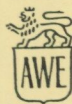


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The chemistry and optical properties of
some minerals of the Alnö alkaline rocks



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**The chemistry and optical properties of some minerals
of the Alnö alkaline rocks**

By HARRY VON ECKERMANN †

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Professor Harry von Eckermann died May 20, 1969. The proofs of this paper were read at the Geological Survey of Sweden.

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Introduction

The original program of my study of the rocks of the Alnö alkaline region included a complete chemical, physical and optical investigation of their minerals. However, owing to financial reasons I have not been able to complete this program yet and several important mineral groups, as for instance carbonates, melilites and fluorites, still remain to be analysed. Others are represented by much-too-short series of analyses. Even if I entertain the hope of being able to add some more analyses and appendant optical data to the 83, which today constitute the result of more than 40 years of intermittent labour, I deem it prudent on account of old age to publish the investigation as it now stands.

The bulk of the costs I have borne myself, but for 38 analyses and arc-spectrograms liberal grants were given by the Lars Hierta Foundation (Stiftelsen Lars Hiertas Minne) and by the Swedish State Research Board (Statens Naturvetenskapliga Forskningsråd, SNFR), for which I am duly grateful. The work started in 1925 in my research laboratory at Ljusne, where the chemist of the local iron works, Mr. G. Haglund, rendered assistance in preparing the samples for analysis as well as preparing the usual standard solutions of the laboratory. It continued when my laboratory was moved to Stockholm in 1926 and was carried on there right up to the closure of the laboratory in 1942. I repeatedly checked my analyses with those of other chemists, as for instance the expert chemist of the University of Zürich, Professor J. Jacob, and believe them to be absolutely reliable. Part of my work was also carried out at the University of Halle, where the late Professor F. von Wolff placed special equipment at my disposal and his assistant Dr. W. Kunitz offered valuable help.

From 1942 I have only done qualitative chemical and micro-chemical work at my

present research laboratory at Ripsa, except for a few complementary quantitative determinations. As early as 1927 I engaged prominent Swedish chemists in order to get the work done quicker. I am greatly indebted to the late Dr. Naima Sahlbom and the late Dr. G. K. Almström, as well as to Miss Telma Berggren of the Boliden Mining Co., to the former head of the laboratory of the mineral department of the Museum of National History of Stockholm (Riksmuseum) Dr. R. Blix and to the late chemist of the Swedish Geological Survey, Captain A. Aaremäe. Besides his own analyses the latter also checked previous analyses and added supplementary determinations.

Qualitative spectrographic analyses of some of the minerals were chiefly made at the Boliden laboratory but a few were carried out elsewhere. The occurrence of elements is symbolized as follows:

- + + Occurs in comparatively large amounts.
- + Occurs. Two of the strongest and last disappearing lines shown in the spectrum.
- [+] Probably occurring, but uncertain. The strongest spectral line observed.
- [-] Uncertain, but probably not occurring.
- Not occurring.

The quantity normally observable was about 0.01 %.

The economizing of research grants prevented me from asking my cooperating chemists for complete analyses, including all minor components. In order to get an indication of their importance besides the one obtained from the arc-spectrograms, the chemical supplementary determinations were restricted to typical minerals within each of the larger mineral groups. For instance, when in case of the micas the SrO contents of 5 analyses out of 11 were found to be less than 0.005 % further determinations were dropped.

For the, unfortunately, rather fragmentary X-ray spectrographic work used for checking the purity of the mineral samples I have to thank my temporary assistant during his short stay in Sweden, the present Professor at the Technische Hochschule in Vienna, Dr. Franz Raaz, who worked at the laboratory of the Riksmuseum, where Professor F. E. Wickman kindly put the necessary equipment at his disposal. I also acknowledge the help of C. Mårtensson, head of the prospecting section of the Swedish Atom Energy Co. (AB Atomenergi), who kindly supplied the uranium and thorium contents of several minerals, and of Dr. Eric Welin, the present acting head of the mineralogical section of the Riksmuseum, who helped me locate radioactive minerals by autoradiograms. Finally, I am very grateful to the late Professor Percy Quenecel, not only for many enlightening discussions at the University and during excursions to Alnö, but also for his kindness to allow me to re-investigate the samples of knopite and pyrochlore originally collected, analysed and described by the late Professor P. J. Holmquist. The latter, who was my teacher at the Technical University (Kungl. Tekniska Högskolan), while still alive took great interest in his old student's work at Alnö and gave me many valuable tips. I also have to thank Miss Barbro Skansfelt for redrawing my diagrams for publication, and SNFR for defrayment of the expenses.

