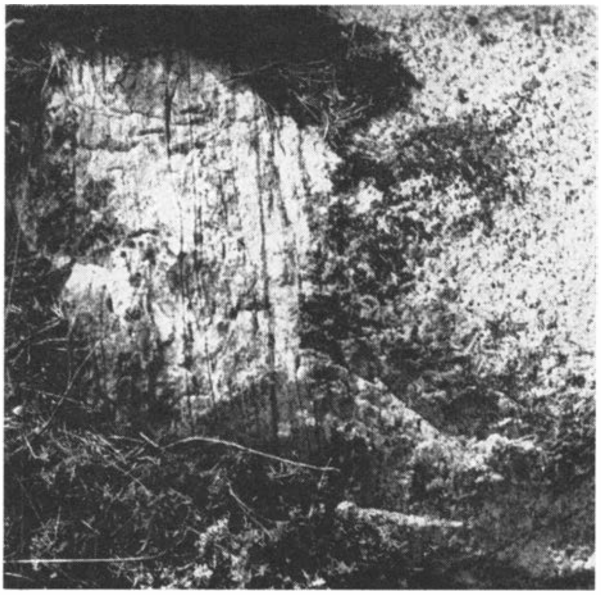


Fig. 12. Albitized zone of dislocation in red acid granite. ENE of Lövhagen.

In the area S of Lake Fladen this stage coincides in places with the appearance of the belt of concentric schistosity and lestivaritic rock. Around the latter there may be a regeneration of aegirine, and, more seldom, riebeckite from the ochreous material or the biotite formed at the expense of the latter. Minute scales of a blue amphibole with $b = Y$, $c \wedge Z = 7°$ and moderate axial angles also make a sporadic appearance. This mineral always seems to be pseudomorphic after aegirine-diopside and is a crossite according to the classification of Winchell (1951). The relations between the chemical composition and the optics in the riebeckite-glaucophane group are, however, of a complex nature—this is amply illustrated by Sundius' compilation (1940)—and so no definite conclusions can be drawn concerning the exact Fe/Mg ratio of this sodic amphibole.

The mostly fine-grained light brownish-yellow rocks of the schistose belt (fine-grained marginal umptekites of the Map, Pl. 1) mainly consist of untwinned or poorly twinned albite, granular microcline, large microcline-albite(-perthite) porphyroblasts, sporadic quartz, and aegirine plus biotite in varying proportions (cf. Tab. 5). The pleochroic colors of the latter mineral are usually X = yellowish green to yellow, $Y = Z$ = deep, often almost opaque, green to reddish-brown with a greenish tinge.

The schistose rocks are usually much more salic than either the massive umptekites or most of the massive fenites, a property earlier mentioned by Quensel (op. cit., p. 158). As can be concluded from the chemical and planimetric analyses available a frequent feature of these rocks is their sodic character, *Analysis No 13.* Dike nordmarkite, Broängen. P. Quensel, op.cit., p. 159

Weight %		Mol. numbers × 100	Norm		Niggli values	
SiO_2	64.74	107.79	or	23.76	si	259.5
TiO_2	0.06	0.08	ab	69.26	qz	−9.0
Al_2O_3	19.94	19.56	an	2.98	al	47.1
Fe_2O_3	0.61	0.38	ne	0.06	fm	6.7
FeO	1.10	1.53	c	1.01	c	4.0
MnO	0.04	0.06	sal	97.07	alk	42.1
MgO	0.18	0.45			k	0.24
CaO	0.94	1.68	fa	1.01 } ol 1.33	mg	0.16
Na_2O	8.20	13.23	fo	0.32	ti	0.19
K_2O	4.02	4.27	mt	0.88	p	0.19
P_2O_5	0.11	0.08	il	0.12	co_2	0.82
S	0.09	0.28	cc	0.34	c/fm	0.60
CO_2	0.15	0.34	ap	0.27	w	0.32
H_2O	0.33		pr	0.17	q	38.4
Sum:	100.51		fem	3.11	L	59.0
− O for S	0.04		Sum:	100.18	M	2.6
					π	0.05
	100.47		$+H_2O$	0.33	γ	0
				100.51	α	−1.12
					μ	0.16
CIPW classification I:5:1:4			ne : or : ab : an	0.1:24.7:72.1:3.1		

which, together with the granular texture, and the prominence of recrystallized crush-zones, relates them to the lestivarite-albitite group of Almunge rocks. Genetically the "fine-grained marginal umptekites" are intimate migmatitic mixtures of altered Archæan rocks, and material rich in sodium predominantly accumulating in zones of mechanical failure. This terrain is traversed by streaks and dikes of lestivarite, albitite and homogeneous sodic umptekite, the latter in places forming independent veins and dikes (QUENSEL's nordmarkite veins, analysis No. 13). Then there are also the quartz-bearing aplites of the previous heading and veins, lenses or *schlieren* of coarse quartz, occurring together with aegirine and ferrohastingsite. Amphibole also fills cracks and healed zones of shear.

Toward the centre of the alkali complex there is in all fenites, schistose or not, a gradual increase in the ferrohastingsite content, this mineral replacing all the other dark constituents. Simultaneously large crystals of microcline-albite-antiperthite or -perthite are seen to take the place of the granular feldspars. These porphyroblasts are often arranged to form fans, emanating from a common focus and enclose the other minerals of the rock in a poikilitic fashion. By a gradual increase in the grain size and the suppression of the granular groundmass and poikilitic granular inclusions, the rock grades into typical umptekite.

Fig. 13. Granulated fenitised grey basic granite. Most of the quartz is gone, large sericitized andesine crystals are replaced by albite. Uddnäs. 2 nic., 35 ×.

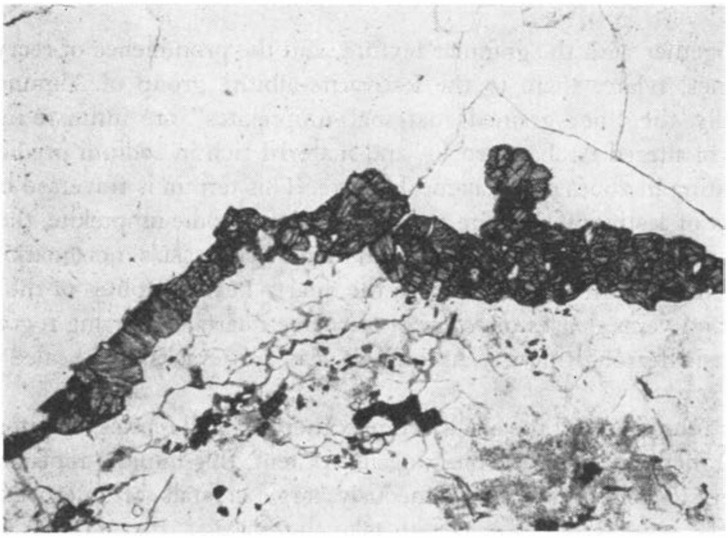
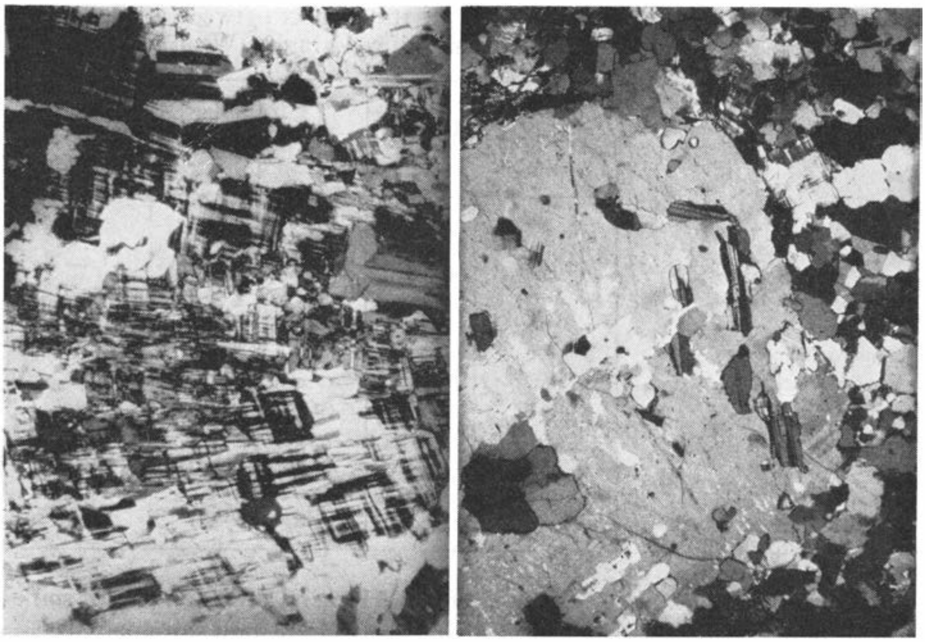


