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ALBITE DIABASES AND ALBITITES
IN ENONTEKIÖ AND KITTILÄ, FINLAND

BY

KAUKO MERILÄINEN

WITH 19 FIGURES AND 24 TABLES

ACADEMICAL DISSERTATION

HELSINKI 1961

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PREFACE

The field observations of the Enontekiö portion of this study were performed during the general geological mapping program of the Geological Survey in the summers of 1951—1954, under the direction of licentiate Arvo Matisto. He also placed the rock material concerning the Enontekiö area at my disposal.

At the recommendation of my esteemed teacher, Professor Martti Saksela, I collected additional material from previously investigated albite diabases and albitites of Kittilä in the autumn of 1955. The complementary work was accomplished in the laboratories of the Geological Survey with the assistance of many persons. A portion of this investigation has been presented in my pro-gradu (1954) and licentiate examination (1960).

Professor Martti Saksela has encouraged me with kind counsel and has shown continued interest in all phases of my work. Docent Dr. Ahti Simonen has similarly sustained me with much advice and has criticized the manuscript.

Mrs. I. Huhta and Messrs. P. Ojanperä, A. Heikkinen and A. Löfgren performed the chemical analyses and Mr. A. Vorma the powder X-ray determinations.

Messrs. P. Ilola and R. Aromaa prepared the thin sections, Miss Thyra Åberg drew the graphical figures, and Mr. E. Halme took most of the photographs.

Dr. Vladi Marmo, Director of the Geological Survey of Finland, kindly accepted my paper for publication in the series Bulletin de la Commission géologique de Finlande.

Mrs. Toini Mikkola translated the greatest part of the present paper into English and Mr. Richard Ojakangas revised the manuscript.

Outokumpu Osakeyhtiön Säätiö (The Foundation of the Outokumpu Company) assisted me economically.

To all persons that have assisted me in my work and to Outokumpu Osakeyhtiön Säätiö, I wish to express my deepest appreciation.

Geological Survey of Finland, Otaniemi, December 1960.

Kauko Meriläinen

ABSTRACT

Albite diabases commonly occur as sills which are simple or composed of two or more varieties in regular order. The characteristic texture of these varieties is ophitic, subophitic or hypidiomorphic. According to mineralogical and chemical compositions, macro-structures and textures, and comparative studies, the albite diabases are differentiated from parent olivine-basaltic magma. Differentiation was aided by the flow of the magma and in the latest stage by the presence of volatiles, especially CO_2 and H_2O. The albite of these rocks is either primary or produced by the epidotization of plagioclase.

Albitites are rocks very rich in albite that crystallize from magmatic liquids or solutions after the crystallization of albite diabases.

Various mineral veins are associated with the albite diabases and albitites.

CONTENTS

INTRODUCTION

Albite diabases and albitites, the latter younger than the former, belong to the spilite-keratophyre association (Dewey and Flett 1911, Turner and Verhoogen 1960). They have intruded, in the early stages of orogeny, into formations comprised mainly of quartzites, graywackes, basic extrusives, black schists and sedimentary carbonate rocks. Albite diabases appear as sills and lenses while albitites often intersect schists and even albite diabases.

Most investigators have described albite diabases with some collective name (albite diabase, metadiabase, intrusive greenstone, leucodiabase); others have divided them into varieties on the basis of external characteristics or mineral assemblages. In many places, transitions from one variety to another occur (Benson 1915, Eskola 1925, Hackman and Wilkman 1926, Väyrynen 1928, 1938 a, Timofejeff 1935, Ödman 1939, 1957, E. Mikkola 1941, A. Mikkola 1949) and even transitions to albitites have been noted (Brauns 1909, Benson 1915, Hackman and Wilkman 1926, E. Mikkola 1941, A. Mikkola 1949, Gjelsvik 1958). Numerous varieties differ from each other only in the comparative amounts of mafic (amphibole and clinopyroxene) and salic (albite) minerals. Many sills show a marked differentiation (Benson 1915, Väyrynen 1928, Bartrum 1936, Ödman 1939, A. Mikkola 1949). Chemically the albite diabases correspond to basic extrusives, the composition of which varies from normal basaltic to sodium-syenitic (Hackman 1927). Mineralogically the albite diabases are composed mainly of sodium-rich plagioclase (albite or oligoclase), augite, hornblende, biotite or chlorite, and often epidote.

Albitites occur as several varieties. Most often they are albite-rich and carbonate-bearing. Some contain quartz (quartz keratophyres) or magnetite (magnetite keratophyres) and others are composed almost entirely of albite. Mafic silicate minerals seldom occur. Chemically the albitites correspond to sodium-rich keratophyre extrusives (Brauns 1909, Dewey and Flett 1911, Benson 1915, Sundius 1915, 1916, 1930, Geijer 1916, 1931, Eskola 1925, Hackman and Wilkman 1926, Hackman 1927, Väyrynen 1928, 1954, Gilluly 1935, Bartrum 1936, Ödman 1939, 1957, E. Mikkola 1941, Eriksson 1954, Holmsen, Padget and Pehkonen 1957, Gjelsvik 1958, Padget 1959).

Mineral veins are associated with the albite diabases and albitites. Most common are quartz-carbonate veins which also contain albite. Many veins include sulphides and oxides, the commonest being iron and copper sulphides and iron oxides. Gold has been met with in some veins. Pitchblende occurs in a vein in Finnmark, Norway. Some other characteristic minerals are titanite, tourmaline, axinite, stilpnomelane, barite, apatite, scapolite, zeolites, chlorite, asbestos, tremolite, epidote, hornblende and hematite (op. cit. and Park, jr. 1946, Saksela 1960).

The peculiar mineral association of albite diabases and albitites, and especially the occurrence of albite as the characteristic component, has given rise to many discussions about their origin. The question under discussion has commonly been whether the albite is primary (crystallized directly from magma) or secondary, produced by albitization of a more basic plagioclase.

The albitization process has been presented in many ways. Those described by many British geologists have played a leading role in later research work. The essential point in their ideas is that the albitization of plagioclase is caused by sodium-rich residual solutions, immediately after the rock has solidified (Bailey and Grabham 1909, Dewey and Flett 1911). Many geologists emphasized the part of volatiles in albitization (Bailey and Grabham 1909, Geijer 1916, Sargent 1917), as well as the autometasomatic character of the process (Bailey and Grabham 1909, Wells 1922, 1923). The explanation advanced by Sundius (1915, 1916) according to which albitization occurred as a regional phenomenon, has not been generally accepted. Later he found (1930) that the differences in the chemical compositions of spilitic rocks and those of normative feldspars must be at least partly primary differences. Eskola (1925) showed that the albite of albite diabases has originated either by the epidotization of plagioclase or by autometasomatic replacement of anorthitic portions by albite. The albitization of anorthite (spilite reaction) has also been performed experimentally (Eskola, Vuoristo and Rankama 1937).

The primary, magmatic character of the albite of albite diabases was raised as an adjudgement against the spilitization theories (Brauns 1909, Benson 1915, Hackman and Wilkman 1926). Later Bartrum (1936) and Ödman (1939) described differentiated albite diabases and alleged that their albite is primary. The albite of the basic border zone of the sills described by Ödman is, however, mainly due to the epidotization of plagioclase. Marmo (1949) also shoved that the albite in dolorites of Olonets is primary magmatic in origin.

The albitites have crystallized from sodium-rich aqueous magmas or residual solutions (Bailey and Grabham 1909, Dewey and Flett 1911, Benson

1915, Geijer 1916, 1931, Eskola 1925, Hackman and Wilkman 1926, Väyrynen 1928, E. Mikkola 1941). The characteristic carbonate content has been explained as primary, but it is also suggested that the magma had assimilated this from carbonate sediments (Hackman and Wilkman 1926). Genetically the albitites are associated with albite diabases and mineral veins.

The basic magma from which various extrusives and intrusives as well as albite diabases and albitites of spilite provinces were differentiated is, according to some investigators, spilitic or at least richer in sodium and poorer in calcium than the parent normal basaltic magma. The average composition of this magma has also been presented as analyses (Sundius 1930, Väyrynen 1938 a, E. Mikkola 1941, A. Mikkola 1949). Normal basaltic magma is often considered to be the parent magma of albite diabases (Sargent 1917, Gilluly 1935, Rösler 1960). According to E. Mikkola (1941), the parent magma can also be gabbroic. It has also been stated that the high sodium content of diabase magma results from the assimilation of geosynclinal sediments (Gilluly 1935) or that the magma is palingenic in origin (Gjelsvik 1958).

The albite diabases and albitites of this paper are from the regions of Enontekiö and Kittilä in northern Finland (Fig. 1).

Enontekiö is the northwesternmost parish in the mountain chain of Finnish Lapland. Albite diabases and albitites mainly occur on the Lätäseno River and its surroundings in the central part of the parish. This area is part of the continuous zone which includes Rautusakara-Soppero (Ödman 1939, 1957) and Kiruna in Sweden (Geijer 1931, Ödman 1957) and is mainly characterized by quartzites and basic extrusives. The bedrock of Enontekiö, largely covered by quaternary deposits, is comprised of quartzites, normal basaltic and spilitic extrusives, and mica gneisses, as well as gabbros and granites. Serpentinites, black schists and sedimentary carbonate rocks are less abundant (Stjernvall 1891, 1892, Meriläinen 1954, 1960, Matisto 1959). Albite diabases and albitites form only a minor part of the whole area. The rock association is typical of spilite provinces.

Kittilä also belongs to a zone characterized by quartzites and basic extrusives. It extends from the Arctic Ocean through Sodankylä (E. Mikkola 1941), Kittilä (Hackman 1927, E. Mikkola 1941), Kuusamo (Hackman and Wilkman 1926), Kainuu (Väyrynen 1928, 1933, Wilkman 1931) and Finnish Karelia (Frosterus and Wilkman 1920, Wilkman 1921, 1931, Hackman 1933) to Lake Ladoga. This zone forks in Kuusamo and joins the extensive spilite province of Olonets (Eskola 1925, Väyrynen 1938 b, Timofejeff 1935, Marmo 1949) in Karelia of the USSR.

The first purpose of this study is to show the field relations, structures, textures and compositions of the albite diabases and albitites of Enontekiö
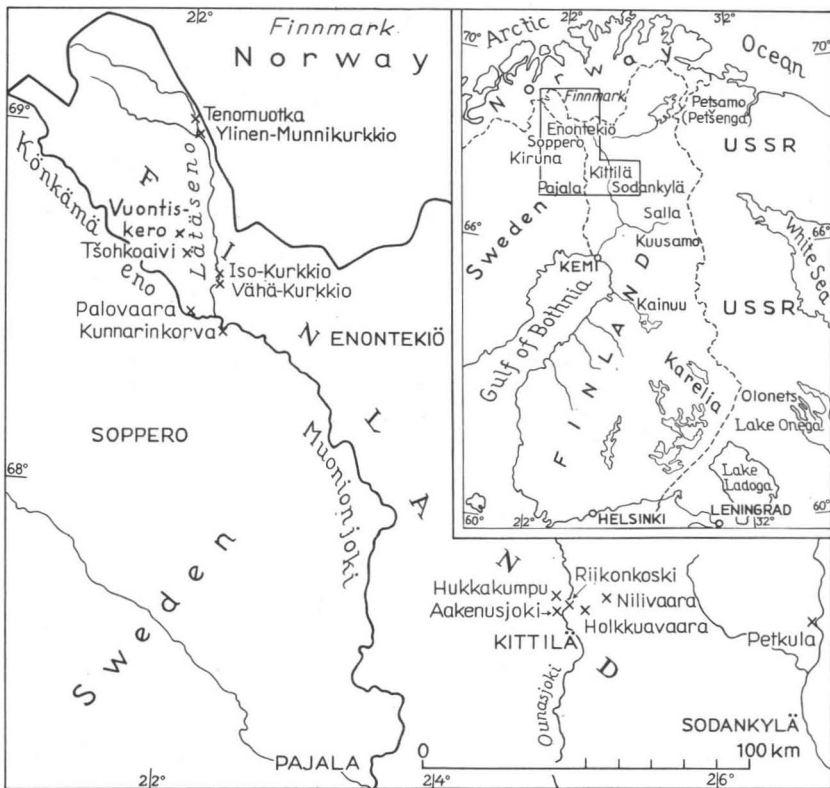
Fig. 1. Map of Northwestern Finland showing the localities of the albite rocks and
albitites in Enontekiö and Kittilä.

and Kittilä. The petrographical description is represented in chapters:
1) albite diabases, 2) albitites, and 3) mineral veins. Attention has been
given to the latter only to the extent that their genetic relations to albite
diabases and albitites have become clear. Some minerals presented in the
separate chapter complete the petrographical description. The primary
purpose of the present study is, however, to determine the general features
and the mode of origin of albite diabases and albitites by comparing the
investigated rocks of Enontekiö and Kittilä with those of other spilite
districts, mainly on the basis of chemical and mineralogical analyses,
structures, and textures as well as field observations.

The double-term »albite diabase» employed in this study is based partly
on the fact that the characteristic mineral of these rocks is albite or albitic
oligoclase. The latter part of this term is primarily historic, for the only
clear features of albite diabases which resemble those of diabases in the

sense shown by British scientists, is their sheet-like mode of occurrence and their usually basic composition. The texture, again, varies considerably and often is not typical of diabases. Albitites are dike-like, more rarely sill-like bodies, rich in albite and poor in mafic silicate minerals, and often rich in quartz and/or carbonate, or magnetite. Associated mineral veins are composed of various minerals. The term mineral vein is not quite correct but is generally used in connection with albite diabases and albitites.

The terms spilite and spilitic indicate only the chemical composition.

ALBITE DIABASES

Five varieties of albite diabases are found in Enontekiö and Kittilä:

1. Amphibole-pyroxene-albite diabases
2. Amphibole-epidote-albite diabases
3. Amphibole-albite diabases
4. Biotite-albite diabases
5. Chlorite-albite diabases

They may occur as simple sills, but most commonly the same sill comprises two or even three different, often regularly arranged, varieties (zones). The varieties differ from each other in their mineral compositions, their grain size, the amount of albite, and colour. The varieties are called amphibole-epidote-albite rock, amphibole-albite rock, biotite-albite rock and so on.

The different zones in the differentiated albite diabases are called: core, inner marginal zone (variety) and outer marginal zone (variety). The outer marginal zone is commonly only a few decimeters thick and even in larger sills its greatest thickness is only a few meters. The inner marginal zone lies between the core and outer marginal zone. It generally forms the main portion of the differentiated albite diabases.

The majority of albite diabases are concordant sills as shown above, but some narrow biotite-albite diabases are discordant. The quartzites and basic extrusives into which the sills were intruded were probably dipping at approximately their present angle of 60°—80° at the time of intrusion and differentiation.

Each albite diabase is described in that section in which belongs the variety characteristic of the main portion of the sill. For example, amphibole-pyroxene-albite rock is the main variety of albite diabases described in the section »amphibole-pyroxene-albite diabases».

AMPHIBOLE-PYROXENE-ALBITE DIABASES

The amphibole-pyroxene-albite diabases occur at Vähä-Kurkkio and Kunnarinkorva of Enontekiö. Both were investigated earlier and called syenite by Stjernvall (1891, 1892). A pyroxene-bearing variety, comparable

to the above-mentioned, is also found as the coarse-grained core of the amphibole-epidote-albite diabase of Tenomuotka (p. 27).

VÄHÄ-KURKKIO

The amphibole-pyroxene-albite diabase of Vähä-Kurkkio is a 50—60 m thick sill situated between quartzite and basic extrusives. All varieties are an amphibole-pyroxene-albite rock, some of them containing abundant scapolite and/or magnetite and titanite.

On the eastern border of the sill towards the quartzite, there is a few meters thickness of fine-grained greyish-green albite-rich rock. This changes towards the core into a darker zone, again a few meters thick, mainly characterized by basic inclusions. The following 30—40 meter thick zone forms the main part of the sill. This changes gradually into the greyish-brown, coarse-grained albite-rich core. The latter is separated by a two meter broad moraine strip from the western outer marginal zone, which is dark green, fine-grained, and contains basic inclusions (Table 1).

With the exception of the coarsest core, the other varieties of the sill show flow structure. The flow structure is very marked in a narrow zone between the main part and the core of the sill, in a variety which otherwise resembles the core. It appears as the parallel arrangement of amphibole and pyroxene and sometimes of albite grains.

The fine-grained ($\emptyset = 0.5$ mm) outer marginal variety adjacent to the quartzite is granular. Its main minerals are albite, clinopyroxene and amphibole. A small amount of biotite is found and accessories are titanite

Table 1. Amphibole-pyroxene-albite diabase. Vähä-Kurkkio, Enontekiö.

	1		2		3		4		5	
Plagioclase	An_{24}	33.3	An_4	38.7	An_{12}	35.4	An_4	46.0	An_4	68.0
Scapolite		—		—		20.3		9.5		—
Pyroxene		10.8		24.8		7.7		9.1		1.4
Amphibole		50.0		34.7		28.7		19.5		23.1
Epidote		2.9		—		—		—		—
Biotite		—		—		—		1.3		—
Titanite		2.5		1.6		2.8		3.6		3.7
Apatite		0.5		0.2		0.1		0.5		0.5
Carbonate		—		—		—		1.0		1.2
Opaques		—		—		5.0		9.5		2.1
		100.0		100.0		100.0		100.0		100.0

1. Early magmatic inclusion in the inner marginal zone of the sill.
2. Dark green variety in the inner marginal zone of the sill (Table 2).
3. The main part of the sill.
4. The variety with flow structure, nearest the coarse-grained core of the sill.
5. The coarse-grained core of the sill (Table 3).

Table 2. Dark green variety, an amphibole-pyroxene-albite rock, in the inner marginal zone of the sill. Vähä-Kurkkio, Enontekiö, Finland (Analysis is calculated according to the analyses in Tables 1, 14 and 15).

Weight %		Atomic ratio × 1 000	Cation %	One-cation molecular norms		Niggli numbers	
SiO₂	56.24	937	51.54	Or	2.75	si	139.20
Al₂O₃	9.88	194	10.67	Ab	50.05	al	14.40
TiO₂	1.00	13	0.71	An	0.28	fm	46.00
Fe₂O₃	3.83	48	2.64	Wo	18.50	c	25.40
FeO	4.59	64	3.52	En	15.08	alk	14.20
MnO	0.04	1	0.05	Fs	2.16	mg	0.64
MgO	7.89	197	10.84	Fo	4.95	k	0.05
CaO	9.60	171	9.41	Fa	0.69	ti	1.93
Na₂O	5.63	182	10.01	Mt	3.96	p	0.10
K₂O	0.47	10	0.55	Il	1.42		
P₂O₅	0.10	1	0.06	Ap	0.16		
F	0.01	—	0.03				
H₂O+	0.68	(38)	(2.20)				
H₂O—	0.04	—	—				
	100.00		100.03				

Note: The mineral composition is listed in Table 1.

and apatite. This rock is penetrated by numerous thin ($\varnothing = 2$—10 mm) albite-hornblende and albite-epidote veins. Their core is usually hornblende or epidote, and their rims, which merge gradually into the adjacent rock, are albite. A few narrow hematite veins have also been observed. In places the rock contains many rounded or oval amygdules, their cores containing biotite or oligoclase clouded by sericite and their rims composed of albite.

The zone characterized by basic inclusions changes in places into an amygdaloidal rock and in places into a hornblende- and clinopyroxene-rich hypidiomorphic-granular rock (Table 2 and Table 21, anal. 5). The latter is the most dominant. It is still fine-grained and contains basic lens-shaped inclusions ($\varnothing = 10$—60×5—20 cm). They are more basic than the mother rock and their rims are darker and richer in hornblende and biotite than the centers (Fig. 2). The longitudinal direction of the inclusions is parallel to that of the sill. Their main minerals are hornblende, plagioclase and clinopyroxene which occur as xenomorphic grains but are often also hypidiomorphic (Williams, Turner and Gilbert 1954). The texture is hypidiomorphic-granular. Titanite, biotite and magnetite are present as minor constituents and the accessory is apatite (Table 1, anal. 1).

The plagioclase (An_{24}, $\gamma = 1.547$) is slightly zoned and clouded by saussurite. In the rims of the inclusions, the plagioclase contains strongly pleochroic pistacite grains. The plagioclase around those grains has been altered to albite (An_8).
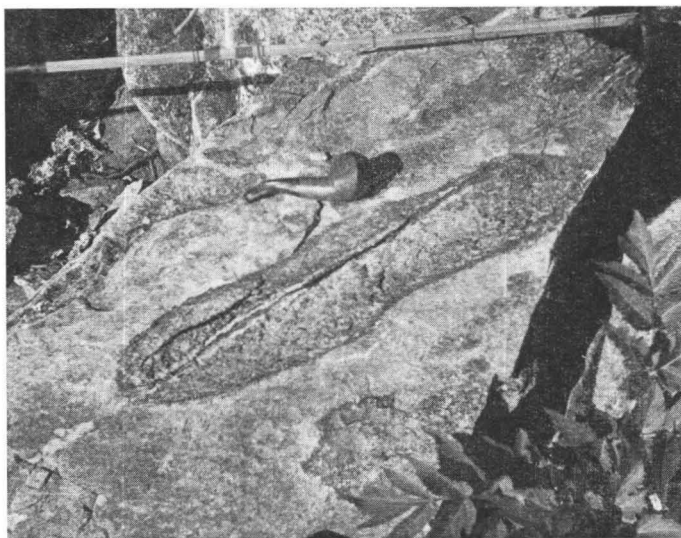
Fig. 2. Basic, early magmatic inclusion. It is penetrated by a thin
epidote-albite vein with an epidote core and albite rims. Vähä-
Kurkkio, Enontekiö. Photo A. Matisto.

