

GEOLOGINEN TUTKIMUSLAITOS

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N:o 185

**THE ALKALINE DISTRICT OF IIVAARA,
KUUSAMO, FINLAND**

BY
MAUNO LEHIJÄRVI

WITH 23 FIGURES, 24 TABLES AND ONE PLATE

ACADEMICAL DISSERTATION

HELSINKI 1960

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Helsinki 1960. Valtioneuvoston kirjapaino

PREFACE

The first time I was confronted with the alkali rocks of Iivaara was back in the year 1945, when, under the direction of my esteemed teacher, Prof. Pentti Eskola, I carried out a special geological research project using the material from the alkaline district of Iivaara in the collections of the Institute of Geology of the University of Helsinki.

In the summer of 1954 I was given the opportunity of doing field work and collecting material from the Iivaara area. In this work and in that carried out on the basis of the earlier material, I received noteworthy assistance from many persons, institutions and foundations.

The chemical analyses performed by the author in 1945 were done from the earlier material at the laboratory of the Geological Survey of Finland under the guidance of Prof. Lauri Lokka and Mr. Pentti Ojanperä. The author's later analyses were performed at the laboratories of the Institute of Geology of the University of Helsinki and of the Institute of Technology. The other chemical analyses were carried out at the laboratory of the Geological Survey by Dr. H. B. Wiik and Messrs. Pentti Ojanperä, Aulis Heikinen and Arvo Löfgren.

The optical determinations and powder X-ray determinations of the minerals were performed at the mineralogical laboratory of the Geological Survey under the direction of Dr. K. J. Neuvonen. In these tasks I received valuable assistance from my colleagues Mrs. Toini Mikkola and Messrs Matti Laitala, Fredrik Pipping and Atso Vorma.

Messrs Harald Nyberg, Pentti Ilola and Raimo Aromaa prepared the thin sections needed. The map was drawn by Miss Thyra Åberg and the photographs taken by Mr. Erkki Halme.

During the course of the work and the writing of the manuscript I received valuable counsel from Profs. Pentti Eskola, Th. G. Sahama and Martti Saksela as well as Drs. Ahti Simonen and K. J. Neuvonen.

Prof. Aarne Laitakari, Director of the Geological Survey, followed the progress of my work with interest and kindly accepted my paper for publication in the »Bulletin de la Commission géologique de Finlande» series.

The translation of my manuscript into English was done by Mr. Paul Sjöblom.

I have been economically assisted by grants from the following foundations: Suomen Luonnonvarojen Tutkimussäätiö (The Foundation for the Study of the Natural Resources of Finland) and Outokumpu Osakeyhtiön Säätiö (The Foundation of the Outokumpu Company).

To all the persons, institutions and foundations that have assisted me in my work, I wish to express my gratitude.

Helsinki, December, 1959.

The Author

CONTENTS

	Page
PREFACE	3
INTRODUCTION	7
PREVIOUS GEOLOGICAL WORKS	7
METHODS	8
SITUATION AND PHYSIOGRAPHY	10
THE COUNTRY ROCKS	11
THE FENITE AND TRANSITIONAL ROCKS BETWEEN FENITE AND THE ALKALINE INTRUSION	12
FIELD OBSERVATIONS	12
PETROGRAPHICAL CHARACTER AND CHEMICAL COMPOSITION	12
FENITES	14
TRANSITIONAL ROCKS	19
PYROXENE JUVITE	20
MALIGNITE	20
CANCRINITE-NEPHELINE-WOLLASTONITE ROCK	21
PYROXENE-AMPHIBOLE-PLAGIOCLASE ROCK	24
GENESIS OF THE FENITE AND THE TRANSITIONAL ROCKS	26
THE CENTRAL MASS OF ALKALI ROCKS	29
FIELD OBSERVATIONS	29
PETROGRAPHICAL CHARACTER AND CHEMICAL COMPOSITION	31
URTITE	31
IJOLITE	32
MELTEIGITE	35
GENESIS OF THE ALKALI ROCKS OF IIVAARA	38
MINERAL DESCRIPTION	44
NEPHELINE	44
CANCRINITE	45
NATROLITE	46
SODALITE	46
ANALCITE	47
PECTOLITE	47
PYROXENE	48
HORNBLLENDE	50
BIOTITE	50
IIVAARITE	51
SPHENE	56
APATITE	56
SUMMARY	58
REFERENCES	60

ABSTRACT

The rocks of the alkaline district of Iivaara are petrographically described and analyses of six of the rocks presented. The chemical composition, optical properties, specific gravity and unit-cell dimensions of the minerals nepheline, sulphatic cancrinite, pyroxene and iivaarite; the chemical composition, optical properties and specific gravity of the minerals pectolite (impure material), biotite, sphene and apatite; the unit-cell dimensions and refractive index of the minerals sodalite and analcite; and the optic properties of hornblende are given.

INTRODUCTION

PREVIOUS GEOLOGICAL WORKS

The Iivaara region was investigated geologically for the first time, so far as is known, by H. J. Holmberg in 1847 on a gold prospecting expedition to northern Finland. Nils Nordenskiöld (1852) studied the material collected by Holmberg and reported that in Kuusamo there had been found *eleolite* (nepheline), *datolite* and *iivaarite*. Regarding the bedrock of Iivaara, Holmberg wrote (1855—1856, p. 42) as follows: »Seine Gebirgsmasse bildet ein eigenthümliches Gestein, das aus *Elaeolith*, *Feldspath* und *Hornblende* besteht, und welches man, den *Elaeolith* als Stellvertreter des *Quarzes* betrachtend, *Elaeolith-Syenit* nennen könnte. Diese Bestandtheile kommen gewöhnlich grobkörnig gemischt vor, treten aber auch bisweilen feinkörnig auf, und alsdann nimmt die *Hornblende* strahlige Textur an. Auch verschwindet letzteres Mineral gänzlich, und als zufällige Bestandtheile erscheinen *Datolith* und ein schwarzes Mineral mit pechartigem Bruch, welches Nordenskiöld nach den Fundorte *Jivaarit* genannt hat.»

In 1876 investigations were carried out at Iivaara by V. L. Åkerblom. He brought back to the mineral collections of the University of Helsinki specimens, which were subsequently more closely studied by F. J. Wiik (1885) who, like Holmberg, described the rock as *eleolite-syenite* and asserted the whole of Iivaara to consist of this rock. According to his description, the rock is medium grain in texture, except that in the vicinity of the summit of the hill there occurs a variety of coarse-grained dike, which, again, is penetrated by narrow bands of a fine-grained rock. The coarse-grained variety consists mainly of *eleolite* and *iivaarite*. The *pyroxene* he described as for the most part having become *uralitized*. He gave a fairly detailed description of the *cancrinite*, remarking that it possibly contained *natrolite* as an alteration product. In blowpipe tests the *pyroxene* and *amphibole* were observed to have a considerable Na content. Wiik stated that he had not found *feldspar* in the samples studied. The fine-grained variety contained an abundance of *pyroxene* and *iivaarite*, whereas *cancrinite* was lacking. In addition, Wiik stated that the mineral called *datolite* by

Nordenskiöld and Holmberg was apatite. He also emphasized the common occurrence of titanium in the said rock complex.

As a result of these earlier investigations, Rosenbusch (1887) expressed the opinion that an igneous rock corresponding to nepheline might possibly be found at Iivaara. In order to obtain a clearer picture of the Iivaara area, W. Ramsay and V. Hackman made a trip there in the summer of 1890. The material collected was studied by W. Ramsay and H. Berghell (1891). Together with the field observations, this study proved that the mineralogical composition presented by Wiik prevailed throughout the Iivaara area and that the rock was not eleolite-syenite but in respect to composition, structure and geological occurrence, a new kind of rock which filled a gap in the petrographic system. This rock was given the name «ijolite».

The year 1894 saw V. Hackman at Iivaara. On the basis of the results of this expedition and his earlier studies, he published in 1900 a detailed account of the rocks occurring in the Iivaara area. He had reached conclusion that not only Iivaara but also Ahvenvaara and Penikkavaara, situated to the south of it, consisted of ijolite, which made the whole alkaline district an estimated 5 km² in area. On the other hand, variations in type could be observed there. On the slopes of Penikkavaara could be found essexite as well as feldspar-bearing ijolite, sussexite, which on account of its Na-dominant composition was dubbed natronsussexite.

In connection with mapping operations carried out in the commune of Kuusamo, R. D. Dillström in 1907, V. Pääkkönen in 1937 and A. Matisto, accompanied by assistants, in 1951 collected numerous rock specimens which the present author has had the opportunity to study. The field investigations for this work were conducted in the summer of 1954 as well as on short excursions in the summers of 1957 and 1959. In working in the field, I had only a map on the scale of 1 : 20 000 of the Iivaara district at my disposal, and it had but a few fixed points. The district was photographed from the air in the autumn of 1959, and the observations are marked on this aerial photograph (Plate I). The majority of the sites on Iivaara and Ahvenvaara could be located precisely for marking. In regard to Penikkavaara, the errors in pinpointing the sites are liable to be within the range of 100 meters.

METHODS

The planimetric determinations of the mineral composition of the rocks were carried out by using a Leitz Integration Stage.

The separation of the minerals was carried out by means of Clerici solution with a centrifuge as well as with a Frantz-type isodynamic magnetic separator. For the No. 1 analyses in Tables 10 and 16, the separation of

minerals was performed by Clerici solution in a separating funnel. The purity of the analyzed minerals was examined with a microscope in an immersion liquid having approximately the same refractive index as the mineral under study. In the refractive index determinations, Waldmann's sphere was used in sodium light. The specific gravity was determined either in Clerici solution employing a Westphal balance or with a pycnometer. The powder patterns were taken with a Philips Norelco Geiger counter diffractometer. The unit cell dimension a_0 of the sodalite, analcite and iivaarite was determined by computing the arithmetic mean of the a_0 values measured. The reflections of the powder pattern of the sulphatic cancrinite (Table 12) were given indices by using a reciprocal lattice. The unit cell dimensions for pyroxene (Table 17) were measured from single-crystal Weissenberg photographs.

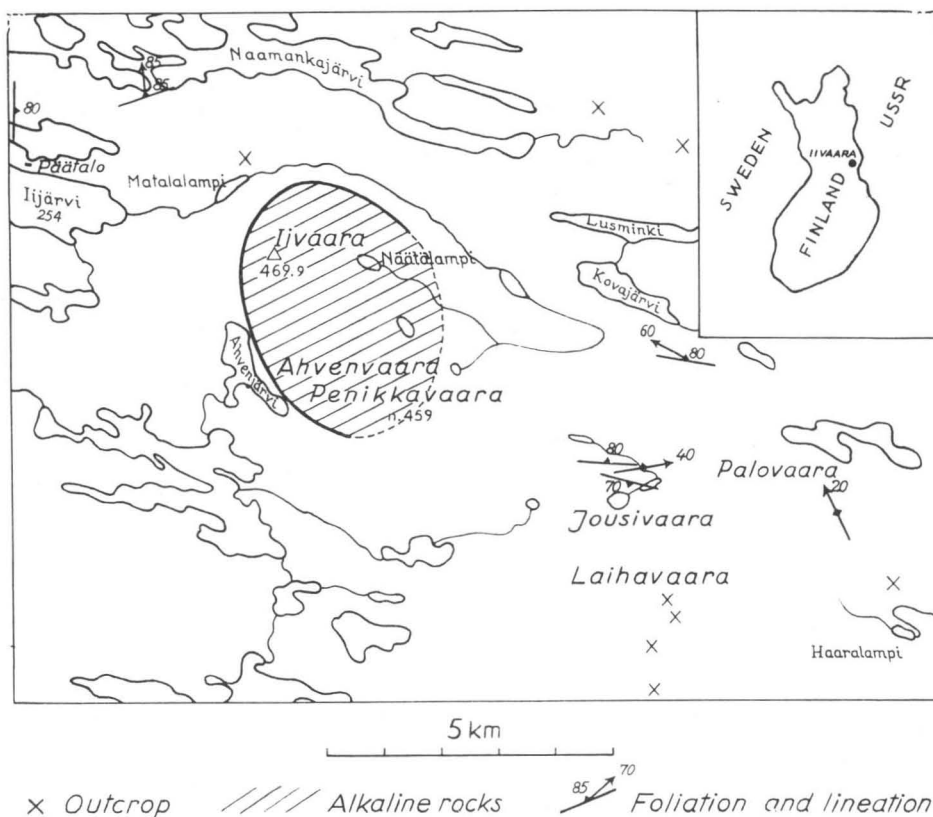


Fig. 1. Situation of the Iivaara Alkaline District

SITUATION AND PHYSIOGRAPHY

The alkaline district of Iivaara is situated in northeastern Finland about 25 km southeast of the village of Kuusamo (Fig. 1). The elevation of Iivaara is 470 meters, and its summit is 216 m above the surface of nearby Iijärvi. It is the highest point in the tract. Direct extensions of Iivaara southward are Ahvenvaara and Penikkavaara, which gradually curve eastward. A characteristic feature of this complex of arctic hills is its horseshoelike structure. The outer curve is formed by the steep northern, western and southern slopes of the hills. Toward the east opens up a kettle-shaped valley.

Outcrops are met with chiefly on the summit of Iivaara and on the southwestern slope of Ahvenvaara, in addition to which there are few scattered exposures on Penikkavaara, about three kilometers to the southeast from the summit of Iivaara (Plate I). Ahvenvaara and Penikkavaara are totally covered with forests, while Iivaara rises somewhat above the timber line.

THE COUNTRY ROCKS

The country rock surrounding the alkaline district of Iivaara has been designated in the explanation to the map of the rocks of Suomussalmi (Matisto 1958) as a granite-gneiss formation. The following description of this formation is based both on the said publication and on personal discussions with Mr. Matisto.

The oldest components of the granite-gneiss formation are inclusions of mica-schist, occurring, e. g., on the northern sides of Palovaara and Lusminki (Fig. 1). At Palovaara the mica-schist fragments occur as conformable bands 1–30 cm thick in a material composed of granodiorite. The schist of Lusminki differs from the foregoing in that its best preserved varieties contain thin quartz-feldspar veins running parallel to the schistosity.

The magmatic rocks of the granite-gneiss formation are hornblende-granodioritic in composition but also somewhat quartz-dioritic, in which metamorphic alterations are limited mainly to the appearance of cataclastic structural features. In the prevailing variety the mineral ingredients of the rock consist of plagioclase, hornblende, quartz, apatite, sphene and magnetite. In addition, it contains as alteration products biotite, muscovite and epidote as well as in places microcline deriving from granite-pegmatite veins. The composition of the plagioclase varies within the limits of An_{5-15} . Judging from the saussuritization, it was originally, however, more alkaline than at present. This is indicated also by the abundance of free epidote. The biotite is as a whole an alteration product of hornblende. Secondary in origin is also the muscovite, which occurs only in mylonitized varieties.

On the northern side of Jousivaara there occurs amphibolite belonging to the Karelian formations. The mineral constituents of the prevailing type are amphibole and plagioclase besides epidote, ore and sphene as accessories.

From the summit of Iivaara about two kilometers northward there occurs a small exposure of diabase, which is the same kind as the uralite-diabases described in the explanation to the map of rocks of Suomussalmi (Matisto 1958, pp. 98 and 113).

THE FENITE AND TRANSITIONAL ROCKS BETWEEN FENITE AND THE ALKALINE INTRUSION

FIELD OBSERVATIONS

A distinct contact between the alkali rocks of the central area of Iivaara and the surrounding country rock is nowhere exposed. On the northern slope of Iivaara (Observation 3) there occur about 10 m apart a pale, gneissic rock rich in feldspar and the alkali rock belonging to the central area. The small exposure situated about 600 m north-northwest of them (Observation 14) consists of diabase occurring frequently in the surrounding country rock. On the western slope of Iivaara are some quite small, separate outcrops of the rock surrounding the central area. The distance of these outcrops from the alkali rock of the central area is a few dozen meters. The rock of the outcrops is highly non-homogeneous; dark veins rich in pyroxene criss-cross the pale rock, while in other places, again, a light material brecciates the dark rock (Observation 13, Fig. 2). In many cases, wollastonite can be seen in the pale rock even with the naked eye.

The rock surrounding the central area is best exposed on the southwestern slope of the steep Ahvenvaara. On the very shore of Ahvenjärvi (Observation 22 A) there occurs a rock outwardly resembling entirely unaltered oligoclase-granite. At a distance of about 100 m from this spot toward the central area there is a steep slope, where, just as in the small exposures of the western slope of Iivaara, dark, pyroxene-rich veins criss-cross the pale rock which, in many cases, contains wollastonite (Observation 21 A, Fig. 3), or coarse-grained feldspar occurs as specks in the dark rock (Observation 22, Fig. 4). Between the ijolite exposure at the summit of Ahvenvaara and the foregoing there lies an unexposed area about 200 meters broad.