Fig. 14. Recrystallized aegirine-augite rim surrounding quartz. Fenitised red granite, S of Lake Fladen. 1 nic., 52 ×

Table 5. Mineral composition (vol. %) of the contact between a fragment of schistose nepheline-syenite and fenitised red granite, W of Uddnäs

	Altered nepheline-syenite	Microcline rim	Albite rim	Fenite	Fenite 2 m off the contact
Width of zone (mm)	15	5	10	30	
nepheline pseudomorphs	0.7	—	—	—	—
quartz	—	—	—	15.2	14.2
albite	63.9	8.2	84.7	37.5	29.6
microcline	18.1	80.5	7.4	38.3	53.9
green biotite	16.6	} 11.0			
brown biotite	—		2.5	0.0	0.2
aegirin e	—	—	5.1	8.6	1.9
ores	—	—	0.3	0.3	—
apatite	0.4	0.1	0.0	0.0	0.1
calcite, fluorite, allanite	0.3	0.2	0.0	0.1	0.0

In intermediate and basic rocks, the course of mineral alteration follows somewhat different paths. Pyroxene rims around quartz are thus considerably less prominent or altogether absent. Though these rocks often alter into diopside-albite or aegirine-diopside-biotite-albite fenites, the new-formed dark minerals here mostly grow at the expense of the biotite and amphibole of the attacked rock. The usually ragged and granulated original dark minerals also display very gradual alterations of their optic properties, especially the colours of pleochroism, altering into "bleached" colourless or faintly greenish hornblende ($c \wedge Z = 16$–$17°$, $2V_x = 80$–$81°$) and weakly greyish-brown biotite, the chemical analysis of which latter mineral proves a high percentage of Mg (analysis of grey mica, Näset, p. 57). This stage of alteration seems to correspond to the early diopside formation in the red granites, and is succeeded by a gradual enrichment in iron, resulting in the formation of bright emerald-green aegirine-augite, bluish-green amphibole and bright-green siderophyllite (analysis p. 57). The granulation and the alterations of the feldspar proceed much as described above, all the rocks eventually becoming more or less typical umptekites. The sequence of fenitisation events as described here, is a general mean of the outer contact belts, local variations being exceedingly common. Thus some of the zones (e.g. ochreous iron-oxides- or pyroxene-) may be very narrow. There may also appear extensive epidote- and chlorite-facies rock, vesuvianite and garnet occasionally entering the composition of moderately fenitised basic rocks encircled by umptekites or fenites of more advanced alteration. In addition granulation, coarsening, homogenization and partial or total mobilisation of the fenites are not uniformly developed, much less rigidly fixed to any definite stage of mineral alterations and desilicification. Although a considerable amount of data concerning fenitisation has been accumulated during the present survey, space and



a b

Fig. 15a and b. Porphyroblasts of perthite in granulated fenitised granodiorite at Uddnäs. 2 nic., 25 ×. Fig. a: Photo E. Norin.

the proportions of this preliminary paper prohibit a more detailed discussion of the process here, let alone a description of the different key localities made the subject of detailed study.

Chemically the Almunge fenitisation implies and addition of Na, K, Fe and probably Al and a corresponding subtraction of Si, Ca and Mg. The formation of Mg-rich minerals in the outermost zone of alteration is suggestive of the existence of a basic front effect. In the acid granites there can actually be traced an absolute enrichment in Mg and possibly also Ca during the early stages of fenitisation. Concerning Mg, this seems to be the case also in the transitional white nepheline-syenites (cf. analysis No. 9) and in small metabasite fragments enclosed in the massive umptekite. Regarding the basic granites and the marginal metabasites the question is not yet definitely settled, the formation of magnesic minerals here possibly being due to a local redistribution of iron. As to the behaviour of Si, part of the original quartz must have been consumed in the formation of *inter alia* pyroxene and feldspars, while some moved on into the basic rocks and the canadites. Still there was undoubtedly an actual, although not very profound, abstraction of this element. The presence of quartz-filled cracks and veins, the tendency of this mineral to recrystallize into discrete lenses, clusters and other accumulations, and the absence of any evidence of silicification in the surrounding Archæan rocks, the latter contrasting to the

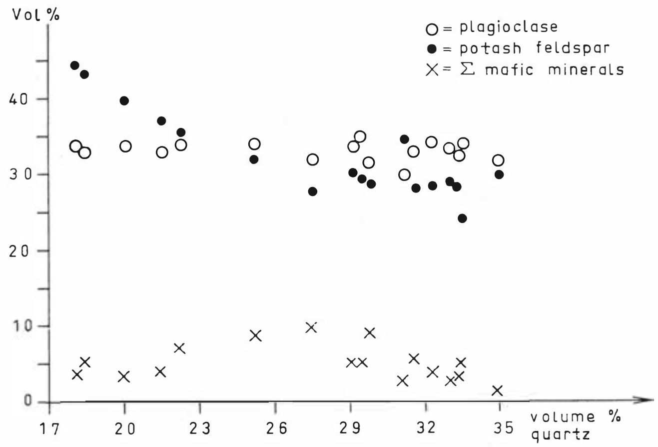


Fig. 16. Diagram showing the mineral composition of fenitised red granite in a section through the belt of fenitisation S of Lake Fladen.

phenomena described from Umptek (KUPLETSKY 1928, p. 85), indicate an early mobilisation and a great mobility of silica as well as a removal of this material from the rocks exposed at the present erosion surface.

Concerning the alkalis there seems to be an early (outer zone of) potash-metasomatism, followed by a surge of sodic material. This is *inter alia* illustrated by the data compiled in the diagram Fig. 16, where the volume percentages of potash-feldspar, albite-oligoclase and mafic minerals will be found plotted against those of quartz in the fenitised red acid granite. The uniform mineral composition of this rock in some areas S and SW of Lake Fladen makes it an especially suitable object of study in investigating the quantitative aspects of fenitisation. In the belt of concentrically schistose rocks this fixed K-Na succession is disturbed by the local accumulation of sodic material, the two successive surges however often reappearing in fenitised, macroscopically still recognizable Archæan rocks found in the more central parts of the complex. This, together with quantitative considerations, indicates that the K-surge effect in the border zones is at least not exclusively due to an expulsion of potassium from the marginal, often sodic, schistose rocks.

While the above is a compilation and interpretation of the consistent qualitative effects of fenitisation, any attempt to produce quantitative aspects will require a lot of chemical data not available for the time being. This applies also to problems imposed by the homogenization of fenites formed from chemically different members of the Archæan bedrock.