The clinopyroxene ($c\varLambda\gamma = 38°—42°$, $\gamma = 1.715$, $\alpha = 1.684$) is dark green
and pleochroic: $\gamma =$ dark green, $\beta =$ pale green, $\alpha =$ yellow green.

The hornblende ($c\varLambda\gamma = 27°—30°$, $\gamma = 1.696$, $\alpha = 1.675$) is dark blue
green and pleochroic: $\gamma =$ dark blue green, $\beta =$ dark green, $\alpha =$ yellow
brown.

Titanite occurs as single grains and clusters. Magnetite and biotite
occur chiefly in the rims of the inclusions.

The inclusions are, according to their mode of occurrence and mineral
composition, early magmatic differentiates.

The main part of the sill is somewhat coarser than the outer marginal
zone ($\emptyset = 0.5—1.0$ mm) and is a hypidiomorphic-granular rock. The main
components are plagioclase, hornblende, scapolite and clinopyroxene. Small
amounts of titanite and magnetite are present and apatite is the accessory
(Table 1, anal. 3). The plagioclase grains (An_{12}) are sometimes hypidio-
morphic, but hornblende and clinopyroxene grains are always irregularly
corroded. The scapolite is marialite-rich (Winchell 1951). Zeolite, when
present, always occurs in connection with scapolite. Titanite is present
around magnetite and forms thin lamellae in it. The main part of the sill
contains sparse, small ($\emptyset = 5—30$ mm), oval epidote-albite aggregates.
Their albite, which occurs either at the rims of the aggregates or mixed
with the epidote, is pale pink and is thus easily discerned from the
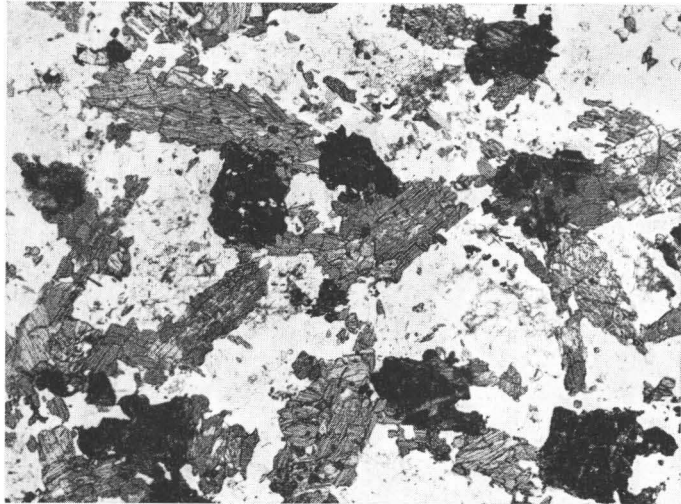
Fig. 3. Hypidiomorphic, corroded hornblende-clinopyroxene grains
of the coarse-grained core of an amphibole-pyroxene-albite diabase.
Vähä-Kurkkio, Enontekiö. Without analyzer. Magn. 10 ×.
Photo E. Halme.

nearly white plagioclase of the mother rock. The epidote individuals are
idiomorphic, much longer (Ø = 1—3 mm) than their breadth. The aggre-
gates, according to their mode of occurrence and structure, are cavity
fillings.

The coarse-grained core of the sill (Ø = 5—10 mm) is a homogeneous,
brownish-grey, unorientated and hypidiomorphic (Fig. 3) rock (Table 3,
and Table 21, anal. 4). It is cut by many thin (2—10 mm) hornblende
veins. The walls of the fissures are often composed of epidote. Albite and
hornblende are the main minerals. Clinopyroxene, titanite and calcite are
found in small amounts and the accessories are biotite, apatite and opaques.

The albite (An_4, $\gamma = 1.540$, $\alpha = 1.529$) is finely-twinned according to
the albite law and is quite clear. Thick, short-prismatic grains are separated
from each other by an albite mortar.

The size of the hornblende grains is comparable to that of albite. They
are elongated and hypidiomorphic and nearly always corroded ($c\Lambda\gamma$ =
20°—24°, $2V\alpha$ = 60°, 62°, 64°, 64°, $\gamma = 1.676$, $\alpha = 1.653$). Pleochroism is
strong: γ = dark bluish green, β = brownish green, α = brownish yellow.
This hornblende was analysed and is presented in Table 14.

The clinopyroxene ($c\Lambda\gamma$ = 48°—53°, $2V\gamma$ = 68°, 70°, 69°, 66°, $\gamma = 1.722$,
$\alpha = 1.694$) occurs in the center of all large hornblende grains as patches
parallel to the c-axis of the hornblende (homoaxially orientated). The

Table 3. The coarse-grained amphibole-pyroxene-albite core of the sill.
Vähä-Kurkkio, Enontekiö, Finland. Anal. A. Heikkinen 1953.

Weight %		Atomic ratio × 1 000	Cation %	One-cation molecular norms		Niggli numbers	
SiO_2	58.92	982	53.57	Or	8.45	si	175.40
Al_2O_3	13.48	264	14.40	Ab	62.75	al	23.60
TiO_2	2.22	28	1.53	An	0.40	fm	34.10
Fe_2O_3	3.01	38	2.07	Wo	11.46	c	19.10
FeO	3.32	46	2.51	En	7.96	alk	23.20
MnO	0.03	—	0.02	Fs	—	mg	0.56
MgO	4.29	107	5.84	Fo	2.82	k	0.12
CaO	5.99	107	5.84	Fa	—	ti	5.00
Na_2O	7.14	230	12.55	Mt	2.94	p	0.04
K_2O	1.44	31	1.69	Hm	0.11		
P_2O_5	0.03	—	0.02	Il	3.06		
CO_2	—	—	—	Ap	0.05		
H_2O+	0.07	(4)	(0.22)				
H_2O-	0.38	—	—				
	100.32		100.04				

Notes: The mineral composition is presented in Table 1. The amphibole and clino-
pyroxene were analysed and are shown in Tables 14 and 15.

colour is pale green and pleochroism is clear but weak: γ = light green,
$\beta = \alpha$ = greenish gray. The chemical analysis of this clinopyroxene is
listed in Table 15.

The titanite grains are large, often twinned and contain inclusions of
small, roundish magnetite grains.

The westerly few meter thick outer marginal zone, is a fine-grained
(Ø = less than 0.5 mm) granular rock. It contains abundant lens-shaped
(Ø = 2—10 cm), hornblende-rich, early magmatic differentiates.

KUNNARINKORVA

The Kunnarinkorva albite diabase is exposed in a few separate places.
The main rock variety is a greyish-brown, medium-grained (Ø = 2—4 mm)
pyroxene-amphibole-albite rock. Some dark brown, lens-shaped (Ø = 5—20
cm), early magmatic differentiates are present and hornblende veins cut
the rock. The texture is hypidiomorphic-granular and albite and clino-
pyroxene are the main minerals. Hornblende and scapolite occur as minor
constituents. Accessories are titanite, opaques, apatite, biotite and zeolite.

The albite grains (An_5) are clear and finely-twinned according to the
albite law. The individuals are short, stumpy laths. They are often granu-
lated by movements and corroded by scapolite and zeolite. The edges of
grains are therefore irregular.
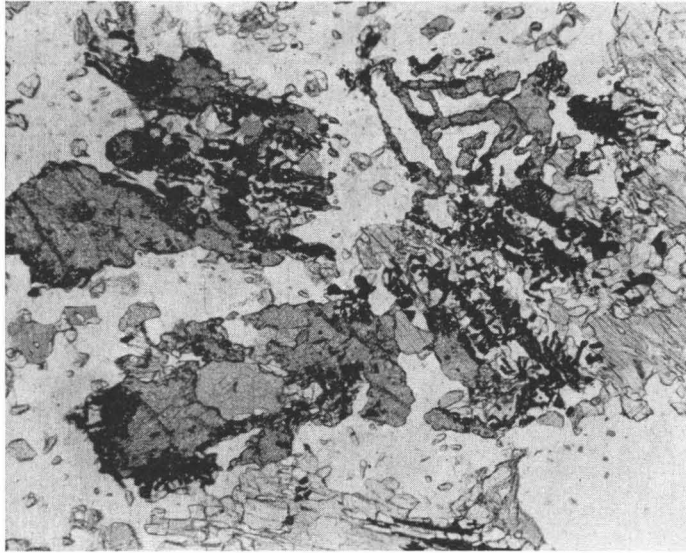
Fig. 4. Corroded clinopyroxene grains with scapolite, zeolite and
magnetite »passages». Magnetite grains form a graphic texture
with clinopyroxene. Kunnarinkorva, Enontekiö. Without analyzer.
Magn. 40 ×. Photo E. Halme.

The clinopyroxene is slightly greenish ($c\varLambda\gamma = 39°$—$42°$, $2V\gamma = 66°$, $66°$, $68°$, $\gamma = 1.714$). The grains are most often xenomorphic, corroded, rarely hypidiomorphic, and contain small drop-like magnetite grains which often combine into a graphic texture (Vaasjoki 1955) (Fig. 4).

The hornblende is an alteration product of clinopyroxene and is brownish green in colour ($c\varLambda\gamma = 20°$—$25°$, $\gamma = 1.676$, $\alpha = 1.658$). It mainly occurs in the rims of clinopyroxene, but also as individual grains.

Scapolite is found as separate grains, clusters of grains and as »passages» corroding albite and clinopyroxene. Its composition is Ma_{77}, according to the refractive indices $\omega = 1.548$, $\varepsilon = 1.540$ and birefringence (ω—$\varepsilon = 0.008$).

Zeolite, chabazite variety (X-ray determination, $\gamma = 1.483$), occurs in connection with scapolite. The chabazite has not been previously found in Finland. The zeolite of Kunnarinkorva, however, was already known in 1954 (Meriläinen 1954), but the variety was optically misidentified.

AMPHIBOLE-ALBITE DIABASES

There are only two localities of amphibole-albite diabases in Enontekiö. One is at Palovaara hill and other at Vuontiskero mountain. Only the

latter is so well exposed that macro-structures could be observed. A previously investigated amphibole-albite diabase from Hukkakumpu in Kittilä (Hackman 1927, E. Mikkola 1941) is also described. An albite-rich amphibole-albite rock occurs as the coarse-grained core of the amphibole-epidote-albite diabase of Ylinen-Munnikurkkio (p. 24).

<div align="center">VUONTISKERO</div>

Two varieties of albite rocks occur at Vuontiskero. They are separated from each other by a moraine strip. One variety is albite-rich and the other hornblende-rich. The former, a few meters broad, may compose the core of the sill and the latter its basic, inner marginal zone. According to the observations of boulders the transition is gradual. Because the breadth of the whole sill is not exposed, the proportions of the above-mentioned varieties are not determinable.

The albite-rich variety is a yellowish-green, fine-grained amphibole-albite rock. Its flow structure and hypidiomorphic-granular texture are still preserved in spite of movements after crystallization. The main minerals are albite and hornblende. Scapolite is also abundant. Minor constituents are epidote, titanite and opaques, and accessories are apatite, zeolite and chlorite (Table 4, anal. 1).

The albite grains (An_5) are clear, short and broad laths and twinned according to the albite law. The rims of grains are granulated and separated from each other by a mortar of albite.

Table 4. Amphibole-albite rocks.

	1	2	3	4	5
Plagioclase	An_5 56.4	An_5 26.9	An_5 38.3	An_1 36.6	An_{10} 50.0
Scapolite	11.1	5.9	—	—	—
Amphibole	24.8	60.4	48.8	35.9	30.0
Epidote	2.1	1.9	2.8	9.3	5.0
Biotite	—	—	2.4	12.3	2.0
Titanite	2.7	2.6	2.9	3.9	3.0
Apatite	0.6	0.5	0.7	0.3	+
Carbonate	—	1.2	—	—	2.0
Opaques	2.3	0.6	4.1	1.7	8.0
	100.0	100.0	100.0	100.0	100.0

1. The core of the amphibole-albite diabase. Vuontiskero, Enontekiö.
2. The inner marginal variety of the amphibole-albite diabase. Vuontiskero, Enontekiö.
3. Amphibole-albite diabase. Palovaara I, Enontekiö.
4. Amphibole-albite diabase. Hukkakumpu, Kittilä (Table 20, anal. 1).
5. Feldspar-rich albite diabase. Biddjovagge, Finnmarksvidda, Norway (Table 24, anal. 15) (Gjelsvik 1958).
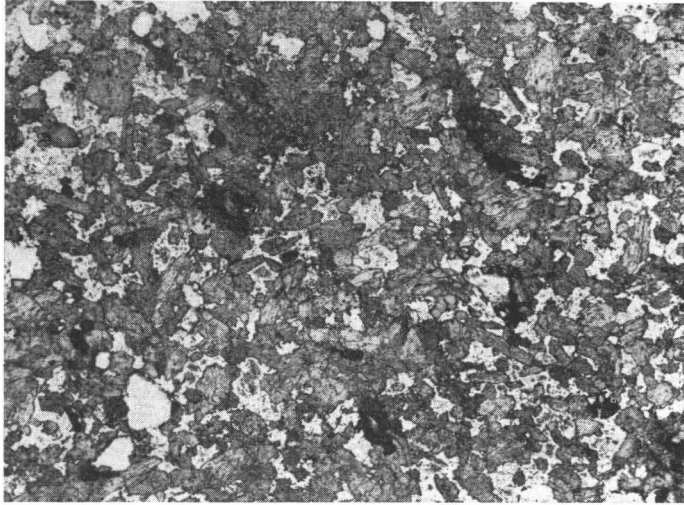
Fig. 5. Poikilitic texture of the hornblende-rich inner marginal zone of amphibole-albite diabase. Idiomorphic hornblende grains occur poikilitically and albite and scapolite fill the interstices. Vuontiskero, Enontekiö. Without analyzer. Magn. 8 ×. Photo E. Halme.

The hornblende grains (c$\Lambda\gamma$ = 16°—18°, 2Vα = 68°, 69°, 72°, 74°, γ = 1.681, α = 1.662) are mainly granular but some show hypidiomorphic outlines. The colour is green and pleochroism is weak: γ = pale bluish green, β = yellowish green, α = yellowish. The bluish colour is strongest on the edges of the grains.

Scapolite is marialite-rich and occurs with titanite and zeolite in thin movement shears.

Epidote grains are large, idiomorphic and rich in pistacite.

The hornblende-rich inner marginal zone of the Vuontiskero sill is a homogeneous, fine-grained amphibole-albite rock (Table 4, anal. 2). Macroscopically it looks ophitic, but microscopically the idiomorphic hornblende grains (0.5—1.0 mm) lie poikilitically in albite, or quite xenomorphic albite and scapolite fill the interstices between the hornblende grains (Fig. 5).

HUKKAKUMPU

In Hukkakumpu, about 6 kilometers north of the church village of Kittilä, is a small, moraine-surrounded exposure of dark green, fine- grained (Ø = 1—2 mm) amphibole-albite diabase. It is ophitic and glomeroporphyritic (Fig. 6). In this latter structure, hornblende and biotite form macroscopic aggregates (Rice 1952). The main minerals are hornblende

Fig. 6. Glomeroporphyritic and ophitic structure of amphibole-albite
rock. Glomeroporphyritic aggregates are composed of hornblende
and biotite. Nat. size. Hukkakumpu, Kittilä.
Photo E. Halme.

and albite. Epidote and biotite are also abundant. Accessories are apatite
and opaques (Table 4, anal. 4 and Table 20, anal. 1).

Lath-shaped albite grains (An_1, X-ray determination) contain an average
of 20 per cent of small pistacite and clinozoisite grains.

The hornblende ($c\Lambda\gamma = 19°—24°$, $2V\alpha = 66°$, $68°$, $64°$, $\gamma = 1.694$,
$\alpha = 1.673$) is xenomorphic and bluish green in colour with pleochroism as
follows: γ = blue green, β = olive green, α = brownish yellow. The colour
and the interference colour are uneven and patchy in the same sections.
The highest interference colour found was greyish green — yellowish brown.
This hornblende was analysed and is presented in Table 13.

Biotite is found interstitially with minute amounts of epidote and
chlorite between hornblende and albite grains as well as in glomeropor-
phyritic aggregates. Some biotite occurs as an alteration product in horn-
blende.

PALOVAARA I

On the eastern slope of Palovaara there is a small exposure (about 2 m^2)
of dark green, fine-grained ($\emptyset = 0.2—0.6$ mm) amphibole-albite rock
(Table 4, anal. 3). Its texture is granular (Fig. 7). The main minerals are
hornblende and albite. Epidote, biotite, titanite and opaques are present
in somewhat equal amounts which exceed 2—4 per cent. The accessory
is apatite.
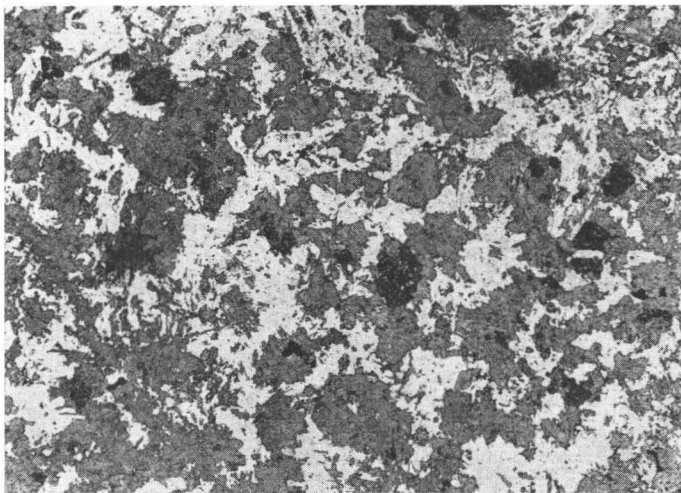
Fig. 7. Granular texture of amphibole-albite rock. Hornblende
often forms aggregates which show the short prismatic form of a
pyroxene grain. Palovaara, Enontekiö. Without analyzer.
Magn. 11 ×. Photo E. Halme.

The albite crystals (An_5) are long ($\emptyset = 0.3$—0.6 mm), rugged laths.
Their centers contain some elongated aggregates of clinozoisite and
pistacite grains.

The hornblende is bluish green with pleochroism as follows: $\gamma =$ bluish
green, $\beta =$ grass green, $\alpha =$ yellowish. The grains ($\emptyset = 0.2$—0.4 mm)
form aggregates which may have originated by the uralitization of pyroxene.
Some aggregates even have the short-prismatic form of a pyroxene (Fig. 7).

Biotite occurs close to magnetite grains, but also as do clinozoisite and
pistacite, in the center of albite.

AMPHIBOLE-EPIDOTE-ALBITE DIABASES

Most albite diabases of Enontekiö are amphibole-epidote-albite rocks.
Some of them are completely homogeneous and simple like the three 2—3
meter broad sills at Tšohkoaivi mountain. The others show two or even
three different varieties. The latter type occurs at Palovaara (two sills),
Ylinen-Munnikurkkio and Tenomuotka. The sill of Ylinen-Munnikurkkio
has been previously investigated and called syenite by Stjernvall (1891,
1892). A previously studied sill from Holkkuavaara of Kittilä (Hackman
1927, E. Mikkola 1941) is also described in this paper.
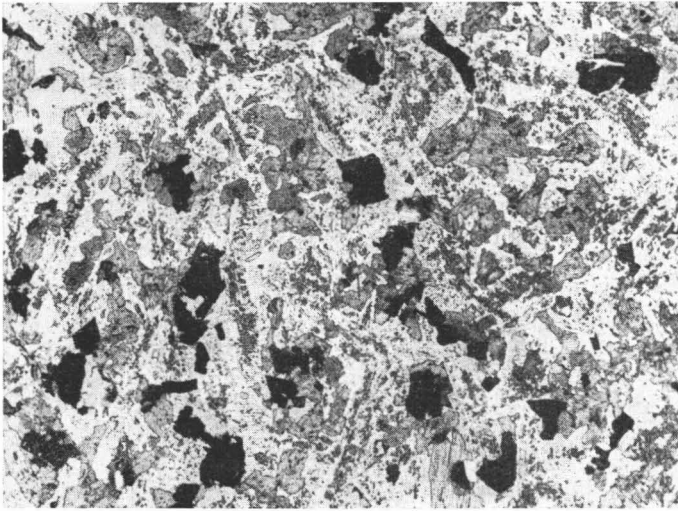
Fig. 8. Subophitic texture of amphibole-epidote-albite rock. Elongated epidote aggregates occur in the middle of albite laths. Palovaara II, Enontekiö. Without analyzer. Magn. 13 ×.
Photo E. Halme.