On the advice of the late Professor Gregory Aminoff no chemicals, neither acetic or hydrochloric acid, nor heavy liquids, were used to separate the minerals from their generally more or less carbonate-rich base. Instead they were either removed by means of a burr-drill or by magnetic and centrifugal separations from the crushed rock, which gave a residue from which the mineral was carefully handpicked under

the microscope. In suitable cases monochromatic light or ultraviolet light of several different wavelengths was used to facilitate the separation. It proved, however, in several cases impossible to pick out minerals absolutely free from minute inclusions of carbonate and occasionally also of apatite and microlites. This difficulty occurred especially in pyroxenes, olivines, nephelines and cancrinites. The remaining impurities, reaching a maximum of about 0.5 %, had, therefore, to be deducted from the original analysis. As the carbonate inclusions could be proved by staining to be either calcitic or dolomitic the deductions could be calculated from the carbonic acid content of the analysis with a fairly high degree of accuracy. In the case of indeterminate microlites an uncertainty of the exact composition of the host mineral was in most cases unavoidable. However, whenever possible the calculated results were checked by volumetric analyses of series of thin sections.

Another difficulty arose from the occurrence of small, microscopical vesicles filled with liquid or gaseous CO_2 . They are mostly observed in carbonates and apatites, but may also occur in other minerals, particularly pyroxenes. The first-named two minerals were, in consequence, ground exceedingly fine before analysis and apatites with many inclusions were avoided. In the case of minerals where the grinding had to be discontinued at a coarser grain or where vesicles were left even after excessive grinding the deduction of CO_2 from the original analysis was based on microscopical determination (necessarily somewhat approximative) of the volume percentage of remaining vesicles.

Another cause for disagreement between the analysed composition of the mineral and its optical properties may be the oxidation ratio of the iron. By mistake a sample of pyroxene was left in a mechanical agate-grinder for 48 hours before it was stopped. In the meantime the sample had been ground to dust and both the sample and the agate-pan were quite hot. My own analysis led to a strongly aegirinic pyroxene—a result which did not at all agree with my previous optical determinations. A new analysis of the same pyroxene, ground for a short time, reduced the Fe_2O_3 content by 1.13 % and increased the FeO content correspondingly (analysis no. 55). The almost identical total iron content of the two analyses, 6.66 resp. 6.64 %, proves the homogeneity of the two samples. A repeated prolonged grinding test of another pyroxene sample was analysed by the author and gave 9.38 % Fe_2O_3 . At my request another part of the same sample, ground for a short time, was analysed by Miss Berggren (analysis no. 54). While the other components were identical within a maximum difference of 0.2 %, the Fe_2O_3 of the new analysis was reduced by 2.60 %, the total iron content remaining identical within a limit of 0.04 %. The oxidation effect of prolonged excessive grinding is accordingly confirmed. As the final grinding of the samples has in most cases been carried out by the engaged chemists and beyond my control, the oxidation ratios of the analyses may in some cases not be quite correct.

Finally, many of the Alnö rock minerals, and especially the feric ones, are more or less heterogeneous due to zonal growth, and even if homogeneous minerals were chosen whenever possible, discrepancies between the chemical compositions of two analyses of the same mineral were sometimes unavoidable. They will be further elucidated in the following description of the minerals.