Of the three analyses of fenites, No. 15 is a granulated "basic granite" (tonalite) embedded in lestivaritic felsic sodic rock, No. 14 is macroscopically a fine- to mediumgrained slightly porphyric umptekite, its field relations, mineralogical

Analysis No 14. Fenitised grey granite, Uddnäs

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	65.64	109.29	q	8.31		si	270.9
TiO_2	0.15	0.19	or	27.05		qz	17.6
Al_2O_3	15.76	15.46	ab	50.75		al	38.3
Fe_2O_3	0.54	0.34	an	2.56		fm	14.8
FeO	2.63	3.66	sal	88.67		c	10.9
MnO	0.13	0.18				alk	36.0
MgO	0.58	1.44	fs	2.86	hy 3.81	k	0.33
BaO	0.06	0.04	en	0.95		mg	0.24
CaO	2.44	4.35	fs	1.50	di 3.88	f	6.00
Na_2O	6.00	9.68	en	0.49		ti	0.47
K_2O	4.58	4.86	wo	1.89		p	0.12
P_2O_5	0.07	0.05	mt	0.79		co_2	1.19
CO_2	0.21	0.48	il	0.29		c/fm	0.74
F	0.46	2.42	cc	0.48		w	0.15
$H_2O^{>105°}$	0.44		ap	0.17		Q	42.0
Sum:	99.69		fr	0.93		L	50.1
− O for F	0.19		fem	10.35		M	7.9
	99.50		Sum:	99.02		π	0.03
$H_2O^{<105°}$	0.12		$+ H_2O^{>105°}$	0.44		γ	0.37
				99.46		a	3.29
						μ	0.15
CIPW classification I:5:1:4			or:ab:an		33.7:63.1:3.2		

composition as well as the presence of incompletely homogenized dark patches characteristic of basic (Uppsala) granite, however, betraying its metasomatic origin. Both rocks are from the outcrops between Uddnäs and Lake Fladen. On the basis of microscopic investigation and analyses of similar rock from other parts of the province of Uppland the original chemical composition of the "basic granite" can be given as about: SiO_2: 66–69%, Al_2O_3: 13–16%, MgO: 2%, FeO + Fe_2O_3: 5%, CaO: 4%, K_2O: 2–3% and Na_2O: 2–3% by weight.

Analysis No. 16, finally, gives the composition of the Mg-rich zone in a fenitised fragment of supracrustal (?) metabasite found in the umptekite at Gränby. This is the rock from which the mica rich in Mg (cf. p. 51) has been isolated.

The rocks most easily losing their identity during the fenitisation are granites and supracrustals of an an approximately granitic composition. Quartzites are somewhat less vulnerable, mafic rocks of all kinds (metabasites, theralites etc) being, finally, the ones most resistant, which applies both to conditions prevailing in the marginal belts of the complex and to fragments enclosed in massive central umptekite. Dikes and layers of these rocks are often seen to be boudin-

Analysis No 15. Fenitised grey granite, Uddnäs

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	62.90	104.73	q	4.81		si	229.7
TiO_2	0.72	0.90	or	23.43		qz	11.5
Al_2O_3	15.24	14.95	ab	48.55		al	32.8
Fe_2O_3	0.54	0.34	an	4.12		fm	24.0
FeO	4.27	5.94	sal	80.91		c	13.7
MnO	0.09	0.13				alk	29.5
MgO	1.68	4.17	fs	3.59	hy 5.94	k	0.31
BaO	0.10	0.07	en	2.35		mg	0.38
CaO	3.47	6.19	fs	2.78		f	1.62
Na_2O	5.74	9.26	en	1.84	di 9.20	ti	1.97
K_2O	3.97	4.21	wo	4.58		p	0.33
P_2O_5	0.21	0.15	mt	0.79		co_2	0.04
CO_2	< 0.02	0.02	il	1.37		c/fm	0.57
F	0.14	0.74	cc	0.02		w	0.10
$H_2O^{>105°}$	0.71		ap	0.50		Q	39.1
			fr	0.25		L	47.7
Sum:	99.79		fem	18.07		M	13.2
− O for F	0.06		Sum:	98.98		π	0.05
	99.73		$+H_2O^{>105°}$	0.71		γ	0.30
$H_2O^{<105°}$	0.15			99.69		α	1.67
						μ	0.26
CIPW classification II : 5 : 1 : 4			or : ab : an		30.8 : 63.8 : 5.4		

aged and broken, the fragments behaving like rigid islands in a plastically deforming mass of leucocratic rock. Around basic fragments enclosed in granite there are often found rims of fine-grained granular albite and microcline, texturally and compositionally resembling the rocks described above as lestivarites and albitites (Fig. 17). This feature can be found quite a long way from the alkali complex proper in macroscopically intact and microscopically very slightly fenitised rock, and evidently represents accumulations of material deposited by fenitising solutions impregnating the granite terrain more homogeneously. Reaction rims of a comparable appearance also develop in the fenites proper, which may or may not be plastically deformed. Microscopic investigation reveals a constant compositional character of these structures, there being around the albitised and microcline-impregnated dark rock first a rim of microcline, often with interstitial iron oxides, followed by a zone of albite and finally, adjoining the granitic fenite, a mafic belt, composed either of aegirine or amphibole and lesser amounts of albite (Fig. 19, Tab. 5).

In the central umptekite area there is either gradual feldspar-impregnation or selective mobilisation of feldspar in the basic inclusions, the second process

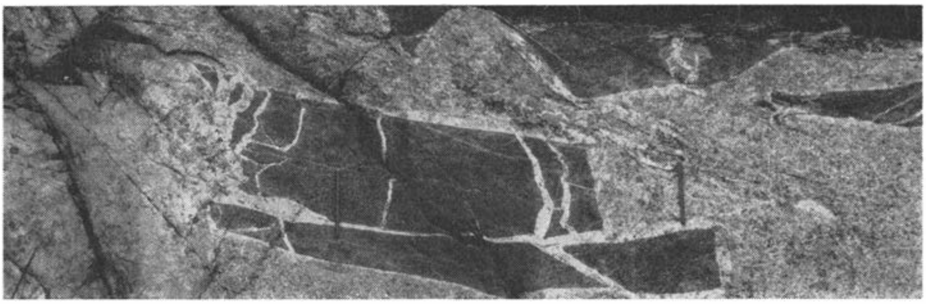


Fig. 17. Alkali-feldspar rims around "indigestible" amphibolite inclusions in plastically deformed, slightly fenitised granodiorite. S of Oppgården. Photo Prof. E. Norin.

Analysis No 16. Fenitised metabasite. Gränby

Weight %		Mol. numbers × 100	Norm			Niggli values	
SiO_2	55.01	91.59	or	25.27		si	148.4
TiO_2	1.06	1.33	ab	31.20		qz	−35.6
Al_2O_3	13.08	12.83	ne	6.65		al	20.8
Fe_2O_3	1.49	0.93	sal	63.12		fm	46.9
FeO	6.06	8.44				c	10.6
MnO	0.11	0.16	fs	2.18	di 13.76	alk	21.7
MgO	7.46	18.50	en	4.48		k	0.34
CaO	3.68	6.56	wo	7.10		mg	0.64
Na_2O	5.47	8.82	fa	5.32	ol 15.20	ti	2.2
K_2O	4.28	4.54	fo	9.88		p	0.2
P_2O_5	0.19	0.13	ac	2.45		co_2	0.03
CO_2	0.01	0.02	mt	0.93		c/fm	0.23
$H_2O^{>105°}$	0.37		il	2.02		w	0.28
			cc	0.02		Q	26.6
Sum:	98.27		ap	0.44		L	42.7
$H_2O^{<105°}$	0.16		fem	34.82		M	30.6
						π	0
			Sum:	97.94		γ	0.18
			$+H_2O^{>105°}$	0.37		α	−0.20
				98.31		μ	0.52
CIPW classification II:5:1:4			or : ab : ne		40.0 : 49.4 : 10.6		

producing a residue rich in biotite or amphibole, the properties of which minerals approach those of the biotite and ferrohastingsite found in the umptekites.