PALOVAARA II

A 15 meter thick amphibole-epidote-albite diabase conformably penetrates the quartzite at Palovaara. The rock is pale green and fine-grained ($\emptyset = 0.5—1.0$ mm). It contains abundant rounded or oval, often bent inclusions, which vary from some mm to 20—30 cm in length. They are clearly richer in epidote and biotite, but poorer in albite and magnetite than the mother rock (Table 5, anal. 1 and 2). In spite of their unusual abundance, the inclusions are probably early magmatic differentiates. The texture of the mother rock is sub-ophitic (Fig. 8).

The optical properties of the minerals of the mother rock and its early magmatic differentiates are similar.

The albite crystals (An_6) are unorientated, rugged, hypidiomorphic laths, 2—5 times as long as they are wide. In the middle of the laths are abundant clusters of clinozoisite and pistacite. The plagioclase must have originally been rather basic and in the early magmatic differentiates was more basic (at least andesine) than in the mother rock.

The hornblende grains are anhedral and more rarely hypidiomorphic. Two varieties of hornblende are often met with in the same grain. One is bluish green and its highest interference colour is greyish green. The pleochroism is as follows: $\gamma =$ pale bluish green, $\beta =$ pale green, $\alpha =$ yellow-

ish (c$\Lambda\gamma$ = 16°—20°, 2Vα = 76°, 77°, 76°, 74°, γ = 1.685, α = 1.665). According to the optical properties it is common green hornblende. It commonly occurs at the rims of the grains. The variety in the middle of the grains is pale green with its highest interference colour orange-violet. Pleochroism is weak: γ = pale green, β = α = yellowish, nearly colourless. The refractive indices are clearly lower than those of the former variety: γ = 1.657, α = 1.640. It is actinolite.

The epidote is pistacite-rich: γ = 1.778, α = 1.728 and γ — α = 0.050, according to which the composition should be Pi$_{34}$ (Winchell 1951).

PALOVAARA III

The outer marginal zone of the second amphibole-epidote-albite diabase of Palovaara lies against quartzite and is a dark grey, fine- to medium-grained biotite-albite rock cut by some calcite veins. The rock changes toward the core of the sill, first into a fine-grained biotite-albite rock (inner marginal zone) with rounded inclusions rich in biotite and then into amphibole-epidote albite rock ($\emptyset$ = 0.5—1.0 mm). The mineral composition of the latter is entirely analogous with the amphibole-epidote-albite rock described above (Table 4, anal. 3). It does not contain any early magmatic basic inclusions.

The biotite-albite rock occurring as the inner marginal zone is hypidiomorphic. The interstices between the hypidiomorphic, elongated and rugged albite laths are filled by a very fine-grained biotite mass with some chlorite, clinozoisite and very pale hornblende. The mineral composition is comparable with that of the biotite-albite diabase of Riikonkoski in Kittilä (Table 6, anal. 2 and 3). The biotite-rich inclusions differ from their mother rock primarily by the abundance of biotite (about 70—90 % biotite). The mode of occurrence and the mineral composition of the inclusions indicates that they are early magmatic biotite concentrates.

YLINEN-MUNNIKURKKIO

The albite diabase of Ylinen-Munnikurkkio is exposed along the shore of the rapids. The breadth and location of the separate varieties of the sill are not determinable. The main part of the exposure is composed of two amphibole-epidote-albite rock varieties with flow structure (Fig. 9). Some early magmatic inclusions ($\emptyset$ = 10—30 cm) rich in amphibole and epidote are present. The coarse-grained variety ($\emptyset$ = 3—7 mm) is probably the core of the sill and macroscopically resembles the core of the albite diabase of Vähä-Kurkkio (p. 16) and Tenomuotka (p. 28).

The amphibole-epidote-albite rock variety rich in hornblende and epidote (Table 5, anal. 4) is macroscopically inhomogeneous due to the glomeroporphy-

Table 5. Amphibole-epidote-albite rocks.

	1		2		3		4		5		6		7		8	
Quartz		—		—		—		0.7		—		—		—		—
Plagioclase	An_6	33.2	An_6	49.4	An_5	40.7	An_3	33.2	An_4	49.2	An_2	69.0	An_1	26.0	An_5	33.0
Amphibole		31.5		26.0		24.3		30.4		14.4		25.0		40.0		42.0
Epidote		17.5		12.6		26.1		20.2		28.5		1.5		24.0		15.0
Biotite		12.6		2.0		0.8		11.2		0.8		1.0		3.5		0.5
Chlorite		—		—		—		1.2		—		—		3.0		5.5
Titanite		3.7		1.8		3.3		0.4		3.5		1.5		2.3		2.5
Apatite		—		—		0.3		—		0.4		0.2		0.2		0.3
Carbonate		—		—		—		—		—		0.4		—		—
Opaques		1.5		8.2		4.5		2.7		3.2		1.4		1.0		1.2
		100.0		100.0		100.0		100.0		100.0		100.0		100.0		100.0

1. Early magmatic inclusion in albite-diabase. Palovaara II, Enontekiö.
2. Amphibole-epidote-albite rock. Palovaara II, Enontekiö.
3. Amphibole-epidote-albite rock. Palovaara III, Enontekiö.
4. Amphibole-epidote-albite rock. Ylinen-Munnikurkkio, Enontekiö.
5. Amphibole-epidote-albite rock. Ylinen-Munnikurkkio, Enontekiö.
6. Amphibole-albite rock, the core of the sill of Ylinen-Munnikurkkio, Enontekiö.
7. Fine-grained amphibole-epidote-albite rock. Holkkuavaara, Kittilä (Table 19, anal. 2).
8. Medium-grained amphibole-epidote-albite rock. Holkkuavaara, Kittilä (Table 19, anal. 5).
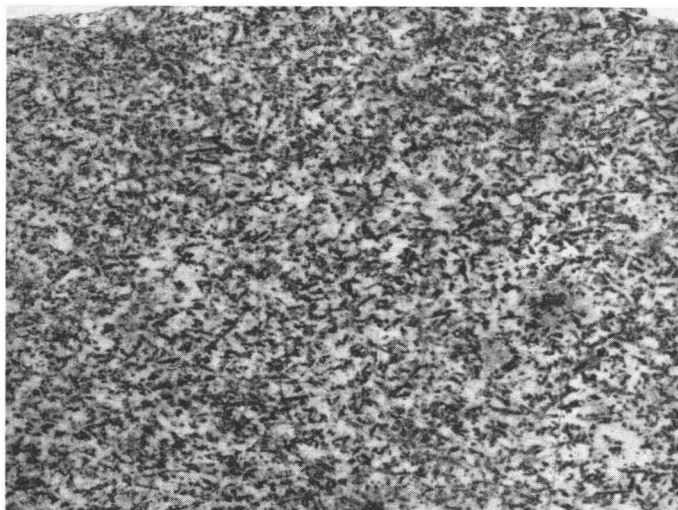
Fig. 9. Flow structure in hypidiomorphic amphibole-epidote-albite rock. The dark grey spots are mainly albite grains which contain unusually abundant epidote inclusions. Ylinen-Munnikurkkio, Enontekiö. Nat. size. Photo E. Halme.

ritic texture. Epidote and hornblende, and sometimes also magnetite and titanite, there form abundant small, roundish aggregates (Ø = 5—10 mm). They do not differ markedly from their surroundings, but merge gradually into it. The texture of this variety is poikilitic. The idiomorphic, often elongated amphibole crystals (Ø = 0.5—2.0 mm) lie poikilitically in large (Ø = 5—10 mm) albite grains which are clouded by epidote.

The albite (An$_3$) is twinned according to the albite law and contains small clinozoisite and pistacite grains which amount to 30—50 % of the whole grain.

The hornblende is actinolitic (c$\varLambda\gamma$ = 18°—21°, γ = 1.661, = 1.639). It is often twinned according to the augite law. Pleochroism is weak: γ = greyish green, $\beta = \alpha$ = colourless.

The epidote is either clearly pleochroic pistacite or clinozoisite.

Biotite is abundant.

Accessories are magnetite, apatite and titanite. The magnetite contains leucoxene lamellae.

The variety that is somewhat richer in albite than the former (Table 5, anal. 5) is hypidiomorphic (Fig. 9) and medium-grained (Ø = 0.5—2.0 mm). Macroscopically it is slightly inhomogeneous due to some small epidote aggregates (Ø = 2—10 mm). Microscopically they are either albite grains which contain unusually abundant epidote inclusions or are individual
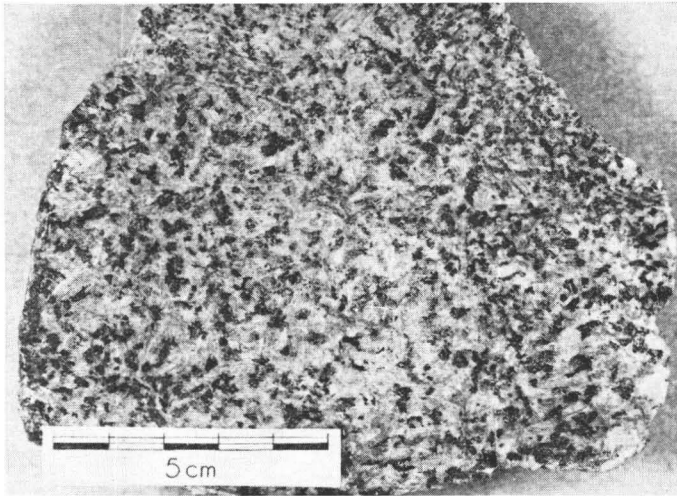
Fig. 10. Albite-rich, hypidiomorphic amphibole-albite rock which
forms the coarse-grained core of the amphibole-epidote-albite
diabase of Ylinen-Munnikurkkio, Enontekiö.
Photo E. Halme.

epidote aggregates. The main minerals are albite (An_4), hornblende, and epidote. Biotite is only sparsely found and the other accessories are magnetite, apatite and titanite.

The coarse-grained ($\varnothing = 3$—7 mm), unorientated albite-rich amphibole-albite rock (Table 5, anal. 6) presumably forms the core of the albite diabase of Ylinen-Munnikurkkio. Macroscopically the rock is homogeneous (Fig. 10). A polished section (10 × 12 cm) reveals, however, that varying amounts of epidote occur in the middle of some albite grains. An unpolished surface does not show this and even a thin section of normal size may display it only occasionally. The texture of this rock is hypidiomorphic. Albite (An_2) and pale green hornblende are the main minerals. Both occur as hypidiomorphic grains; the albite, however, more frequently. Only small amounts of epidote, carbonate and titanite are found. Accessories are opaques, biotite, chlorite and apatite.

The core of the sill is cut by one 4—5 cm thick and by two 1—2 cm thick albitite veins.

TENOMUOTKA

The albite diabase of Tenomuotka is a 15—20 m thick sill intruded into quartzite. Its main part is amphibole-epidote-albite rock. This passes in one direction into the coarse-grained amphibole-pyroxene-albite rock which

forms the core of the sill, and in the other direction into the fine-grained amphibole-albite rock. The latter, a few decimeters wide, is the outer marginal zone of the sill. It contains some chlorite and eye-like epidote amygdules.

Amphibole-epidote-albite rock, the main part of the sill, is medium-grained (0.5—2.0 mm), pale green and clearly orientated. Orientation is partly original flow structure and partly due to the movements. The rock is penetrated by thin epidote veins. Epidote also occurs as small, eye-like amygdules ($\varnothing = 2$—4 mm), and epidote and hematite can be found at the walls of fissures. The texture is granular but some hornblende grains show hypidiomorphic outlines. Albite, hornblende and epidote are the main minerals and chlorite is present in small amounts as an alteration product. Titanite, opaques and apatite occur as accessories.

The albite (An_6, $\gamma = 1.542$) is slightly zoned and in the middle of all larger grains some saussurite and sericite occur. The grains are approximately equidimensional and angular.

The hornblende ($\gamma = 1.650$) is pale green with pleochroism as follows: γ = pale green, $\beta = \alpha$ = yellowish, nearly colourless. The highest interference colour is greyish green. Many grains have been partially altered to chlorite.

The core of the Tenomuotka sill is markedly coarser ($\varnothing = 2$—5 mm) than the main part. It is an albite-rich amphibole-pyroxene-albite rock. Macroscopically this rock is similar to the coarse-grained core of the albite diabase of Vähä-Kurkkio and Ylinen-Munnikurkkio, but it has an orientated structure. Orientation, as previously mentioned, is caused partly by flow structure and partly by movements. The texture is hypidiomorphic-granular. The main minerals are oligoclase, clinopyroxene and hornblende. Marialitic scapolite is also abundant, but it is unevenly distributed. Accessories are apatite, titanite and opaques.

The oligoclase (An_{12}) is slightly zoned and twinned according to the albite law. In the middle of the grains there is some saussurite and the core of some larger grains is richer in anorthite (An_{20}).

The clinopyroxene is diopsidic ($c \varLambda \gamma = 39°$, $2V\gamma = 61° \pm 2°$). The grains are elongated, often hypidiomorphic and corroded. They pass along the edges into a strongly pleochroic, bluish-green hornblende.

HOLKKUAVAARA

On Holkkuvaara hill, about 9 kilometers to the northeast of the church village of Kittilä, there is an amphibole-epidote-albite diabase. It is estimated to be several tens of meters broad but is mostly covered by till. Two varieties are found in the exposures. Macroscopically they
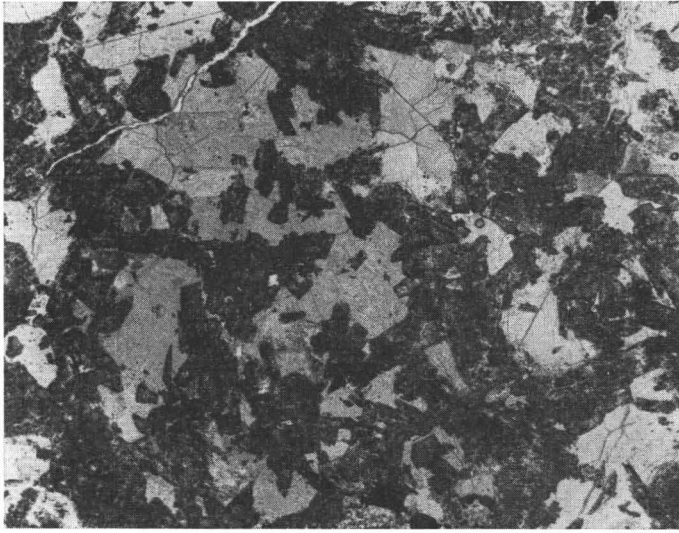
Fig. 11. Ophitic texture of the amphibole-epidote-albite rock.
Holkkuavaara, Kittilä. Without analyzer. Magn. 8 ×.
Photo E. Halme.

are distinguishable from each other mainly on grain size: fine-grained and medium-grained. The former, which is greyish green, is somewhat darker in colour. Both varieties are ophitic (Fig. 11).

The albite (An_1) of the fine-grained ($\emptyset = 1.0—1.5$ mm) variety contains over 50 % clinozoisite and hence its plagioclase must have originally been very rich in anorthite (Table 5, anal. 7).

The amphibole is nearly colourless actinolite with pleochroism as follows: γ = greyish green, $\beta = \alpha$ = colourless; $c\varLambda\gamma = 16°—19°$, $2V\alpha = 78°$, 76°, 76°, 80°, 80°, $\gamma = 1.661$, $\alpha = 1.640$. The highest interference colour is violet. Some grains are twinned according to the augite law. The grains are xenomorphic and have in some cases been altered partly or wholly to chlorite. Table 12 shows the chemical composition of this actinolitic amphibole.

The albite (An_5) of the medium-grained ($\emptyset = 2—3$ mm) variety contains less than 20 % clinozoisite, but otherwise the mineralogy of the rock is as above (Table 5, anal. 8).

BIOTITE-ALBITE DIABASES

A biotite-albite rock occurs as the inner and outer marginal zones of an amphibole-albite diabase of Palovaara III in Enontekiö (p. 24). Similar rocks occur as several thin veins in the same hill. In Kittilä, biotite-albite

Table 6. Biotite-albite rocks.

	1		2		3		4		5
Quartz		2.3		—		0.8		—		0.5
Plagioclase	An_3	31.1	An_3	43.6	An_3	50.5	An_7	43.5	An_3	69.5
Amphibole		—		—		—		14.5		1.6
Biotite		55.0		42.0		39.4		34.0		13.5
Chlorite		2.1		—		—		—		2.1
Titanite		—		0.3		—		1.5		0.7
Apatite		—		1.1		—		—		—
Carbonate		2.3		13.0		1.8		—		2.8
Opaques		7.2		—		7.5		6.5		9.3
		100.0		100.0		100.0		100.0		100.0

1. Biotite-albite rock. Koivu, Tervola (A. Mikkola 1949).
2. Medium-grained biotite-albite rock. Riikonkoski, Kittilä (Table 7).
3. Fine-grained biotite-albite rock. Riikonkoski, Kittilä.
4. Hornblende-bearing biotite-albite rock. Pikku-Akanjoki, Savukoski (E. Mikkola 1941).
5. Biotite-albite rock. Aakenusjoki, Kittilä.

diabases several meters broad are found on the Aakenusjoki and Ounasjoki Rivers. The latter, at Riikonkoski, has been described earlier (Hackman 1927, E. Mikkola 1941).

Several varieties of biotite-albite rocks are met with. The principal differences are in grain size, in colour and comparative amounts of biotite and albite (Table 6). The colour is commonly dark or pale grey, sometimes orange or reddish due to the colour of the albite. The grain size varies from fine-grained (Ø = 0.1—1.0 mm) to medium-grained (Ø = 2—3 mm). Fine-grained varieties often resemble mica gneisses. Thin carbonate veins often cut biotite-albite rocks. Some carbonate amygdules and dark biotite-rich inclusions which differ sharply from the mother rock are present. The inclusions are early biotite concentrates (p. 24). The amount of hornblende, chlorite, carbonate, magnetite and quartz can amount to several per cent. The abundance of magnetite and apatite is often a characteristic feature. The iron-bearing carbonate often results in a reddish-brown weathering surface. Hornblende-bearing varieties of biotite-albite rocks form transitional rocks to the amphibole-albite rocks described above, chlorite-bearing varieties grade into the chlorite-albite rocks, and the varieties poor in biotite grade into albitites. The texture of biotite-albite rocks is hypidiomorphic or granular and sometimes also glomeroporphyritic.

AAKENUSJOKI

The biotite-albite diabase of Aakenusjoki is greyish green and medium-grained (Ø = 2—3 mm). The texture is hypidiomorphic and also glomero-
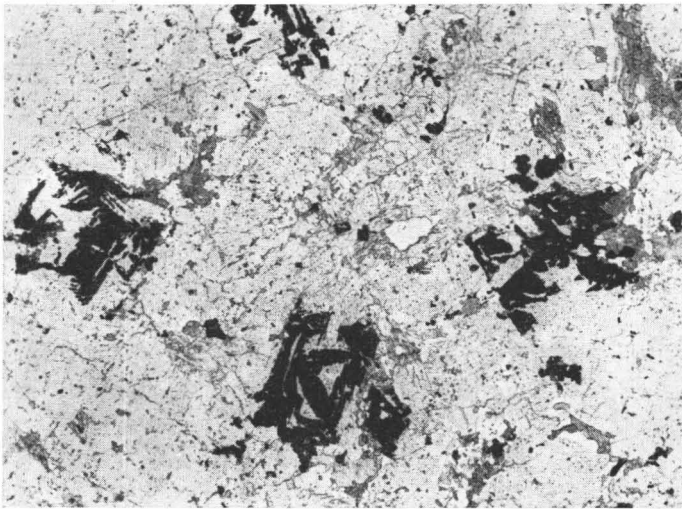
Fig. 12. Magnetite grains from which the leucoxene lamellae are corroded away and now filled by albite. Biotite-albite rock. Aakenusjoki, Kittilä. Without analyzer. Magn. 11 ×. Photo E. Halme.

porphyritic. The hypidiomorphic texture resembles that of medium-grained albitites (Fig. 15). Biotite occurs interstitially between thick, short prismatic albite grains. The glomeroporphyritic aggregates are composed mainly of biotite and magnetite. The main minerals are albite and biotite, but magnetite is also abundant. Hornblende, chlorite and carbonate are observed only in small amounts. Accessories are rutile, leucoxene and apatite (Table 6, anal. 5).

Short albite (An$_3$) crystals are clouded by some minute biotite grains. Twinning is according to the albite law and often to the pericline law. The biotite is brown. Leucoxene lamellae in magnetite grains are almost entirely corroded and those places are now filled by albite (Fig. 12).

RIIKONKOSKI

The biotite-albite diabase of Riikonkoski is exposed as a few small rocks in the rapids. The breath of this sill is at least ten meters, but cannot be exactly determined. Two varieties are found, differing in grain size and biotite content. Both varieties are cut by some thin carbonate veins and here and there carbonate amygdules are found (Table 6, anal. 2 and 3).

The medium-grained greyish-brown variety (∅ = 1—2 mm) is hypidiomorphic-granular. The main minerals, albite and biotite, occur in both

Table 7. Medium-grained biotite-albite rock. Riikonkoski, Kittilä, Finland.
Anal. A. Heikkinen 1957.