PETROGRAPHICAL CHARACTER AND CHEMICAL COMPOSITION

The metasomatic effect of the intrusion of alkali rock at Iivaara on the surrounding country rock extends on the southwestern slope of Ahvenvaara at least 300 meters from the edge of the alkaline central area. On

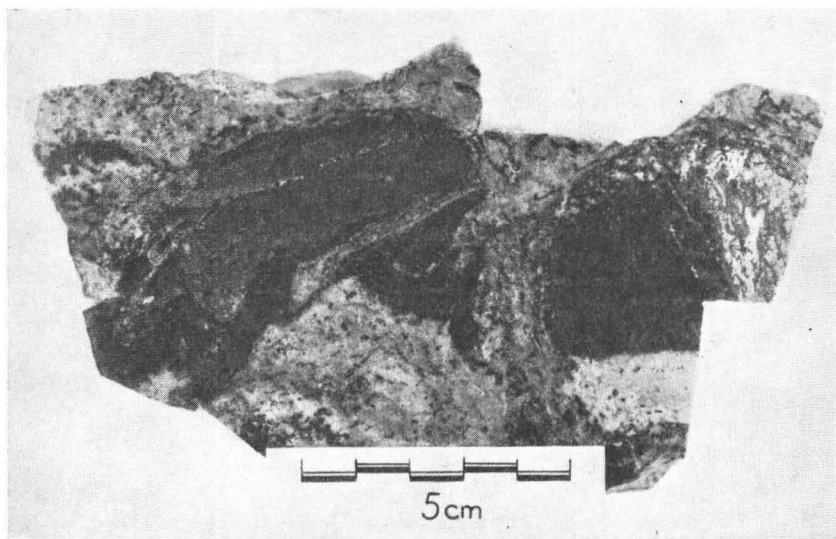


Fig. 2. Cancrinite-nepheline-wollastonite rock (pale) brecciates cancrinite-syenitic fenite (dark). Western slope of Iivaara (Observation 13). Photo E. Halme.



Fig. 3. Pyroxene-rich veins criss-cross the pale rock. Southwestern slope of Ahvenvaara (Observation 21 A). Photo M. Lehijärvi.

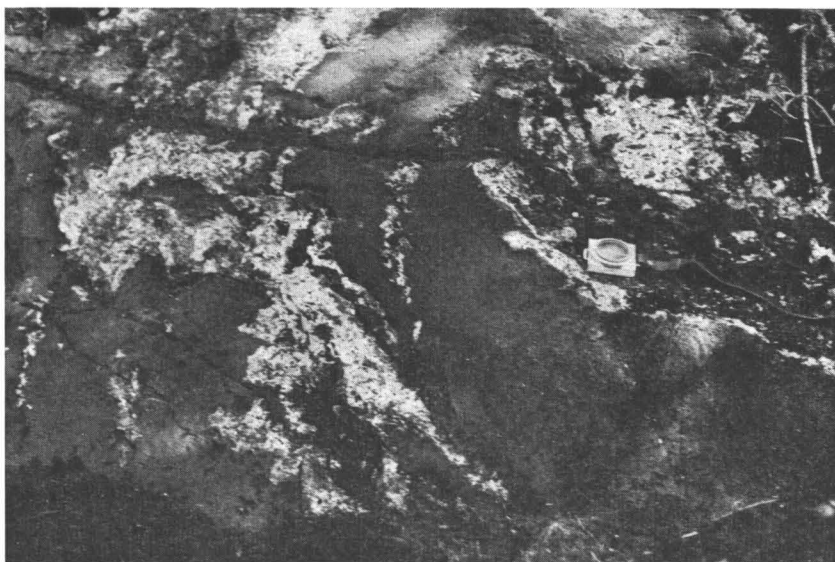


Fig. 4. Cancrinite-syenitic fenite, in which coarse-grained feldspar occurs as specks. These specks are cut by a cancrinite-ijolite dike. Southwestern slope of Ahvenvaara (Observation 22). Photo M. Lehijärvi.

account of the lack of exposures, observations cannot be made any farther. In the diabase outcrop about 600 m from the edge of the central area on the north-northwestern side of Iivaara, no metasomatic effect can be traced. Elsewhere the exposures of the surrounding country rock in which any effect of metasomatism can be noticed are situated less than 100 m from the alkaline central area.

This metasomatic alteration was termed by Brögger (1921, p. 171) »finitization,» and since then this term has generally been applied in geological literature to signify Na-metasomatism in both acid and basic rocks. Brögger's term »fenite» applied to altered rock, has been used in the present article in the same sense as by von Eckermann (1948, p. 13) to mean »in situ metasomatically altered (with or without substantial material exchanges) older contacting rocks irrespective of composition, but the term does not apply to mobilized (rheomorphic) and transported hybridic mixed rocks.»

FENITES

Signs of incipient finitization are noticeable in the shore exposure at Lake Ahvenjärvi (Observation 22 A). The rock is granodioritic in composition.

Table 1. Analysis of granodiorite (slightly fenitized) from Ahvenvaara. Specimen 22/57 ML. Anal. Pentti Ojanperä, 1958.

Weight per cent		Mol. prop.	Cation %	O in oxides	Niggli numbers	
SiO ₂	73.10	12 165	68.32	136.64	si	397.2
TiO ₂	0.15	19	0.11	0.22	qz	151.6
Al ₂ O ₃	13.87	1 360	15.27	22.91	ti	0.62
Fe ₂ O ₃	0.64	40	0.45	0.68	al	44.4
FeO	0.78	109	0.61	0.61	fm	9.8
MnO	0.04	6	0.03	0.03	c	9.4
MgO	0.43	107	0.60	0.60	alk	36.4
CaO	1.62	289	1.62	1.62	mg	0.21
Na ₂ O	4.49	724	8.12	4.06	k	0.35
K ₂ O	3.69	392	4.39	2.20	c/fm	0.96
P ₂ O ₅	0.07	5	0.06	0.15		
CO ₂	0.33	75	0.42	0.84		
H ₂ O+	0.59	(328)	(1.84)			
H ₂ O—	0.15					
99.95			100.00	170.56		
			—O for (OH)	1.84		
			O	168.72		
			(OH)	3.68		
			Anions pro 100.00 cations	172.40		

Weight norm		One-cation molecular norm		Planimetric mineral composition	
Q	29.52	Q	27.68	Quartz	34.0
or	21.81	Or	21.95	Feldspar	60.1
ab	37.97	Ab	40.60	Biotite and pyroxene	5.6
an	5.48	An	5.50	Accessories	0.3
C	0.48	C	0.56		100.0
fs	0.74	Fs	0.62		
en	1.07	En	1.20		
mt	0.93	Mt	0.67		
il	0.29	Il	0.22		
ap	0.17	Ap	0.16		
cc	0.75	Cc	0.84		
	99.21		100.00		
H ₂ O+	0.59				
H ₂ O—	0.15				
	99.95				

The oligoclase and potash feldspar are turbid, and between the grains there often occurs a fine-grained mass. The quartz has a faint undulatory extinction. In connection with the biotite there are some green pyroxene needles. Table 1 shows the chemical composition, Niggli numbers and norms of this granodioritic rock.

Fenitization has proceeded farther in the exposure at the foot of the steep slope at the northern end of Ahvenjärvi (Observation 19). The feld-

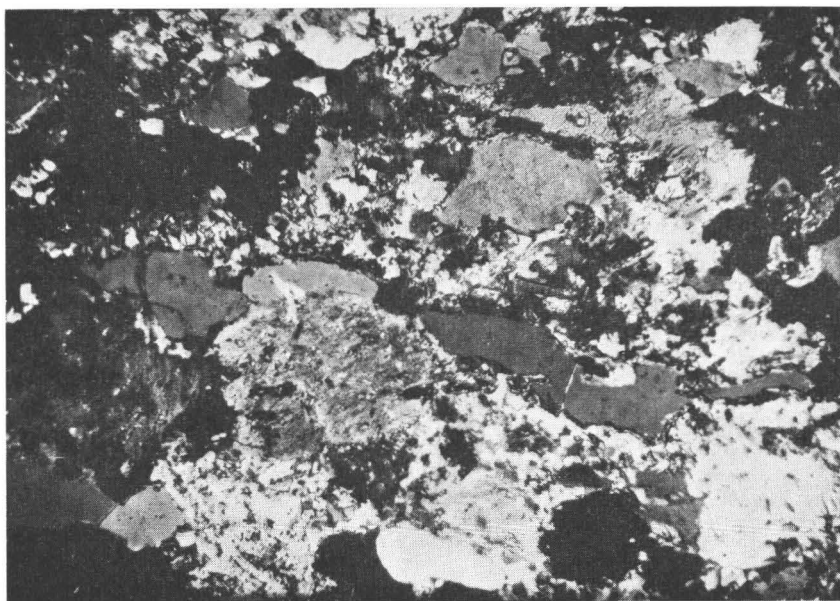


Fig. 5. Fenite. Southwestern slope of Iivaara (Observation 19). Nicols crossed. Magnification 40 \times . Photo E. Halme.

spar, which is both plagioclase and potash feldspar, occurs as large grains, between which small-grained feldspar occurs, serving as a mortar (Fig. 5). The composition of the large plagioclase grains is An_{25} and of the small ones An_{15} . Quartz with a faint undulatory extinction occurs in rows as large grains, and they are regularly bordered by small aegirine-augite grains. The rock still retains its original orientation. The biotite has largely been replaced by aegirine-augite. The formation of albite is at its incipient stage.

During the following fenitization stage, the quartz disappears and the biotite is wholly replaced by aegirine-augite (Observations 3, 10, 19 A, 20, 20 A, 21, 21 A, 24). The rock is syenitic in composition and Hackmann (1900) termed his specimens pyroxene-syenites. The feldspar is microperthite and the grains form a sutured texture. A portion of the feldspar grains are large in size. At the center of these grains there are small aegirine-augite needles which, in some cases, are clearly oriented. At the center of some of the large microperthite grains, there are small specks with approximately the same refraction as albite but with a different optical orientation (Fig. 6). The powder pattern given by such a grain exhibited, in addition,

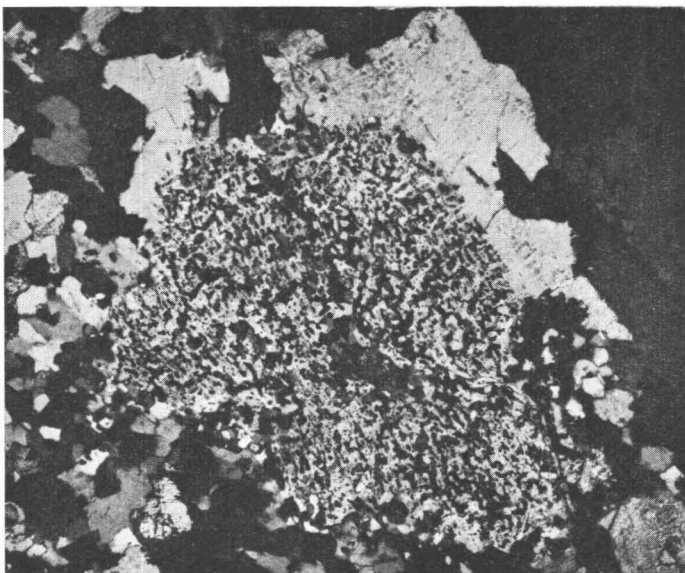


Fig. 6. Microperthite with incipient nephelinization. Western slope of Iivaara (Observation 10). Nicols crossed. Magnification 30 \times .
Photo E. Halme.

tion to the feldspar lines, the strongest nepheline lines, though faintly. The aegirine-augite content of the rock averages 10—30 %. It usually accumulates in clusters, or occurs here and there as solitary grains. In places there is an abundance of calcite, and quite commonly there occurs wollastonite too. Accessories are sphene, apatite, cancrinite and fluorite. Table 2 reveals the chemical composition, Niggli numbers and norms of this fenite. The most conspicuous difference, upon the advance of fenitization, between the chemical compositions of Table 1 and 2 is that the SiO_2 has decreased while the Al_2O_3 and the alkalies have increased. Of the alkalies the Na_2O has increased markedly more than the K_2O .

In such syenitic fenite there gradually begins to appear cancrinite (Observations 12, 13, 18). The cancrinite content is likely in some instances to rise considerably (Table 4, No. 2). It usually occurs as indistinct grains between other minerals and it has a tendency to become concentrated in areas of the rock rich in pyroxene. In association with the cancrinite, nepheline is in some cases present. Aegirine-augite occurs on occasion in the rock as coarse-grained veins and in other places as smaller, more evenly distributed grains or, then, lumped together in a single spot. The feldspar

Table 2. Analysis of fenite from Ahvenvaara. Specimen 21 B/54 ML.
Anal. Pentti Ojanperä, 1958.

Weight per cent	Mol. prop.	Cation %	O in oxides	Niggli numbers	
SiO ₂	63.19	10 516	57.04	114.08	si 238.2
TiO ₂	0.49	61	0.33	0.66	qz —10.9
Al ₂ O ₃	16.52	1 620	17.58	26.34	ti 0.14
Fe ₂ O ₃	1.87	117	1.27	1.91	al 36.7
FeO	1.35	188	1.02	1.02	fm 13.8
MnO	0.08	11	0.06	0.06	c 10.5
MgO	0.71	176	0.96	0.96	alk 39.0
CaO	2.59	462	2.51	2.51	mg 0.47
Na ₂ O	7.76	1 252	13.58	6.76	k 0.27
K ₂ O	4.42	469	5.09	2.55	c/fm 0.76
P ₂ O ₅	0.22	16	0.17	0.43	
CO ₂	0.32	73	0.39	0.78	
H ₂ O+	0.43	(239)	(1.30)		
H ₂ O—	0.08				
100.03		100.00	158.06		
		—O for (OH)	1.30		
		O	156.76		
		(OH)	2.60		
		Anions pro 100.00 cations	159.36		

Weight norm	One-cation molecular norm	Planimetric mineral composition
or 26.09	Or 25.45	Feldspar and nepheline 80.6
ab 57.19	Ab 59.10	Cancrinite 2.1
ne 1.72	Ne 2.01	Pyroxene 16.4
ac 4.66	Ac 4.36	Sphene 0.8
fs 1.61	Fs 1.32	Accessories 0.1
en 1.78	En 1.92	
wo 3.90	Wo 3.68	100.0
mt 0.37	Mt 0.27	
il 0.93	Il 0.66	
cp 0.54	Ap 0.45	
ac 0.73	Cc 0.78	
99.52	100.00	
H ₂ O+ 0.43		
H ₂ O— 0.08		
100.03		

is micropertthite. Accessories are sphene, apatite and wollastonite. The amount of feldspathoids is likely in spots to be so large that the corresponding magmatic rock would be cancrinite- or nepheline syenite. In some instances the feldspar occurs in part of the thin section in the form of lamellae (Fig. 7). In such spots the pyroxene content is usually slight. Brögger (1921, p. 157) calls a rock of this variety pulaskitic fenite.



Fig. 7. Pulaskitic fenite. Southwestern slope of Iivaara (Observation 18). Nicols crossed. Magnification 20 \times . Photo E. Halme.

TRANSITIONAL ROCKS

On the western slope of Iivaara (Observation 13) a few dozen meters from the alkali rock of the central area, there is a breccia (Fig. 2) in which a pale cancrinite-nepheline-wollastonite rock brecciates a cancrinite-syenitic fenite. On the same slope and apparently also fairly near edge of the alkali rock of the central area, there occur small outcrops of heterogeneous rocks (Observations 4, 11, 16). For lack of suitable exposures, it cannot be decided for sure in what way these rocks are related to their environment. It would appear, however, that these rocks are situated in between the fenites proper and the alkali rocks. Brögger (1921) describes such rocks (juvite, malignite, etc.) from the area of Fen, observing (p. 366): »Diese sind vielleicht aus Mischung von Fenit mit Ijolithmagma gebildet, sind aber vielleicht auch durch Differentiation aus einem Ijolithmagma entstanden.» Saether (1957, pp. 49—51) writes: »There seems to be no material difference in age between the fenite and the basic rocks. The irregular intermingling of the two rock groups and the illdefined, streaky boundaries between them suggest that they have been mobile at the same time. It is then easily understandable that a heterogeneous group of hybrid rocks have been formed along the contacts between the two magmas.»



Fig. 8. Pyroxene-juvite. Western slope of Iivaara (Observation 10). Nicols crossed. Magnification 30 \times . Photo E. Halme.