Before the minerals were separated from the rocks by crushing or burr-drill a representative set of thin sections was made from each rock sample. From these sections the axial angles and extinctions of the mineral were determined on the universal stage and the average obtained from each set of thin sections taken to represent the optical constants of the mineral. In zonal minerals these average constants are not

necessarily in complete agreement with the chemical composition. In cases of strong contrasts between kernels and rims both the central and marginal zones were measured and maximum and minimum numerical values recorded.

The refractive indices were in most cases determined by the use of immersion liquids. In cases where even a slight heterogeneity made the determination difficult only maximum and minimum values of n_γ and n_α were recorded. The calculated birefringence was checked against the directly measured one. In a few cases the indices were determined with greater accuracy and four decimals by the tedious method of producing polished prisms and measuring the minimum deviation of a ray of light. The wavelength of light used during the optical determinations is not uniform, but restricted to 589×10^{-6} (D) in most cases and to 550×10^{-6} in some strongly coloured minerals.

The specific gravity was determined by weighing in benzol. As some of the samples included the above-mentioned impurities and vesicles, the true specific gravity of the mineral may in some cases differ somewhat from the one given in this paper. Prolonged pulverization of the sample could, of course, have eliminated the vesicles, but may, on the other hand, in minerals rich in iron have introduced an "oxidation-error" if not carried out in neutral atmosphere, for which method of grinding I lacked the necessary equipment.

The microscopic determinations and the volumetric analyses were mainly carried out with equipment supplied by Leitz. In cases of perfect homogeneity a perfectly adjustable special universal microscope, built to order by the late Fuess, was used when measuring the optic axial angle. While the limits of error of the Leitz detachable universal stage are at least $\pm 1^\circ$ even when great care is taken when attaching and adjusting the stage, those of the Fuess microscope are only $16'$ – $20'$. The accurate determination, however, often presented difficulties in the case of both microscopes owing to strong absorption and dispersion.

Some optical data of the Alnö rock minerals were given in my Alnö Memoir of 1948 (9e). The general aspects of the mineral parageneses were discussed by the author in *Mineralogical Magazine* 1950 (9f) and the C^{12}/C^{13} ratios of the calcite in *Geochimica et Cosmochimica Acta* 1952 (9g). In *Arkiv för mineralogi och geologi* the distribution of Ba and Sr in the minerals has been dealt with in 1952 (9h), the radioactivity of the minerals in 1964 (9q) and the optical data of olivine in 1963 (9p). A paper on the age of radioactive minerals was published together with F. E. Wickman in 1956 (9j) and another on montmorillonite in 1954 (9i). At the meeting of I.M.A. in New Delhi 1964 the analyses and optical properties of a series of Alnö-pyroxenes were discussed and later published in the I.M.A. volume 1966 (9r). Finally, in 1967 the occurrence of wollastonite in Alnö carbonatite rock was described in *Geochimica et Cosmochimica Acta* (9s).

To the now-published sequence of 83 complete mineral analyses and a few partial analyses with appended optical and physical data, I wish to add a caution against believing them wholly representative of the localities where their parent rocks were sampled. Even in one and the same locality the same mineral may show variations in both optical, physical and chemical properties although sampled only a few centimetres or decimetres apart. This is probably due to heterogeneity of the sövitic magma, to local differences in composition and pressure of the volcanic gases and to chemical reactions between dikes and wallrocks.

In the present author's suggestion (9n) the sövite is an accumulation of carbonatitic globules, during a considerable period of time arisen from great depths to the

top of the intruding kimberlite magma. This is the probable explanation of its emplacement, and its heterogeneity is accounted for. If, on the other hand, the sövite should be a transient intrusion of an already-formed differentiate from some deep-seated magma chamber, a more homogeneous composition than the one actually existing would have been expected.

The aberrations of appositional crystals of one and the same mineral may also be due to the heterogeneous composition of the migmatitic gneiss-granite and the more or less rheomorphically liquefied fenites surrounding the sövite. The optical, physical and chemical data of the present investigation are, therefore, average values which are not necessarily in complete agreement with each other although referring to one and the same mineral sample. But even if some data are somewhat approximate, I believe them to give a fairly satisfactory general conception of the characteristics of the Alnö rock minerals.