Weight %		Atomic ratio × 1 000	Cation %	One-cation molecular norms		Niggli numbers	
SiO_2	43.73	729	39.46	Or	23.55	si	130.40
Al_2O_3	14.20	278	15.05	Ab	23.50	al	24.90
TiO_2	1.10	14	0.76	Ne	9.45	fm	50.10
Fe_2O_3	1.91	24	1.30	An	6.23	c	4.30
FeO	6.16	86	4.66	Fo	11.74	alk	20.70
MnO	0.04	—	0.03	Fa	4.92	mg	0.61
MgO	9.51	238	12.89	Mt	1.95	k	0.37
CaO	5.20	93	5.04	Il	1.52	ti	2.50
Na_2O	4.49	145	7.85	Ap	2.32	p	1.41
K_2O	4.07	87	4.71	$CaCO_3$	4.68		
P_2O_5	1.12	16	0.87	$MgCO_3$	10.14		
CO_2	6.03	137	7.41				
H_2O+	2.19	(122)	(6.61)				
H_2O-	0.17	—	—				
	99.92		100.03				

Notes: The mineral composition is listed in Table 6. The carbonate and biotite were analysed and are presented in Tables 14 and 18. In calculations of Niggli numbers, CO_2 is assumed to be in carbonates and is omitted as $CaCO_3 : MgCO_3$ = 1: 1.

hypidiomorphic and granular grains. The chemical composition of this variety is listed in Table 7.

The albite (An_3) is finely twinned according to the albite law and clouded by sericite and chlorite.

The biotite, the chemical analysis of which is in Table 16, occurs interstitially between albite crystals as fine-grained masses and as larger hypidiomorphic grains (Fig. 13). It contains some zircon and rutile inclusions.

Carbonate occurs in abundance as xenomorphic grains and clusters of grains. It was analysed and is presented in Table 18.

Accessories are apatite and titanite. Apatite is abundant and mainly occurs as xenomorphic grains.

The fine-grained variety ($\emptyset = 0.1—1.0$ mm) is hypidiomorphic. Mineralogically it differs from the above-mentioned mainly on the basis of a lower biotite and carbonate content and by higher amounts of albite and magnetite.

CHLORITE-ALBITE DIABASES

Chlorite-albite diabases are not found in Enontekiö. A previously investigated sill in Kittilä near the village of Nilivaara has been described
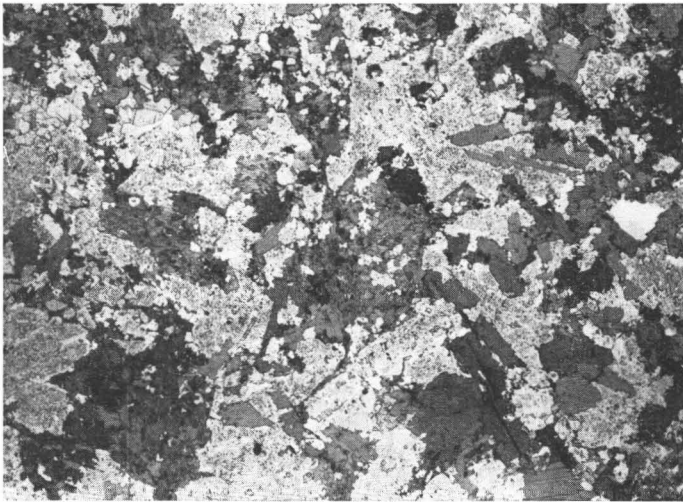
Fig. 13. Medium-grained biotite-albite rock. Riikonkoski, Kittilä,
Finland. Without analyzer. Magn. 11 ×. Photo E. Halme.

(E. Mikkola 1941). The mineralogy of two other occurrences is known (E. Mikkola 1941). One is in Sodankylä and the other in Kittilä (Table 8, anal. 2 and 3). Chlorite-albite rock resembling chlorite schist also occurs as an outer marginal zone of amphibole- or pyroxene-bearing albite diabases (E. Mikkola 1941).

Table 8. Chlorite-albite rocks.

	1	2	3
Quartz	5.0	—	1.0
Plagioclase	An_3 60.7	An 46.0	An 51.5
Biotite	3.4	—	1.2
Chlorite	20.7	34.5	25.0
Talc	5.6	—	—
Titanite	—	+	3.3
Apatite	0.2	—	—
Carbonate	4.0	18.0	9.5
Opaques	0.4	1.5	8.5
	100.0	100.0	100.0

1. Chlorite-albite rock. Nilivaara, Kittilä (Table 9).
2. Albite-chlorite-carbonate rock. Kuolavaara, Kittilä (E. Mikkola 1941).
3. Albite-chlorite rock. Sattaslompolo, Sattasjoki, Sodankylä (E. Mikkola 1941).

Table 9. Medium-grained chlorite-albite rock. Nilivaara, Kittilä, Finland.
Anal. P. Ojanperä 1956.

Weight %		Atomic ratio × 1 000	Cation %	One-cation molecular norms		Niggli numbers	
SiO_2	59.62	994	55.28	Q	10.47	si	227.50
Al_2O_3	16.42	322	17.91	Or	4.45	al	36.80
TiO_2	0.76	9	0.50	Ab	57.85	fm	34.60
Fe_2O_3	1.73	22	1.22	An	3.45	c	3.00
FeO	3.67	51	2.84	C	4.07	alk	25.60
MnO	0.05	1	0.05	En	8.50	mg	0.18
MgO	3.92	98	5.45	Fs	3.56	k	0.07
CaO	1.90	34	1.89	Mt	1.83	ti	2.06
Na_2O	6.45	208	11.57	Il	1.00	p	0.03
K_2O	0.76	16	0.89	Ap	0.02		
P_2O_5	0.02	—	0.01	$CaCO_3$	2.40		
CO_2	1.90	43	2.40	$MgCO_3$	2.40		
H_2O+	2.38	(132)	(7.34)				
H_2O-	0.13	—	—				
	99.71		100.01				

Notes: The mineral composition is listed in Table 8. The chlorite was analysed and
is presented in Table 17. In calculations of Niggli numbers, CO_2 is assumed
to be in carbonates and is omitted as $CaCO_3 : MgCO_3 = 1: 1$.

NILIVAARA

The contacts of the chlorite-albite diabase of Nilivaara are not exposed,
but judging from the topography of the area, its breadth is 50—60 m.
Many varieties are found in the exposures, but their location in the sill
cannot be determined. From the commonest variety, described below,
there are transitions to pure albitite. Macroscopically this change appears
as a decrease in chlorite. Albitite contains scarsely more than 1—2 per
cent chlorite, but the most basic chlorite-albite rock contains 30—40 per
cent. Albitites probably occur as large segregations in chlorite-albite rock.

The commonest variety of chlorite-albite diabase at Nilivaara is a
greyish-green and medium-grained (Ø = 2—3 mm) rock. It is cut by
numerous 1—10 mm wide hematite veins. The texture is hypidiomorphic—
granular. The chemical composition of this rock is given in Table 9.

The albite grains (An_3), twinned according to the albite law, are
often hypidiomorphic but also form a granophyric texture with quartz.
The albite contains abundant inclusions of small grains of chlorite and talc.

Chlorite grains or aggregates often show the prismatic form of pyroxene
or amphibole, and can even be seen macroscopically (Fig. 14). Many chlorite
grains contain biotite and sometimes biotite and chlorite scales alternate in
the same grain. Rutile quite commonly forms inclusions in chlorite. The colour
of the chlorite is green, with pleochroism: $\gamma =$ light green, $\beta = \alpha =$ colour-
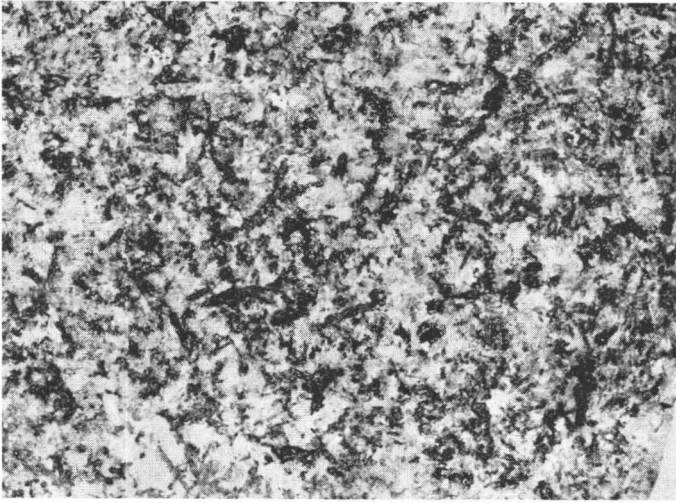
Fig. 14. Chlorite-albite rock. Chlorite aggregates and grains often show the prismatic form of pyroxene or amphibole. Niilivaara, Kittilä, Finland. $1\,^3/_4 \times$ nat. size. Photo E. Halme.

less. The highest interference colour is greyish brown and in places lavender-blue. Table 17 shows the chemical composition of this chlorite.

Rutile (X-ray determination) occurs here and there between albite grains as microscopic aggregates which are composed of either some or numerous idiomorphic needle-like or short grains. Apatite and opaques also occur as accessories.

Many chlorite-albite rock varieties of Nilivaara contain some unevenly distributed carbonate which occurs between albite grains and in their cracks as xenomorphic grains. A carbonate from a thin carbonate vein in albitite from Nilivaara was analysed and is shown in Table 18.

ALBITITES

The albitites of Enontekiö and Kittilä always appear in the same areas as albite diabases. In Enontekiö they occur as numerous large boulders and as a few small exposures in the quartzite zone of Iso-Kurkkio, and as veins cutting albite diabase in the rapids of Ylinen-Munnikurkkio. Albitites are found in large areas in Kittilä, but were investigated only in the immediate neighborhood of the church village, on the Aakenusjoki River.

The thickness of the albitites varies from a few centimeters to 10—20 meters. The contacts are, except for those thin veins which cut albite diabases and schists, covered by moraine. The weathering surface of albitites is often, due to the decomposition of carbonates, rusty-red or brown with various shades of colour. The surface of these rocks is then corroded and the pits are now filled by an ochre-like mass. Pale, even greyish-white varieties, also exist and they lack the characteristic weathering surface. A fresh surface is yellowish, red, orange, brown, greenish or white. The colour of the main minerals, albite and carbonate, generally determines the colour of the rock. The surface of these rocks is also often patchy due to the streaks and spots of biotite, albite and, most important, carbonate. Fine-grained, white varieties resemble quartzites and those rich in carbonate resemble limestones and dolomites.

The abundance of albite and scarcity of mafic minerals is a distinctive feature of albitites. Most varieties contain abundant carbonates, some are quartz-bearing (quartz keratophyres) or magnetite-rich (magnetite keratophyres), while some are composed almost entirely of albite. Many transitional rocks are found between albitites and the most common varieties of amphibole-albite, biotite-albite and chlorite-albite rocks (Table 22).

ISO-KURKKIO

Albite-rich, carbonate-rich and magnetite-rich albitites are found at Iso-Kurkkio.

Fig. 15. Hypidiomorphic texture of medium-grained albitite.
Iso-Kurkkio, Enontekiö, Finland. Nicols crossed. Magn. 11 ×.
Photo E. Halme.

Albite-rich, medium-grained albitite is found only as boulders in the rapids. Its weathering surface is brown and a fresh break is greyish brown. The texture is hypidiomorphic. The albite (An_2) shows albite and pericline twins. The grains are thick, short prismatic, often markedly idiomorphic (Fig. 15) and are often bent and broken.

Carbonate occurs as xenomorphic grains or groups of grains between the albite individuals and fills their fissures (microbreccia).

Small amounts of biotite and chlorite are found and accessories are opaques, apatite and rutile.

The carbonate-rich variety is a dense, greyish-green rock. Its weathering surface is characteristically brown. The texture is granular. The mineral composition can be derived only from the chemical analysis (Table 10), because only a few individual grains are big enough to be clearly distinguished microscopically. The carbonate was analysed and is shown in Table 18.

Magnetite-rich albitite penetrating quartzite exists at Iso-Kurkkio as a vein about 10 m thick. The rock is cut by numerous 10—20 mm thick magnetite veins rich in hornblende. The main minerals are albite (An_4) (about 70 %), magnetite (20 %) and hornblende (7 %). Accessories are chlorite, apatite and titanite.

Table 10. Dense, carbonate-rich albitite. Iso-Kurkkio, Enontekiö, Finland.
Anal. A. Heikkinen 1953.

Weight %		Atomic ratio × 1 000	Cation %	One cation molecular norms		Niggli numbers	
SiO_2	48.76	813	41.61	Q	4.64	si	295.60
Al_2O_3	13.46	264	13.51	Or	2.30	al	48.00
TiO_2	0.55	7	0.36	Ab	56.05	fm	6.19
Fe_2O_3	—	—	—	An	4.60	c	4.36
FeO	1.02	14	0.72	Wo	—	alk	41.45
MnO	0.05	1	0.05	En	—	mg	0.12
MgO	6.20	155	7.93	Fs	0.22	k	0.04
CaO	9.25	165	8.44	Il	0.72	ti	2.55
Na_2O	6.80	219	11.21	Ap	0.13	p	0.18
K_2O	0.44	9	0.46	$CaCO_3$	14.88		
P_2O_5	0.07	1	0.05	$MgCO_3$	15.86		
CO_3	13.48	306	15.66	$FeCO_3$	0.60		
H_2O+	—	—	—				
$H_2O—$	0.35	—	—				
	100.43		100.00				

Notes: The mineral composition is listed in Table 23. The carbonate was analysed
and is shown in Table 18. In calculation of Niggli numbers, CO_2 is assumed
to be in carbonates and is omitted as $CaCO_3 : MgCO_3 = 1: 1$.

AAKENUSJOKI

The weathering surface of the albitite of Aakenusjoki is characteristically red brown due to the decomposition of carbonate. A fresh break is orange brown due primarily to the orange colour of albite and brown colour of carbonate. The texture is hypidiomorphic.

Albite laths (An_3) are clouded by numerous minute and insignificant biotite, sericite, carbonate, apatite and opaque grains. Twinning is generally according to the albite and pericline laws. The thickness of the albite lamellae is variable, the phenomenon common in hypidiomorphic albitites (Fig. 15).

The carbonate content of this rock averages 10—20 per cent. It occurs interstitially between short albite laths, and also as veinlets in the albite (microbreccia). Two varieties of carbonates are present. The dominant one is slightly yellowish brown and the other is colourless. The yellowish colour is possibly due to clouding by hematite. In some grains the centers are coloured and the borders colourless, but commonly these varieties occur side by side without clear difference in the age and optics. X-ray determination shows only dolomite. The twinning and the cleavage, which is parallel to the rhomb faces, are distinct. Table 18, analysis 3, shows the chemical composition and physical properties of this dolomite.

Accessories are rutile, apatite, opaques and very minor zircon. Rutile occurs in clusters of extremely small grains, commonly as inclusions in carbonate and less often in albite.

MINERAL VEINS

Mineral veins in the districts of Enontekiö and Kittilä were observed only in the acid, sodium-rich albite rock varieties and in a few cases in the quartzites immediately adjacent to them. The veins are mostly discordant and are not broader than a centimeter or two. The mineral assemblages are simple. The most common minerals are carbonate, quartz, hornblende, magnetite, epidote, albite, hematite, scapolite, titanite and zeolite. These minerals, however, never all occur in the same vein. Minor amounts of apatite, pyrite and chalcopyrite are sometimes present. Gold is found only in a chemical analysis of a narrow hematite-carbonate vein near Palovaara.

Amphibole-albite and epidote-albite veins cut the amphibole-pyroxene-albite diabase of Vähä-Kurkkio. The cores are composed of amphibole or epidote and the rims of albite. Titanite often occurs abundantly. These veins also penetrate the quartzite country rock.

Carbonate- and quartz-bearing veins a few millimeters thick cut the biotite-albite diabase of Riikonkoski and Palovaara. These veins often contain hematite.

Hematite veins varying in thickness from 1—2 mm to one centimeter are abundant in the chlorite-albite diabase of Nilivaara. Small amounts of magnetite are also present.

Magnetite-hornblende veins ($\varnothing = 10$—20 mm) are abundant in magnetite-rich albitite at Iso-Kurkkio. They also contain hornblende, albite and apatite. The magnetite is partly altered to hematite.

SOME MINERALS OF ALBITE DIABASES AND ALBITITES

In order to complete the petrographical study and the discussion of the genesis of albite diabases and albitites, three amphiboles, one clinopyroxene, one chlorite, one biotite and five carbonates were analysed chemically and also studied optically in more detail. The separation of the minerals was made with Clerici's solution in a centrifuge and with a magnetic separator. Optical properties given are for sodium light. The specific gravity of the minerals was determined with a pycnometer.

AMPHIBOLES

Amphiboles are prevalent mafic minerals in the albite diabases of most spilite provinces. Chemically, however, they have been very poorly investigated. In the above-mentioned papers, pp. 7—9, there is only one chemical analysis from those amphiboles (Eskola 1925). The literature does, however, present several analyses of amphiboles from rocks which correspond chemically and mineralogically to albite diabases and are metamorphosed under conditions of albite-epidote-amphibolite or greenschist facies. Optically the amphiboles of albite diabases form a complete series from colourless actinolites to common dark green hornblendes (Eskola 1925) and are well investigated.

The chemically analysed amphiboles in the albite diabases of Enontekiö and Kittilä are from Holkkuavaara, Hukkakumpu and Vähä-Kurkkio. The amphibole of Maaselkä, Olonets, USSR (Eskola 1925) is also described.

The amphibole of Maaselkä is a colourless actinolitic hornblende from amphibole-epidote-albite rock. The mineralogical and chemical compositions of this rock are the same as those of Perttilahenvaara (Table 19, anal. 4). Chlorite and iron ore with leucoxene borders are, however, somewhat more abundant than in the rock of Perttilahenvaara. The texture is ophitic. Table 11 shows the chemical composition and physical properties of this actinolite.

The amphibole of Holkkuavaara is from amphibole-epidote-albite rock (Table 19, anal. 2). The amphibole is very pale actinolite, only slightly

Table 11. Chemical composition and physical data of amphibole from amphibole-epidote-albite rock. Maaselkä, Olonets, USSR. Anal. P. Eskola (Eskola 1925).

Weight %		Atomic ratio × 1 000	Cations per 24 0 atoms	Physical data	
SiO_2	50.54	842	7.24	Sp.gr.	3.035
Al_2O_3	4.32	85	0.73	$2V\alpha$	large
TiO_2	1.70	21	0.18	$c\varLambda\gamma$	—
Fe_2O_3	2.94	37	0.32	γ	1.635
FeO	10.14	141	1.21	α	1.620
MnO	0.28	4	0.03	Colorless	
MgO	14.02	351	3.02		
CaO	12.58	225	1.94		
Na_2O	0.80	26	0.22		
K_2O	0.00	—	—		
Loss on ignition	2.68	(149)	2.56		
	100.00				

pleochroic: γ = very pale greyish green, $\beta = \alpha$ = colourless. The highest interference colour is violet. The rock is ophitic and the amphibole occurs as xenomorphic grains which are in places converted partially or wholly to chlorite. Some grains are twinned according to the augite law. Epidote is pistacitic or clinozoisitic and occurs with chloritized amphibole grains and as minute inclusions in the albite. The epidote grains among chlorite are generally pistacitic in composition. Table 12 shows the chemical composition and physical properties of the actinolite of Holkkuavaara.

Table 12. Chemical composition and physical data of amphibole from amphibole-epidote-albite rock. Holkkuavaara, Kittilä, Finland. Anal. P. Ojanperä 1956.

Weight %		Atomic ratio × 1 000	Cations per 24 0 atoms	Physical data	
SiO_2	50.02	834	7.20	Sp.gr.	3.16
Al_2O_3	4.57	90	0.78	$2V\alpha$	76°—80°
TiO_2	0.38	5	0.04	$c\varLambda\gamma$	16°—19°
Fe_2O_3	2.44	31	0.27	γ	1.661
FeO	14.09	196	1.69	α	1.640
MnO	0.58	8	0.07		
NiO	0.017	—	—		
MgO	13.26	332	2.87	Pleochroism:	
CaO	11.10	198	1.71		
Na_2O	0.64	21	0.18	γ = pale greyish green	
K_2O	0.00	—	—	β = colorless	
P_2O_5	0.00	—	—	α = colorless	
F	0.015	(1)	0.01		
H_2O+	3.17	(176)	3.04		
H_2O-	0.12				
	100.402				

Note: NiO and F contents in Tables 12—15 were made by A. Heikkinen.

Table 13. Chemical composition and physical data of amphibole from amphibole-albite rock. Hukkakumpu, Kittilä, Finland. Anal. P. Ojanperä 1956.