Pyroxene-juvite. On the western slope of Iivaara (Observation 10) there is a rock nepheline-syenitic in mineral composition. The nepheline appears in thin section idiomorphically as square and as hexagonal grains (Fig. 8). The diameter of the largest grains is about 1 mm. As inclusions there occur pyroxene needles, which in some cases are arranged in conformity with the crystal faces. The cancrinite is sulphatic cancrinite of low birefringence. It is easily distinguishable from the rather bright nepheline and feldspar on account of its dirty gray color, owing to pigmentation. It also clearly exhibits hexagonal forms. Under high magnification, tongues of albite are visible in the potash feldspar, proceeding from the edges of the grains toward the center. A large feldspar grain is likely to contain several idiomorphic nepheline and cancrinite grains as inclusions. The pyroxene is zoned and the edges richer in aegirine than the center. Accessories are sphene, apatite and ore. Idiomorphic nepheline grains are also likely to be met with as inclusions in large grains of sphene. The rock resembles the pyroxene-juvite described by Brögger (1921, p. 86) from the Fen area.

Malignite. The small rocky projections on the western slope of Iivaara (Observation 16) contain malignite. The color of the rock is dark gray.

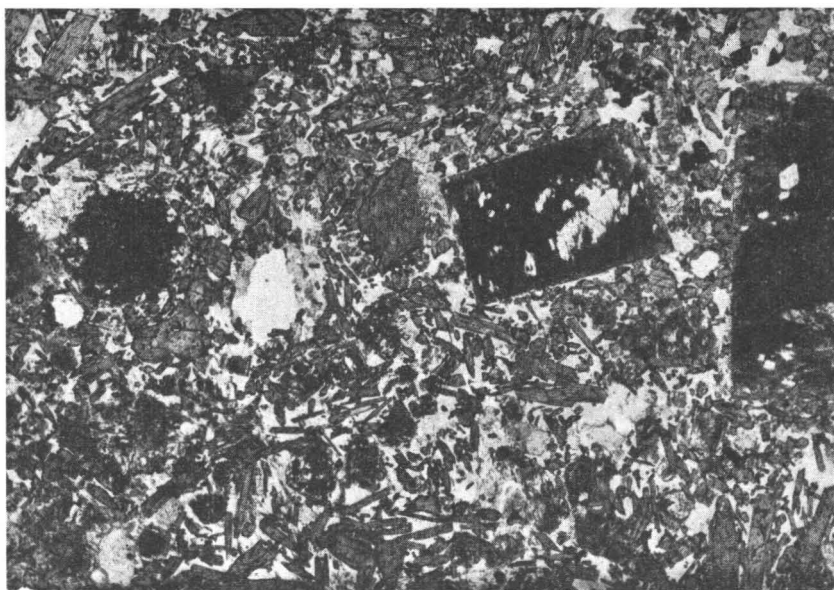


Fig. 9. Malignite. Idiomorphic nepheline, dark from alteration products, (analcite). Western slope of Iivaara (Observation 16). Without analyzer. Magnification $10\times$. Photo E. Halme.

The size of the grain averages 1—3 mm. The pyroxene content is considerable. It is a dark green aegirineaugite, $\alpha_{Ac} = 17^\circ$. The center of the grains is in some cases a colorless diopside poor in aegirine, $\alpha_{Ac} = 35^\circ$. The pyroxene often exhibits idiomorphism. The rock contains approximately equal amounts of feldspar and nepheline. The feldspar is microperthite. The anorthite content of the plagioclase in it = $An_3 \pm 1$ (Smith 1956). The feldspar has been homogenized by heating it for twenty hours at a temperature of 900°C , and applying the standard of $(\text{NH}_4)_2\text{SO}_4$ a result of $43 \pm 2\%$ potash feldspar has been obtained (Bowen and Tuttle 1950). The large feldspar grains contain inclusions of wholly idiomorphic nepheline grains (Fig. 9). The nepheline is generally turbid, full of alteration products (according to the powder pattern, evidently analcite), but in some cases the center of the grains is quite bright and unaltered nepheline. There is an abundance of sphene, also as idiomorphic crystals. Accessories are apatite, sodalite and ore. Table 3 shows the chemical composition, Niggli numbers and norms of the malignite.

Cancrinite-nepheline-wollastonite rock. On the western slope of Iivaara (Observation 13) a pale rock brecciates a dark cancrinite-syenitic fenite (Fig. 2; Table 4, No. 1).

Table 3. Analysis of malignite from Iivaara. Specimen 16/54 ML.
Anal. Pentti Ojanperä, 1958.

Weight per cent		Mol. prop.	Cation %	O in oxides	Niggli numbers	
SiO ₂	51.94	8 644	49.26	98.52	si	139.9
TiO ₂	1.88	235	1.42	2.84	qz	—32.1
Al ₂ O ₃	10.96	1 075	12.26	18.39	ti	0.38
Fe ₂ O ₃	6.42	402	4.57	6.89	al	17.4
FeO	3.92	546	3.10	3.10	fm	34.2
MnO	0.27	38	0.21	0.21	c	28.6
MgO	2.91	722	4.11	4.11	alk	19.8
CaO	9.91	1 767	10.06	10.06	mg	0.70
Na ₂ O	5.78	932	10.62	5.31	k	0.24
K ₂ O	2.70	287	3.26	1.63	c/fm	0.84
P ₂ O ₅	1.42	100	1.13	2.83		
CO ₂	0.00					
H ₂ O+	1.48	(822)	(4.68)			
H ₂ O—	0.22					
99.81			100.00	153.89		
			—O for (OH)	4.68		
			O	149.21		
			(OH)	9.36		
		Anions pro 100.00 cations		158.57		

Weight norm		One-cation molecular norm		Planimetric mineral composition	
or	15.96	Or	16.32	Feldspar	28.0
ab	33.08	Ab	36.31	Nepheline and its alteration	
ne	4.45	Ne	5.22	products	27.8
ac	6.65	Ac	6.48	Pyroxene	40.4
fs	1.20	Fs	0.82	Sphene	2.9
en	7.22	En	8.22	Apatite	0.4
wo	16.64	Wo	16.36	Accessories	0.5
mt	5.98	Mt	4.42		
il	3.57	Il	2.84		100.0
ap	3.36	Ap	3.01		
	98.11		100.00		
H ₂ O+	1.48				
H ₂ O—	0.22				
	99.81				

Table 4. Planimetric mineral determinations from specimen 63e/KM. Observation 13.
Western slope of Iivaara.

	1.	2.
Feldspar	14.3	59.5
Nepheline	24.7	—
Wollastonite	24.6	—
Cancrinite	28.9	10.9
Pyroxene	6.8	28.4
Accessories	0.7	1.2
	100.0	100.0

1. Cancrinite-nepheline-wollastonite rock.
2. Cancrinite-syenitic fenite.

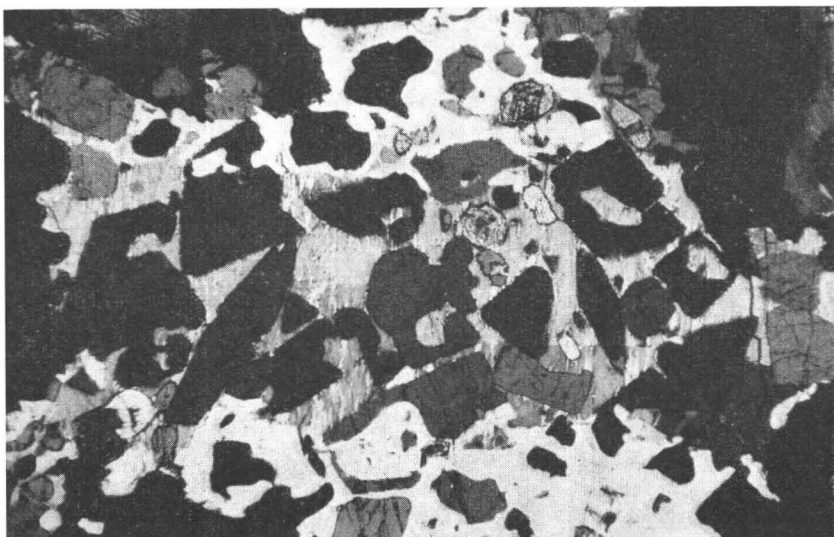


Fig. 10. Cancrinite-nepheline-wollastonite rock (Observation 13, Specimen 63e/KM). Dark crystals nepheline and sphene. Nicols crossed. Magnification 55 \times . Photo E. Halme.

As Table 4, No. 1, shows, the pale rock contains principally cancrinite, nepheline and wollastonite as well as some feldspar and pyroxene. Accessories are sphene, sodalite and apatite. The feldspar is microperthite. The KAlSi_3O_8 content of the homogenized feldspar is 72 % (Bowen and Tuttle 1950). A large microperthite grain is likely to contain as inclusions numerous nepheline grains, which are in part idiomorphic but conspicuously corroded (Fig. 10). The cancrinite, in turn, has corroded the microperthite grains and, to a high degree, the nepheline grains as well. The pyroxene is the same kind of dark green, weakly zoned aegirine-augite as in the malignite. The grains are often idiomorphic, but their center is full of nepheline grains. The wollastonite is also partly idiomorphic, but it likewise in some cases contains inclusions of nepheline. The sphene grains too are full of nepheline inclusions. The sequence of crystallization seems to be as follows: nepheline, wollastonite, sphene, pyroxene, microperthite, cancrinite. Table 5 shows the chemical composition of this rock, together with the Niggli numbers and norms.

The same kind of rock occurs on the western slope of Iivaara (Observation 11). The amount of pyroxene in these specimens is larger. Around the wollastonite grains pectolite has often crystallized (Fig. 21, p. 48), apparently without following any geometric structure characterizing wollas-

Table 5. Analysis of cancrinite-nepheline-wollastonite rock from Iivaara.
Specimen 63e/KM. Anal. Pentti Ojanperä, 1958.

Weight per cent		Mol. prop.	Cation %	O in oxides	Niggli numbers	
SiO ₂	46.99	7 820	42.30	84.60	si	114.6
TiO ₂	0.28	35	0.19	0.38	qz	—70.2
Al ₂ O ₃	13.99	1 372	14.84	22.26	ti	0.05
Fe ₂ O ₃	0.62	39	0.42	0.63	al	20.1
FeO	1.37	191	1.03	1.03	fm	5.4
MnO	0.18	25	0.13	0.13	c	50.0
MgO	0.29	72	0.39	0.39	alk	24.5
CaO	19.13	3 411	18.45	18.45	mg	0.20
Na ₂ O	9.35	1 508	16.31	8.16	k	0.10
K ₂ O	1.53	162	1.75	0.88	c/fm	9.26
P ₂ O ₅	0.66	46	0.50	1.25		
CO ₂	2.55	580	3.14	6.28		
SO ₃	0.60	75	0.41	1.23		
S	0.08	25	0.14			
H ₂ O+	2.26	(1 255)	(6.79)			
H ₂ O—	0.17					
100.05			100.00	145.67		
—O = S			—O for (OH)	6.79		
0.04						
100.01			O	138.88		
			(OH)	13.58		
			Anions pro 100.00 cations	152.46		

Weight norm		One-cation molecular norm		Planimetric mineral composition	
or	9.02	Or	8.75	Feldspar	14.3
ab	15.32	Ab	13.22	Nepheline	24.7
ne	26.08	Ne	31.34	Wollastonite	24.6
th	1.06	Th	1.23	Cancrinite	28.9
ns	2.25	Ns	3.96	Pyroxene	6.8
ac	1.80	Ac	1.68	Accessories	0.7
fs	2.23	Fs	1.80		
en	0.73	En	0.78		100.0
wo	31.11	Wo	29.12		
il	0.53	Il	0.38		
ap	1.54	Ap	1.25		
pr	0.15	Pr	0.21		
cc	5.80	Cc	6.28		
	97.62		100.00		
H ₂ O+	2.26				
H ₂ O—	0.17				
	100.05				

tonite crystals, judging from the fact that within the same grain of pectolite there are likely to be wollastonite grains in different optical orientation.

Pyroxene-amphibole-plagioclase rock. On the western slope of Iivaara (Observation 4) there occurs a dark, fine-grained rock, whose relation to its environment cannot be accurately determined for lack of suitable outcrops.

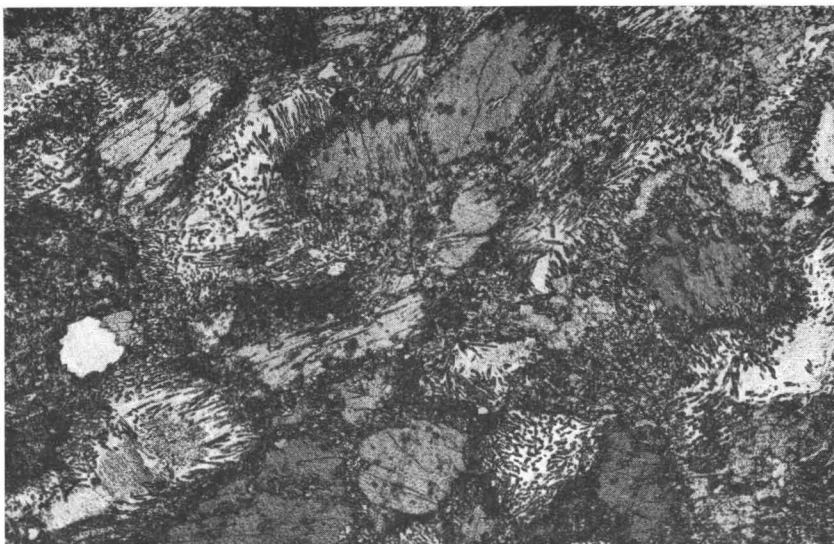


Fig. 11. Pyroxene-amphibole-plagioclase rock (Observation 4). Western slope of Iivaara. Without analyzer. Magnification 35 \times . Photo E. Halme.

Mafic minerals make up about 70 % of the rock. The amphibole is hornblende, pleochroism α = light brown, $\beta = \gamma$ = greenish brown, $2V\alpha = 72^\circ$, $\gamma\Delta c = 16^\circ$. In places biotite is intergrown together with the hornblende, though on the whole the latter occurs as pure, uniform grains. The pyroxene, on the other hand, appears mostly as small needles, which usually surround hornblende grains (Fig. 11). More rarely does the pyroxene appear as large, uniform grains. The pyroxene is light greenish aegirine-augite, $2V\gamma = 70^\circ$, $\alpha\Delta c = 37^\circ$. The rock contains an abundance of small grains of ore, which have often arranged themselves around mafic minerals. A light mineral is plagioclase, whose composition, judging on the basis of its angle of extinction, is An_{45} . There is also some amount of nepheline. A thin section made from the other end of the same specimen, measuring about 10 cm in length, contains a somewhat more greenish pyroxene as a mafic mineral. It also appears as more uniform grains than in the slide prepared from the other end of the specimen. In spots there is a trifling amount of biotite intergrown with the pyroxene. Hornblende is totally lacking. Light minerals are nepheline, cancrinite and zeolite (evidently natrolite). Accessories are apatite and sphene.

The rock described in the foregoing resembles to some extent the essexite of Penikkavaara reported by Hackman (1900), which he said possibly oc-

curred as a dike in the ijolite. According to the microscopic observations made by Hackman, this rock contains as mafic minerals augite, barkevikite and green hornblende. Of the amphiboles, barkevikite is the prevailing mineral and it is often intergrown with green hornblende. The feldspar is mainly andesine, but a slight amount of orthoclase likewise occurs. An abundance of ore is present; in part it is pyrite, but mostly it is ilmenite. In place rutile is also met with. The rock of such dikes has been designated by Johannsen (1949) as »penikkavaarite.»

GENESIS OF THE FENITE AND THE TRANSITIONAL ROCKS

Occurrences of alkali rocks are usually surrounded by a zone of altered, fenitized rocks, as in the region of Fen, in Norway (Brögger 1921, Saether 1957), and the region of Alnö, in Sweden (von Eckermann 1948). In the foregoing we have described corresponding alterations in the granodioritic country rock surrounding the occurrence of alkali rock at Iivaara. It is thus quite evident that there must be a genetic relation between this alteration zone and the occurrence of alkali rock.

The fenitization processes in the regions of Fen and Alnö have been described in considerable detail in the aforesaid publications. It is purposed in the following to illuminate this process by means of the material collected in the Iivaara district.

In the country rock surrounding the alkaline complex at Iivaara, there are fissure veins in abundance, which vary in breadth from one millimeter to several centimeters (Fig. 3). In mineral composition they are usually cancrinite-ijolite, but in some cases normal ijolite. The surrounding country rock is thus greatly broken up, and the fissures have filled with a basic silicate magma. The abundance of cancrinite proves that the molten material contained water and was rich in carbon dioxide.

The first sign of fenitization is the appearance of aegirine in the granodiorite, where it gradually totally replaces the biotite. As explained by, e. g., Saether (1957), in this process the sodium has apparently been conveyed through a pore liquid and combined with iron from the original material to form aegirine. As the fenitization continues, the potash feldspar of the granodiorite changes into microperthite and the oligoclase into pure albite. In many of the thin sections studied, the separation of calcite is apparent in connection with the albitization of oligoclase. Thereafter, the quartz disappears suddenly, and the rock becomes a typical fenite. An even more advanced stage of fenitization is represented by cancrinite- and nepheline-syenitic fenite.