Comparing the frequency of occurrence of different Archæan rocks inside and outside the alkali complex, there is a marked tendency for basic rocks and fragments and, in a lesser degree, quartz-mica supracrustals to be relatively more

Table 6. Chemical analyses of Almunge biotites

1. Greyish-brown biotite from fenitised amphibolite, Gränby.
2. Green siderophyllite from fenitised supracrustal rock, Uddnäs.
3. Numbers of atoms of analysis 2, corrected for intergrown apatite and calculated on the basis of 24 O.

	1	2	3		
SiO_2	41.61	32.03	Si	5.33	8.00
TiO_2	0.93	1.08	Al	2.67	
Al_2O_3	9.93	18.32			
Fe_2O_3	2.30	2.90	Al	0.92	
FeO	13.07	26.35	Fe^{3+}	0.36	
MnO	0.20	0.86	Fe^{2+}	3.67	5.51
MgO	17.41	1.26	Mn	0.12	
CaO	1.41	2.47	Mg	0.31	
Na_2O	0.21	0.47	Ti	0.13	
K_2O	9.53	8.00	Ca	0.13	
P_2O_5	0.11	1.32	Na	0.15	1.98
F	1.23	0.67	K	1.70	
Cl	< 0.01	n.d.			
$H_2O^{>105°}$	0.30	3.32	OH	3.68	3.97
$H_2O^{<105°}$	0.10	0.08	F	0.29	
Sum:	98.24	99.13			

prominent in the umptekite area, which bears witness to the selective nature of umptekitization. This applies to the macroscopic effect of the colour and mineral changes and does not necessarily suggest that the alterations effected by fenitisation are less profound in basic and quartzitic rocks.

Regarding the different kinds of granite, the acid red one is somewhat more easily altered than the basic grey type. The apparent difference is, however, largely a matter of traceability, the colour of the red rock being the one most similar to the reddish-brown of the umptekites. Microscopic investigation too reveals that the difference in the behavior of the two main types of granite is not a very profound one, and consequently, as this statement is based on laboratory and detailed field evidence, I am not in a position to find any marked consistent difference in the development of the margins of the alkali complex, when bordering on red and grey granite respectively. As stated above, tectonic factors are prominent in determining the detail character of the contact zones.

VII. Some Chemical Features of the Almunge Rocks

A compilation of data obtained from the chemical analyses of Almunge rocks gives a comprehensive picture of the characteristics and trends of the different petrographic groups. As is evident from the diagrams Figs. 21 and 22 the canadites form a well defined sodic series of, to use NIGGLI's term, atlantic affinities.

Fig. 18. Remains of grey supracrustal rock in schistose sodic fenite. Black dots and rims are aegirine. W of Uddnäs.

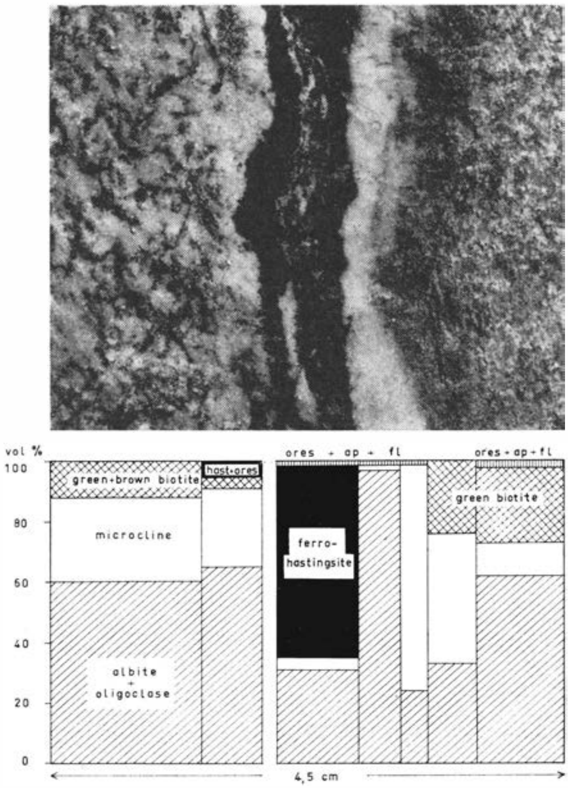


Fig. 19. Section through the reaction rim around an inclusion of supracrustal rock (to the right) in thoroughly fenitised red granite. S of Lake Fladen. Photo G. Andersson.

Table 7. Actual mineral composition of fenitised granites and marginal „umptekites" (vol. %)

	1. Quartz	2. Microcline	3. Plagioclase	4. Alteration products of 3.	5. Biotite	6. Riebeckite	7. Amphibole other than 6.	8. Diopside, aegirine	9. Ores	10. Sphene	11. Epidote	12. Calcite	13. Apatite	14. Zircon	15. Fluorite	16. Alia, mainly chlorite
53. Slightly fenitised red acid granite[1]	31.1	29.5	31.3	1.8	2.7	—	0.5	1.0	0.3	0.1	0.2	0.5	0.2	0.1	0.2	0.5
54. Moderately fenitised red acid granite[2]	20.6	36.4	33.1	1.6	2.3	—	3.2	0.7	0.3	0.2	0.0	0.5	0.2	0.1	0.6	0.2
55. Fenitised red granite, Uddnäs	11.6	31.3	55.5	—	—	—	—	1.1	0.1	—	—	0.2	0.2	—	0.0	—
56. Fenitised basic granite, Gränby	10.7	22.1	49.5	1.4	1.1	—	10.6	—	0.8	1.6	0.3	0.2	0.3	0.2	0.0	1.2
57. Fenitised basic granite, Uddnäs	5.6	23.0	44.8	3.1	7.2	—	0.1	9.8	0.0	0.9	1.0	—	0.3	0.1	—	4.1
58. Fenitised basic granite, Gränby	10.7	36.1	46.1	0.0	1.2	—	3.3	—	0.1	0.7	—	1.0	0.1	0.0	0.4	0.3
59. Fenitised basic granite, Uddnäs	4.5	30.5	53.7	0.1	—	—	8.5	0.3	0.3	0.2	0.0	0.5	0.0	0.1	0.4	0.9
60. Fenitised basic granite, Uddnäs	2.3	31.7	57.1	—	5.3	—	0.3	0.8	0.0	0.1	—	0.2	0.1	0.0	0.2	1.9
61. Fenitised basic granite, Gränby	0.1	33.0	61.4	0.5	3.6	—	—	—	0.0	—	—	0.5	0.1	0.1	0.0	0.7
62. Fenitised basic granite, Uddnäs	0.0	25.9	55.7	—	14.3	—	2.8	—	0.2	—	—	0.8	0.1	—	0.2	—
63. Fine-grained marginal rock, Uddnäs	—	32.8	58.5	—	3.9	0.8	0.0	0.6	2.8	—	0.0	0.5	0.1	0.0	0.0	—
64. Fine-grained marginal rock, Uddnäs	—	22.2	66.4	0.1	—	3.6	0.1	5.2	2.4	0.0	—	—	0.0	—	0.0	—
65. Fine-grained marginal rock, Uddnäs	—	26.1	64.9	—	4.1	—	4.3	—	0.1	—	—	0.0	0.2	—	0.1	0.2
66. Fine-grained marginal rock, Uddnäs	0.0	31.8	61.2	—	2.0	0.6	—	3.6	0.2	—	—	0.0	0.0	—	0.0	0.6
67. Fine-grained marginal rock, Uddnäs	0.3	23.9	73.7	0.1	0.2	0.4	—	0.2	1.2	0.0	—	0.0	—	0.0	0.0	0.0
68. Fine-grained marginal rock, Uddnäs	—	17.4	59.0	8.4	12.9	—	—	—	1.6	0.0	0.1	0.1	0.4	—	0.1	—
69. Fine-grained marginal rock, Uddnäs	—	29.0	52.0	0.1	5.9	0.1	—	6.4	6.3	0.0	—	—	0.1	0.0	0.1	0.0
70. Fine-grained marg. rock, Uddnäs[3]	—	38.0	54.4	—	—	—	4.0	—	3.4	—	—	0.0	0.2	—	—	—
71. Fine-grained marg. rock, Uddnäs[3]	0.1	37.7	59.7	—	1.8	—	0.1	0.1	0.1	—	—	—	—	0.0	0.1	0.3
72. Dike nordmarkite, Broängen	0.1	29.7	65.4	0.0	1.4	—	0.2	—	2.0	—	—	0.8	0.4	—	0.0	—