Weight %		Atomic ratio × 1 000	Cations per 24 0 atoms	Physical data	
SiO_2	46.40	773	6.93	Sp.gr.	—
Al_2O_3	7.50	147	1.32	$2V\alpha$	64°—68°
TiO_2	0.89	11	0.10	$c\Lambda\gamma$	19°—24°
Fe_2O_3	4.30	54	0.48	γ	1.694
FeO	17.38	241	2.16	α	1.673
MnO	0.26	4	0.04		
NiO	0.004	—	—		
MgO	8.20	205	1.84	Pleochroism:	
CaO	11.70	209	1.87		
Na_2O	0.94	30	0.27	γ = blue green	
K_2O	0.52	11	0.10	β = olive green	
P_2O_5	—	—	—	α = brownish yellow	
F	0.04	(2)	0.02		
H_2O+	2.28	(127)	2.28		
H_2O-	0.04				
	100.454				

The amphibole of Hukkakumpu is from epidote-bearing amphibole-albite rock (Table 20, anal. 1). The rock is ophitic and glomeroporphyritic (Fig. 6). Hornblende and biotite form macroscopic aggregates in the latter texture. The biotite content is higher than in albite diabases of Maaselkä, Holkkuavaara and Vähä-Kurkkio. It occurs interstitially with some epidote and chlorite between albite and amphibole. The epidote is pistacite or clinozoisite and occurs interstitially between hornblende and albite grains and also as minute amounts in albite.

The hornblende is blue-green in colour but nonhomogeneous as it contains small pale green spots. The refractive indices of these spots are lower and their birefringences somewhat higher than that of the main part of the hornblende grains. The optical properties were determined only for the blue-green parts of grains. The pale spots are not numerous and since they are also green hornblende the analysis does not differ very much from the determined hornblende. Table 13 shows the chemical composition and physical properties of this hornblende.

The amphibole of Vähä-Kurkkio is from albite-rich, coarse-grained amphibole-pyroxene-albite rock (Table 3). The texture of this rock is hypidiomorphic-granular (Fig. 3). Albite occurs as clear, thick, short-prismatic grains, which are often separated from each other by an albite mortar. Magnetite and titanite grains are numerous. The amphibole is deep bluish green, occurring as individual grains or including a few clinopyroxene patches parallel to the c-axis (homoaxially orientated). The

Table 14. Chemical composition and physical data of amphibole from albite-rich amphibole-pyroxene-albite rock. Vähä-Kurkkio, Enontekiö, Finland.
Anal. P. Ojanperä 1956.

Weight %		Atomic ratio × 1 000	Cations per 24 0 atoms	Physical data	
SiO$_2$	47.34	789	6.97	Sp.gr.	3.17
Al$_2$O$_3$	5.20	102	0.90	2Va	60°—64°
TiO$_2$	0.90	11	0.10	c$\Lambda\gamma$	20°—24°
Fe$_2$O$_3$	6.75	84	0.74	γ	1.676
FeO	9.84	137	1.21	a	1.653
MnO	0.10	1	0.01		
NiO	0.004	—	—		
MgO	13.89	347	3.07	Pleochroism:	
CaO	10.80	193	1.71		
Na$_2$O	2.44	79	0.70	γ = dark bluish green	
K$_2$O	0.61	13	0.11	β = brownish green	
P$_2$O$_5$	0.04	1	0.01	a = brownish yellow	
F	0.03	(2)	0.02		
H$_2$O+	1.91	(106)	1.87		
H$_2$O—	0.12	—	—		
	99.974				

Note: The clinopyroxene shown in Table 15 is from the same specimen.

grains are commonly corroded. Table 14 presents the chemical composition and physical properties of this amphibole (ferri-edenite).

Most amphiboles of albite-diabases in Enontekiö and Kittilä are optically intermediate between those of Holkkuavaara and Hukkakumpu. The colour is most often bluish green with various shades and intensities. Colourless varieties like that of Maaselkä are not found in rocks of these areas. The lightest varieties are optically similar to the actinolite of Holkkuavaara. Generally the amphiboles of amphibole-epidote-albite rocks are lighter than those of amphibole-albite rocks. The latter are thus richer in iron, especially ferric (Fe$^{...}$), as a high iron content and high oxidation degree of iron are the characteristic features of blue and blue-green amphiboles (Kunitz 1930, Seitsaari 1951, 1953, 1956). The amphiboles of albite diabases are rich in silica and poor in alumina and titania, similar to rocks which are metamorphosed under conditions of albite-epidote-amphibolite and greenschist facies. The sodium-rich, blue-green variety found in the amphibole-pyroxene-albite diabase of Vähä-Kurkkio occurs only at that locality.

CLINOPYROXENE

Clinopyroxenes are found in three amphibole-pyroxene-albite rocks of Enontekiö. Two are amphibole-pyroxene-albite diabases of Vähä-Kurkkio and Kunnarinkorva and the third forms the core of the amphibole-epidote-albite diabase of Tenomuotka.

Table 15. Chemical composition and physical data of clinopyroxene from albite-rich
amphibole-pyroxene-albite rock. Vähä-Kurkkio, Enontekiö, Finland.
Anal. P. Ojanperä 1956.

Weight %		Atomic ratio × 1 000	Cations per 18 0 atoms	Physical data	
SiO$_2$	53.24	887	5.91	Sp.gr.	3.42
Al$_2$O$_3$	1.13	22	0.15	2Vγ	66°—70°
TiO$_2$	0.16	2	0.01	c$\Lambda\gamma$	48°—53°
Fe$_2$O$_3$	6.01	75	0.50	γ	1.722
FeO	4.74	66	0.44	α	1.694
MnO	0.09	1	0.01		
NiO	0.004	—	—		
MgO	12.40	310	2.07	Pleochroism:	
CaO	20.08	359	2.39		
Na$_2$O	2.38	77	0.51	γ = light green	
K$_2$O	0.01	—	—	β = nearly colorless,	
P$_2$O$_5$	0.04	1	0.01	greenish gray	
F	0.005	—	—	α = colorless	
H$_2$O+	0.07	—	—		
H$_2$O—	0.08	—	—		
	100.439				

Note: The amphibole shown in Table 14 is from the same specimen.

The analysed clinopyroxene is from the coarse-grained, hypidiomorphic
(Fig. 3) core of amphibole-pyroxene-albite diabase from Vähä-Kurkkio
(Table 3). The rock is albite-rich. Clinopyroxene occurs as patches in the
center of all large, commonly corroded hornblende grains, parallel to their
c-axis, and also as some independent crystals. Titanite and magnetite are
abundant and the accessories are biotite, apatite and carbonate. The
analysed amphibole (Table 14) is also from this specimen. Table 15 shows
the chemical composition and physical properties of clinopyroxene from
Vähä-Kurkkio.

The chemical composition of this clinopyroxene is comparable with the
zoned pyroxene in ijolite from Iivaara (Lehijärvi 1960). The calculated
composition of clinopyroxene from Vähä-Kurkkio shows 67 % diopside,
15 % hedenbergite and 18 % acmite, thus corresponding to aegerine-augite.
The optical properties agree with this fact. The clinopyroxenes of Teno-
muotka and Kunnarinkorva may also be sodium-bearing for their optics are
very similar with those of Vähä-Kurkkio. The other albite rock varieties of
Vähä-Kurkkio also include aegerine-augitic clinopyroxenes.

BIOTITE

Biotite is the other main component of biotite-albite rocks. It is
commonly sparser than albite but sometimes conspicuously more abundant

Table 16. Chemical composition and physical data of biotite from medium-grained biotite-albite rock. Riikonkoski, Kittilä, Finland. Anal. I. Huhta 1960.

Weight %		Atomic ratio × 1 000	Cations per 24 0 atoms	Physical data	
SiO_2	37.38	623	5.56	Sp.gr.	2.98
Al_2O_3	14.65	287	2.56	2Vα	small
TiO_2	2.38	30	0.27	γ	1.638
Fe_2O_3	3.78	47	0.42	α	1.588
FeO	11.78	164	1.46		
MnO	0.02	—	—		
MgO	16.37	409	3.65	Pleochroism:	
CaO	0.38	7	0.06		
BaO	0.16	1	0.01	γ = brown	
Na_2O	0.14	5	0.04	β = yellowish	
K_2O	8.78	187	1.67	α = colorless	
Li_2O	0.08	4	0.03		
P_2O_5	0.10	1	0.01		
CO_2	0.14	3	0.03		
F	0.25	(13)	0.12		
Cl	0.63	(18)	0.16		
H_2O+	2.96	(164)	2.93		
H_2O-	0.08	—	—		
	100.06				
Less O	0.25				
	99.81				

(Table 6). In amphibole-epidote-albite and amphibole-albite rocks, biotite is a common minor constituent (Tables 5 and 4).

The analysed biotite is from hypidiomorphic-granular biotite-albite rock from Riikonkoski in Kittilä (Table 7). Biotite occurs interstitially with carbonate between albite laths as a fine-grained mass (Fig. 13). Many grains, however, are larger and distinctly hypidiomorphic. Zircon with pleochroic halos and some rutile are found as inclusions. Rutile usually occurs at rims of grains in minute amounts. Accessory apatite is abundant. Biotite is brown in colour and pleochroic: γ = brown, β = yellowish, α = colourless. Table 16 presents the chemical composition and physical properties of this biotite.

The chemical composition of biotite from Riikonkoski is quite similar to that of melteigitic ijolite from Iivaara in Kuusamo (Lehijärvi 1960). The only marked difference is the paucity of ferric iron in biotite from Iivaara. Optically this is reflected in the higher refractive indices of biotite from Riikonkoski. The high chlorine and fluorine content of the latter biotite is also conspicuous. The unusually high chlorine content is accentuated by the fact that the highest previously found in biotites was 1.11 per cent (Lee 1958). Other chlorine contents reported by Lee were as small

Table 17. Chemical composition and physical data of chlorite from chlorite-albite rock. Nilivaara, Kittilä, Finland. Anal. P. Ojanperä 1956.

Weight %		Atomic ratio × 1 000	Cations per 18 O atoms	Physical data	
SiO_2	27.80	463	2.83	Sp.gr.	2.88
Al_2O_3	19.39	380	2.32	$2V\gamma$	$> 10°$
TiO_2	0.23	3	0.02	β	1.619
Fe_2O_3	2.91	36	0.22		
FeO	18.25	253	1.54		
MnO	0.08	1	0.01	Pleochroism:	
NiO	0.024	—	—		
MgO	20.04	501	3.06	$\gamma = \beta =$ light green	
CaO	0.02	—	—	α = yellowish	
Na_2O	0.32	10	0.06		
K_2O	0.00	—	—		
F	0.08	(4)	0.03		
H_2O+	11.36	(631)	7.70		
H_2O-	0.02				
	100.524				

as 0.25 per cent or less. However, there is generally a lack of information on the chlorine of biotites.

CHLORITE

Chlorite is the main mafic component of chlorite-albite rocks. Small amounts, commonly a few per cent, are found in many ampibole-epidote-albite and amphibole-albite rocks (Tables 4, 5 and 8).

The analysed chlorite is from chlorite-albite rock from Nilivaara (Table 9). The rock is hypidiomorphic-granular, but albite also forms a graphic texture with quartz. Chlorite occurs either as individual grains or aggregates which often have the prismatic form of pyroxene or amphibole (Fig. 14). Many grains contain some biotite, often alternating with chlorite scales. The colour of chlorite is green and the highest interference colour is greyish brown. Rutile is commonly found as inclusions in chlorite. Table 17 presents the chemical composition and physical data of this chlorite.

CARBONATES

Carbonates are, next to albite, the most predominant constituents of many albitites. Their amount is variable (Table 24), seldom more than thirty per cent and commonly five to twenty per cent. Carbonates are also found to a variable extent in certain chlorite-albite and biotite-albite rocks (Table 6 and 8). On the other hand, they seldom occur in albite-

Table 18. Chemical composition and physical data for carbonates.
Anal. A. Heikkinen 1953 and 1960.

	1		2		3		4		5	
	Weight %	Atomic ratio × 1 000	Weight %	Atomic ratio × 1 000	Weight %	Atomic ratio × 1 000	Weight %	Atomic ratio × 1 000	Weight %	Atomic ratio × 1 000
FeO	0.93	13	3.28	46	5.65	78	4.71	65	6.23	87
MnO	0.05	1	0.14	2	0.28	4	0.45	6	0.20	3
MgO	6.08	152	19.00	475	14.15	354	7.82	196	17.50	438
CaO	9.29	166	30.00	536	26.37	471	16.07	287	29.70	530
CO_2	13.48	306	46.66	1 060	39.80	905	24.41	555	46.24	1 052
H_2O	0.35	—	—	—	—	—	3.45	—	—	—
Insol.	69.41 *	—	0.60	—	14.00	—	43.52	—	0.40	—
$CaCO_3$	50.08		50.62		51.93		51.81		50.10	
$MgCO_3$	45.78		44.85		39.03		35.38		41.40	
$FeCO_3$	3.92		4.34		8.60		11.73		8.22	
$MnCO_3$	0.22		0.19		0.44		1.08		0.28	
Sp.gr.	—		2.88		2.94		2.97		2.94	
ω	—		1.686		1.697		1.706		1.697	

*) The analysis also includes 0.32 SiO_2 and 0.27 Al_2O_3.

1. Carbonate from albitite. Iso-Kurkkio, Enontekiö, Finland. (Rock analysis in Table 10.).
2. Carbonate from albitite. Petkula, Sodankylä, Finland. (Rock analysis in Table 23).
3. Carbonate from albitite. Aakenusjoki, Kittilä, Finland.
4. Carbonate from carbonate vein in albitite. Nilivaara, Kittilä, Finland. (Rock analysis in Table 9).
5. Carbonate from medium-grained biotite-albite rock. Riikonkoski, Kittilä, Finland. (Rock analysis in Table 7).

richer amphibole-albite and amphibole-pyroxene-albite rocks, and are only accessories in amphibole-epidote-albite and most amphibole-pyroxene-albite and amphibole-albite rocks.

The analysed carbonates are from albitites of Aakenusjoki, Iso-Kurkkio and Petkula (Sodankylä), from the medium-grained biotite-albite rock of Riikonkoski and from a carbonate vein (Ø = 10 mm) cutting the albitite of Nilivaara. Table 18 shows the chemical compositions and physical data of these carbonates.

The occurrences of the analysed carbonates are very similar. They lie interstitially between albite grains as xenomorphic crystals and often as macroscopic and microscopic streaks and spots as well as veinlets in albite (microbreccia). This microbreccia is best seen in albitites. Rhomb-shaped minute grains are sometimes found as inclusions in albite. Apatite, rutile (or titanite) commonly occur with carbonate. In albitite from Aakenus-

joki, the groups of extremely small rutile grains are not found between albite or carbonate grains but generally lie as inclusions in the centers of some carbonate crystals or more seldom in albite. In biotite-albite rocks titanite occurs instead of rutile.

The analysed carbonates are very similar and mainly dolomitic, or more strictly speaking, ankeritic dolomites. The main differences are in the relative amounts of $MgCO_3$ and $FeCO_3$. High $MnCO_3$ contents are associated with higher $FeCO_3$ contents. The powder X-ray determinations show only dolomite. A comparison of the analysed carbonates with sedimentary dolomites from the Kemi-Rovaniemi area (Härme 1949) shows distinct differences in the amount of $FeCO_3$. In albite rocks and albitites, the proportion of $FeCO_3$ is clearly higher than in those dolomites. The MgO/CaO ratio, however, is very similar.

STRUCTURE, TEXTURE, COMPOSITION AND GENESIS OF ALBITE DIABASES AND ALBITITES

The albite diabases of Enontekiö and Kittilä are either simple or composed of two or more varieties. The latter are thus differentiated sills.

Simple albite diabases are, except for the minor inhomogeneities met with in contact zones, rather homogeneous. According to the mineral assemblages they are either amphibole-epidote-albite, amphibole-pyroxene-albite, amphibole-albite, chlorite-albite or biotite-albite rocks. They form, with their transitional rocks (biotite-albite rocks excluded), a series in which one end member is »normal basaltic» amphibole-epidote-albite rock and the other is sodium-rich amphibole-albite or chlorite-albite rock poor in Mg, Fe and Ca (Tables 19—22). Since the range of variations in the chemical compositions of albite diabases is equivalent to those of other spilite districts, they are formed by differentiation of olivine-basaltic magma.

The differentiated character of the albite diabases is especially stressed by the fact that most of the albite diabases of Enontekiö and Kittilä are composed of two or more varieties mentioned above. In the most common case the main part (the inner marginal zone) of the sill is amphibole-epidote-albite rock, and the core is coarser-grained amphibole-albite rock conspicuously richer in albite (Ylinen-Munnikurkkio). Both biotite-albite and chlorite-albite rocks may also occur as outer and inner marginal varieties in such sills (Palovaara III). The differentiation of albite diabases often appears only as amphibole- or pyroxene-rich inner marginal zones and albite-rich and coarser-grained cores (Vähä-Kurkkio, Vuontiskero). The structure of the sills is the result of their steeply dipping attitude during the intrusion and differentiation of the magma. Observations similar to those in Enontekiö and Kittilä have also been made in other spilite provinces. Transitions from one albite rock variety to another occur in many places (Brauns 1909, Eskola 1925, Hackman and Wilkman 1926, Timofejeff 1935) and even transitions to albitites have been described (Brauns 1909, Benson 1915, Hackman and Wilkman 1926, E. Mikkola 1941, A. Mikkola 1949, Gjelsvik 1958). Some varieties of albite diabases differ from each other only in their relative amounts of mafic and salic minerals. Some are more
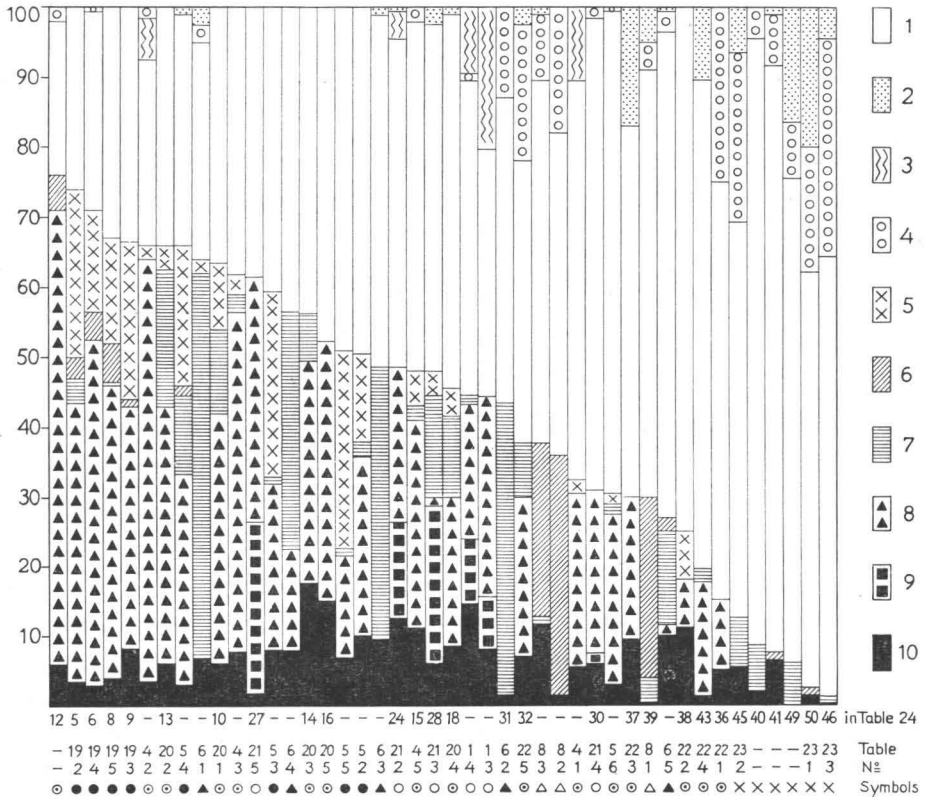
Fig. 16. The mineralogical composition of albite rocks and albitites. All examples are from Fennoscandia. The black triangles indicate biotite-albite rocks. The other symbols are as in Figure 17. 1, albite; 2, quartz; 3, scapolite; 4, carbonate; 5, epidote; 6, chlorite; 7, biotite; 8, amphibole; 9, clinopyroxene; 10, accessories.

markedly differentiated (Benson 1915, Väyrynen 1928, 1938 a, Bartrum 1936, Ödman 1939, A. Mikkola 1949).

The chemical compositions of the varieties of the differentiated albite diabases vary within the same limits as do those of the various simple homogeneous sills (Tables 1—9 and 19—22). The inner marginal zones of the most common sill type (amphibole-epidote-albite diabases) are thus nearly normal basalt in composition, while the core is more acid and richer in sodium (Ylinen-Munnikurkkio, Tenomuotka). Similar differences in composition also prevail between the inner marginal zone and core of the differentiated amphibole-pyroxene-albite and amphibole-albite diabases (Vähä-Kurkkio, Vuontiskero).