The material from the region of Alnö led von Eckermann (1948, p. 42) to conclude that from the fenite had become eliminated the Na and Si,

Table 6.

	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
Fenite	0.49	16.52	1.87	1.35	0.08	0.71	2.59	7.76	4.42	0.22
Granodiorite	0.15	13.87	0.64	0.78	0.04	0.43	1.62	4.49	3.69	0.07
Difference	0.34	2.65	1.23	0.57	0.04	0.28	0.97	3.27	0.73	0.15
Ijolite	0.38	15.70	3.55	3.40	0.18	5.52	14.16	7.24	2.61	0.77
Per cent of the component that has shifted from the ijolite to the fenite	90	17	35	17	22	5	7	45	28	20

whereas the amount of CO₂, F, H₂O, Fe, Ti, Ca, P, Ba and K had increased. In the region of Fen, Brögger (1921, p. 173) observed the amounts of K and Si to have decreased and those of Na, Al and, to some extent, also of Ca to have increased. Saether (1957, p. 23) endeavored to estimate the change of material occurring in the fenitization process and reported: »It is seen that Al₂O₃, CaO, Na₂O, K₂O, and CO₂ must have been added to the rock in quantities of round 2 % each, while 7—8 % SiO₂ must have been carried away. For TiO₂, Fe₂O₃, FeO, and MgO the calculated substance transfers are small and varying in sign, and no transport of these substances has probably taken place.» Strauss & Truter (1951, p. 93) observed in regard to the Spitzkop complex: »In the transition from normal granite to pyroxene umptekite, the decrease in Si is accompanied by an increase in Na and Al, and a slight and irregular increase in Fe''', the total iron remaining practically constant.»

The analysis in Table 1 was made from a rock in which a few small aegirine-augite needles provide evidence of incipient fenitization. However, the analysis yielded a result approaching the granodiorite of the Iivaara surroundings. The analysis in Table 2 was made from a typical fenite. In Table 6 the components have been calculated in which an increase has taken place in proceeding from granodiorite to fenite. If we assume that this increase has come from a material ijolitic in composition, represented by the analysis in Table 7, and estimate how many % this increase is of the ijolite's corresponding component, then we perceive that the increase of Al₂O₃ is about one-half the increase of alkalis and that N₂O has increased proportionally more than K₂O. Likewise, Fe₂O₃ has increased relatively little considering the available quantity. The MnO content of the rock is so slight that considering a possible error in the analysis they cannot be compared. The amounts of TiO₂ and P₂O₅ are likely to vary locally along irregular lines. SiO₂ has decreased upon proceeding from granodiorite to fenite about 10 %, while CO₂ has remained approximately unchanged. The abundant occurrence of wollastonite between the fenitic and alkaline areas is probably due to the fact that relatively little CaO has gone into the fenite, and

instead been enriched in this zone. The SiO_2 liberated in connection with the fenitization is perhaps to be found in the feldspar accumulations so often met with in fenitized zones (Fig. 4).

The heterogeneous transitional rocks (juvite, malignite, cancrinite-nepheline-wollastonite rock, etc.) present between the alkali rocks and the fenites proper have evidently crystallized from the molten mixture of the basic silicate magma and the country rock partially fused by it. The existence of such a molten material is proved by the breccias which the transitional rocks form together with the fenites proper.

THE CENTRAL MASS OF ALKALI ROCKS

FIELD OBSERVATIONS

The entire central area of Iivaara consists of nepheline-pyroxene rocks. They are classified according to their nepheline content (or alteration products) as follows (Johannsen, 1949): urtite = nepheline content in excess of 70 %, ijolite = nepheline content 50—70 %, and melteigite = nepheline content less than 50 %.

The variations in mineral composition and structure occur in the Iivaara area generally on a small scale; accordingly, the rock is unhomogeneous throughout the area. For this reason and because of the lack of suitable exposures, it has not been possible to mark out separately the different va-

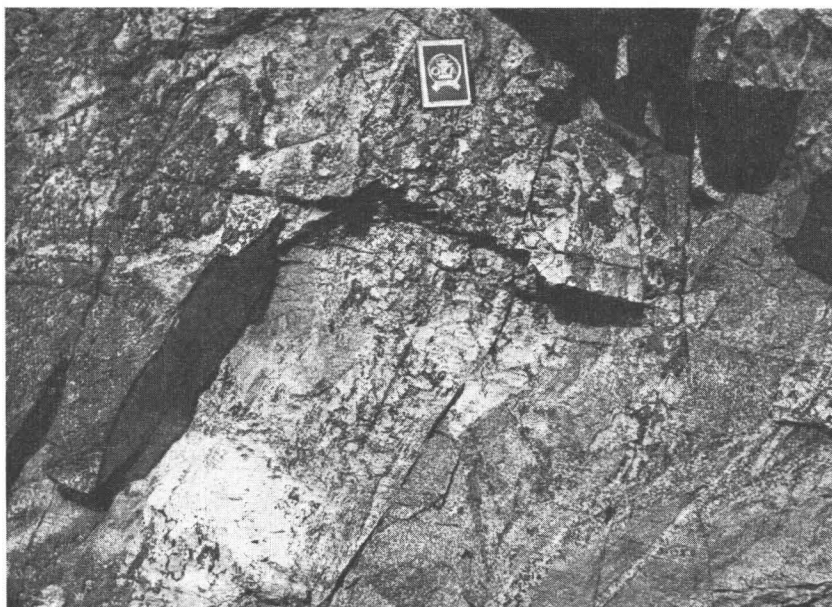


Fig. 12. Fine-, medium- and coarse-grained ijolite as well as urtite and melteigite. About 100 m southwest of the summit of Iivaara. Photo M. Lehijärvi.

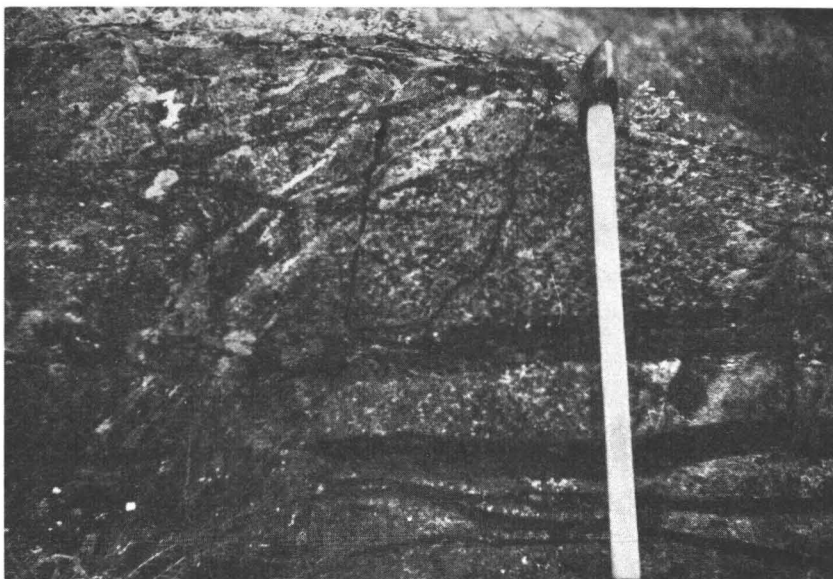


Fig. 13. Fine-grained ijolite as dark dikes in medium-grained ijolite. Also pale nepheline-rich veinlets. Photo A. Matisto.

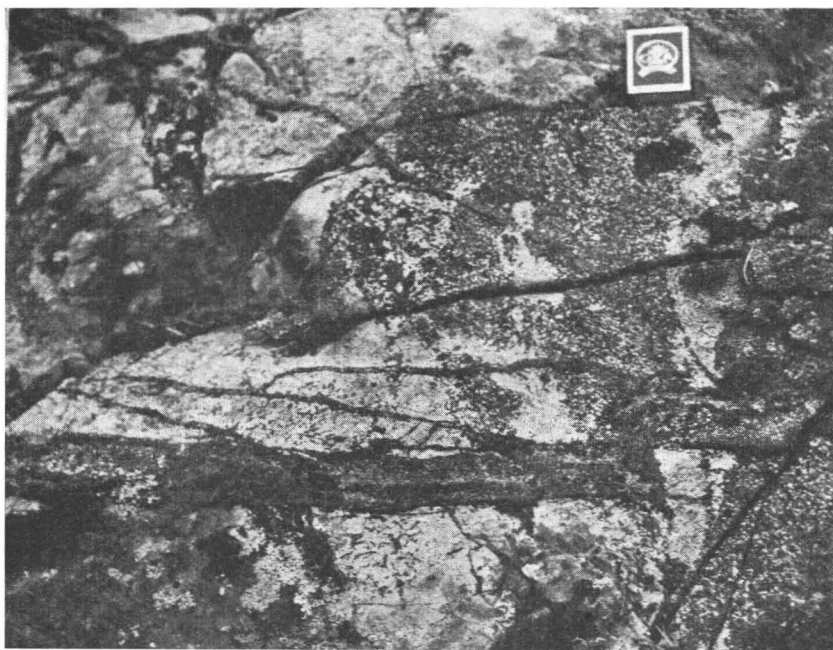


Fig. 14. Ijolite dike cut by fault penetrates urtite. In upper part of picture normal ijolite as irregular inclusion in urtite. About 100 m southwest of the summit of Iivaara. Photo M. Lehijärvi.



Fig. 15. Fissure dike, which contains pyroxene in long laminae lying perpendicular to the walls of the dike. A match as scale. About 50 m southeast of the summit of Iivaara. Photo M. Lehijärvi.

rieties on the map. The field observations give the impression that ijolite is the prevailing type of rock. Melteigite would seem to occur more abundantly in the marginal part of the mass on the northwestern slope of Iivaara. Urtite is best in evidence in the area immediately surrounding the summit of Iivaara.

The nepheline-pyroxene rocks of Iivaara are primarily of medium grain (diameter 2—5 mm), but quite often the size of the grain varies from fine to coarse (Fig. 12). In some cases, rock of medium or coarse grain contains bands appearing dark on account of the fine grain as well as indistinct patches, though the mineral composition is quite identical (Fig. 13). In places the urtite is penetrated by a dike of ijolite. Such a dike is likely to be cut by a fault (Fig. 14). In many places there also occur fissure veins about 0.5—20 cm broad situated both vertically and almost horizontally, which contain pyroxene in long laminae lying perpendicular to the walls of the dike (Fig. 15).

PETROGRAPHICAL CHARACTER AND CHEMICAL COMPOSITION

Urtite. In the vicinity of the summit of Iivaara there occur here and there in areas of a few square meters nepheline-pyroxene rocks with a nepheline content over 70 % (Fig. 14). Earlier nepheline-rich rocks poor in mafic minerals from the Kola Peninsula were called urtite by Ramsay (1896). This name is here applied to the corresponding rock type from Iivaara which, however, differs from the Kola urtite in the composition of its pyroxene



Fig. 16. Ijolite (margins of pyroxene grains richer in aegirine than center). Summit of Iivaara (Observation 33). Without analyzer. Magnification $30\times$. Photo E. Halme.

which is aegirine, while the Iivaara rock contains aegirine-augite like the ijolite. The nepheline is usually coarse-grained and xenomorphic. At times hexagonal forms are observable in the nepheline. Cancrinite is present as an alteration product in cracks in the nepheline as well as in patches within it. The pyroxene is aegirine-augite and it is partially idiomorphic and zoned, its margins richer in aegirine than its center; to some extent it occurs as an interstitial material in between nepheline grains. At times such nepheline-rich spots are likely to contain an uncommon abundance of apatite. Accessories are sphene, biotite and ore. The structure of the rock is hypidiomorphic.

Ijolite. Ordinarily the ijolite is of medium grain and its structure is hypidiomorphic (Fig. 16). The nepheline is gray or faintly reddish in color (analysis in Table 10). It is mostly irregular in form, but on occasion hexagonal forms are likely to be observable even megascopically. The pyroxene is aegirine-augite, which occurs as indefinite grains or long prisms, more rarely as idiomorphic grains (analysis in Table 16). Zoning is distinct (Fig. 16), the center is pale greenish and edges dark greenish, richer in aegirine than the center. The twinning according to the augite law is general. Among accessory minerals, sphene is often concentrated in association with pyroxene.

Table 7. Analysis of medium-grained ijolite from Iivaara Specimen Pä 2b, R.D.
19. 8. 07. Anal. Mauno Lehijärvi, 1945.

Weight per cent		Mol. prop.	Cation %	O in oxides	Niggli numbers	
SiO ₂	46.15	7 680	41.20	82.40	si	97.0
TiO ₂	0.38	47	0.25	0.50	qz	—80.3
Al ₂ O ₃	15.70	1 540	16.52	24.78	ti	0.61
Fe ₂ O ₃	3.55	222	2.38	3.57	al	19.6
FeO	3.40	473	2.54	2.54	fm	29.6
MnO	0.18	25	0.13	0.13	c	32.3
MgO	5.52	1 369	7.35	7.35	alk	18.5
CaO	14.16	2 525	13.55	13.55	mg	0.59
Na ₂ O	7.24	1 167	12.53	6.27	k	0.19
K ₂ O	2.61	277	2.97	1.48	c/fm	1.09
P ₂ O ₅	0.77	54	0.58	1.45		
H ₂ O	0.93	(516)	(2.77)			
100.59			100.00	144.02		
			—O for (OH)	2.77		
			O	141.25		
			(OH)	5.54		
			Anions pro 100.00 cations	146.79		

Weight norm		One-cation molecular norm		Planimetric mineral composition	
or	5.54	Or	5.30	Nepheline	57.1
lc	7.75	Lc	7.64	Cancrinite	2.2
ne	33.15	Ne	37.59	Pyroxene	38.8
an	2.67	An	2.55	Accessories	1.9
fs	3.02	Fs	2.46		100.0
en	13.74	En	14.70		
wo	26.12	Wo	24.14		
mt	5.15	Mt	3.57		
il	0.71	Il	0.50		
ap	1.81	Ap	1.55		
	99.66		100.00		
H ₂ O	0.93				
	100.59				

In color it is honey-yellow. Apatite is present in small prisms, evenly distributed through the whole rock. The cancrinite is generally carbonatic cancrinite of strong birefringence. In places also iivaarite and ore grains are met with. Table 7 presents the chemical composition, Niggli numbers and norms of medium-grained ijolite.

In structure the ijolite described in the foregoing is, according to my observations, the dominant rock type in the Iivaara area. In places, however, there does occur a rock that structurally deviates from the main type but is ijolitic in mineral composition.

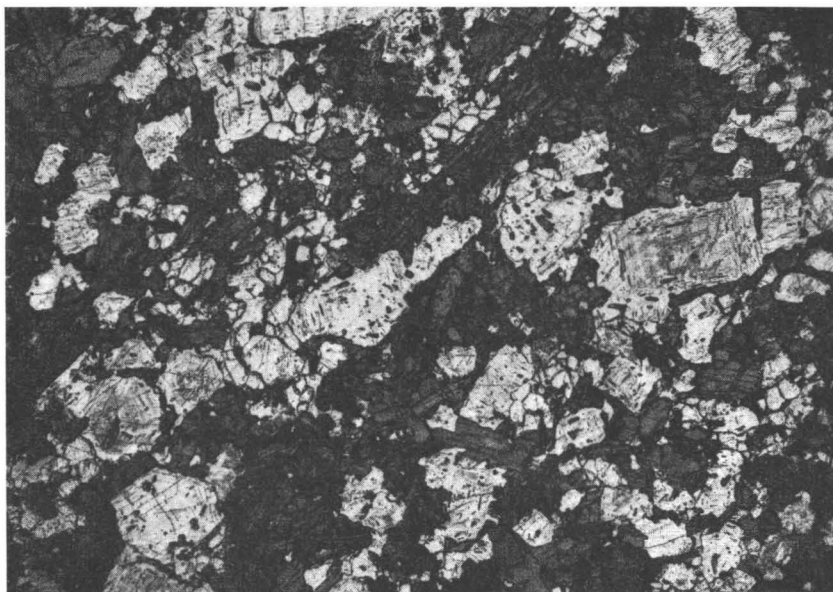


Fig. 17. Ijolite (idiomorphic nepheline). About 200 m south-southeast from the summit of Iivaara (Observation 29). Without analyzer. Magnification 17 \times .
Photo E. Halme.

Some 300 m south-southwest of the summit of Iivaara (Observation 27), pyroxene laminae about 4—5 cm long occur scattered about in the medium-grained ijolite.

In the fissure dikes (Fig. 15) the pyroxene characterized by long laminae is weakly zoned as well as generally twinned and idiomorphic. In some instances there is an abundance of apatite, in others, again, sphene and iivaarite. Accessories are cancrinite, zeolite, ore and some flakes of biotite.