A map indicating the sites of the sampled minerals is included at the end of this paper. A list of references is also given, and I avail myself of the opportunity to thank my colleagues all over the world for their contributions to my library on alkaline rocks and their minerals. Especially I am under great obligation to Professor Olga Vorobieva of the Academy of Science, Moscow, and her many co-workers, as well as to other prominent Russian scientists for having enlarged my library with many rare books and reprints on alkaline rocks, which have been of great value when studying the similarities and dissimilarities between Russian and Swedish alkaline rock minerals. Unfortunately, limited space allows reference to only a few of my benefactors.

The author is responsible for all micro-photographs as well as for their development. They were all taken on glass-plates, using a Leitz special photographic microscope apparatus.

Sulphides and sulphates

The following minerals have been observed: pyrite, pyrrhotite, chalcopyrite, arsenopyrite, marcasite, sphalerite and barite. Of these only the pyrite and barite have so far been analysed.

Pyrite

Pyrite occurs in most of the Alnö rocks and in increasing percentage towards the sövitic centre, viz. in the marginal fenite zone 0.0–0.4 %, in the central fenite zone 0.3–1.5 %, in the inner leucocratic zone 0.1–2.3 %, and in the inner melanocratic fenite zone 0.1–4.1 % (cf. 9e, p. 43). Of the rheomorphic alkaline rocks the leucocratic ones contain 0.2–0.3 % and the melanocratic ones 0.1–1.8 %.

A concentration of pyrite is found in a few sövite dikes, probably contemporary with the post-magmatic barite dikes, and representing the last hydrothermal volcanic activity. It generally occurs in the centre of the dikes, the marginal parts being almost pure calcite. The crystal forms are commonly cubes, but a few pyritohedra have been observed. A sample was isolated from a dike west of Ås village (cf. 9e, p. 73) and the analysis is given as no. 1.

Fluorite is found to occur within the pyrite crystals as minute inclusions, trapped during the crystallization of the host crystal. This is also shown by the lime and

Analysis no. 1. Pyrite.

Locality: Central zone of a sövite dike rich in pyrite, west of Ås village. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100		Weight %	Mol. prop. × 100
Fe	44.87	80.36	MgO	tr.	—
Pb	0.00	—	MnO	0.00	—
Cu	0.01	—	CO ₂	0.00	—
Bi	0.00	—	Cl	tr.	—
As	0.01	—	SO ₃	0.00	—
S	51.48	160.58	P ₂ O ₅	0.00	—
Se	0.00	—	H ₂ O & F	1.48 ^a	—
CaO	1.46	2.60		99.31	

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 5.098$.

Qualitative spectrographic analysis: Ag +, Ga +, Sb[+].

^a Shown by the author's qualitative analysis to be essentially fluorine.

fluorite contents of the analysis as well as by the specific gravity, which is about 0.030 lower than normal.

Except for inclusions the pyrite is remarkable pure—the only impurities being 0.01 % of Cu and As. The reflectivity for white light ($\lambda = 550$) measured against the “standard” of my collections is 54.1 or slightly lower than that accepted as normal. Optical anisotropy occurs.

Barite

Barite occurs occasionally in most of the rheomorphic alkaline rocks around the sövite centre, in the fenite contacts towards sövite and in the sövite itself. It was found by the old Swedish master Högbom during his first classic survey of the Alnö Island at the end of last century and mentioned in his paper (18, p. 137) but he missed, however, the accumulations of barite in veins, discovered by the present writer in 1940 (9*e*, p. 82). These veins are presumed to represent the last fissures kept open during post-magmatic activity. Three of them are known, one at the bottom of a well, now inaccessible on account of superincumbent buildings, and the other two occurring in the neighbourhood of the villages of Hartung and Pottäng. At Hartung the overburden was removed from part of the vein and samples collected, but no quarrying started, while at Pottäng the deposit was extensively mined during the last world war and supplied the most pressing needs of Swedish industry. Both veins are now waterlogged. Their length are at present unknown, but erratics found between the two localities suggest a more or less continuous series of veins. A total length of 110 metres was exposed during the survey and the mining.