Fig. 16 shows the variations in mineralogical compositions of albite rocks and albitites and Fig. 17 shows the variations in mineralogical compositions of chemically analysed albite rocks and albitites.
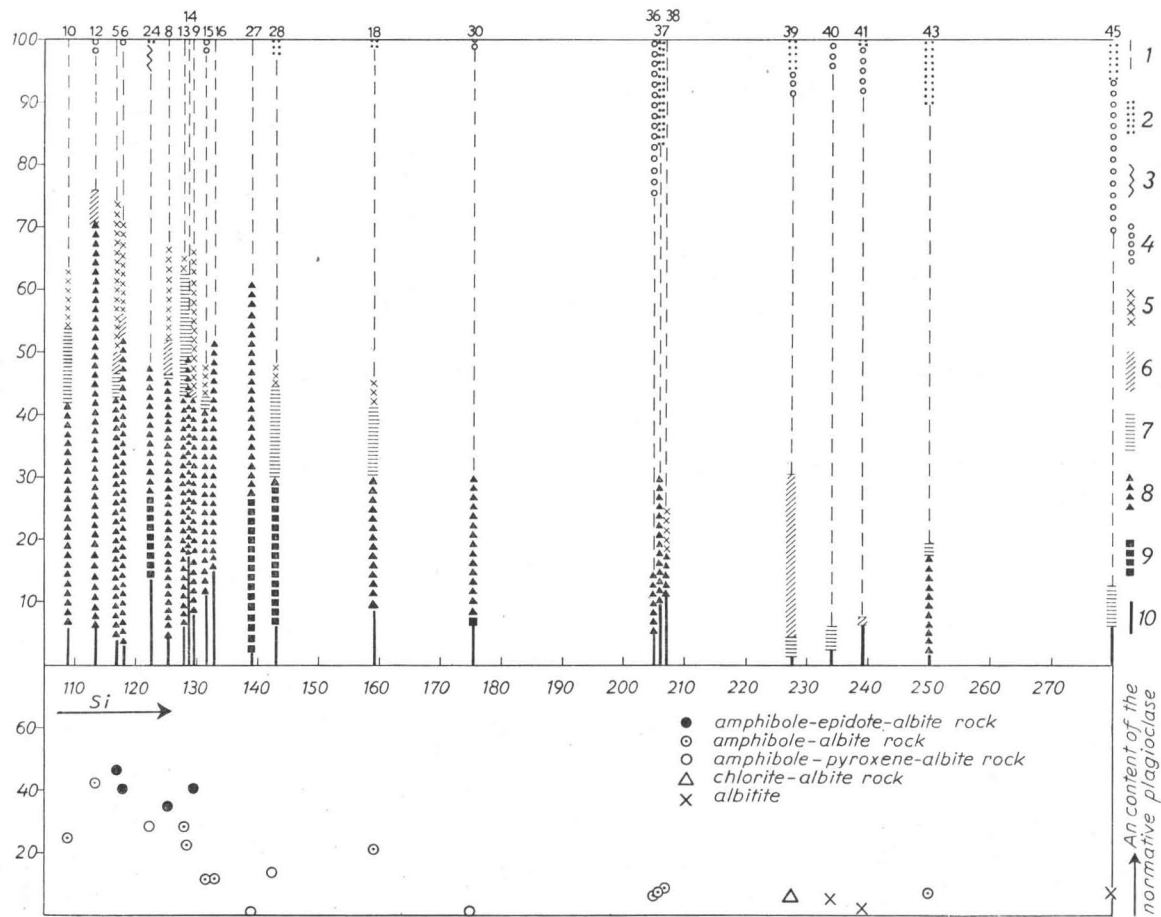
Fig. 17. The mineralogical composition of chemically analysed albite rocks and albitites. All examples are from Fennoscandia. The numbers refer to specimens listed in Table 24. 1, albite; 2, quartz; 3, scapolite; 4, carbonate; 5, epidote; 6, chlorite; 7, biotite; 8, amphibole; 9, clinopyroxene; 10, accessories.

The differentiated character of albite diabases also appears in the textures of separate albite rock varieties. These textures are most frequently presented as ophitic. Scrutiny of the textures of the different albite rock varieties of Enontekiö and Kittilä has revealed that they developed within the limits dictated by a respective crystallizing melt and that the most basic varieties (amphibole-epidote-albite rocks) have generally crystallized with an ophitic texture, whereas the most acid (albite-rich amphibole-pyroxene-albite and amphibole-albite rocks) have a hypidiomorphic texture.

Many more basic (richer in amphibole and epidote) amphibole-albite rocks are identical to normal basaltic amphibole-epidote-albite rocks in ophitic texture (Fig. 11). The albite of each of these albite rock varieties generally contains epidote either scattered throughout the whole grain or as elongated aggregates in the grain center. This means that the plagioclase has been, before its albitization through epidotization, markedly basic and often zoned. On the basis of the compositions of normative feldspars, the plagioclases of amphibole-epidote-albite rocks (An_{35-55}), must have been at least andesinic and those of the aforementioned amphibole-albite rocks andesinic—andesine-oligoclasic.

Presumably the majority of amphibole-albite rocks are subophitic (Fig. 8). Since their albite contains some epidote, the original, probably zoned, plagioclase may have started to crystallize simultaneously with pyroxene or hornblende (Barth 1952). Coarse-grained albite-rich amphibole-albite rocks and amphibole-pyroxene-albite rocks are hypidiomorphic (Fig. 3 and 10). Their hornblende or pyroxene has undoubtedly crystallized before albite. This fact is of special importance, because it sustains the experimental results of L. N. Bowen (1915), according to which no ophitic rocks similar to albite diabases could crystallize from a spilitic melt. The compositions of normative feldspars in many amphibole-pyroxene-albite rocks (Table 24, An_{1-40}) and amphibole-albite rocks (Table 24, An_{14-42}) are much poorer in anorthite than are those of ophitic amphibole-epidote-albite rocks (Table 24, An_{35-55}). This is also in agreement with their textures. Descriptions of the idiomorphic pyroxene and amphibole grains of albite-diabases are also found in the literature (Eskola 1925, Hackman and Wilkman 1926, Timofejeff 1935, Väyrynen 1938 a, Marmo 1949) but their textures have nevertheless been generally interpreted as ophitic.

Poikilitic texture, which is seen in an amphibole-epidote-albite and an amphibole-albite rock in Enontekiö, is characterized by idiomorphic amphibole grains in large albite crystals (Fig. 5). This texture shows that amphibole or pyroxene must have crystallized earlier than albite (Vuontiskero) or basic plagioclase (Ylinen-Munnikurkkio).

Table 19. Amphibole-epidote-albite rocks.

	1		2		3		4		5	
	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %
SiO_2	48.95	46.82	49.11	47.23	51.87	50.00	49.54	47.52	50.58	48.70
Al_2O_3	14.61	16.41	14.11	15.97	12.56	14.21	14.61	16.46	12.89	14.62
TiO_2	0.30	0.23	2.00	1.44	1.71	1.21	0.62	0.46	2.10	1.50
Fe_2O_3	4.00	2.87	2.32	1.67	5.92	4.28	2.64	1.90	2.61	1.91
FeO	7.34	5.85	10.15	8.13	5.11	4.10	10.29	8.23	10.56	8.49
MnO	0.40	0.34	0.24	0.18	0.18	0.14	0.22	0.17	0.32	0.29
MgO	9.18	13.20	6.96	10.03	6.63	9.59	6.51	9.38	6.80	9.82
CaO	9.14	9.35	9.10	9.40	10.01	10.34	8.76	8.98	7.18	7.39
Na_2O	2.40	4.42	2.70	5.02	2.80	5.20	3.51	6.50	3.58	6.64
K_2O	0.26	0.34	0.72	0.87	0.64	0.81	0.33	0.40	0.42	0.52
P_2O_5	0.18	0.17	0.09	0.06	0.17	0.12	—	—	0.14	0.12
H_2O+	3.22	(10.26)	2.18	(6.98)	2.11	(6.76)	3.14	(10.01)	2.42	(7.74)
H_2O-	0.03	—	—	—	0.09	—	—	—	0.24	—
	100.01	100.00	99.68	100.00	99.80	100.00	100.17	100.00	99.84	100.00
Norms										
Q		—		—		7.25		—		0.15
Or		1.70		4.35		4.05		2.00		2.60
Ab		22.10		25.10		26.00		32.50		33.20
An		29.12		25.20		20.50		23.90		18.65
Wo		6.50		8.52		12.08		8.40		6.92
En		26.12		17.94		19.18		11.16		19.64
Fs		9.00		10.80		1.78		8.37		12.66
Fo		0.21		1.59		—		5.70		—
Fa		0.04		0.96		—		4.20		—
Mt		4.30		2.50		6.42		2.85		2.86
Il		0.46		2.88		2.42		0.92		3.00
Ap		0.45		0.16		0.32		—		0.32
Mode										
Albite			An_1	26.00	An_8	33.20	An_4	28.70	An_5	33.00
Amphibole				40.00		35.10		49.40		42.00
Epidote				24.00		22.60		14.60		15.00
Biotite				3.50		—		—		0.50
Chlorite				3.00		0.80		4.10		5.50
Titanite				2.30		5.50		2.90		2.50
Apatite				0.20		—		—		0.30
Carbonate				—		—		0.30		—
Opaques				1.00		2.80		—		1.20
				100.00		100.00		100.00		100.00

1. Greenstone (albite diabase). W. of Lake Ahvenjärvi, Kemi area, Finland. Anal. V. Leppänen (Härme 1949).
2. Albite diabase. S. end of Holkkuavaara hill, 9 km NE of the church, Kittilä, Finland. Anal. L. Lokka (E. Mikkola 1941).
3. Albite-epidote-hornblende diabase. Runkausvaara, Simo, Finland. Anal. H. B. Wiik (A. Mikkola 1949).
4. Hornblende-albite-epidote rock from Perttilahenvaara, Paadane, Aunus, USSR. Anal. P. Eskola (P. Eskola 1925).
5. Albite diabase S. end of Holkkuavaara hill, 9 km NE of the church, Kittilä, Finland. Anal. L. Lokka (E. Mikkola 1941).

Table 20. Amphibole-albite rocks.

	1 Weight %	1 Cation %	2 Weight %	2 Cation %	3 Weight %	3 Cation %	4 Weight %	4 Cation %	5 Weight %	5 Cation %
SiO_2	46.24	44.75	50.98	48.18	50.56	47.49	54.84	52.59	49.96	48.88
Al_2O_3	12.44	14.16	15.84	17.63	15.59	17.24	13.25	14.96	11.39	13.09
TiO_2	3.70	2.67	1.03	0.74	2.00	1.41	2.21	1.61	3.13	2.29
Fe_2O_3	5.49	4.00	2.71	1.93	9.03	6.37	7.00	5.06	4.50	3.29
FeO	11.33	9.11	7.62	6.01	6.03	4.73	6.52	5.24	13.61	11.09
MnO	0.18	0.17	0.08	0.06	—	—	0.19	0.17	0.26	0.23
MgO	5.60	8.13	8.87	12.59	4.23	5.97	3.96	5.70	3.31	4.87
CaO	8.12	8.42	3.71	3.74	5.56	5.58	4.38	4.49	5.24	5.52
Na_2O	3.50	6.56	4.20	7.65	5.18	9.41	4.41	8.17	4.62	8.74
K_2O	1.51	1.86	1.21	1.47	1.25	1.52	1.44	1.78	1.33	1.64
P_2O_5	0.18	0.17	tr	tr	0.10	0.06	0.28	0.23	0.19	0.18
CO_2	—	—	—	—	tr	tr	—	—	—	—
S	—	—	—	—	0.12	0.22	—	—	0.08	0.18
Cl	—	—	0.17	0.28	—	—	—	—	—	—
H_2O+	1.10	(3.67)	2.69	(8.45)	0.76	(2.37)	1.14	(3.62)	3.09	(9.70)
H_2O-	0.18	—	0.35	—	0.10	—	0.42	—	—	—
	99.57	100.00	99.46	100.28	100.51	100.00	100.04	100.00	100.71	100.00

Norms

Q		—		—		—		9.04		—
Or		9.30		7.35		7.60		8.90		8.20
Ab		32.80		38.25		47.05		40.85		43.70
An		14.35		18.70		15.77		12.55		6.77
C		—		1.03		—		—		—
Wo		10.54		—		4.66		3.40		7.76
En		5.34		14.30		11.54		11.40		8.14
Fs		3.10		5.14		—		2.54		12.12
Fo		8.19		8.16		0.30		—		1.20
Fa		4.59		2.70		—		—		1.86
Mt		6.00		2.89		9.55		7.59		4.93
Hm		—		—		0.22		—		—
Py		—		—		0.33		—		0.27
Il		5.34		1.48		2.82		3.22		4.58
Ap		0.45		—		0.16		0.51		0.47

Mode

Quartz		—		—		—		0.70		—
Albite	An_1	36.60	An_9	33.90	An-	43.80	An_2	53.80	An_5	47.66
Amphibole		35.90		36.70		31.90		21.30		37.17
Epidote		9.30		3.60		—		3.90		—
Biotite		12.30		19.70		6.70		11.80		—
Titanite		3.90		—		3.30		2.30		1.96
Apatite		0.30		—		0.20		0.20		0.34
Carbonate		—		—		—		—		—
Opaques		1.70		3.80		14.00		6.00		10.45
		100.00		97.70		99.90		100.00		97.58

1. Albite diabase. Hukkakumpu, Kittilä, Finland. Anal. L. Lokka (E. Mikkola 1941).
2. Uralite diabase. Leppälä, Paanajärvi, Kuusamo, USSR. Anal. E. Ståhlberg (Hackman and Wilkman 1926).
3. Transitional rock between leucodiabase and common metadiabase. Ruskeakallio, Kuusamo, USSR. Anal. E. Mäkinen (Hackman and Wilkman 1926).
4. Greenstone (albite diabase). Kemi area, Finland. Anal. M. Tavela (Härme 1949).
5. Ophitic albite-hornblende rock (intrusive spilite), Kulmuksa, Aunus, USSR. Anal. P. Eskola (Eskola 1925).

Table 21. Amphibole-pyroxene-albite rocks.

	1		2		3		4		5	
	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %
SiO_2	50.11	47.88	50.39	47.72	51.46	50.26	58.92	53.57	56.24	51.54
Al_2O_3	14.53	16.34	12.81	14.26	11.58	13.30	13.48	14.40	9.88	10.67
TiO_2	1.85	1.32	1.47	1.02	3.38	2.46	2.22	1.53	1.00	0.71
Fe_2O_3	0.04	—	6.07	4.32	6.63	4.86	3.01	2.07	3.83	2.64
FeO	11.16	8.89	7.97	6.31	10.25	8.32	3.32	2.51	4.59	3.52
MnO	0.17	0.11	0.08	0.06	0.32	0.29	0.03	0.02	0.04	0.05
MgO	6.03	8.66	4.83	6.88	2.88	4.22	4.29	5.84	7.89	10.84
CaO	9.44	9.69	9.69	9.83	5.60	5.86	5.99	5.84	9.60	9.41
Na_2O	3.43	6.36	4.12	7.56	4.68	8.85	7.14	12.55	5.63	10.01
K_2O	0.59	0.75	1.15	1.36	1.02	1.29	1.44	1.69	0.47	0.55
P_2O_5	—	—	0.37	0.28	0.34	0.29	0.03	0.02	0.10	0.06
Cl	—	—	0.25	0.40	—	—	—	—	—	—
H_2O+	2.69	(8.54)	0.89	(2.84)	2.54	(8.26)	0.07	(0.22)	0.68	(2.20)
H_2O-	0.13	—	0.40	—	—	—	0.38	—	0.04	—
	100.17	100.00	100.49	100.00	100.68	100.00	100.32	100.04	99.99	100.00
Norms										
Q		—		—		4.94		—		—
Or		3.75		6.80		6.45		8.45		2.75
Ab		31.80		29.80		44.25		62.75		50.05
An		23.07		14.35		7.90		0.40		0.28
Sc		—		6.80		—		—		—
Wo		10.16		12.96		7.60		11.46		18.50
En		8.64		13.40		8.44		7.96		15.08
Fs		7.64		6.22		7.44		—		2.16
Fo		6.51		0.27		—		2.82		4.95
Fa		5.79		0.12		—		—		0.69
Mt		—		6.48		7.29		2.94		3.96
Hm		—		—		—		0.11		—
Il		2.64		2.04		4.92		3.06		1.42
Ap		—		0.76		0.77		0.05		0.16
Mode										
Quartz				0.40		2.60		—		—
Plagioclase		An_{14}		46.90	An_6	49.40	An_4	68.00	An_4	38.7
Scapolite				4.00		—		—		—
Pyroxene				13.60		22.60		1.40		24.8
Amphibole				21.60		+		23.10		34.7
Epidote				—		3.30		—		—
Biotite				—		14.80		—		—
Titanite				3.60		—		3.70		1.6
Apatite				0.90		1.30		0.50		0.2
Carbonate				—		—		1.20		—
Opaques				8.60		4.80		2.10		—
				99.60		98.80		100.00		100.0

1. Medium-grained spilitic diabase. Kammikivitunturi, Petsamo, USSR. Anal. L. Lokka (Väyrynen 1938 a).
2. Metadiabase. Märkäjärvi, Kuolajärvi, (Salla), Finland. Anal. E. Ståhlberg (V. Hackman and Wilkman 1926).
3. Ophitic albite-clinopyroxene rock (intrusive spilite) Kendjärvi, Aunus, USSR. Anal. P. Eskola (P. Eskola 1925).
4. The coarse-grained core of amphibole-pyroxene-albite diabase. Vähä-Kurkkio, Enontekiö, Finland. Anal. A. Heikkinen 1953.
5. The amphibole-rich amphibole-pyroxene-albite rock. Vähä-Kurkkio, Enontekiö, Finland. (The analysis is calculated according to the analyses in Tables 1, 13 and 14).

Table 22. Transitional rocks between the most common varieties of albite rocks and albitites (Carbonate- and quartz-bearing amphibole-albite rocks) See also Tables 7 and 9.

	1		2		3		4		5	
	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %
SiO_2	46.65	41.07	57.88	51.60	60.67	57.90	65.27	59.68	41.65	40.43
Al_2O_3	13.39	13.83	16.11	16.90	11.59	13.00	15.74	16.95	21.58	24.64
TiO_2	1.60	1.06	3.57	2.41	1.85	1.32	0.69	0.49	0.97	0.70
Fe_2O_3	2.33	1.53	4.82	3.21	5.72	4.13	2.23	1.54	2.69	1.98
FeO	4.23	3.12	0.50	0.37	7.29	5.78	3.17	2.41	8.96	7.22
MnO	0.11	0.07	0.01	—	0.09	0.06	tr	—	0.23	0.17
MgO	4.57	6.02	2.02	2.73	1.86	2.69	1.05	1.43	3.33	4.83
CaO	9.11	8.61	3.33	3.16	3.35	3.44	2.74	2.69	6.63	6.87
Na_2O	7.07	12.04	7.96	13.68	5.84	10.76	8.02	14.21	2.78	5.24
K_2O	0.12	0.14	0.27	0.32	0.33	0.40	0.36	0.44	0.81	0.99
P_2O_5	0.16	0.11	0.39	0.27	0.60	0.46	0.18	0.16	0.05	0.06
CO_2	10.32	12.40	—	—	—	—	—	—	5.20	6.87
S	—	—	3.21	5.35	0.03	0.06	—	—	—	—
H_2O+	0.47	(1.37)	0.63	(1.87)	1.33	(4.24)	0.49	(1.48)	4.48	(14.50)
H_2O-	0.06	—	0.30	—	—	—	0.08	—	0.16	—
	100.23	100.00	99.80	100.00	100.55	100.00	100.02	100.00	99.52	100.00
Norms										
Q		0.27		3.38		14.71		9.57		7.68
Or		0.70		1.60		2.00		2.20		4.95
Ab		60.20		68.40		53.80		71.05		26.20
An		4.12		7.25		4.60		5.75		17.15
C		—		—		—		—		11.55
Wo		2.82		—		3.50		2.56		—
En		—		5.46		5.38		2.86		2.80
Fs		2.58		—		5.86		2.30		11.40
Mt		2.30		1.11		6.19		2.31		2.97
Hm		—		0.87		—		—		—
Py		—		4.81		0.09		—		—
Il		2.12		—		2.64		0.98		1.40
Sp		—		5.25		—		—		—
Ru		—		1.15		—		—		—
Ap		0.29		0.72		1.23		0.42		0.16
$CaCO_3$		12.40		—		—		—		6.88
$MgCO_3$		12.04		—		—		—		6.86
$FeCO_3$		0.16		—		—		—		—
Mode										
Quartz		—		—		17.00		10.40		2.50
Albite	An_5	60.00	An_3	75.00	An_4	53.00	An_7	70.20	An_{10}	39.80
Amphibole		10.00		7.00		20.50		16.10		23.10
Epidote		+		7.00		—		—		—
Biotite		+		—		—		2.00		7.80
Chlorite		+		+		—		—		—
Titanite		3.00		8.00		1.00		—		—
Apatite		+		—		1.50		0.40		—
Sericite		—		+		—		—		—
Carbonate		25.00		—		—		—		20.00
Opaques		2.00		+		7.00		0.90		6.80
		100.00		97.00		100.00		100.00		100.00

1. Carbonate-rich leucodiabase. Biddjovagge, Finnmark, Norway (Gjelsvik 1958).
2. Sphene-rich leucodiabase. Biddjovagge, Finnmark, Norway (Gjelsvik 1958).
3. Granophyric albite-hornblende rock. Kuusniemi, Jängärvi, Aunus, USSR. Anal. P. Eskola (Eskola 1925).
4. Quartz keratophyre. Salmijärvi, Puolanka, Finland (Väyrynen 1928).
5. Albite-carbonate diabase. Kitkiövaara, Karunki, Finland. Anal. H. B. Wiik (A. Mikkola 1949).