The mineral composition of the fine-grained dark dikes occurring in numerous places and giving the impression of being rich in pyroxene is likely to be totally ijolitic. In a specimen taken from such a dike about 200 m south-southeast from the summit of Iivaara (Observation 29), the nepheline appears in the thin section as hexagonal and rectangular grains somewhat irregular along the edges (Fig. 17). There are numerous liquid and gas inclusions as well as small pyroxene needles, which are ordinarily arranged according to the crystal faces. The pyroxene is a dark green aegirine-augite, somewhat zoned and weakly idiomorphic. The cancrinite is both carbonatic and sulphatic cancrinite. Zeolite often occurs in association with the

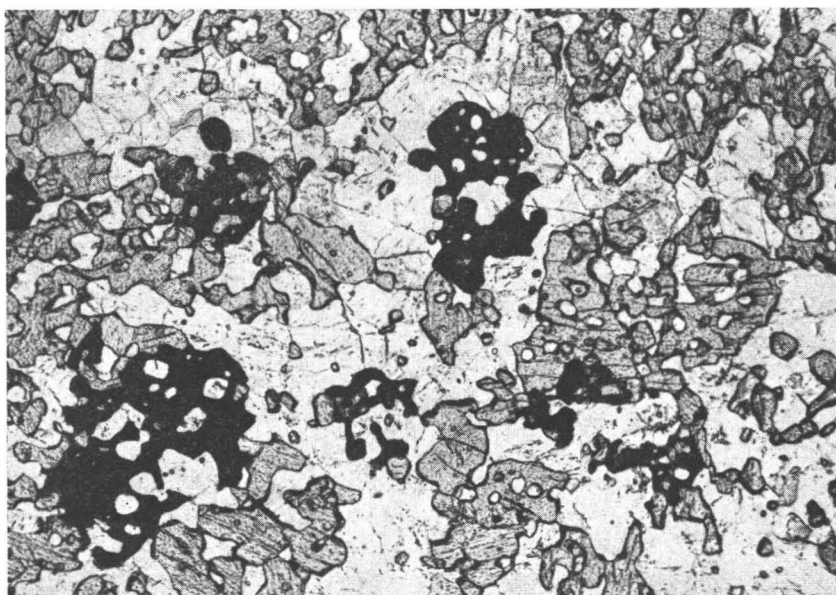


Fig. 18. Ijolite. Nepheline intergrown poikilitically with pyroxene and iivaarite. About 800 m north-northeast of summit of Iivaara (Observation 8). Without analyzer. Magnification 60 \times . Photo E. Halme.

latter. There is a relative abundance of apatite and sphene as well as some iivaarite and ore.

Some 800 m north-northeast of the summit of Iivaara (Observation 8), there occurs fine-grained ijolite, the pyroxene and iivaarite of which poikilitically contain nepheline (Fig. 18). Minerals of the cancrinite group sometimes occur so abundantly (Observations 5 and 31) that the rock might be termed cancrinite-ijolite (Lehijärvi 1956). An analysis of the nepheline of the cancrinite-ijolite is presented in Table 10, No. 2; of the pyroxene in Table 16, No. 2; and of the cancrinite in Table 12.

Melteigite. Near the marginal zone on the northwestern and northern slopes of Iivaara (Observations 1, 2, 4, 9 and 10), there are nepheline-pyroxene rocks whose pyroxene content exceeds 50 %, that is, melteigite. For lack of suitable exposures, no conclusions can be drawn regarding the mode of occurrence of the melteigite. Judging from the mineral composition melteigite occurs also in the easternmost outcrops of the area (Observations 7 and 25), but their relation to the marginal zone cannot be determined in lack of exposures. In the central parts of the area, melteigite is likely to be present in the ijolite as small, indistinct patches (Fig. 12). Table

Table 8. Planimetric mineral determinations from the melteigite.

	1.	2.	3.	4.
Pyroxene	58.4	52.4	34.6	75.3
Hornblende	—	—	—	8.7
Nepheline	29.2	33.9	30.9	15.5
Cancrinite	—	5.9	7.1	—
Iivaarite	—	—	23.3	—
Biotite	3.7	—	—	0.5
Apatite	1.2	5.8	3.6	—
Sphene	—	1.4	0.5	—
Ore	7.5	0.6	—	—
	100.0	100.0	100.0	100.0

1. Observation	4, Plate I
2. »	25, »
3. »	9, »
4. »	32, »

8 presents some planimetric mineral determinations made from the melteigite.

The pyroxene content of the melteigite on the northwestern slope of Iivaara and the southwestern slope of Ahvenvaara (Observations 1, 2 and 22 B) is roughly 70—80 %. Sphene occurs abundantly as idiomorphic crystals. Apatite has accumulated in places in large clusters. The predominant feldspathoid is cancrinite. There is very little nepheline. Accessories are carbonate and ore. The rock further has fissure veins about 1 mm broad, consisting primarily of natrolite (identified by the X-ray method) but also containing some cancrinite and pectolite. The rock might possibly be termed cancrinite-melteigite.

The melteigite encountered on the northwestern slope of Iivaara (Observation 4, Table 8, No. 1) is similar to the fine-grained ijolite described by Hackman (1900, Fig. 2, Table 1). The pyroxene is pale green aegirine-augite, $\alpha \wedge c = 35^\circ$. It is quite ragged and in association with it there are commonly small grains of ore and biotite. The zoning is weak. The nepheline is bright. Accessories are apatite and sphene.

On the eastern side of Iivaara (Observation 7) melteigite occurs in a small outcrop. It contains apatite nodes measuring about 5 cm in diameter (analysis in Table 24).

Near the summit of Iivaara (Observation 33) melteigite occurs in the ijolite as indistinct specks (Fig. 12), which in spots contain abundant honey-yellow sphene (analysis in Table 23).

An exposure on the northern slope of Penikkavaara (Observation 25, Table 8, No. 2) consists of a dark, pyroxene-banded rock, the mineral composition of which is melteigitic. The pyroxene is dark green, zoned but xenomorphic. In the nepheline, on the other hand, square forms are likely to be noticed on occasion. Usually the pyroxene encircles such grains. Small

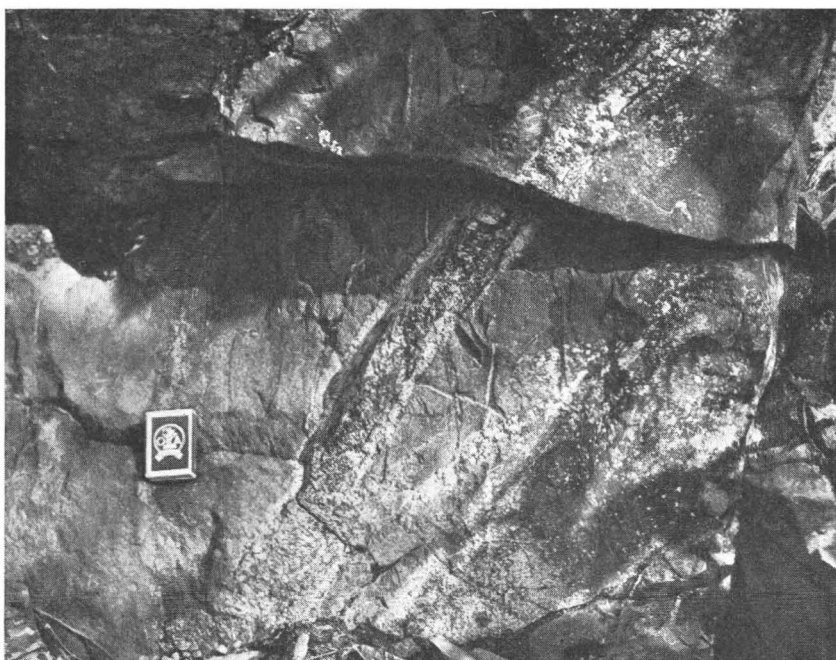


Fig. 19. Part of a several meters broad fine-grained dike, penetrated by ijolite (Observation 32). Photo M. Lehijärvi.

pyroxene needles often are present in the nepheline as inclusions. Apatite is abundant. Accessories are sphene and ore.

On the northern slope of Iivaara (Observation 9, Table 8, No. 3) there occurs a coarse-grained rock, the diameter of the nepheline grains of which is likely to measure 10–15 mm and the length of the pyroxene laminae 20–30 mm. Certain of the pyroxene grains are distinctly idiomorphic, the best developed faces are (110), (100), (001) and (111). The nepheline has an abundance of gas and liquid inclusions as well as, on occasion, small pyroxene needles. Idiomorphism is lacking. The cancrinite is both of the carbonatic and sulphatic variety. The apatite occurs as long prisms or as large, irregularly shaped grains. Sphene is present as scarce idiomorphic crystals or indistinct grains. An abundance of iivaarite is characteristic, so the rock might be termed iivaarite-melteigite.

From the summit of Iivaara about 200 meters northward (Observation 32) there is a fine-grained dike several meters broad running N 80° W and penetrated by the surrounding ijolite (Fig. 19). The same dike apparently comes into sight again at Observation Site 10.

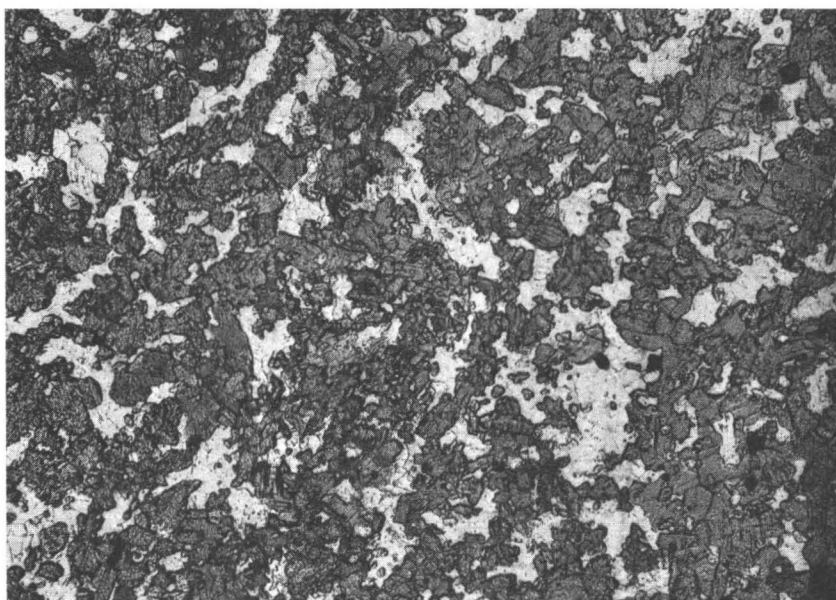


Fig. 20. Hornblende-biotite-melteigite (Observation 32). Without analyzer.
Magnification 35 \times . Photo E. Halme.

As to mineral composition, the dike is primarily hornblende-biotite-melteigite (Table 8, No. 4; Fig. 20). Among the mafic minerals, pyroxene dominates (analysis in Table 17). The amounts of biotite (analysis in Table 18) and hornblende vary. In addition to nepheline, there is some sodalite (p. 46). Table 9 presents the chemical composition, Niggli numbers and norms of the melteigite.

The dike is not, however, melteigite throughout. Feldspar is present in it as a light mineral, in some places in addition to nepheline and in others by itself. In one such specimen a weakly ophitic texture can be imagined. The dike is accordingly likely to be originally one of the diabase dikes quite commonly encountered in the country rock of the vicinity.

GENESIS OF THE ALKALI ROCKS OF IIVAARA

The alkaline district of Iivaara lies within the seismic zone (Sahlström 1930) that joins the alkaline regions of the Kola peninsula with the eruptive rock complex of the Permian epoch in the vicinity of Oslo. To this same zone are closely associated apparently also the other Fennoscandian occurrences of alkali rocks: Kuolajärvi, Alnö, Särna, Almunge, Norra Kärr and

Table 9. Analysis of melteigite from Iivaara. Specimen 32/54 ML.
Anal. Pentti Ojanperä, 1958.

Weight per cent		Mol. prop.	Cation %	O in oxides	Niggli numbers	
SiO ₂	51.12	8 507	46.45	92.90	si	116.7
TiO ₂	0.66	83	0.45	0.90	qz	—49.7
Al ₂ O ₃	10.41	1 021	11.15	16.72	ti	0.11
Fe ₂ O ₃	4.72	296	3.23	4.84	al	14.0
FeO	4.47	622	3.40	3.40	fm	42.1
MnO	0.20	28	0.15	0.15	c	25.5
MgO	7.38	1 830	9.99	9.99	alk	18.4
CaO	10.43	1 860	10.16	10.16	mg	0.60
Na ₂ O	6.77	1 092	11.92	5.96	k	0.18
K ₂ O	2.31	245	2.68	1.34	c/fm	0.61
P ₂ O ₅	0.14	10	0.11	0.27		
CO ₂	0.25	57	0.31	0.62		
H ₂ O+	1.05	(583)	(3.18)			
H ₂ O—	0.11					
100.02			100.00	147.25		
			—O for (OH)	3.18		
			O	144.07		
			(OH)	6.36		
		Anions pro 100.00 cations		150.43		

Weight norm		One-cation molecular norm		Planimetric mineral composition	
or	13.64	Or	13.40	Nepheline	15.5
ab	1.49	Ab	1.25	Pyroxene	75.3
ne	21.24	Ne	24.66	Hornblende	8.7
ns	0.24	Ns	0.44	Biotite	0.5
ac	13.67	Ac	12.92		100.0
fs	7.48	Fs	6.20		
en	18.37	En	19.98		
wo	20.56	Wo	19.34		
il	1.26	Il	0.90		
ap	0.34	Ap	0.29		
cc	0.57	Cc	0.62		
	98.86		100.00		
H ₂ O+	1.05				
H ₂ O—	0.11				
	100.02				

Fen. Brögger (1921, pp. 394—395) pointed out — and according to him even earlier references had been made — that the Fennoscandian alkali rock complexes are situated in a zone running parallel to the Caledonian mountain chain and that this circumstance must involve some genetic connection. The classical and well studied alkali rock complexes of Fen and Alnö as well as the alkaline districts of Afrikanda, Khabozero and Turja in the Kola peninsula compare with the alkaline district of Iivaara in size and, besides, all the occurrences mentioned contain basic or ultrabasic silicate rocks. The

carbonate rocks characteristic of the formations of Fen and Alnö as well as of Turja have not been encountered at Iivaara.

Brögger (1921) presents extensive observation material as well as a detailed petrographical description of the rocks of the Fen region. In explaining the genesis of these rocks, he expresses the assumption that a moderately alkaline (essexitic) magma had partly assimilated, partly melted Archean limestone deep inside the earth's crust. The magma was thus desilicized, according to Daly's theory (1910, 1918), and out of it evolved the ultra-basic rocks characteristic of the region of Fen. The molten limestone behaved eruptively together with the silicate magma.

Bowen (1924, 1926) agrees with Brögger in considering the rocks of the vipetoite-melteigite-ijolite series as magmatic and fenites as metasomatic, but he rejects the idea of the existence of a carbonate magma.

Saether (1957) also regards the alkali rocks of the Fen district as magmatic and writes: »For an explanation of the genesis of the rock province of the Fen area I infer a kimberlitic parent magma originating in a relatively deep level in the lithosphere. It carried carbon dioxide, which likewise was derived from a deep level. As the magma rose to higher levels, it developed (by diffusion processes caused by instability of a homogeneous composite liquid in the gravity field, and by fractional crystallisation caused by cooling of its upper parts) a top portion which was poor in silica and enriched in CO₂, alkalies, and lime.»

Regarding the genesis of the alkali rocks of the Alnö area, von Eckermann (1950, p. 97) writes: »... the nepheline syenites surrounding the central sövite are not the differentiates of any primary sub-alkaline magma, but solely the products of the silication of a very basic carbonatitic magmatic liquid rich in volatiles, which exchanged part of its lime, carbon dioxide and potash for silica and soda from the surrounding fenitized rocks. Within this hybrid magma a limited crystal differentiation may have taken place, as a result of the gravitational settling of femic minerals, especially pyroxenes and melanite, and rising of soda-orthoclase and nepheline, leading to the ultimate formation of jacupirangites and juvites, respectively.»

In his publication on the alkaline and carbonatitic dikes of the Alnö formation, von Eckermann (1958) writes: »The basaltic layer of the earth crust in conjunction with a so far unexplained local concentration of fugitive carbon has been suggested as the origin of an alkaline magma of melitite-basaltic (alnöitic) chemical composition from which the different types of Alnö rocks derive.» In the same publication von Eckermann writes that Saether's (1957) conclusion concerning the kimberlitic parent magma toward explaining the genesis of the alkali rocks of the Fen area agrees with his own conclusions, »especially as the damtjernite and the alnöite may be

termed 'kimberlites deficient in olivine', but leaves the ultimate genesis, that of the kimberlite, unexplained.»