The width of the veins varies from one to three metres of which the central $\frac{2}{3}$ are almost pure barite, while the marginal parts consist of a mixture of barite, calcite and fluorite. The zones of barite and fluorite seem, consequently, to be the inverted ones of, for instance, those found in the Cornish veins (8, Vol. 5, p. 192). The fluorite is in this case also of several different colours occurring in separate zones (see p. 121).

While the barite at Pottäng is slightly pink in patches, the one at Hartung is uniformly white. This difference is not easily explained as the difference in total iron is only 0.001 %. Two analyses, nos. 2 and 3, were made, one from each locality. The

*Analysis no. 2. Barite.**Locality:* Dike north of Pottäng, Alnö Island. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	(Ba,Sr)SO ₄	Impurities and gas- and liquid-filled vesicles
SiO ₂	0.04	0.07		0.07
CO ₂	0.00	—		
TiO ₂	0.00	—		
ZrO ₂	0.00	—		
P ₂ O ₅	n.d. ¹			
Al ₂ O ₃	0.00	—		
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃ (tot.)	0.003	—		
FeO	n.d.			
MnO	0.00	—		
MgO	0.00	—		
CaO	0.00	—		
BaO	65.16	42.49	42.49	
SrO	0.03	0.03	0.03	
Na ₂ O	0.06	0.10		0.10
K ₂ O	0.01	0.01		0.01
F	0.00	—		
Cl	0.02	0.06		0.06
S	n.d.			
SO ₃	34.37	42.93	42.52	0.41
NH ₄ (by author)	0.00	—		
H ₂ O ⁺	0.36	2.00		2.00
H ₂ O ⁻	0.00			
	100.05			

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 4.439$; $2 V_{\text{Na}}$ (observed) = $36^{\circ} \pm 30'$; $2 V_{\text{Na}}$ (calculated) = $35^{\circ}28'$; $n_{\alpha\text{Na}} = 1.636 \pm 0.002$; $n_{\beta\text{Na}} = 1.637 \pm 0.002$; $n_{\gamma\text{Na}} = 1.648 \pm 0.002$; $\delta_{\text{Na}} = 0.012 \pm 0.002$.

¹ n.d. = not determined.

samples, which represent an average across the central barite of each vein, were carefully handpicked in order to eliminate all calcite. In consequence, the analyses contain not even traces of carbonic acid. Analysis no. 2 of the Pottäng barite shows 99.22 % of pure barite, a very small amount of strontium included, and the impurities seem to consist of some kind of hydrous alkali sulphate, silica and chlorine. Analysis no. 3 of the Hartung barite indicates, SrO included, a pure barite content of 98.20 % and a "constitutional" content of 1.09 % of calcium sulphate besides 0.62 % of hydrous alkali sulphate, chlorine and silica. In both cases these impurities were not observable in thin sections, even at high magnification, neither in ordinary, nor in polarized or ultraviolet light. The barites are not fluorescent, while the calcite of the marginal zones strongly fluoresces at a wavelength of 2.537 Å in bright red colour, and the fluorite in different colours (see p. 121).

The specific gravities, the refractive indices and the axial angles are slightly smaller than those generally given in text books, which may be due to the impurities. The barite at Pottäng has crystallized in platy aggregates of locally rose-shaped habit. At Hartung the texture is mostly granular. The marginal contacts of the veins and the adjoining fenite contain several not-yet-determined minerals, which will be made the subject of a later investigation.