Table 23. Albitites.

	1 Weight %	1 Cation %	2 Waight %	2 Cation %	3 Weight %	3 Cation %	4 Weight %	4 Cation %	5 Weight %	5 Cation %
SiO_2	60.54	53.76	50.13	44.42	48.76	41.61	55.52	51.10	57.82	53.53
Al_2O_3	11.85	12.36	13.02	13.55	13.46	13.51	16.05	17.40	14.91	16.21
TiO_2	0.45	0.32	1.51	1.01	0.55	0.36	1.38	0.94	2.10	1.44
Fe_2O_3	0.10	0.05	1.38	0.90	—	—	5.84	4.03	7.63	5.27
FeO	0.81	0.59	3.38	2.50	1.02	0.72	2.74	2.10	3.60	2.78
MnO	0.05	0.05	0.44	0.32	0.05	0.05	0.12	0.11	0.01	—
MgO	3.82	5.11	3.73	4.94	6.20	7.93	0.47	0.66	1.93	2.67
CaO	5.94	5.65	7.91	7.49	9.25	8.44	4.90	4.86	2.62	2.61
Na_2O	6.66	11.45	6.75	11.59	6.80	11.21	7.01	12.49	8.29	14.83
K_2O	0.30	0.32	0.12	0.16	0.44	0.46	2.85	3.37	—	—
P_2O_5	0.17	0.11	0.26	0.21	0.07	0.05	tr	tr	0.26	0.22
CO_2	8.46	10.23	10.70	12.91	13.48	15.66	2.31	2.94	0.35	0.44
H_2O+	0.46	(1.39)	0.09	(0.27)	—	—	0.62	(1.88)	0.36	(1.11)
H_2O-	0.06	—	0.13	—	0.35	—	0.07	—	0.10	—
	99.67	100.00	99.55	100.00	100.43	100.00	99.88	100.00	99.98	100.00
FeS_2			0.47							
Norms										
Q		18.08		7.37		4.64		0.17		3.88
Or		1.60		0.80		2.30		16.85		—
Ab		57.25		57.95		56.05		62.45		74.15
An		1.48		4.50		4.60		3.85		3.45
Wo		—		—		—		2.30		2.22
En		0.10		—		—		1.32		5.34
Fs		—		—		0.22		—		—
$CaCO_3$		10.34		12.48		14.88		5.88		0.88
$MnCO_3$		10.12		9.88		15.86		—		—
$FeCO_3$		—		3.46		0.60		—		—
Mt		0.10		0.24		—		3.81		4.02
He		—		0.74		—		1.49		2.59
Il		0.64		2.02		0.72		1.88		2.88
Ap		0.29		0.56		0.13		—		0.59
Mode										
Quartz		20.00		6.50		4.50				
Albite	An_3	59.50	$An-$	57.18	An_2	63.00				
Amphibole		—		—		—				
Biotite		—		6.88		1.00				
Chlorite		1.00		—		—				
Titanite		—		—		—				
Rutile		1.50		2.51		0.20				
Apatite		—		0.60		0.10				
$CaCO_3$		9.60		13.52		14.90				
$MgCO_3$		7.90		4.86		15.80				
$FeCO_3$		0.50		5.09		0.50				
$MnCO_3$		—		0.71		—				
Opaques		—		2.17		—				
		100.00		100.02		100.00				

1. Albite rock (karjalite) Petkula, Sodankylä, Finland. Anal. H. Lönnroth (E. Mikkola 1941).
2. Gabbroic leucodiabase. Ruskeakallio, Kuusamo, USSR. Anal. E. Mäkinen (Hackman and Wilkman 1926).
3. Albitite. Iso-Kurkkio, Enontekiö, Finland. Anal. A. Heikkinen 1953.
4. Keratophyre. Orshoaivi, Petsamo, USSR. Anal. H. Lönnroth (Väyrynen 1938 a).
5. Leucodiabase. W of Teukavaara, Soppero, Sweden. Anal. Th. Berggren (Ödman 1957).

Table 24. Niggli numbers, normative feldspars and carbonate percentages of albite rocks and albitites compared with those of basalts.

													Carbo-

No.	si	al	fm	c	alk	mg	k	ti	p	Or	An	Cc
				Basalts								
1a.	102.2	19.8	53.1	20.9	6.2	0.52	0.09	5.26	0.28	4.2	52.4	—
1b.	115.3	19.4	49.8	23.8	7.0	0.48	0.14	3.83	0.33	8.0	46.8	—
1c.	124.9	19.9	46.0	25.7	8.4	0.42	0.21	3.41	0.31	12.5	40.4	—
				Amphibole-epidote-albite rocks								
2.	109.0	13.7	54.9	24.8	6.6	0.63	0.04	1.68	—	2.5	34.9	1.56
3.	110.9	19.4	52.7	22.2	5.7	0.59	0.07	0.54	0.17	3.2	55.0	—
4.	113.8	18.6	52.7	21.5	7.2	0.49	0.08	1.97	0.09	3.8	44.4	—
5.	117.0	19.8	49.6	23.3	7.3	0.50	0.14	3.57	0.09	7.9	46.1	—
6.	117.8	20.4	48.8	22.2	8.6	0.48	0.06	1.14	—	3.4	40.1	—
7.	121.9	28.8	36.8	24.1	10.3	0.38	0.14	5.32	0.41	7.6	46.9	1.52
8.	125.6	18.8	52.9	19.1	9.2	0.48	0.08	3.87	0.15	4.8	34.3	—
9.	129.5	18.4	47.0	26.8	7.8	0.53	0.13	3.14	0.18	8.0	40.6	—
				Amphibole-albite rocks								
10.	108.9	17.2	52.1	20.5	10.2	0.49	0.22	6.50	0.18	16.5	25.4	—
11.	112.0	18.9	56.0	13.1	12.0	0.62	0.22	0.67	0.04	16.9	22.8	—
12.	113.6	18.0	50.8	23.7	7.5	0.45	0.07	2.49	0.13	3.8	42.3	1.70
13.	127.8	23.5	54.6	9.9	12.0	0.61	0.16	1.96	tr	11.7	27.8	—
14.	129.3	23.5	46.5	15.2	14.8	0.35	0.14	3.83	0.11	10.8	22.4	—
15.	131.3	19.6	51.8	13.0	15.6	0.43	0.03	2.31	0.19	2.6	11.4	1.92
16.	133.3	17.8	53.1	15.0	14.1	0.25	0.16	6.24	0.21	14.0	11.5	—
17.	151.1	22.5	40.0	20.4	17.1	0.40	0.15	4.48	0.18	6.3	13.8	0.52
18.	159.0	22.6	48.9	13.6	14.9	0.35	0.17	4.87	0.34	14.3	20.1	—
19.	159.7	26.8	46.9	9.5	16.8	0.40	0.03	5.40	0.65	3.1	18.1	—
				Amphibole-pyroxene-albite rocks								
20.	115.3	20.4	45.8	23.4	10.4	0.44	0.10	3.60	0.08	6.5	32.4	0.68
21.	120.9	21.8	41.8	23.6	12.8	0.50	0.06	4.89	0.24	3.9	26.6	3.62
22.	121.4	20.8	49.2	18.1	11.9	0.37	0.05	5.42	0.37	3.7	27.8	—
23.	122.6	20.9	45.2	24.8	9.1	0.49	0.11	3.38	—	6.4	39.4	—
24.	122.6	18.2	45.1	25.3	11.4	0.39	0.15	2.63	0.38	13.4	28.2	—
25.	128.8	23.4	44.4	21.4	10.8	0.30	0.06	2.93	0.20	3.6	35.0	0.46
26.	137.1	22.7	47.7	17.4	12.2	0.38	0.12	5.47	0.45	7.9	28.8	—
27.	139.0	14.4	46.0	25.4	14.2	0.64	0.05	1.93	0.10	5.2	0.5	—
28.	142.8	18.8	50.2	16.7	14.3	0.24	0.13	6.99	0.40	11.0	13.5	—
29.	169.4	22.8	43.3	13.7	20.2	0.40	0.11	8.33	0.57	9.9	6.5	tr
30.	175.4	23.6	34.1	19.1	23.2	0.56	0.12	5.00	0.04	11.8	0.6	—
				Biotite-albite, chlorite-albite and amphibole-albite rocks and albitites								
31.	130.4	24.9	50.1	4.3	20.7	0.61	0.37	2.50	1.41	43.5	11.6	14.82
32.	139.1	42.3	35.1	11.8	10.8	0.08	0.17	2.40	0.07	10.3	35.5	13.74
33.	188.7	28.6	37.8	7.6	26.0	0.25	0.00	5.09	0.36	—	4.5	0.88
34.	196.3	30.3	30.3	13.0	26.4	0.22	0.22	1.57	0.00	16.1	5.5	—
35.	200.7	34.3	27.1	7.6	31.0	0.10	0.21	3.69	tr	20.3	4.6	5.88
*36.	205.8	34.7	22.8	12.2	30.3	0.00	0.01	5.29	0.35	1.1	6.3	24.80
37.	205.9	23.0	45.0	12.2	19.8	0.21	0.03	4.68	0.86	3.3	7.6	—
*38.	207.1	33.9	25.3	12.7	28.1	0.43	0.02	9.66	0.59	2.1	9.4	—
39.	227.5	36.8	34.6	3.0	25.6	0.18	0.07	2.06	0.03	6.8	5.3	4.80
40.	233.7	39.5	12.0	12.4	36.1	0.00	0.01	0.24	0.02	0.9	4.6	8.36
41.	239.0	39.4	20.2	2.5	37.9	0.00	0.01	10.08	0.40	0.7	1.9	13.42
42.	245.6	43.9	18.5	1.7	35.9	0.17	0.03	2.44	0.21	3.1	7.5	3.46
*43.	250.1	35.4	22.5	11.3	30.8	0.27	0.03	2.07	0.29	2.8	7.3	—

No.	si	al	fm	c	alk	mg	k	ti	p	Or	An	Cc
					Niggli numbers					Normative feldspar		Carbonate in percentage
44.	251.8	31.1	33.5	11.4	24.0	0.24	0.31	2.83	0.59	26.7	13.3	0.12
45.	280.5	42.6	13.6	6.9	36.9	0.00	0.01	6.38	0.61	1.3	7.1	25.82
46.	295.6	48.0	6.2	4.4	41.4	0.12	0.04	2.55	0.18	3.7	7.3	31.32
47.	325.7	46.4	8.9	3.8	40.9	0.07	0.01	1.73	0.20	1.2	6.3	3.36
48.	344.5	33.2	28.3	14.2	24.3	0.31	0.06	1.16	0.41	2.8	15.5	1.02
49.	352.9	43.1	9.1	4.7	43.1	0.00	0.09	2.02	0.31	8.6	—	13.64
50.	405.2	46.6	5.2	4.0	44.2	0.00	0.03	2.41	0.50	2.7	2.5	20.46
51.	453.6	45.7	13.0	2.2	39.1	0.19	0.02	1.08	0.10	21.3	7.7	tr

Notes: In analyses 31—51, the CO_2 is omitted before calculation as carbonates: $CaCO_3 : MgCO_3 = 1 : 1$. If not enough Mg is present, the required amount has been added from Fe .

Cc is the carbonate content in percentage from one cation molecular norm.

*Amphibole-albite rock in Figure 16, transitional rock in Table 22.

All calculations have been made by the author.

Original rock names, localities and references are shown in the Appendix, p. 70.

In the textures of chlorite-albite and biotite-albite rocks as well as of albitites, small grains of chlorite and biotite fill the interstices between albite grains (Fig. 13). Both chlorite and biotite have crystallized before albite. This is often characterized by the glomeroporphyritic textures of biotite-albite rocks (p. 30), and by inclusions of biotite in albite.

The differentiation of albite diabases is visualized by Niggli numbers (Table 24). The amphibole-epidote-albite rocks are clearly »nearly normal basaltic» with si-numbers 108—130; si = 115 represents normal basalt (Eskola 1946). Amphibole-pyroxene-albite and amphibole-albite rocks fall along the entire differentiation area of albite diabases with si-numbers 108—250. This is in exellent accord with the fact that these rocks often form the amphibole- and/or pyroxene-rich inner marginal zones and the albite-rich cores of the sills. The most acid albite rock varieties, albite-rich amphibole-albite, pyroxene-albite and chlorite-albite rocks, fall on si-numbers 170—250. It must therefore be pointed out in this context that the albite rocks with these values occur as both the most acid component of differentiated albite-diabases (Vähä-Kurkkio, Tenomuotka, Vuontiskero, Ylinen-Munnikurkkio) and as simple sills and even cross-cutting dikes (Gjelsvik 1958). Certain amphibole-poor and often quartz- and/or carbonate-bearing amphibole-albite rocks (Table 22 and 23), commonly called granophyres and keratophyres or sometimes leucodiabases (Hackman and Wilkman 1926, Gjelsvik 1958), are thus really transitional rocks between the most common varieties of albite diabases and albitites. The whole differentiation area of albite diabases, based on the examples available, is limited to the
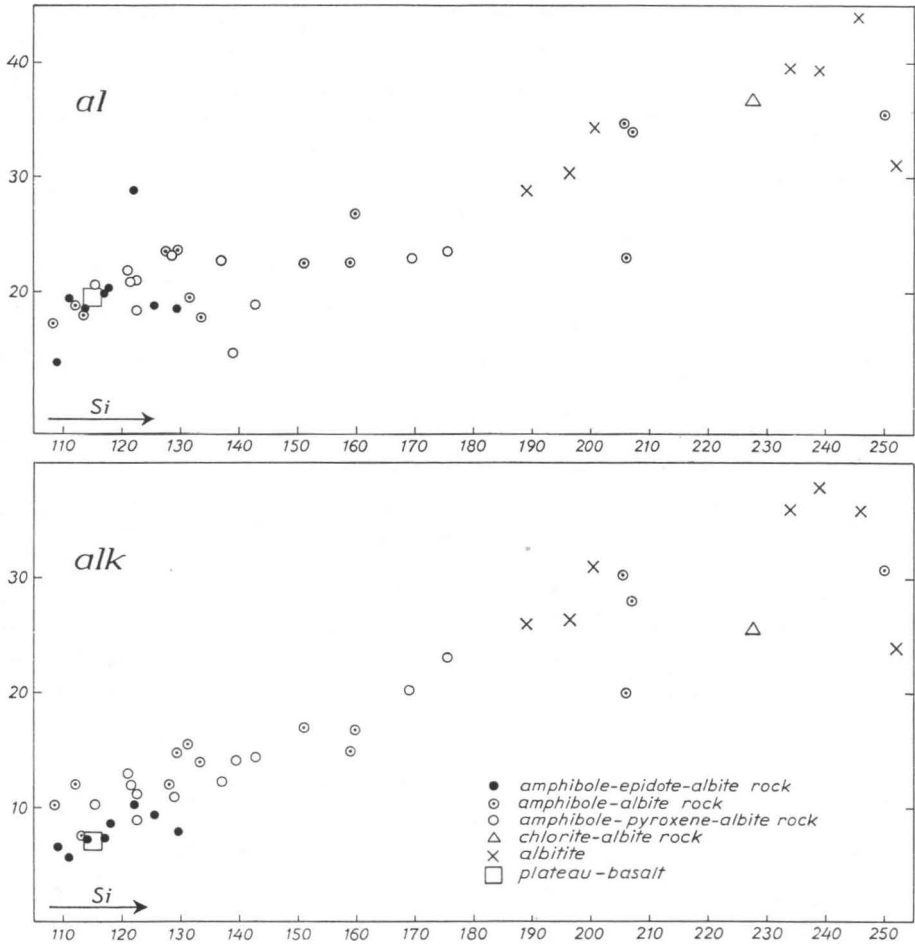
Fig. 18. al- and alk-numbers of Niggli numbers of albite rocks and albitites (Table 24).

si-numbers 108—250. Thus the difference between the si-numbers of the inner marginal zone and core of the most common sill-type, amphibole-epidote-albite diabase, is, in extreme cases, similar to that described above. Albite diabases gradually pass into albitites, as already mentioned, because the composition of the most basic albitites fall on both sides of si-numbers 200 (Table 24). Generally the composition of albitites is between si-numbers 200—500 due to the varying carbonate-, quartz- (quartz keratophyres) and magnetite- (magnetite keratophyres) content. In calculations, CO_2 is assumed to be in carbonates and is omitted as $CaCO_3 : (MgCO_3 + FeCO_3) = 1 : 1$.

The graphic presentation of Niggli-numbers shows that the differentiation of albite diabases takes place after the rules, for with increasing acidity
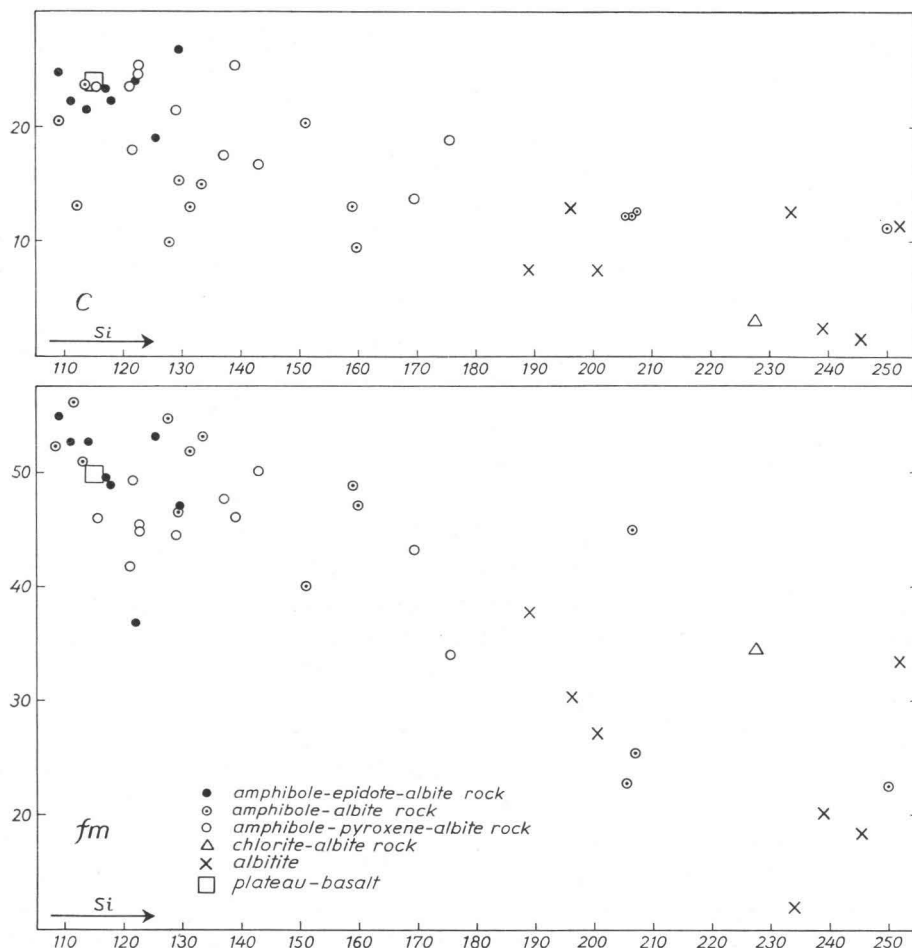
Fig. 19. c- and fm-numbers of Niggli numbers of albite rocks and albitites (Table 24).

of the rocks, the alk- and al-numbers of albite rock varieties increase and the fm- and c-numbers decrease (Fig. 18 and 19).

The distribution of individual metals in albite rock varieties is conformable with magmatic differentiation, or in other words, they obey their geochemical character (Sahama 1947, Rankama and Sahama 1950). The distribution of Al, Mg, Ca, Na and K is especially strict, but the behavior of Fe is vacillating. The Fe percentage is generally higher in amphibole-albite rocks (Table 20) than in amphibole-epidote-albite rocks (Table 19), particularly as regards Fe···, although it should decrease with advancing differentiation as do Mg and Ca. Both the norms and point-counter analyses show, however, that the abundance of iron in the amphibole-albite rocks is partly

caused by the abundance of magnetite. It is worthy of notice that some later differentiates can be rather rich in magnetite as are, for example, magnetite keratophyres and biotite-albite rocks (Table 6). Another cause for the high Fe content of amphibole-albite rocks is that their amphiboles are generally richer in Fe·· and especially in Fe···, than those of amphibole-epidote-albite rocks (p. 43). The behavior of Fe in albite-diabases is clearly similar to that of Fe in quartz-diabases. It is suggested that the high Fe-content of such later differentiates is mainly a result of the different compositions of early- and late-formed mafic minerals (amphiboles, pyroxenes and olivines). This also could have occurred during the differentiation of albite diabases. The concentration of magnetite may be primarily influenced by the abundance of volatiles in the crystallizing magma.