In the alkaline area of Kuolajärvi described by Sundell (1905) and Hackman (1925), ijolite has been encountered only as detached boulders, which are nevertheless fairly certainly of local origin. Furthermore, there occur in this area cancrinite-syenite, nepheline-porphyry and nepheline-basalt. Associated closely with this area is also the limestone deposit at Vuorijärvi. On account of the scarcity of outcrops, it is not possible to make sufficient field observations regarding the relation between alkali rocks and limestone. Hackman, however, assumes that the alkali magma was as it now is already when it came into contact relation with the limestone which Hackman conceives to be of sedimentary origin.

The occurrences of alkali rocks in the Kola peninsula are divided by Kupletsky (1936) into three different categories:

1) Nepheline-syenites, which are genetically related to the alkali granites (occurrences of Umpjek = Khibina and Lujavrut = Lovozero). In regard to the genesis of these rocks, Kupletsky (Fersman 1937) arrived at the conclusion that steam and other volatile substances played a prominent part in the formation of the alkali magma.

2) Alkali rocks associated with basic rocks (Gremyakh, Afrikanda). Regarding the Afrikanda formation, Kupletsky (1938) writes: »Analysing genetic questions of this interesting intrusion, the author arrives at the conclusion that the ultra-basic magma here assimilated the calcareous formations, which, in view of the rich volatile components of the magma, created favourable conditions for this trend of differentiation of magma which gave rise here to the formation of alkaline residuary fusion and the appearance, in the ultimate stage of differentiation, of nepheline pegmatites and ijolites.»

Another pyroxenite intrusion traversed by nepheline rocks was discovered by V. A. Afanasyev near the station Khabozero on the Ozernaya Varaka (Kupletsky 1937, p. 41). In 1937 prof. Pentti Eskola brought from this area a representative collection of rock samples, which are at the Geological Institute of the University of Helsinki. The ijolitic rocks of Khabozero are, according to these samples, exactly similar to those of Iivaara.

3) Ijolite intrusions involving contact interactions with the country rock (Turja, Ena-Kovdora). The Turja occurrence in especial contains an abundance of Ca-bearing minerals, such as perovskite, melilite, apatite, fluorite, cancrinite, etc. In this area there also occur carbonatite dikes. In Kupletsky's mind, »the carbonate syntexis theory might probably find here a ready application.»

Kranck (1928, p. 83) writes about the Turja occurrence: »... it seems quite as probable that the occurrence of calcite in the rocks in question is a consequence of a primary presence of CO_2 in their magma, as that their

percentage of CO_2 should on the contrary depend on limestone later dissolved in it.»

A feature that appears to be generally shared by alkali rock formations is the concurrent presence of carbonate minerals and carbonate rocks too. In his report on carbonatites in Africa, Smith (1956, p. 212) writes that the theory concerning the genesis of carbonatites should provide an answer to the question as to how to explain »the very close association of the carbonatites with ijolites and pyroxenites, and their perhaps less constant association with nepheline-syenites.»

In writing about Daly's hypothesis designed to explain the genesis of alkali rocks, Shand (1945, p. 503) observes: »... there is no hypothesis which fits the field evidence so well as Daly's, or makes so few and reasonable assumptions. Every one of the three stages in the process of desilication pictured by Daly, namely the reduction of granite to syenite, of syenite to foyaite, and of foyaite to ijolite, is supported by field evidence which hardly admits of any other interpretation than the one under discussion.» After Shand about 95 per cent of all known bodies of feldspathoidal rocks are in regions where limestone is present.

Pecora (1956) states: »One great difficulty of the Daly-Shand limestone syntexis hypothesis is in creating great volumes of the mafic, subsilicic, potassium-rich magma.» When considering the field and geochemical relationships of the carbonatites and alkalic igneous rocks he concludes that »carbonatites were deposited by carbonatic solutions having a wide range of temperature, pressure, and concentration and derived from alkalic magmas during the process of silicate crystallization.» — »The source of the carbon dioxide and other minor constituents lies deep in the crust, as does the source of the alkalic magma — out of sight but not out of mind. Their origin must be linked to continental history.»

In the Iivaara area the carbonates belong, on the whole, among the accessory minerals, nor have carbonate rocks been encountered in any of the exposures known at present. This does not, however, exclude the possibility that they might be associated with this formation. The present erosion level happens to be such that the carbonate content is not very much in evidence.

The alkali rock at Iivaara is by and large homogeneous in its area measuring about four kilometers across and its magmatic character is obvious. The presence of ijolitic dikes in the country rock bears testimony to the existence of alkaline magma in this locality. The abundance of cancrinite indicates that the magma has been rich in carbon dioxide. The magma has been capable of causing the fenitization of the country rock as well as the partial melting of the country rock and the formation of heterogeneous hybrid types of rocks (juvite, malignite, etc.).

The magma out of which the alkali rocks of Iivaara have derived must have a long and complicated evolutionary history. On the basis of present observations, it is hard to decide which of the theories discussed in the foregoing is best applicable to the Iivaara formation. Many researchers are of the opinion that alkali rocks are likely to evolve in numerous different ways. Or, to quote Barth (1939): »Es ist anzunehmen, dass die meisten Alkaligesteine eine recht komplizierte Bildungsgeschichte aufweisen und dass infolgedessen keine einzige der erwähnten Hypothesen in der Lage ist, ihre Entstehungsweise restlos zu erklären. Die Alkaligesteine sind sicherlich 'polyphyl' (um einen Ausdruck aus der Paläontologie zu entlehnen): Sie können von mehreren Seiten stammen. Darüber sind sich wohl jetzt alle Petrographen einig.»

No absolute age determinations of the minerals of the Iivaara alkali rock formation have so far been made. On geological grounds nothing else regarding the age of this formation can be stated except that it is younger than the surrounding Archean country rock. Nevertheless, in age too it can probably be compared with the other alkali rock occurrences of Fennoscandia. In respect to age the alkali rocks of Kola are divided into two groups: 1. The occurrences of Eno-Kovdozero, Afrikanda and Vuorijärvi: 345—375 million years (Caledonian). 2. The occurrences of Khibina and Lovozero: 280 million years (Hercynian) (Krats & Numerova 1957, p. 31; Gerling & Polkanov 1958, p. 698). The age of the alkali rock occurrence of Fen has been placed at 400—600 million years (Saether 1957, p. 136) and that of the alkali rock of Alnö at 562 million years (von Eckermann and Wickman 1956, p. 123).

MINERAL DESCRIPTION

NEPHELINE

In color the nepheline of Iivaara is gray or faintly reddish. Some 150 meters south of the summit of Iivaara (Observation 28), an ijolite of medium grain containing a gray-colored nepheline is quite sharply bounded by an ijolite containing a nepheline of a reddish color. The form of the nepheline

Table 10. Chemical composition and physical data for nepheline

1.				2.			
Weight %		Atomic ratio $\times 10^4$		Weight %	Atomic ratio $\times 10^4$		Unit-cell content
SiO ₂	41.36	Si	6 883	41.48	Si	6 903	7.96
TiO ₂	n. d.	Al	6 656	0.00	Al	6 693	7.72
Al ₂ O ₃	33.93	Fe ³⁺	135	34.12	Fe ³⁺	158	0.18
Fe ₂ O ₃	1.08	Fe ²⁺	25	1.26	Fe ²⁺	40	0.05
FeO	0.18	Ca	26	0.29	Mg	30	0.04
MnO	n. d.	Na	5 269	0.00	Na	5 227	6.03
MgO	tr.	K	1 268	0.12	K	1 287	1.48
CaO	0.15	OH	866	tr.	OH	189	0.22
Na ₂ O	16.33	O	26 838	16.20	O	27 314	31.50
K ₂ O	5.97			6.06			
H ₂ O+	} 0.78			0.17			
H ₂ O—				0.00			
	99.78			99.70			

Physical data	
Sp.gr. (pycnometer)	2.638
ω	1.545
ϵ	1.541
a_0	10.001
c_0	8.379 \pm 0.003 Å ¹⁾
Volume	725.8 Å ³

1. Nepheline from medium-grained ijolite from Iivaara. Specimen Pä 2b, R.D. 19 VIII 07. Anal. Mauno Lehijärvi, 1945. (Rock analysis in Table 7).
2. Nepheline from cancrinite-ijolite from Iivaara. Specimen No. 5737 Geologia Fennoscandiae, Institute of Geology, University of Helsinki. Anal. Mauno Lehijärvi, 1953. (Lehijärvi 1956).

¹⁾ Determined by Sahama.

is generally irregular. Quite by chance an occasional hexagonal form may crop up, even macroscopically. Quite commonly there are gas and liquid inclusions in the nepheline of Iivaara, as well as pyroxene needles, which in some cases are arranged in conformity with the crystal faces (Fig. 17). Cancrinite occurs at the edges of the nepheline grains as well as along the cracks as alteration products. Table 10 presents the chemical composition and physical properties of the nepheline of Iivaara.

Sahama (1958) has noted that the ordinary nepheline cell is only a pseudo cell and that the true cell is notably larger. Both the pseudo cell and the true cell are hexagonal. The dimensions of the true cell are: $a_0 = 17.4 \text{ \AA}$ and $c_0 = 76 \text{ \AA} \pm 1$ or 2 %.

The ratio of alkalis in the nepheline of the Iivaara district is practically constant. Table 11 presents the alkali ratio, as determined by the X-ray method (Smith & Sahama, 1954), in nephelines of different types.

Table 11. X-ray determination of the K/(K + Na) ratio for nepheline.

Specimen	2 θ for (21.0)	100K/ (K + Na)	2 θ for (20.2)	100K/ (K + Na)	Average
1. 6/54 MI	27.239	19.10	29.662	19.31	19.20
2. 9/54 ML	27.234	19.99	29.660	19.60	19.80
3. 28B/54 ML	27.236	19.63	29.665	18.88	19.25
4. 63e/KM	27.238	19.28	29.664	19.01	19.15
5. 5737	27.245	18.05	29.660	19.60	18.84

1. Nepheline from fissure vein (Fig. 14).
2. Nepheline from coarse-grained iivaarite-melteigite.
3. Reddish nepheline from ijolite.
4. Corroded nepheline from cancrinite-nepheline-wollastonite rock.
5. Nepheline from cancrinite-ijolite (Smith & Sahama 1954, Lehijärvi 1956).

CANCRINITE

Carbonatic cancrinite is a common accessory mineral in the alkali rock of Iivaara. In the narrow dikes present in the fenitized zones as well as in the melteigite on the northwestern slope of Iivaara, the carbonatic cancrinite is in some spots the dominant feldspathoid. Also the amount of sulphatic cancrinite is in some cases notable — about 20 % (Lehijärvi, 1955). Under the microscope the sulphatic cancrinite appears, on account of the pigment, to be a dirty gray. In conjunction with it there occur small pigment-free carbonatic cancrinite grains. In some grains hexagonal forms are likely to be met with. Table 12 presents the chemical composition and physical properties of the sulphatic cancrinite.

Table 12. Chemical composition and physical data for sulphatic cancrinite from cancrinite-ijolite. Specimen No. 5737 Geologia Fennoscandiae, Institute of Geology, University of Helsinki. Anal. Mauno Lehijärvi, 1954.

Weight %		Atomic ratio $\times 10^4$		Unit cell content	Physical data	
SiO ₂	35.40	Si	5 891	6.25	Sp.gr. (pycnometer) ..	2.402
TiO ₂	0.00	Al	5 842	6.20	ω	1.499
Al ₂ O ₃	29.78	Fe ³⁺	6	0.01	ε	1.493
Fe ₂ O ₃	0.05	Fe ²⁺	58	0.06	a_0	12.74 Å
FeO	0.42	Mg	32	0.03	c_0	5.22 Å
MnO	0.00	Ca	200	0.21	Volume	733.2 Å ³
MgO	0.13	Na	6 702	7.11		
CaO	1.12	K	204	0.22		
Na ₂ O	20.77	Cl	99	0.11		
K ₂ O	0.96	SO ₄	587	0.62		
Cl	0.35	CO ₃	491	0.52		
SO ₃	4.70	OH	2 315	2.46		
CO ₂	2.16	O	20 347	21.58		
H ₂ O+	4.17					
H ₂ O—	0.00					
	100.01					
—O = Cl	0.08					
	99.93					

NATROLITE

On the northwestern slope of Iivaara (Observation 1), in the melteigite there are fissure veins about 1 mm wide which consist primarily of natrolite (identified by means of a diagram plotted with an X-ray diffraction meter). Also in the fissure veins (Fig. 15) containing pyroxene characterized by long laminae, there is commonly considerable natrolite. Natrolite occurs in conjunction with cancrinite quite as an accessory.

SODALITE

Sodalite is present to a very slight extent in biotite-hornblende-melteigite (Observation 32). The grains are xenomorphic, colorless and bright. The

Table 13. Powder diffraction data, unit cell dimension and refractive index for sodalite. Specimen 32/54 ML. Filtered Copper Radiation with NaCl Standard.

hkl	I	d	hkl	I	d	Unit cell dimension and refractive index	
110	40	6.28	330, 411	40	2.095		
200	10	4.44	521	10	1.626	n	1.487
211	100	3.63	440	10	1.571		
222	30	2.565	600	10	1.482	a_0	8.89 Å
321	30	2.375	611	10	1.442		

sodalite occurs in accumulations in a single spot or forms rows running right across the thin section. Table 13 reveals the physical properties of this sodalite. The d -values were computed by means of a diagram plotted with an X-ray diffraction meter. The unit cell dimension is obtained by computing the arithmetical mean of the a_0 -values of the different reflections.

ANALCITE

Analcite was observed in the nepheline of the maliginite as an alteration product (Sample 16/54 ML) as well as in the cavities in some cases occurring (Sample 17/54 ML) between the grains in the feldspar accumulations (Fig. 4) present in the fenitized zone. In these cavities the analcite occurs as small, colorless and bright grains. The birefringence is 0.002. Table 14 presents the physical properties of this analcite. The d -values have been obtained from a diagram plotted with an X-ray diffraction meter. The unit cell measurement was made by computing the arithmetic mean of the a_0 -values obtained from the different reflections.

Table 14. Powder diffraction data, unit cell dimension and refractive index for analcite. Specimen 17/54 ML. Filtered Copper Radiation with NaCl Standard.

hkl	I	d	hkl	I	d	Unit cell dimension and refractive index
211	40	5.60	521	20	2.503	n 1.489 a_0 13.71 Å
220	10	4.84	440	10	2.429	
321	10	3.67	640	20	1.902	
400	100	3.43	633	10	1.868	
332	50	2.924	732, 651	20	1.743	
431	20	2.694	1011	10	1.358	

PECTOLITE

Pectolite has been met with as small pockets in a fissure vein about 1 mm broad (Observation 1) occurring in melteigite.

Pectolite occurs in some abundance in an altered zone surrounding the area of alkali rock, where it is found in cancrinite-nepheline-wollastonite rock (Sample 11/54 ML). It is likely to occur quite by chance in fenite in conjunction with wollastonite. In a large pectolite grain there are likely to be several wollastonite grains optically orientated in different ways as inclusions (Fig. 21); and accordingly intergrowth does not follow any geometric structure characterizing wollastonite crystals. The physical properties of this pectolite are shown in Table 15. In separation it was not



Fig. 21. Pectolite (P) around wollastonite grain (W) (Observation 11). Without analyzer. Magnification 50 \times . Photo E. Halme.

possible to separate the pectolite in a wholly pure state, but about one-third of it was wollastonite. An analysis of this impure material appears in Table 15.

Table 15. Physical data for pectolite and analysis of material containing about 2/3 pectolite and 1/3 wollastonite. Cancrinite-nepheline-wollastonite rock. Specimen 11/54 ML. Anal. Pentti Ojanperä, 1958.

Physical data		Weight %	
Sp.gr.	2.886	SiO ₂	51.84
α	1.602	R ₂ O ₃	1.92
β	1.609	MgO	0.10
γ	1.637	CaO	38.74
		Na ₂ O	4.83
		K ₂ O	0.23
		H ₂ O+	2.06
		H ₂ O—	0.00
			99.72

PYROXENE

The pyroxene appears in the form of long prisms or grains of indefinite shape. The edges of the grains are ordinarily greener than the center, pleo-

Table 16. Chemical composition and physical data for pyroxene.