Analysis no. 3. Barite.
Locality: 240 m west of Hartung village, Alnö Island. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Impurities and gas- and (Ba,Ca,Sr)SO ₄ liquid-filled vesicles	
SiO ₂	0.13	0.22		0.22
CO ₂	0.00	—		
TiO ₂	0.00	—		
ZrO ₂	0.00	—		
P ₂ O ₅	n.d.			
Al ₂ O ₃	0.01	0.01		0.01
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃ (tot.)	0.002	—		0.002
FeO	n.d.			
MnO	0.00	—		
MgO	0.00	—		
CaO	0.45	0.80	0.80	
BaO	64.48	42.04	42.04	
SrO	0.06	0.06	0.06	
Na ₂ O	0.10	0.16		0.16
K ₂ O	0.03	0.03		0.03
F	0.00	—		
Cl	0.02	0.06		0.06
S	n.d.			
SO ₃	34.45	43.03	42.90	0.13
NH ₄ (by author)	0.00	—		
H ₂ O ⁺	0.18	1.00		1.00
H ₂ O ⁻	0.00			
	99.91			

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 4.399$; $2 V_{\text{Na}}$ (observed) = $35^{\circ}50'$; $2 V_{\text{Na}}$ (calculated) = $35^{\circ}16'$; $n_{\alpha_{\text{Na}}} = 1.635 \pm 0.002$; $n_{\beta_{\text{Na}}} = 1.636 \pm 0.002$; $n_{\gamma_{\text{Na}}} = 1.646 \pm 0.002$; $\delta_{\text{Na}} = 0.011 \pm 0.002$.

Oxides and hydrous oxides

The following minerals have been observed: Magnetite, titaniferous magnetite, ilmenite, haematite, chromite (chrome-spinel), corundum, rutile, anatase, periclase, perovskite, dysanallyte, knopite, pyrochlore and goethite. Of these rutile, anatase, corundum and goethite have not been analysed. The chromite (chrome-spinel), which occurs in kimberlites and alnöites, and the goethite found in mineral pseudomorphs and in radially crystallized grains in the barite vein contacts were only analysed partially or qualitatively.

Magnetite

Pure magnetite seems to be lacking as a primary mineral. Slightly "contaminated" by titanium it occurs, however, as a secondary precipitate within altered olivines. Such olivines were recovered from a large boulder on the sandy sea shore at Släda-viken bay. The boulder must have derived from a large, somewhat metamorphosed kimberlite dike and consisted mostly of olivine pseudomorphs, calcite, phlogopite

Analysis no. 4. Magnetite from boulder on the east coast of Alnö.*Analyst:* N. Sahlbom.

	Weight %	Mol. prop. × 100
SiO ₂	0.05	0.08
TiO ₂	0.26	0.33
Al ₂ O ₃	0.20	0.20
Fe ₂ O ₃	68.31	42.78
FeO	30.76	42.82
n.d.	0.61	
	100.19	

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 5.144$.

and ores of ilmenitic and chromitic composition. The same type of rock has been observed on the mainland in kimberlite dikes, rich in calcite.

The olivine pseudomorphs were crushed and the magnetite separated magnetically. It was only analysed in part and the result is given above as analysis no. 4.

Titaniferous magnetite

The mineral occurs in sövite at Prickskär reef in the sea north of Alnö Island and near the supposed location of the centre of the submerged sövite area. The mineral contains minute microscopical inclusions of pyrite and pyrochlore. It also contains a small amount of silica, which could not, however, be traced by microscopic examination of polished and etched samples. In order not to risk an alteration of the ferric/ferrous ratio by too much grinding these impurities were left in the analysed sample, analysis no. 5. The mineral paragenesis of the Prickskär sövite is: calcite, magnetite, phlogopite and pyrochlore. The magnetite probably represents the last metamorphic stage of an earlier primary ankeritic carbonatite or (and) the ultimate stage of the iron content of fenitized wallrock fragments. As the sövite, according to my interpretation, constitutes the accumulation of ankeritic and dolomitic carbonate globules arisen through the kimberlite magma from great depths and carrying already crystallized pyrochlore (cf. 9*g*, p. 482) the inclusion of the latter in the later crystallized magnetite is but a natural consequence.

The titaniferous magnetite crystals are generally nicely developed octahedrons, but twins have not been observed. The chemical composition is given by analysis no. 5. Of particular interest is the vanadium content.