Sodium in amphibole-albite rocks is on the average 1 ½ times and potassium 2 ½ times as abundant as in amphibole-epidote-albite rocks. Potassium therefore has been concentrated in the most acid members of albite diabases to a more marked extent than sodium, thus obeying its geochemical character. There is therefore no reason to doubt that the occurrence of alkali metals is conformable with the magmatic differentiation. In albitites, on the other hand, the amount of potassium has generally definitely decreased when compared with that of albite rocks (Table 24 this paper and Padget 1959). The low potassium content in albitites can not always be referred entirely to its concentration in the more acid varieties of albite diabases. Potassium even concentrates most abundantly in biotite-albite rocks which can occur both as outer and inner marginal zones of albite diabases rich in amphibole and/or pyroxene (p. 24 this paper, Eskola 1925, Väyrynen 1928, 1938 a, A. Mikkola 1949), and as separate sills and veins (p. 29 this paper, Brauns 1909, Eskola 1925, Hackman and Wilkman 1926, Väyrynen 1928, Timofejeff 1935, E. Mikkola 1941, A.·Mikkola 1949, Zbinden 1950).

The enrichment of potassium in biotite-albite rocks is comparable to that in trondhjemites. There the biotite crystallizes from water-bearing magma, with the water derived from sediments, in the early stages of differentiation and results in the paucity or lack of K-feldspar in the later differentiates (Goldschmidt 1922). The crystallization of the biotite of biotite-albite rocks is, however, influenced by the water content of magma, the presence of other volatiles (CO_2, Cl, F, P....) and by the abundant Mg and Fe in the crystallizing magma. The abundance of magnetite and apatite and the high chlorine and fluorine content of biotite in biotite-albite rocks indicates the presence of abundant Fe and volatiles (Tables 6, 7 and 16). An important feature which illustrates the geochemistry of potassium in albite diabases and albitites is the greater enrichment of potassium compared to sodium in some varieties of keratophyres and weilburgites in

certain spilite districts in Germany (Brauns 1909, Lehmann 1933, 1952). Similarly, K-rich syenitic rocks are in some cases found with albite diabases (Väyrynen 1938 a, A. Mikkola 1949). In such associations, the parent magma may have been sporadically differentiated to a more alkalic magma before the intrusion, or very intensive differentiation of a relatively great amount of magma has taken place during and after the intrusion as shown by Rösler (1960). In any case, such »a small part» of the parent basaltic magma from which an albite diabase is differentiated into its respective varieties, is not able to give rise to any K-rich residual magma of »granitic character» because the enriched potash goes into more acid, albite-richer varieties of the main phase of crystallization and to biotite-albite rocks before the residual magma stage (albitites).

The high sodium content of many albite rocks is often explained by the spilitization theory whereby the anorthite part of the original basic plagioclase (labradorite or andesine) is replaced autometasomically by albite (Eskola 1925, 1946). Indefinite relics of basic plagioclase in albite are presented as evidence (Bailey and Grabham 1909, Sundius 1915, Gilluly 1935). It has been stated above in many ways, however, that the sodium content of albite rocks changes with the increase in their acidity as regularly as that of other components and in the manner peculiar to magmatic differentiation. The relics of basic plagioclase can be interpreted as unbalanced relics after some earlier composition of magma. Due to the differentiated structure of many albite diabases the presence of such relics is not only likely but also to be expected. Also, it is not possible to interpret with the spilitization theory, the differentiated structure of many albite diabases, the ophitic texture of basic albite rocks and the hypidiomorphic texture of most acid albite rocks. The sodium-rich clinopyroxene and amphibole of Vähä-Kurkkio, shown in Tables 14 and 15, is also in excellent harmony with the other differentiation phenomena found in albite-diabases.

Calcium of albite rocks is mainly included in epidote, albite, amphibole and clinopyroxene. It is therefore most abundant in the most basic members of albite diabases, true to its geochemical character. Carbonates on the contrary, do not occur in albite rocks, except in a few varieties closely connected with albitites (Tables 6—9, 22 and 24). In albitites, on the other hand, carbonates appear in abundance. This cannot be considered as evidence of the albitization of albite diabases, for the carbonates of albitites are, as members of the dolomite-ankerite series, rich in Mg and Fe-bearing (Table 18). Thus the source of the carbonate cannot have been calcium released by the albitization of basic plagioclase, as the spilite theory presupposes (Eskola 1925, Eskola, Vuoristo and Rankama 1937). The carbonates of albitites are in any case magmatic in origin, which is stressed mainly by the facts that the rock association of albite diabases and albitites occurs

in all spilite provinces and that the albitites pass in places into albite dia-
bases and cut and even brecciate the albite diabases and the wall rocks.
A question which arises in the discussion of albitites is whether they are
crystallized from carbonatic liquids or from solutions assisted by CO_2 and
other volatiles (H_2O, Cl, F, P...). This problem is a complex one and is
also met with in carbonatite studies (Russell, Hiemstra and Groeneveld
1954, Pecora 1956, Smith 1956, Wyllie and Tuttle 1960).

Many similarities and differences occur in rocks of both associations.
Carbonatites, comparable in their high carbonate content to albitites (Öd-
man 1939), are mainly associated with pyroxenites and ijolites. Other
alkali rocks such as nepheline syenites are also often present. The feniti-
zation of wall rocks is a general feature.

The carbonatites frequently occur as one or more bodies in stocks or plugs
of alkalic igneous rocks. Dike-like bodies are rare, but breccias are common
(Pecora 1956). The structure of carbonatites is usually similar to some
fine-grained, nonhomogeneous albitites, for they have markedly weathered
surfaces and compositional differences within individual units. Differences
in grain size, composition and texture occur in bands and knots. They are
weathered out and show »flow structures», which have caused the suggestion
that carbonatites were emplaced in at least a »plastic» state. In albitites
this »flow structure» is visible as variations in biotite content and, most
important, as carbonate-rich streaks (Ödman 1939) and spots. In some
cases this structure was formed in connection with late granulating move-
ments, but may also be a primary magmatic phenomenon. In albite rocks,
and in albitites which are composed almost entirely of albite, true flow
structure is often visible.

Most carbonatites are fairly pure calcite rocks, some are dolomitic, and
some even ankeritic. In albitites, ankeritic dolomite (Table 18) is the
dominant carbonate and calcite is present only in certain thin, cross-cutting
veins.

The »essential» mafic minerals in carbonatites are (Smith 1956, Pecora
1956) biotite, magnetite, apatite, and in some localities, olivine, pyroxene
and occasionally amphibole. They are frequently concentrated in knots,
sheets or veins. The main salic minerals are orthoclase, microperthite,
albite and nepheline. In addition to the »essential» minerals, many acces-
sories are found, some of these occurring in places in noticeable quantities.
The accessories and some main minerals carry rare elements including Ba,
Sr, Nb, Ta, Zr, Ti, Ce, U, Th, and rare earths and also volatile constituents:
Cl, F, P, (H_2O). The carbonatites are distinguishable from metamorphosed
sedimentary carbonate rocks on the basis of rare elements. Some rare
elements such as Zr, Ti, U and volatiles such as H_2O, Cl, F, P, SO_3 .. are
also slightly concentrated in certain albitites and albite-richer albite rocks,

but more commonly in the mineral veins cutting albitites, albite rocks and wall rocks (cit. p. 8).

The structures and textures of albitites are often similar to those of granular or hypidiomorphic albite rocks and hence there is nothing to indicate that they are not liquid-magmatic. On the other hand, some albitites which brecciate wall rocks were intruded very rapidly and were accompanied by gases produced by boiling of the liquid during crystallization. The origin of »veined» albitites (Ödman 1939) may be more disputable. If they were intruded during movements, which is highly possible, their non-homogeneous structure with streaks and spots of carbonate, biotite and sometimes of quartz or magnetite, is not in contradiction to the liquid-magmatic genesis. The hydrothermal and pneumatolytic origin must be, however, kept in mind. The final crystallization of some granophyric rocks such as chlorite-albite rock (p. 32), granophyres (Eskola 1925, Väyrynen 1928) leucodiabases (Gjelsvik 1958) and albitites (Väyrynen 1928, Ödman 1939), could take place from eutectic liquids of albite and quartz (Barth 1952, Turner and Verhoogen 1960). Minor granophyric residual liquids also form during differentiation of quartz diabases and gabbros, which also strengthens the possibility of a liquid-magmatic origin for albitites. But can the carbonates be liquid-magmatic in albitites too?

Some years ago it was impossible, on the grounds of experimental investigations, to suggest any carbonatite magma though such a magma was presented on the plea of field relations, structures, textures and compositions (Tomkeieff 1938, von Eckerman 1948). Recent experiments, however, show that water-bearing carbonatite magma with a composition 68 CaO, 19 CO_2 and 13 H_2O in weight per cent may remain liquid at temperatures of 683° C and at pressures of 1 000 bars. This evidence is strongly against any hypothesis of gas transfer (Wyllie and Tuttle 1960). »Carbonatite liquids can exist either with or without a vapour phase. If the former condition obtains in natural systems, the vapour phase remaining after crystallization of the magma is an adequate source of solutions. If the latter conditions obtains, an external source must supply the circulating solutions and this source might be the parent magma itself. A liquid existing originally without vapour can give off vapour during crystallization. Hydrothermal solutions could then result from condensation at lower temperatures of the vapour produced by boiling during crystallization» (op. cit.).

The carbonates most often separate almost completely from crystallizing albite rocks into »albitite» liquids. After crystallization of albite from this liquid, the carbonate may remain in a plastic state and crystallize slightly later. Due to the internal pressure produced by additional CO_2 ($+H_2O$), crystallizing carbonate finally fractures the albite around it, and fills the cracks (microbreccia). It can also be possible that the albite and

carbonate form two insoluble liquids from which the albite crystallizes first. In that manner the streaks of carbonate etc. are also explicable.

After experimental results, field relations, structures, and textures studied, the liquid magmatic origin of albitites seems possible. The vesicles and spherulites present in some albitites could be due to the boiling of volatiles from crystallizing »albitite» liquid, but they are not by any means proof of the hydrothermal origin of all albitites. It would be, on the contrary, curious if during crystallization of some albitites, such phenomena did not occur. In some instances the evolution of »albitite» magma could occur slowly. The crystallization and cooling finally develop side by side under pneumatolytic or hydrothermal conditions. Possibly in this instance the rare elements have been left in albitites. Such cases are, however, rare.

The role played by volatiles in the differentiation of albite diabases is emphasized by the carbonate content of albitites and by the minerals veins associated with them and albite diabases. However, the volatiles have also been concentrated in the albite diabases. Biotite-albite rocks and grano-phyres (Tables 6, 7 and 22 this paper, Brauns 1909, Eskola 1925) have abundant phosphorus in apatite and many acid varieties of differentiated albite diabases of Enontekiö have chlorine and sulphur in marialitic scapolite (Ohlson 1949). This scapolite is, according to its mode of occurrence, mag-matic in origin. In the albitites of Enontekiö, however, scapolite was never observed. The influence of volatiles in crystallizing magma in general tends to lower its crystallization temperature and advances its differenti-ation. The share of individual components of volatiles (H_2O, CO_2, Cl, F, P..) in the distribution of metals of the principal crystallization products is seldom directly traced. The best examples of this are in albite diabases and albitites; the enrichment of potassium in biotite-albite rocks influenced by the concentration of water; and the enrichment of Ca, Mg and Fe as carbonates in most albitites due to the presence of H_2O and CO_2.

The albite diabases and albitites occur in areas where the initial mag-matic activity is characteristic. The parent magma from which the albite diabases started to crystallize was »normal basaltic» and more strictly speak-ing, probably olivine-basaltic in composition. The olivine-basaltic character of the supposed parent magma is emphasized first by the fact that most common varieties of albite rocks are »nearly olivine-basaltic» or olivine-basaltic amphibole-epidote-albite rocks (Tables 19 and 24). The compo-sitions of all those rocks, however, are not comparable with olivine-basalt magma (plateau magma-type, Bowen 1928/Turner and Verhoogen 1960) for at least slight differentiation has taken place during the intrusion. Also

since the extrusives of spilite-keratophyre associations are »normal basaltic», spilitic and keratophyric (albititic) in composition, similar to the varieties of albite diabases and albitites (Dewey and Flett 1911, Turner 1960), the resumption of an independent spilitic magma in orogenic zones appears quite uncalled-for. In all probability the differentiation of the parent olivine-basaltic magmas, assisted by volatiles as well as tectonical movements, have also given rise to the spilitic and keratophyric extrusives. The course of this process exists, as if consolidated at its various stages, in the different varieties of albite rocks and albitites.

SUMMARY

Albite diabases are either simple or differentiated sills, derived from parent olivine-basaltic magma. Simple albite diabases are homogeneous amphibole-epidote-albite, amphibole-pyroxene-albite, pyroxene-albite, amphibole-albite, chlorite-albite or biotite-albite rocks. Differentiated sills are formed by two or more of the varieties mentioned above. With regard to their chemical compositions, these albite rock varieties form a complete series from the »normal basaltic» (si = 108—130) to the Na-syenitic (si = 230). The latter change gradually into albitites (si = 180—500) which are either carbonate-, quartz- or magnetite-bearing, rich in these minerals, or composed almost entirely of albite. According to the Niggli numbers, the differentiation of albite diabases is regular and the distribution of individual metals has taken place according to their geochemical character.

In addition to the mineral and chemical compositions, the differentiation of albite diabases can be detected in the macrostructures of various differentiated sills and also in the textures of separate albite rock varieties.

The outer marginal variety of the commonest differentiated sill-type, amphibole-epidote-albite diabase, is sometimes biotite-albite or chlorite-albite rock. Immediately on the inside of the outer marginal variety is ophitic »normal basaltic» amphibole-epidote-albite rock. This usually forms the main part of the sill, while the core has been enriched in sodium through a process whereby amphibole crystals were separated from the liquid by differentiation, assisted by magma movements, and volatiles (H_2O, CO_2 Cl, F, P, ...) and the liquid finally crystallized as a coarser-grained, hypidiomorphic amphibole-albite rock very rich in albite. The flow structures are proof of magma movements during crystallization of albite diabases.

Often the differentiation of albite diabases appears only as amphibole- and/or pyroxene-rich inner marginal zones (main part) and coarser-grained cores rich in albite. This may have taken place chiefly because of magma movements and differentiation in the presence of volatiles. The often corroded forms of pyroxene and amphibole grains imply that they must have »swum» in the melt before its final solidification.

The differentiation of albite diabases appears in textures, as the most basic varieties are generally ophitic, the intermediate ones are subophitic, and the most acid ones are hypidiomorphic. The development of textures has thus taken place inside the limits dictated by the composition of the crystallizing melt. The dependence of the textures on the composition of the crystallizing melt is well illustrated by the composition of normative feldspars which are An_{35-55} in nearly normal basaltic amphibole-epidote-albite rocks, An_{14-42} in amphibole-albite rocks and An_{1-40} in amphibole-pyroxene-albite rocks.

Albitites have crystallized from magmatic liquids or solutions after the crystallization of albite diabases.

Mineral veins associated with albite diabases and albitites often characterize the volatiles of the parent magma.

APPENDIX

Explanation to Table 24

Basalts

No

1a. Olivine-basalt magma, Mull; 3 analyses (plateau magma-type) (Mull Memoir, Nos. I—III, 1924/Turner and Verhoogen 1960).

1b. Plateau basalt, 43 analyses (Eskola 1939).

1c. Tholeiitic magma, Hebridean province; 8 analyses (nonporphyritic central magma-type) (Mull Memoir, Nos I—III, 1924/Turner and Verhoogen 1960).

Amphibole-epidote-albite rocks

2. Leucodiabase. W. of Teukavaara, Soppero, Sweden (Ödman 1957).
3. Greenstone (albite diabase). Ahvenjärvi, Kemi-area, Finland (Härme 1949).
4. Intrusive spilite. Valkeasiipivaara, Kiruna, Sweden (Sundius 1930).
5. Albite diabase. Holkkuavaara, Kittilä, Finland (E. Mikkola 1941).
6. Hornblende-albite-epidote rock. Perttilahenvaara, Paadane, Aunus, USSR (Eskola 1925).
7. Albite diabase. Trusham Station Quarry, Teign, Devon, Great-Britain (Dewey and Flett 1911).
8. Albite diabase. Holkkuavaara, Kittilä, Finland (E. Mikkola 1941).
9. Albite-epidote-hornblende diabase. Runkausvaara, Simo, Finland (A. Mikkola 1949).

Amphibole-albite rocks

10. Albite diabase, Hukkakumpu, Kittilä, Finland (E. Mikkola 1941).
11. Intrusive spilite. Valkeasiipivaara, Kiruna, Sweden (Sundius 1930).
12. Hornblende-rich albite diabase. Biddjovagge, Finnmark, Norway (Gjelsvik 1958).
13. Uralite diabase. Leppälä, Paanajärvi, Kuusamo, USSR (Hackman and Wilkman 1926).
14. Transitional rock between leucodiabase and common metadiabase. Ruskeakallio, Paanajärvi, Kuusamo, USSR (Hackman and Wilkman 1926).
15. Feldspar-rich albite diabase. Biddjovagge, Finnmarksvidda, Norway (Gjelsvik 1958).
16. Ophitic albite-hornblende rock. Kulmuksa, Aunus, USSR (Eskola 1925).
17. Albite diabase. Biennejavrre, 3 km E of Masi, West-Finnmark, Norway (Holmsen, Padget and Pehkonen 1957).
18. Greenstone (albite diabase). Kemi area, Finland (Härme 1949).
19. Albite diabase. Poorman Mine, E- Oregon, USA (Gilluly 1935).

Amphibole-pyroxene-albite and pyroxene-albite rocks

20. Dolerite in Serpentine. Chrome Hill, Bowling Alley Point, Nundle, New South Wales, Australia (Benson 1915).
21. Spilite. Frenchman's Spur, Nundle, New South Wales, Australia (Benson 1915).
22. Dolerite, Munro's Creek, Bowling Alley Point, Nundle, New South Wales, Australia (Benson 1915).
23. Medium-grained spilitic diabase. Kammikivitunturi, Petsamo, USSR (Väyrynen 1938 a).
24. Metadiabase. Märkäjärvi, Kuolajärvi (Salla), Finland (Hackman and Wilkman 1926).
25. Albitic spilite. Portion 48, Parish of Nemingha, Nundle, New South Wales, Australia (Benson 1915).
26. Quartz-dolerite. Munro's Creek, Nundle, New South Wales, Australia (Benson 1915).
27. Amphibole-rich amphibole-pyroxene-albite rock. Vähä-Kurkkio, Enontekiö, Finland.
28. Ophitic albite-clinopyroxene rock (intrusive spilite). Kendjärvi, Aunus, USSR (P. Eskola 1925).
29. Quartz-dolerite. Hanging Rock, Nundle, New South Wales, Australia (Benson 1915).
30. Albite-rich amphibole-pyroxene-albite rock. Vähä-Kurkkio, Enontekiö, Finland.

Biotite-albite, chlorite-albite and amphibole-albite rocks and albitites

31. Medium-grained biotite-albite rock. Riikonkoski, Kittilä, Finland.
32. Albite-carbonate diabase. Kitkiövaara, Karunki, Finland (A. Mikkola 1949).
33. Albitite. SW of Öv. Soppero, Sweden (Ödman 1939).
34. Keratophyre. Gwavas Quarry, Newlyn, Cornwall, Great Britain (Dewey and Flett 1911).
35. Keratophyre. Orshoaivi, Petsamo, USSR (Väyrynen 1938).
36. Carbonate-rich leucodiabase. Biddjovagge, Finnmark, Norway (Gjelsvik 1958).
37. Granophyric albite-hornblende rock. Kuusniemi, Jängärvi, Aunus, USSR (Eskola 1925).
38. Sphene-rich leucodiabase. Biddjovagge, Finnmark, Norway (Gjelsvik 1958).
39. Chlorite-albite rock. Nilivaara, Kittilä, Finland.
40. Albite-carbonate rock. Njallavžže, Finnmark, Norway (Holmsen, Padget and Pehkonen 1957).
41. Albite-carbonate rock. Čuojavarre, Finnmark, Norway (Holmsen, Padget and Pehkonen 1957).
42. Keratophyre. Hanging Rock, Nundle, New South Wales, Australia (Benson 1915).
43. Quartz keratophyre. Salmijärvi, Puolanka, Finland (Väyrynen 1928).
44. Albite porphyre. Great King Island, New Zealand (Bartrum 1936).
45. Gabbroic leucodiabase. Ruskeakallio, Kuusamo, USSR (Hackman and Wilkman 1926).
46. Albitite. Iso-Kurkkio, Enontekiö, Finland.
47. Leucodiabase. W of Teukavaara, Soppero, Sweden (Ödman 1957).
48. Quartz keratophyre. Portion 175, Parish of Nemingha, Nundle, New South Wales, Australia (Benson 1915).
49. Albitite. Riettejokka, Finnmark, Norway (Holmsen, Padget and Pehkonen 1957).
50. Albite rock (karjalite). Petkula, Sodankylä, Finland (E. Mikkola 1941).
51. Quartz keratophyre. Great King Island, New Zealand (Bartrum 1936).

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