[1] Mean value for red granites (n = 10) with 25–35 % quartz, Uddnäs.
[2] Mean value for red granites (n = 8) with 15–25 % quartz, Uddnäs.
[3] Microcline-porphyric rock.

Proceeding from the theralites to the leucocratic canadites there is a steady increase in al and alk and a corresponding drop of the c and fm percentages as well as the mg value of the rock. As far as the main canadite body is concerned these changes are, however, not accompanied by a corresponding increase in the k-value, which remains remarkably constant between 0.15 and 0.17. Thinking in terms of magmatic differentiation this may imply an evolution by means of gravitational separation of the mafic minerals, more precisely of pyroxenes or amphiboles compositionally corresponding to hastingsite with an ever increasing percentage of iron. The textural relations found in the canadites, as well as the trend illustrated in the QLM-diagram (Fig. 20). can also be taken to speak

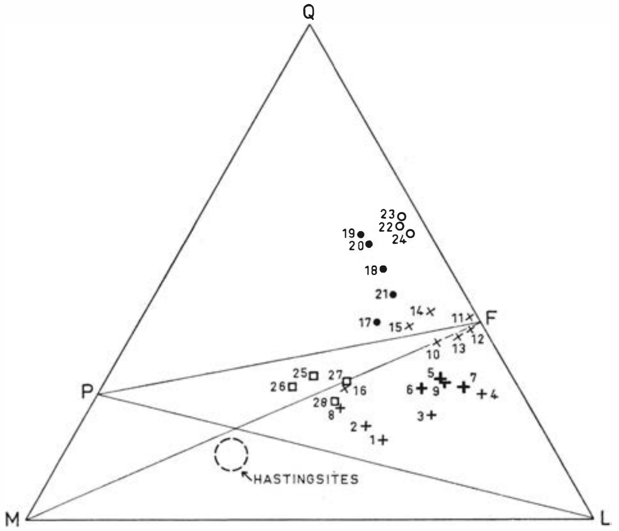


Fig. 20. QLM-diagram of the Almunge rocks. Legend: + = canadite, **+** = dike-, schistose-, marginal canadites, × = umptekites, lestivarites, fenites, ● = basic-, ○ = acid Archæan granites, □ = Archæan amphibolites and basic plutonics. No 1–16 refer to the numbers of analyses published in this paper. 17 to 21 are basic granites and gneiss-granites from P. H. Lundegårdh 1946 (p. 48 and 49), 1955 (p. 11) and E. Wiman 1930 (p. 30), 22 = red microcline granite (Lundegårdh 1946, p. 83), 23 = Vänge microcline granite (Wiman 1930, p. 37), 24 = Arnö granite (Wiman 1930, p. 42), 25 = gabbro (Lundegårdh 1955, p. 11), 26 = diorite (Lundegårdh 1946, p. 40), 27 = older amphibolite (Lundegårdh 1946, p. 34), 28 = younger amphibolite (Lundegårdh 1946, p. 95).

in favour of this supposition. This course of evolution, which must, by evidence of the age relations revealed in the canadite outcrops, be considered to stem from a melanocratic basic rock to more acid salic types, finally entering the "thermal valley" of Bowen (1937) (Fig. 24), includes a marked drop in the al/alk ratio. The variations of the c/fm quotient are less pronounced, showing only a slight tendency of decrease.

The dike canadites in some respects (e.g. al/alk) exhibit different relations. The high k values of these rocks are, however, at least partly due to alterations effected by postemplacement processes. This is confirmed by the field relations as well as by the chemical composition of the umptekitized specimen represented by analysis No. 6. In the QLM-diagram the dike canadites (analyses 5, 6 and 7) are seen to occupy an intermediary position between the field of canadite and the point (No. 10) representing umptekite. This latter rock is, as will be found from the QLM, $k\pi$ and $mg\gamma$ variation diagrams, somewhat off the line of evolution of the canadites. One of the most striking features of the umptekite is the high k value, unparallelled in any of the other—whether younger or older—analyzed rock-members of the Almunge alkali complex. Indeed the umptekite is the only rock potassic in the sense of Niggli.

Analyses 14, 15 and 16 representing fenitised basic granite and metabasite, are, as would be expected, intermediary between umptekite and the unaltered

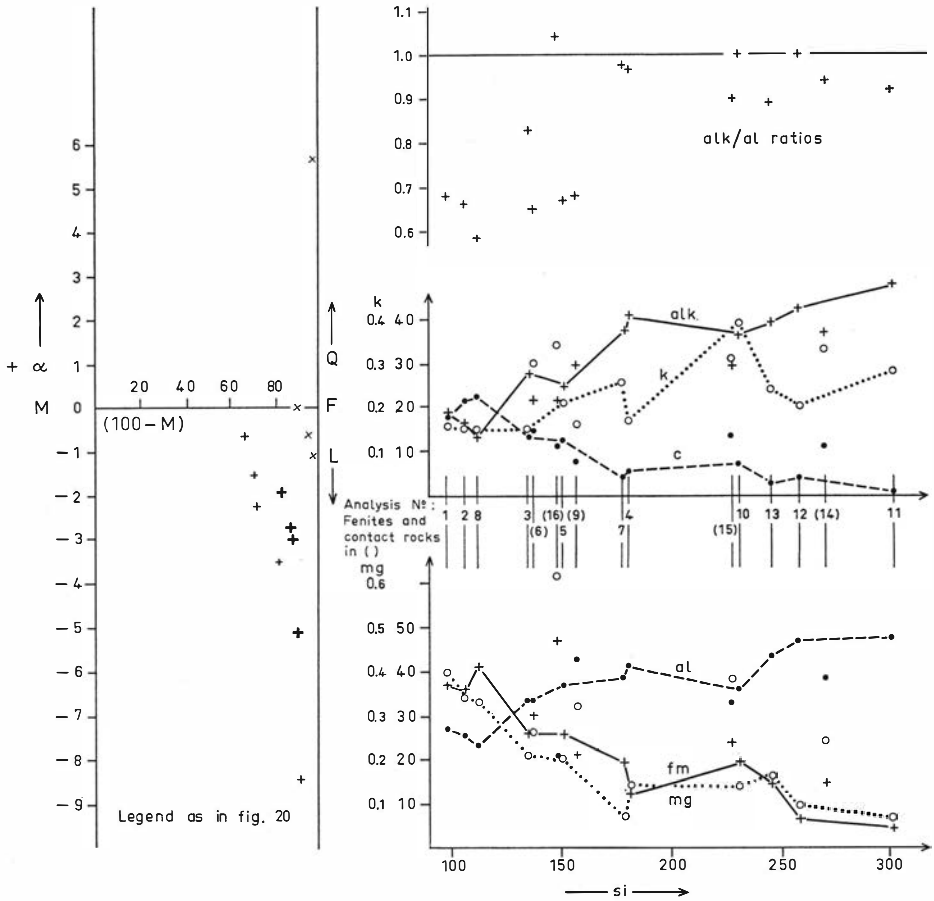


Fig. 21. LM-α-diagram, alk/al ratios, and Niggli variation-diagram of the Almunge rocks.

counterparts of these rocks. This is evident from the QLM, kπ, and mgγ diagrams, into which the Niggli values of some Archæan rocks found in the province of Uppland (pts. 17–28, for legend see fig. 20) have been inserted for comparison.