1.			2.		
Weight %		Atomic ratio $\times 10^4$	Weight %	Atomic ratio $\times 10^4$	
SiO ₂	51.39	Si 8 552	51.92	Si	8 640
TiO ₂	0.53	Al 88	0.64	Al	263
Al ₂ O ₃	0.45	Ti 66	1.34	Ti	80
Fe ₂ O ₃	6.55	Fe ³⁺ 820	7.15	Fe ³⁺	896
FeO	6.97	Fe ²⁺ 970	6.36	Fe ²⁺	885
MnO	0.40	Mn 56	0.28	Mn	39
MgO	10.46	Mg 2 494	10.31	Mg	2 557
CaO	20.17	Ca 3 596	19.73	Ca	3 518
Na ₂ O	2.42	Na 781	2.28	Na	736
K ₂ O	0.30	K 64	0.15	K	32
H ₂ O+	} 0.13	OH 144	0.05	OH	56
H ₂ O—		O 26 164	0.00	O	26 533
	99.77		100.21		
Physical data					
Sp.gr. (pycnometer)		3.415			
		Dark green zone		Light green zone	
α		1.700		1.697	
γ		1.734		1.724	
$\alpha A c$		22°		29°	

1. Pyroxene from medium-grained ijolite from Iivaara. Specimen Pä 2b, R.D. 19 VIII 07. Anal. Mauno Lehijärvi, 1945. (Rock analysis in Table 7).
2. Pyroxene from cancrinite-ijolite from Iivaara. Specimen No. 5737 Geologia Fennoscandiae, Institute of Geology, University of Helsinki. Anal. Mauno Lehijärvi, 1953. (Lehijärvi 1956).

chroism α = grass green and γ = yellowish green. In places there are several zones. Some grains exhibit distinct idiomorphism. Best developed are faces (110), (100), (001) and (111). Face (010) is only seldom observable weakly developed. Twinning according to the augite law is general. Table 16 presents the chemical composition and physical properties of the pyroxene separated from the ijolite of Iivaara. The analyses have been made from material in which the different zones have not been separated from each other.

In the biotite-hornblende-melteigite (Observation 32) the pyroxene is indefinite in form, grass green in color and not zoned. Table 17 shows the chemical composition and physical properties of this pyroxene, which bring out the fact that in question is aegirine-augite. In composition, it corresponds to the dark-green marginal part of the pyroxene contained in the ijolite.

Table 17. Chemical composition and physical data for pyroxene from melteigite. Specimen 32/54 ML. Anal. Pentti Ojanperä, 1958. (Rock analysis in Table 9).

Weight %		Atomic ratio $\times 10^4$		Unit cell content	Physical data	
SiO ₂	52.66	Si	8 764	7.93	Sp.gr.	3.416
TiO ₂	0.57	Al	196	0.18	α	1.708
Al ₂ O ₃	1.00	Ti	71	0.06	β	1.720
Fe ₂ O ₃	9.06	Fe ³⁺	1 135	1.03	γ	1.741
FeO	5.60	Fe ²⁺	780	0.71	2V γ	88°
MnO	0.28	Mn	39	0.04	αAc	18°
MgO	9.90	Mg	2 455	2.22	a_0	9.71 Å
CaO	16.83	Ca	3 001	2.72	b_0	8.96 Å
Na ₂ O	4.15	Na	1 339	1.21	c_0	5.24 Å
K ₂ O	0.06	K	13	0.01	β	105.3°
H ₂ O+	0.06	OH	67	0.06	Volume	439.7 Å ³
H ₂ O—	0.02	O	26 583	24.05		
	100.19					

HORNBLENDE

In the central area of Iivaara, hornblende has been encountered only in the biotite-hornblende-melteigite (Observation 32). In form it is indefinite and in color brown, $2Va = 41^\circ$, $\gamma Ac = 20^\circ$, $\alpha = 1.649$, $\gamma = 1.665$ and specific gravity = 3.240.

BIOTITE

Biotite is encountered only seldom as an accessory in ijolite. In melteigite it occurs in slightly greater abundance (a few per cent) in a couple of spots (Observations 4 and 32). The biotite analyzed was separated from the melteigite of the latter observation site, where it occurs in addition to pyroxene

Table 18. Chemical composition and physical data for biotite from melteigite. Specimen 32/54 ML. Anal. H. B. Wiik, 1958. (Rock analysis in Table 9).

Weight %		Atomic ratio $\times 10^4$		Physical data	
SiO ₂	37.48	Si	6 237	Sp.gr.	3.014
TiO ₂	2.27	Al	2 999	α	1.580
Al ₂ O ₃	15.29	Ti	284	β	1.626
Fe ₂ O ₃	0.00	Fe ²⁺	2 046	γ	1.626
FeO	14.70	Mn	30	2Va	14°
MnO	0.21	Mg	4 097		
MgO	16.52	Ca	18		
CaO	0.1	Na	313		
Na ₂ O	0.97	K	1 902		
K ₂ O	8.96	F	5		
CO ₂	0.00	OH	3 919		
H ₂ O+	3.53	O	22 877		
H ₂ O—	0.06				
F	0.01				
	100.10				

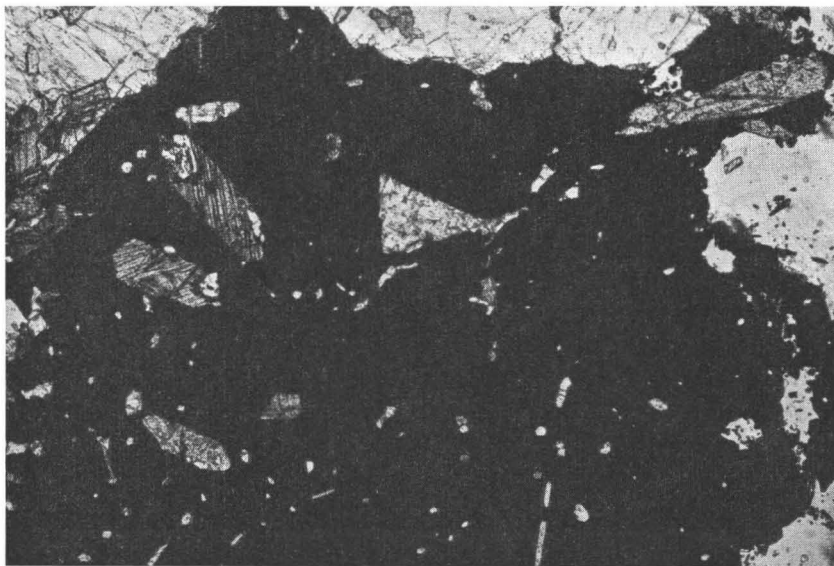


Fig. 22. Iivaarite containing idiomorphic pyroxene, nepheline and apatite needles as inclusions. Without analyzer. Magnification 20 \times . Photo E. Halme.

either accompanied by hornblende or in its absence. It contains small pyroxene grains as inclusions. Table 18 shows the chemical composition and physical properties of this biotite.

In respect to chemical composition, this biotite fits in Nockolds' (1947, Fig. 2, p. 416) diagram, made for alkali rocks, in which it falls into the pyroxene-paragenesis field. The chemical composition and physical properties of the Iivaara biotite are very much like those of the biotite described by Pulfrey (1951, Table XVIII, p. 452). The most marked difference is that the biotite of Iivaara contains only ferrous iron.

IIVAARITE

Titanium-bearing Ca-Fe-garnets have been designated as melanite and titanium-rich types schorlomite. Zedlitz (1933, p. 225) proposes a 15 % TiO_2 content as the boundary between the two. As early as the year 1852 Nils Nordenskiöld gave the titanium-rich Ca-Fe-garnets of Iivaara the name iivaarite, which is the term used in the following. Strunz (1957) has retained the terms iivaarite and schorlomite as varieties of melanite.

Iivaarite occurs in ijolite and melteigite usually as crystals of indefinite shape, which in some cases contain inclusions of idiomorphic pyroxene,

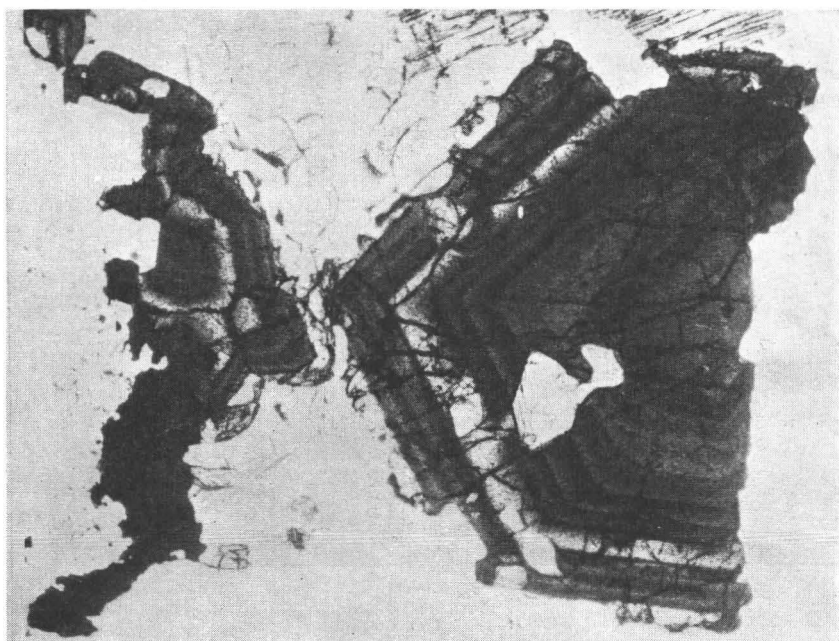


Fig. 23. Zoned iivaarite. Without analyzer. Magnification $30\times$. Photo E. Halme.

nepheline, apatite needles and sphene (Figs. 22 and 18). In a thin section of normal thickness it is quite opaque and dark brown only on edges ground down in a wedge-shaped form. No optical anomalies have been detected. Idiomorphic and beautifully zoned iivaarite (Fig. 23) occurs in a fissure-vein-like formation containing pyroxene consisting of long laminae (fig. 14).

It has been assumed that the variations in color occurring by zones in Ca-Fe-garnets are due to the titanium content. Zedlitz (1935) studied the zoned schorlomite of Magnet Cove with this in mind. Such a crystal was heated for about twenty minutes at a temperature of 1170° . Thereafter it was suddenly cooled and a thin section was prepared from it. The zoned structure had almost totally vanished. According to Zedlitz, also the unit cell dimension increases about 0.01 \AA , while the TiO_2 content grows 1 %. A measurement of the unit cell dimension from carefully separated different zones did not reveal any significant differences in them. It is conceivable that the color changes in the different zones of these garnets are due to the presence of titanium and iron at different stages of oxidation.

On the northern slope of Iivaara (Observation 9) there occurs coarse-grained melteigite in places. According to a planimetric determination (Table 8, No. 3), the rock contains 23.3 % iivaarite. From this melteigite I have

Table 19. Chemical composition and physical data for iivaarite from coarse-grained melteigite. Specimen 9/54 ML. 1. Anal. Mauno Lehijärvi, 1955.
2. Anal. H. B. Wiik, 1958.

1.				2.	
Weight %		Mol. prop.	Unit-cell content	Weight %	Mol. prop.
SiO ₂	27.67	4 605	Si 18.51	27.24	4 533
TiO ₂	14.20	1 777	Ti 7.14	16.82	2 105
Al ₂ O ₃	3.05	299	Al 2.40	1.50	147
Fe ₂ O ₃	19.28	1 207	Fe ³⁺ 9.70	17.69	1 108
FeO	3.62	501	Fe ²⁺ 2.01	3.64	507
MnO	0.22	31	Mn 0.12	0.21	30
MgO	tr.		Ca 22.28	0.90	224
CaO	31.08	5 542	Na 0.80	31.25	5 572
Na ₂ O	0.62	100	K 0.17	(0.62)	
K ₂ O	0.20	21	O 94.37	(0.20)	
H ₂ O—	0.00			0.00	
Loss on ign.	0.11			(0.11)	
	100.05			(100.18)	

Physical data

Sp.gr.	3.732
n	1.97
a ₀	12.138 ± 0.006 Å
Volume	1 788.3 Å ³

separated and analyzed the iivaarite, where no zoned structure was detectable, and determined its refractive index (by the prism method), specific gravity and unit cell dimension. The analysis and physical data are presented in Table 19, together with the analysis performed by Dr. H. B. Wiik on the same material.

The spectrum analysis made from the iivaarite at hand yielded the following result:

Mg, Si, W, Fe, Ge, Mo, Sn, V, Cu, Ag, Zn, Ti, Zr, Ni, Pd, Co, Re,
+ M — M + + + + — + M + — — + +

Ca, Al, Yb, Mn, Nb, Ta, Li, Ba
M + + + + + — — + —

M = main component, + + + = 5.0—0.5 %, + + = 0.5—0.1 %, + = 0.1 %, — = 0.00 %.

The following observations should be made regarding analysis No. 1 in Table 19 (Anal. Mauno Lehijärvi):

In order to determine the titanium content as accurately as possible, the TiO₂ determination was carried out in three different ways: 1) Gravimetri-

Table 20.

Spectrophotometric determination		Potentiometric titration	Gravimetric determination
TiO ₂	15.28 %	14.20 %	14.64 %
Fe ₂ O ₃	22.46 %	23.30 %	
	37.74 %	37.50 %	

cally, according to R. Přibil and P. Schneider (1951), by precipitating the titanium with ammonia from the titanium (IV) chloride solution in the presence of ethylene-diaminetetra-acetic acid, disodium salt (Komplexon III). 2) With Hilger's Spectrophotometer. 3) Potentiometric titrating with a chromosulphate solution. This determination was carried out by Mr. O. Jäntti from the same solution as was used in making the spectrophotometric determination. According to Jäntti, the error in the amounts of Fe₂O₃ and TiO₂ in potentiometric titration is ± 0.1 %. Values obtained by this method are used in the analysis table, for in the gravimetric determination iron and aluminium are likely to have become precipitated along with the rest, and because when amounts as large as the present are involved, determinations based on the colorimetric method are generally inaccurate. Table 20 presents the results obtained by means of the different methods.

The aluminium has also been determined by applying a direct method. After the separation of silica, the iron and titanium are precipitated by excess caustic potash, whereupon the aluminium remains in the filtrate as aluminate. The filtrate is then made acid with nitric acid and thereafter the aluminium precipitated with ammonia. The result obtained Al₂O₃ = 3.30 % corresponds well to the figure presented in the analysis table, Al₂O₃ = 3.05 %, determined in the usual way.

In the iivaarite of Iivaara the analysis by Thoreld (Ramsay-Berghell, 1891) shows 0.87 % SnO. I carried out, after the determination of silica, a precipitation with hydrogen sulphide, applying the normal method. A beautiful yellow sulphide precipitate resulted. Mr. Leo Lappi has taken a spectrum from this precipitate, which proved to be principally a titanium compound and not SnS.

The course of the analysis made from the same material by Dr. Wiik (Table 19, No. 2) was as follows:

1) Silica, total iron, lime and ammonia precipitate sum were determined by the normal analytic method. The magnesium precipitate was impure, so Mg was determined directly from the original material spectrographically.

2) The aluminium and the manganese, in addition, were determined directly from the original material (cobalt as the inner standard). The aluminium thus obtained and the total iron and the silicic acid contained in the ammonia precipitate were subtracted from the sum of the ammonia precipitates, whereupon titanium was indirectly obtained. Phosphorus was not present and, accordingly, did not have to be subtracted.

3) Ferrous iron was determined by the normal method directly from the original material.

The molecular number reveal that by combining, as usual, the tetra-valent, trivalent and divalent (+alkalies) components, a result corresponding to the stoichiometric formula for garnet is not obtainable. According to Zedlitz (1933), the combination might be carried out as follows:

Table 21.

Cations with 4-co-ordination		Cations with 6-co-ordination		Cations with 8-co-ordination	
SiO ₂	4 605	$\frac{1}{2}$ Fe ₂ O ₃	2 414	CaO	5 542
TiO ₂	1 287	$\frac{1}{2}$ Al ₂ O ₃	598	FeO	78
		FeO	423	MnO	31
		TiO ₂	490	$\frac{1}{2}$ Na ₂ O	200
				$\frac{1}{2}$ K ₂ O	42
	5 892		3 925		5 893
= 3 ×	1 964	= 2 ×	1 962	= 3 ×	1 964

Toward determining the unit-cell dimension, a powder pattern of iivaarite was taken with the results shown in Table 22.

Table 22. Powder diffraction data and unit-cell dimension for iivaarite. Specimen 9/54 ML. Filtered Cobolt Radiation with Silicon Standard.

θ	I	d	N	hkl	a
17.1	60	3.04	16	400	12.160
19.2	100	2.715	20	420	12.141
20.21	10	2.590	22	332	12.148
21.15	40	2.479	24	422	12.144
22.07	10	2.382	26	510, 431	12.145
27.015	10	1.970	38	611, 532	12.143
32.098	10	1.684	52	640	12.143
33.471	50	1.623	56	642	12.145
36.130	10	1.518	64	800	12.144
42.496	10	1.325	84	842	12.144
43.737	10	1.295	88	664	12.145
46.936	10	1.225	98	770	12.127

$$a_0 = 12.138 \pm 0.006 \text{ \AA}$$

According to Zedlitz (1935) and Mackowsky (1939), the unit-cell dimension increases rather in a direct proportion to the amount of TiO_2 . Kunitz (1936) reports the dependence of the refractive index of the titanium-bearing garnets on the TiO_2 content. The values obtained from iivaarite agree well with these observations.