Considering the abundance of slightly quartziferous umptekite in the Almunge complex, the mean composition of this alkali rock group would, when plotted in the QLM-diagram probably be represented by a point falling into the area between pts. 10 and 14–15, thus demonstrating a nordmarkitic character.

In fact, considering the absence of lenads, the prominence of K_2O and the scarcity of CaO, it must be said that the Almunge rock does not agree very well with the definition of umptekite as given by RAMSAY (1894, p. 205) and JOHANNSEN (1938, IV, p. 8–9), or with RAMSAY's (op. cit., p. 205–207) reasons for introducing the term. Remembering that RAMSAY's analysis represents the

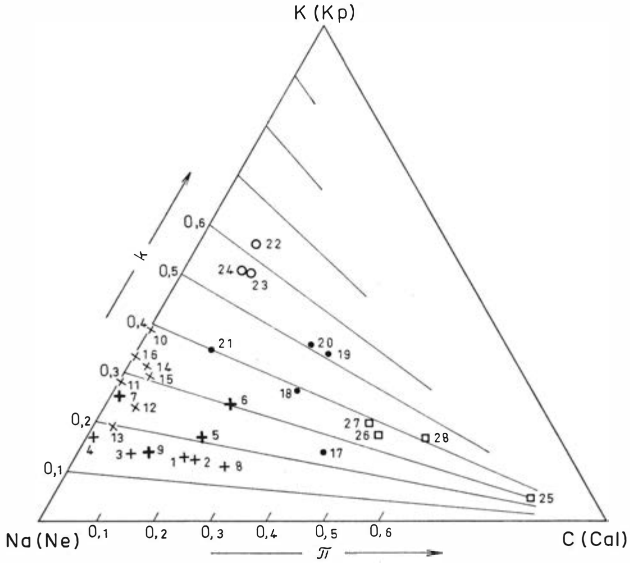


Fig. 22. kπ-diagram of the Almunge rocks. Legend as in Fig. 20.

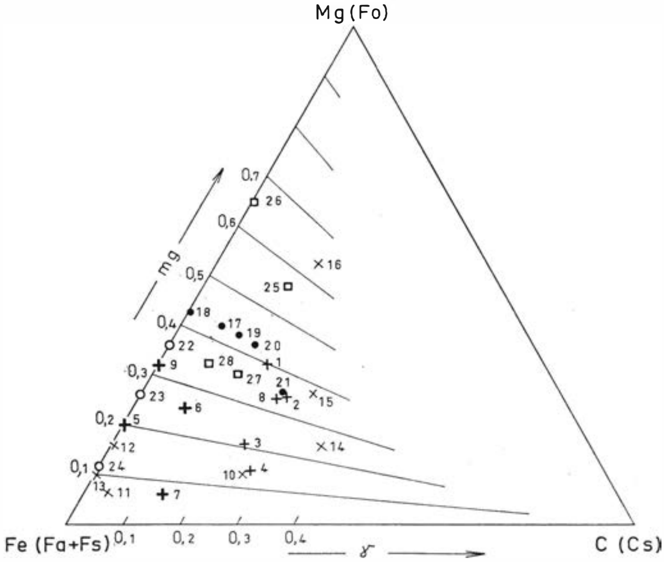


Fig. 23. mgγ-diagram of the Almunge rocks. Legend as in Fig. 20.

"*sauerster*" member of the Umptek umptekite and that the analyzed Almunge rock is one of the least acid, the difference stated here becomes still more apparent.

Tab. 8 shows the canadites to be considerably richer in water than any—with the possible exception of some fenites—of the other Almunge alkali rocks, which however, does not necessarily have any bearing on the conditions prevailing

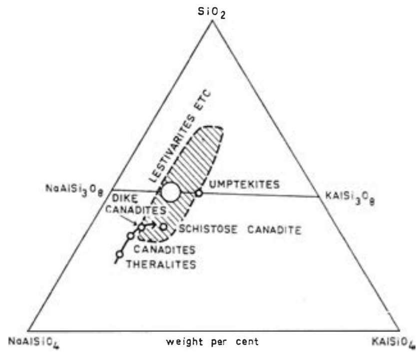


Fig. 24. Normative ne,ab,or,q inserted into the $NaAlSiO_4$–$KAlSiO_4$–SiO_2 diagram. Shaded: "thermal valley" (Bowen 1937).

during the formation of the alkali complex. Even apart from petrogenetic argument and other convincing general considerations compiled e.g. by Gilluly (1937), the distribution of water is, in the present case, evidently governed by the ease of nepheline hydration, which mineral must be expected to absorb water from whatever aqueous solutions of suitable temperature and composition existed during the post-magmatic, metasomatic, and other periods of evolution.

Of greater interest is the inverse relationship between carbon dioxide and fluorine, evidenced by the data of Tab. 8. Whereas CO_2 is enriched in the late leucocratic canadites—which, by the way, is accompanied by a rise in the oxidation ratio w (Tab. 8, Col. 4)—,the contents of fluorine is highest in the theralitic canadites. There being no fluorite in these rocks, it is tentatively suggested that this mode of distribution is due to the early crystallization of apatite and amphibole, possibly in an environment deficient in water (cf p. 37). Considering this, it should be remembered, that the conditions governing the formation of amphiboles and, more specially alkaline ones, are no by means fully elucidated. Whereas these minerals are generally considered to belong to the hydratogenic group, experimental data (Bowen 1958, p. 92) may indicate exceptions to this rule, at least as far as comparatively high-temperatured melts are concerned. Also the relative importance of chemical vs. pt- and volatile- control of the character of the dark minerals is not as yet firmly established (cf. Kennedy 1935).

There are—which is much to be regretted—no quantitative data concerning the amounts of carbon dioxide and fluorine contained in umptekite, both fluorite and calcite, however, occurring accessorily in this rock. In comparison with the nepheline-syenites the umptekites and lestivarites are strikingly low in phosphorus, which element has no prominent part in the process of fenitisation either. Another remarkable feature is the scarcity of volatiles in the lestivarite–albitite group of rocks. It is still unsettled whether this is a "primary" feature, or whether the volatiles failed to be retained in this type of rock. As mentioned before, there is a high content of fluorite in the fenites, which

Table 8. Oxidation ratios and volatiles content of Almunge rocks

Anal. No.	Rock	H_2O wt. p. c.	Niggli values			
			w	p	f	co_2
1.	Theralitic canadite	0.89	0.14	1.32	1.43	n. d.
2.	Theralitic canadite	1.79	0.21	1.35	1.73	1.05
8.	Theralite (?)	1.48	0.27	0.77	1.61	0.62
3.	Normal canadite	1.73	0.30	0.65	0.53	4.18
4.	Leucocratic canadite	1.16	0.37	0.08	0.31	5.70
5.	Dike canadite	2.54	0.34	0.37	0.75	4.58
6.	Dike canadite, dike margin	1.73	0.13	0.79	n. d.	4.50
7.	Schistose canadite	0.75	0.35	0.13	n. d.	n. d.
9.	White transitional syenite	2.21	0.23	0.33	n. d.	2.33
10.	Umptekite	0.37	0.22	0.31	n. d.	n. d.
13.	Dike nordmarkite	0.33	0.32	0.19	n. d.	0.82
12.	Lestivarite	0.32	0.55	0.05	0.60	0.49
11.	Lestivarite	0.15	0.28	0.03	<0.03	0.05
14.	Fenitised basic granite	0.44	0.15	0.12	6.00	1.19
15.	Fenitised basic granite	0.71	0.10	0.33	1.62	0.04
16.	Fenitised metabasite	0.37	0.28	0.21	n. d.	0.03

observation is amply confirmed by the data of analyses 14 and 15. The hydration zone surrounding the umptekite areas is, further, suggestive of the importance of water in the process of fenitisation.

VIII. Discussion

The evidence collected during the present survey of the Almunge alkali complex suggests the probability of at least three phases of nepheline-syenite formation, starting with dark theralites, and followed by normal, and finally leucocratic cancrinite-nepheline canadites. The age relationship between canadite and umptekite is of a complex nature and as yet not established in full detail (cf. page 31).

There is however little room for doubt that the canadites have never occupied most—or even all—of the alkali complex. Indeed, apart possibly from an area in the northern parts of the complex these rocks have not taken up very much more terrain than the present area of the nepheline-syenites and some types of sodic umptekite.

Proof of this statement is to be found in the evidence offered by the distribution of the different canadite types, and the configuration of these rocks in a set of dikes and sills, some of these not conforming with the macrostructure of the umptekites. In addition, remains of comparatively fine-grained trachytoid texture, parallel to the length axes of the respective bodies are found in canadite dikes in the S, NE and central parts of the area. This result of the investigation is relevant when considering the mode of umptekite formation, as the canadite dikes, if magmatic and older than the umptekites, clearly must have intruded into some preexisting rock. The distribution and strikes of these dikes indicate that they are not casual inclusions brought up by an umptekite magma.

While, as becomes apparent from the previous chapters, there is much in favour of a several-stages-magmatic-intrusion origin of the canadites, a different mode of formation of, at least some of, the nepheline-bearing rocks, implying a metasomatic origin of nepheline, cannot be entirely omitted from the discussion. The course of metabasite fenitisation, as exemplified by analysis No. 16, is not in conflict with such an assumption. Notwithstanding the absence of actual nepheline in the sodic plagioclase-biotite-aegirine-sphene-ores paragenesis of the rock, a slight aggravation of alkalinization as well as a change of mineral facies might well be thought to produce the lenad in question. Concerning the large canadite bodies, however, the presence of epidote-chlorite facies along the whole parameter of the white syenites between the amphibole (-perthite) parageneses of both umptekite and canadite—in addition to other chemical and tectonic considerations—does not warrant a direct parallel with the nephelinisation here touched upon. Another process indicated by field and microscopic evidence is the alteration of some canadites in the pegmatitic stage. The extension and importance of this action has not yet been the subject of systematic investigation.

The *mise-en-place* relations of the umptekitic group of rocks differ fundamentally from those of the canadites, in that the former are associated with extensive migmatites and contain innumerable fragments and ghosts of Archæan bedrock, thus demonstrating the prominence of absorption and metasomatic phenomena.

This is further confirmed by some field observations related above, the selective prominence of intact basic remains inside the complex, as well as the existense in some areas of pre-umptekitic macrotectonic features belonging here. On the other hand, however, intense brecciation, flow-structures and perhaps some mineralogical features, indicate the actual existence of an umptekite melt or a rock of very low competency. In explaining the formation and genesis of this group of rocks, we have thus to reckon on a process comprising a double origin, by alteration in situ and magmatic crystallization or at least mobility, both leading to the formation of very similar or identical rocks.

Looking for parallels in other alkali areas, the almost invariable prominence of rocks described as umptekites, åkerites, pulaskites, nordmarkites or just fenites, in the marginal parts of the complexes immediately attracts attention. These rocks—most of them very similar to the Almunge umptekites—are either explicitly stated to be products of metasomatic alteration, e.g. in the

Fen (BRØGGER 1920, SAETHER 1957), Spitskop (STRAUSS and TRUTER 1950), Alnö (v. ECKERMANN 1948), Afrikanda etc. (SERGEEV 1959) and Vuorijärvi-Pyhäkuru (HACKMAN 1925, VOLOTOVSKYA 1958) areas, or are considered to be marginal differentiation products with (HÖGBOM 1892, RAMSAY and HACKMAN 1894, USSING 1911) or without (KUPLETSKY 1928, 1937, ELISEEV *et al.* 1937) considerable wall-rock absorption. In addition rocks described as fenites in Norra Kärr (O. ADAMSSON 1944) are, as is seen from some specimens in the possession of the museum of this institute, mineralogically and texturally identical with many an "umptekite" of the Almunge area. In all these cases—regardless of the mode of final crystallization and the agpaitic or miaskitic character of the mother rocks—the space relations evidently suggest some kind of nepheline-syenite—bedrock interaction.

As early as 1921 BRØGGER (op. cit., p. 387) emphasized the similarity of the Almunge umptekites and the Fen fenites, suggesting a similar origin for both. This point of view is indeed made highly probable by the results of the present investigation. The distribution and orientation of canadite and Archæan rocks inside the complex, as well as the type variation of the umptekites make one single violent upsurge and still more a prolonged flow of a compact viscose umptekite magma utterly improbable, suggesting instead a combination of metasomatic processes, migmatization, plastic deformation, intense mobilisation and magmatic intrusions.

In the border zones of the complex, evidence is very strong that the parallel structures characteristic of parts of these areas, are not mainly due to violent movement in any magma. Proof of this is the marked general fenite character of the marginal parts of the complex, a very great part of the schistose rocks present certainly being incapable of any magmatic flow. The schistosity found here is due, in all probability, to a combination of radial pressure from the central parts of the umptekite area, and fault movements along the "zone of maximal schistosity" partly affecting very poorly fenitised granites. Whether there was any larger amount of telescopic or cauldron subsidence, as is proposed for the Pilansberg (SHAND 1928) and the Messum (KORN and MARTIN 1954) areas is still open to discussion (cf. NORIN and GORBATSCHEV 1960). In any case there are no marked discontinuities in the character and strikes of the Archæan rocks inside and outside the complex (cf p. 39). If the age of the Almunge syenites, in analogy with the Oslo, Kola, Fen etc. alkali complexes is Paleozoic this hypothetical subsidence can, considering the existence in the area of a Subcambrian peneplain, probably not be thought of as a very large one, as in this case it would have brought Paleozoic sediments into the profile of the present erosion section. Such rocks are, however, not found in the Almunge area.

Turning finally to the hypothesis of limestone absorption, the presence of vesuvianite and the abundance of cancrinite were previously considered to indicate the prominence of this process in the Almunge rocks. New aspects on the genesis of vesuvianite have been produced during the present reinvestigation (p. 15); the other Ca-rich minerals found in the area (diopside, epidote, garnet) can also be shown to be typical of the zones of fenitisation, viz. transitional areas between the umptekites and Archæan bedrock (granites etc). Consequently there remain the presence of cancrinite and the comparatively high CaO contents in the canaditic rocks. While neither can be considered surprising, there is in the petrographic data nothing explicitly to rule out the existence of lime absorption. Limestones are indeed exposed 7 km to the south and 10 km to the east of the alkali area. While none of them are of very great dimensions, mostly comprising thin lenses only, the existence of limestone at deeper levels bordering on the Almunge complex can consequently not be disproved.