SPHENE

Sphene occurs in the area of Iivaara generally as an accessory mineral. It is often found in abundant concentrations in pyroxene-rich, melteigitic spots. In color it is honey - yellow. Ordinarily it occurs as beautiful, idiomorphic crystals, but in some cases it is likely to be altogether ragged, enclosing nepheline and pyroxene grains. Table 23 presents the chemical composition and physical properties of sphene separated from melteigite.

Table 23. Chemical composition and physical data for sphene from melteigite. Specimen 33/54 ML. Anal. Aulis Heikkinen, 1956.

Weight %		Atomic ratio $\times 10^4$		Physical data	
SiO_2	29.95	Si	4 984	Sp.gr.	3.515
TiO_2	38.93	Ti	4 872	α	1.91
Al_2O_3	0.37	Al	73	$2V\gamma$	26°
Fe_2O_3	0.77	Fe^{3+}	96		
FeO	0.14	Fe^{2+}	19		
MnO	0.04	Mn	6		
MgO	0.14	Mg	35		
CaO	28.44	Ca	5 071		
Na_2O	0.31	Na	100		
K_2O	0.00	P	3		
P_2O_5	0.02	V	13		
CO_2	n. d.	F	53		
H_2O^+	0.32	OH	355		
$\text{H}_2\text{O}-$	0.00	O	24 981		
V_2O_5	0.12				
F	0.10				
	99.65				
$-0 = \text{F}_2$	0.04				
	99.61				

APATITE

The apatite content of Iivaara ijolite averages about 3 %. In some cases it occurs as accumulations measuring about 5 cm in length in spots rich in pyroxene and in nepheline. As to form, it occurs as long prisms or as irregularly shaped grains. The chemical composition and physical properties of this apatite are given in Table 24. A spectrographic test gave only traces of rare earths.

Table 24. Chemical composition and physical data for apatite from melteigite.
Specimen 7/54 ML. Anal. Pentti Ojanperä, 1957.

Weight %		Atomic ratio $\times 10^4$		Physical data	
SiO ₂	0.12	Si	20	Sp.gr.	3.161
TiO ₂	0.00	Al	55	ω	1.6453 ± 0.006
Al ₂ O ₃	0.28	Fe ³⁺	20	ε	1.6404 ± 0.002
Fe ₂ O ₃	0.16	Mn	3		
FeO	0.00	Mg	12		
MnO	0.02	Ca	9 946		
MgO	0.05	Na	48		
CaO	55.78	P	5 844		
Na ₂ O	0.15	V	6		
K ₂ O	0.00	F	684		
P ₂ O ₅	41.48	CO ₃	223		
CO ₂	0.98	OH	244		
H ₂ O+	0.22	O	23 853		
H ₂ O—	0.00				
V ₂ O ₅	0.05				
F	1.30				
Cl	0.00				
	100.59				
—O=F ₂	0.55				
	100.04				

SUMMARY

The occurrence of alkali rock measuring about four kilometers in length at Iivaara is situated in the northeastern part of the region covered by the map sheet of Suomussalmi (The General Geological Map of Finland, Sheet D 5, Suomussalmi). Alkali rocks comprise a unified mass extending across the arctic hills named Iivaara, Ahvenvaara and Penikkavaara. A characteristic feature of this complex of hills is its horseshoe-shaped structure. The surrounding country rock is veined, cataclastic hornblende-granodiorite and in part also quartz-diorite.

The alkali rocks of the central area are surrounded by a 200—300 meter-broad zone of metasomatically altered rocks. This zone is best exposed on the southwestern slope of Ahvenvaara, where the pale rock is criss-crossed by an abundance of dark dikes ranging from a millimeter to a few centimeters in breadth. In mineral composition these dikes are usually cancrinite-ijolite, in some cases normal ijolite. The surrounding country rock is thus conspicuously broken up, and the cracks have filled with an alkaline magma. The abundant presence of cancrinite proves that the magma had been hydrous and rich in carbon dioxide.

Part of the changes in the surrounding country rock took place »in situ» (ordinary fenite), part in a mobile state (transitional rocks). The first sign of fenitization was the appearance of aegirine in the granodiorite, where it gradually replaced the biotite in full. As the fenitization continued, the potash feldspar of the granodiorite changed into microperthite and the oligoclase into pure albite. Thereafter, the quartz suddenly disappeared, and the rock became a typical fenite. In such syenitic fenite there then gradually began to appear cancrinite and in some cases nepheline as well. The amount of feldspathoids is likely to be so large in some instances that the corresponding magmatic rock would be cancrinite- or nepheline-syenite.

In between the fenites proper and the alkali rocks there appear to be present heterogeneous types of transitional rocks (juvite, malignite, cancrinite-nepheline-wollastonite rock, etc.). In places such a type of transitional rock brecciates fenites proper, having evidently crystallized from the mixed magma consisting of alkaline magma and country rock partially melted by

it. For lack of suitable outcrops, it is not, however, always possible to decide for sure in what way these rocks are related to their environment.

The central area of Iivaara consists exclusively of nepheline-pyroxene rocks (urtite, ijolite, melteigite). The variations in mineral composition and texture ordinarily are apparent on a small scale, with the result that, when viewed over the whole of the area, the rock exhibits a non-homogeneous appearance. On the basis of field observations, ijolite seems to be the dominant type of rock. Melteigite would appear to be present in greater abundance in the marginal part of the mass along the northwestern slope of Iivaara. Urtite is best in evidence in the vicinity of the summit of Iivaara. The magmatic character of the alkali rocks is obvious. The occurrence of ijolitic dikes in the country rock proves the existence of an alkaline magma in this area. The abundant presence of cancrinite indicates that the magma had been quite rich in carbon dioxide. This magma was instrumental in bringing about the fenitization of the country rock as well as melting a portion of it and forming heterogeneous hybrid rocks (juvite, malignite, etc.).

Carbonatites have not been encountered in any of the exposures known at present in the Iivaara area. This does not, however, exclude the possibility that they might be associated with this formation. The present erosion level happens to be such that the carbonate content is not very much in evidence.

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*N:o 19.	Trüstedt, Otto. Die Erzlagerstätten von Pitkäranta am Ladoga-See. S. 1—333. 80 Fig. 19 Taf. 1 Karte. 1907	—
N:o 20.	Tanner, V. Zur geologischen Geschichte des Kilpisjärvi-Sees in Lappland. S. 1—23. 3 Fig. 2 Taf. 1 Karte. 1907	100: —

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*N:o 30.	Sederholm, J. J. Sur la géologie quaternaire et la géomorphologie de la Fennoscandia. P. 1—66. 13 fig. 6 cartes. 1911	—
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N:o 33.	Wilkman, W. W. Kvartära nivåförändringar i östra Finland. S. 1—40.9 fig. Deutsches Referat. 1912	150: —
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N:o 43.	Wilkman, W. W. Kaleviska bottenbildningar vid Mölönjärvi. S. 1—36. 11 fig. Résumé en français. 1915	100: --
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N:o 45.	Ailio, Julius. Die geographische Entwicklung des Ladogasees in postglazialer Zeit und ihre Beziehung zur steinzeitlichen Besiedelung. S. 1—158. 51 Abbild. 2 Karten. 1915	250: —
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N:o 51.	Laitakari, Aarne. Einige Albitepidotgesteine von Südfinnland. S. 1—13. 5 Abbild. 1918	100: —
N:o 52.	Brenner, T. H. Über Theralit und Ijolit von Umptek auf der Halbinsel Kola. S. 1—30. 4 Fig. 1920	100: —
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N:o 56.	Metzger, Adolf A. Th. Beiträge zur Paläontologie des nordbaltischen Silurs im Ålandsgebiet. S. 1—8. 3 Abbild. 1922	100: —
*N:o 57.	Väyrynen, Heikki. Petrologische Untersuchungen der granitodioritischen Gesteine Süd-Ostbothniens. S. 1—78. 20 Fig. 1 Karte. 1923	—
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N:o 59.	Berghell, Hugo und Hackman, Victor. Über den Quarzrit von Kallinkangas, seine Wellenfurchen und Trockenrisse. Nach hinterlassenen Aufzeichnungen von Hugo Berghell zusammengestellt und ergänzt von Victor Hackman. S. 1—19. 19 Fig. 1923	100: —
N:o 60.	Sauramo, Matti. Studies on the Quaternary Varve Sediments in Southern Finland. P. 1—164. 22 fig. in the text. 12 fig., 1 map and 2 diagrams on 10 plates. 1923	250: —
N:o 61.	Hackman, Victor. Der Pyroxen-Granodiorit von Kakskerta bei Åbo und seine Modifikation. S. 1—23. 2 Fig. 1 Karte. 1923	100: —
N:o 62.	Wilkman, W. W. Tohmajärvi-konglomeratet och dess förhållande till kaleviska skifferformationen. S. 1—43. 15 fig. 1 karta. Deutsches Referat. 1923	100: —
N:o 63.	Hackman, Victor. Über einen Quarzsyenitporphyr von Saariselkä im finnischen Lappland. S. 1—10. 2 Fig. 1923	100: —
N:o 64.	Metzger, Adolf A. Th. Die jätulischen Bildungen von Suojärvi in Ostfinnland. S. 1—86. 38 Abbild. 1 Taf. 1 Karte. 1924	150: —
N:o 65.	Saxén, Martti. Über die Petrologie des Otravaara-gebietes im östlichen Finnland. S. 1—63. 13 Abbild. 5 Fig. auf 1 Taf. 2 Karten. 1923	150: —
N:o 66.	Ramsay, Wilhelm. On Relations between Crustal Movements and Variations of Sea-Level during the Late Quaternary Time, especially in Fennoscandia. P. 1—39. 10 fig. 1924	100: —

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N:o 67.	Sauramo, Matti. Tracing of Glacial Boulders and its Application in Prospectin. P. 1—37. 12 fig. 1924	100: —
N:o 68.	Tanner, V. Jordskredet i Jaarila. S. 1—18. 2 fig. 10 bild. Résumé en français. 1924	100: —
N:o 69.	Auer, Väinö. Die postglaziale Geschichte des Vanajavesisees. S. 1—132. 10 Fig. 10 Taf. 11 Beil. 1924	250: —
N:o 70.	Sederholm, J. J. The Average Composition of the Earth's Crust in Finland. P. 1—20. 1925	100: —
N:o 71.	Wilkman, W. W. Om diabasgångar i mellersta Finland. S. 1—35. 8 fig. 1 karta. Deutsches Referat. 1924	100: —
N:o 72.	Hackman, Victor. Das Gebiet der Alkaligesteine von Kuolajärvi in Nordfinland. S. 1—62. 6 Fig. 1 Taf. 1925	150: —
N:o 73.	Laitakari, Aarne. Über das jotnische Gebiet von Satakunta. S. 1—43. 14 Abbild. 1 Karte. 1925	150: —
N:o 74.	Metzger, Adolf A. Th. Die Kalksteinlagerstätten von Ruskeala in Ostfinland. S. 1—24. 9 Abbild. 2 Karten. 1925	100: —
N:o 75.	Frosterus, Benj. Ueber die kambrischen Sedimente der karelischen Landenge. S. 1—52. 1 Fig. 1925	150: —
N:o 76.	Hausen, H. Über die präquartäre Geologie des Petsamo-Gebietes am Eismeere. S. 1—100. 13 Fig. 2 Taf. 1926	150: —
N:o 77.	Sederholm, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part II. The Region around the Barö-sundsfjärd W. of Helsingfors and Neighbouring Areas. P. 1—143. 57 fig. in the text and 44 fig. on 9 plates. 1 map. 1926	300: —
N:o 78.	Väyrynen, Heikki. Geologische und petrographische Untersuchungen im Kainuugebiete. S. 1—127. 37 Fig. 2 Taf. 2 Karten. 1928	200: —
N:o 79.	Hackman, Victor. Studien über den Gesteinsaufbau der Kittilä-Lappmark. S. 1—105. 23 Fig. 2 Taf. 2 Karten. 1927	200: —
N:o 80.	Sauramo, Matti. Über die spätglazialen Niveauverschiebungen in Nordkarelien, Finnland. S. 1—41. 8 Fig. im Text. 11 Fig., 1 Karte und 1 Profildiagr. auf 7 Taf. 1928	100: —
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N:o 82.	Lokka, Lauri. Über Wiikit. S. 1—68. 12 Abbild. 1928	150: —
N:o 83.	Sederholm, J. J. On Orbicular Granite, Spotted and Nodular Granites etc. and on the Rapakivi Texture. P. 1—105. 19 fig. in the text and 50 fig. on 16 plates. 1928	250: —
N:o 84.	Sauramo, Matti. Über das Verhältnis der Ose zum höchsten Strand. S. 1—17. 1928	50: —
N:o 85.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, I. P. 1—88. 1 stéréogramme. 1929	200: —
N:o 86.	Sauramo, Matti. The Quaternary Geology of Finland. P. 1—110. 39 fig. in the text and 42 fig. on 25 plates. 1 map. 1929	300: —
N:o 87.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, II. P. 1—175. 48 fig. 8 planches. 1929	350: —
N:o 88.	Tanner, V. Studier över kvartärsystemet i Fennoskandias nordliga delar. IV. Om nivåförändringarna och grunddragen av den geografiska utvecklingen efter istiden i Ishavsfinland samt om homotaxin av Fennoskandias kvartära marina avlagringar. S. 1—589. 84. fig. 4 tavl. 1 karta. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fennoscandie. IV. Sur les changements de niveau et les traits fondamentaux du développement géographique de la Finlande aux confins de l'Océan Arctique après l'époque glaciaire et sur l'homotaxie du quaternaire marin en Fennoscandie. 1930	750: —
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N:o 91.	Sederholm, J. J. Pre-Quaternary Rocks of Finland. Explanatory Notes to accompany a General Geological Map of Finland. P. 1—47. 40 fig. 1 map. 1930	150: —
N:o 92.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, III. P. 1—140. 29 fig. 3 planches. 1930	250: —
N:o 93.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, IV. P. 1—68. 12 fig. 6 planches. 1931	200: —
N:o 94.	Brenner, Thord. Mineraljordarternas fysikaliska egenskaper. S. 1—159. 22 fig. Deutsches Referat. 1931	350: —
N:o 95.	Sederholm, J. J. On the Sub-Bothnian Unconformity and on Archæan Rocks formed by Secular Weathering. P. 1—81. 62 fig. 1 map. 1931	250: —
N:o 96.	Mikkola, Erkki. On the Physiography and Late-Glacial Deposits in Northern Lapland. P. 1—88. 25 fig. 5 plates. 1932	250: —
N:o 97.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, V. P. 1—77. 15 fig. 1932	200: —
N:o 98.	Sederholm, J. J. On the Geology of Fennoscandia. P. 1—30. 1 map. 1 table. 1932	150: —
N:o 99.	Tanner, V. The Problems of the Eskers. The Esker-like Gravel Ridge of Čahpatoaiv, Lapland. P. 1—13. 2 plates. 1 map. 1932	100: —
N:o 100.	Sederholm, J. J. Über die Bodenkonfiguration des Päijänne-Sees. S. 1—23. 3 Fig. 1 karte. 1932	250: —
N:o 101.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, VI. P. 1—118. 17 fig. 5 planches. 1933	250: —
N:o 102.	Wegmann, S. E., Kranck, E. H. et Sederholm, J. J. Compte rendu de la Réunion internationale pour l'étude du Précambrien et des vieilles chaînes de montagnes. P. 1—46. 1933	150: —
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N:o 104.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, VIII. P. 1—156. 33 fig. 7 planches. 1934	250: —
N:o 105.	Lokka, Lauri. Neuere chemische Analysen von finnischen Gesteinen. S. 1—64. 1934	150: —
N:o 106.	Hackman, Victor. Das Rapakiwiranagebiet der Gegend von Lappeenranta (Willmanstrand). S. 1—82. 15 Fig. 2 Taf. 1 Analysentab. 1 Karte. 1934	200: —
N:o 107.	Sederholm, J. J. † On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part III. The Åland Islands. P. 1—68. 43 fig. 2 maps. 1934	200: —
N:o 108.	Laitakari, Aarne. Geologische Bibliographie Finnlands 1555—1933. S. 1—224. 1934	250: —
N:o 109.	Väyrynen, Heikki. Über die Mineralparagenesis der Kieserze in den Gebieten von Outokumpu und Polvijärvi. S. 1—24. 7 Fig. 1 Karte. 1935	100: —
N:o 110.	Saksela, Martti. Über den geologischen Bau Süd-Ostbothniens. S. 1—35. 11 Fig. 1 Titelbild. 1 Taf. 1 Karte. 1935	150: —
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