In considering the influence of limestone absorption, the prominence in the area of other Archæan rocks, however, cannot be ignored. Indeed only a moderate absorption of the supracrustal rocks, let alone the granite, would be sufficient to completely outweigh any desilicification brought about by limestone inmelting. Considerable amounts of quartzites moreover have the advantage of factual existence, being present all round and inside the alkali complex. Indeed any absorption of a greater amount of country rock would serve not only to annihilate the undersaturated character of the canadites, but probably, *inter alia*, also greatly increase the k-value above the 0.15–0.17 of this rock group. A similar process may be exactly what happened during the formation of the umptekites. Failure to absorb considerable amounts of country-rock thus seems to be a prerequisite for the existence of the canadites, if formed out of a melt.

As a result the present proposition of the origin of canadite and umptekite suggests that the section at present exposed by erosion represents a rather high profile through the main mass of the alkaline intrusion, even if this profile is deep-seated in relation to any hypothetical volcano at its top. This is supported by the general marginal position of umptekitic and similar rocks, by the abundance of Archæan inclusions and by the dike intrusions character of most Almunge canadite bodies.

Appendix

In connection with the geophysical investigations now under the leadership of Dr. Tengström in progress in the Almunge area, the specific weights of some Almunge rocks from the Sågen–Hällen–Upptorp area have been determined as follows:

	Mean values:
Theralitic canadite, Upptorp: 2.953	
Theralitic canadite, Skallerbol: 2.85, 2.85, 2.85, 2.83, 2.80	2.84
Normal canadite: 2.67, 2.63, 2.68, 2.70, 2.68, 2.75	2.69
White transitional syenite: 2.73, 2.63, 2.67, 2.63, 2.62, 2.66, 2.64, 2.70	2.66

Normal umptekite: 2.66, 2.64, 2.63, 2.63, 2.67, 2.68, 2.67, 2.65	2.65
Basic umptekite: 2.77, 2.73, 2.74	2.75
Archæan metabasite: 2.97	
Uppsala granite, fenitised: 2.77	
Red acid granite: 2.63	
Archæan supracrustals: 2.67, 2.76, 2.76, 2.61	
Lestivarites and albitites: 2.62, 2.66	

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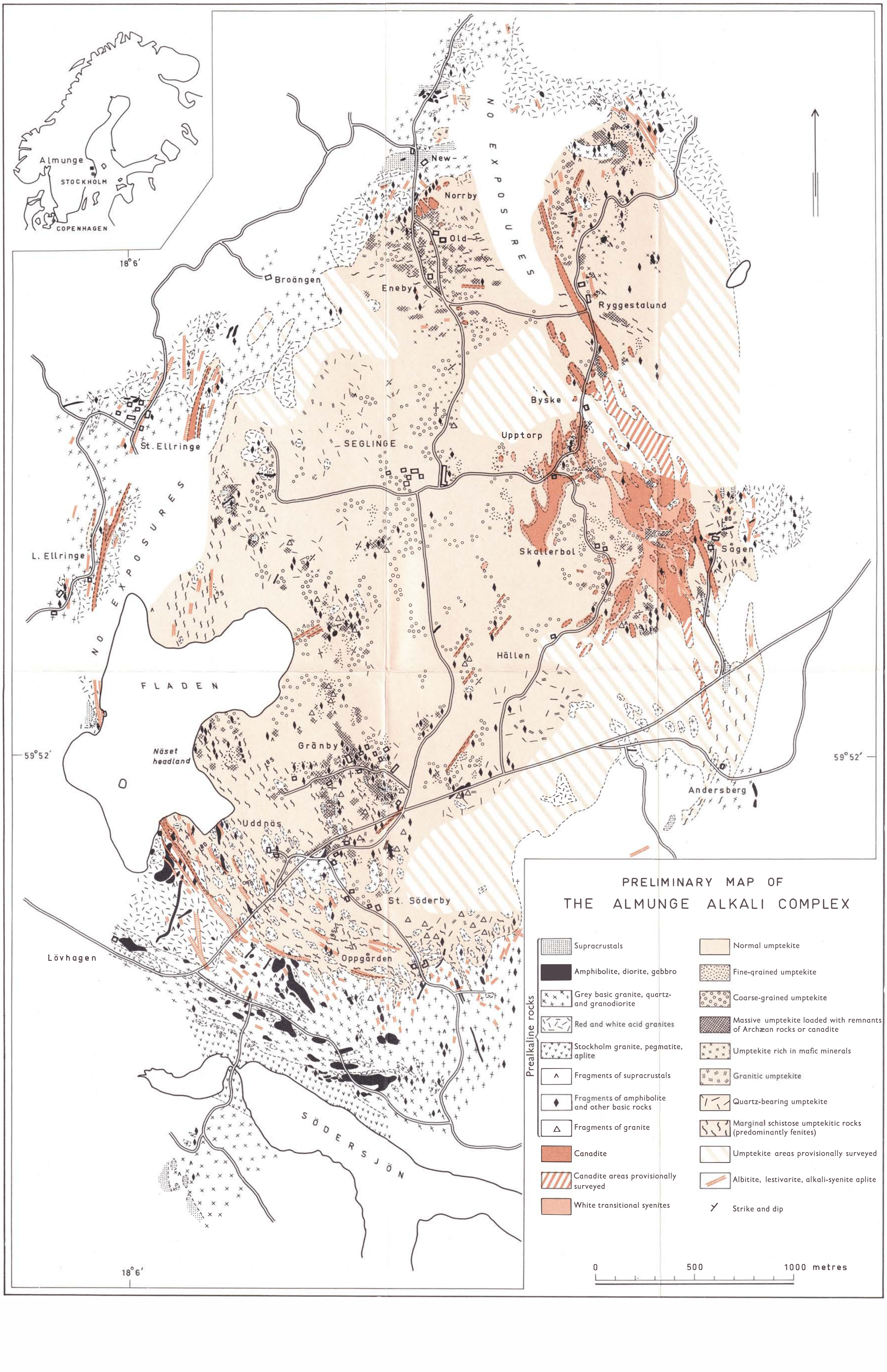

Almunge
STOCKHOLM
COPENHAGEN
18°6′
Broängen
New-
Norrby
Old-
Eneby
NO EXPOSURES
Ryggestalund
Byske
Upptorp
SEGLINGE
St. Ellringe
NO EXPOSURES
L. Ellringe
Skallerbol
Sågen
Hällen
FLADEN
Näset headland
Gränby
59°52′
59°52′
Andersberg
Uddnäs
St. Söderby
Lövhagen
Oppgården
SÖDERSJÖN
18°6′
PRELIMINARY MAP OF
THE ALMUNGE ALKALI COMPLEX
Prealkaline rocks
Supracrustals
Amphibolite, diorite, gabbro
Grey basic granite, quartz- and granodiorite
Red and white acid granites
Stockholm granite, pegmatite, aplite
Fragments of supracrustals
Fragments of amphibolite and other basic rocks
Fragments of granite
Canadite
Canadite areas provisionally surveyed
White transitional syenites
Normal umptekite
Fine-grained umptekite
Coarse-grained umptekite
Massive umptekite loaded with remnants of Archæan rocks or canadite
Umptekite rich in mafic minerals
Granitic umptekite
Quartz-bearing umptekite
Marginal schistose umptekitic rocks (predominantly fenites)
Umptekite areas provisionally surveyed
Albitite, lestivarite, alkali-syenite aplite
Strike and dip
0
500
1000 metres