Another locality, where nicely crystallized titaniferous magnetite octahedrons are found is the now-abandoned sövite quarries south of the western Stolpås farm. The mineral carries inclusions of small phlogopite flakes and minute crystals of pyrrhotite. The phlogopite was removed as well as a few larger pyrrhotites when preparing the analysis-sample, while the minute pyrrhotites were left in order to avoid too-long grinding. The pyrrhotitic nature of the sulphide was checked by the present author by a qualitative analysis. The chemical composition of this titaniferous magnetite is given by analysis no. 6. The content of vanadium was not determined, but a spectrogram indicated its presence together with some Ag, Ga and Sb.

Analysis no. 5. Magnetite rich in titanium.

Locality: In the sövite at Prickskär reef, north of the Alnö Island. Analyst: T. Berggren.

	Weight %	Mol. prop. × 100			Schematic composition (weight %)
		Analysis	Mineral	Pyrite	
SiO ₂	0.32	0.53			Magnetite 71.72
CO ₂	0.00	—			Jacobsite 9.65
TiO ₂	3.89	4.87	4.87		Magnesianferite 8.79
ZrO ₂	n.d.				Ilmenite 7.54
P ₂ O ₅	n.d.				Spinel 1.70
Al ₂ O ₃	1.19	1.17	1.17		Maghemite 0.60
Cr ₂ O ₃	n.d.				100.00
Fe ₂ O ₃	61.86	38.74	38.74		
FeO	25.92	36.08	35.20	0.88	
MnO	2.91	4.10	4.10		
MgO	2.21	5.48	5.48		
CaO	0.13	0.23			0.23
BaO	n.d.				
SrO	n.d.				
Na ₂ O	0.02	0.03			0.03
K ₂ O	0.26	0.28			0.28
F	n.d.				
Cl	n.d.				
S	0.56	1.75		1.75	
SO ₃	n.d.				
V ₂ O ₃	0.55	0.36	0.36		
(Nb,Ta) ₂ O ₅	0.32	0.12			0.12
H ₂ O ^{+105°}	0.14	0.78			
H ₂ O ^{-105°}	0.05				
	100.33				
— O = S	0.27		97.65	1.18	1.17 = 100 % weight
	100.06				

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 4.980$.

Qualitative spectrogr. analysis: Ag +, Ga +, Sb[+], Pb[+].

At Stavsätt iron ore concentrations within the jacupirangite were once mined and used by the small charcoal-blastfurnaces, existing along the western coast of the Baltic during the last century. The ore is a strongly titaniferous magnetite occurring together with titaniferous augite, olivine (partly serpentinized) and apatite (cf. 9e, p. 57). The magnetite seems to have been the last crystallized mineral and shows generally no regular polyhedral forms. A sample of the mineral was prepared from the central part of one of the "ore"-concentrations, containing about 35 % magnetite. Inclusions of olivine could be removed by a moderate pulverization of the sample. The chemical composition is given by analysis no. 7.

Of particular interest is the vanadium oxide content of this analysis, too. When calculating the schematic composition the vanadium has been added to the magnetite. The trace elements have only been determined spectrographically and the presence in all three analyses of similar contents of Ag and Ga is noticeable.

Before the foundation of bridge-pillar no. 8 of the new bridge from the mainland

*Analysis no. 6. Titaniferous magnetite.**Locality:* In the sövite at Stolpås, Alnö Island. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100			Schematic composition (weight %)
		Analysis	Mineral	Impurities	
SiO ₂	0.00	—			Magnetite 69.92
CO ₂	0.00	—			Magnesianoferrite 13.15
TiO ₂	5.83	7.30	7.30		Ilmenite 11.10
ZrO ₂	n.d.				Jacobsite 4.33
P ₂ O ₅	< 0.01	—		< 0.01	Mg-spinel 1.53
Al ₂ O ₃	1.10	1.08	1.08		Impurities 0.07
Cr ₂ O ₃	n.d.				
Fe ₂ O ₃	61.51	38.52	38.52		100.10
FeO	26.91	37.46	37.43	0.03	
MnO	1.30	1.83	1.83		
MgO	3.08	7.64	7.64		
CaO	< 0.01	—		< 0.01	
BaO	n.d.				
SrO	n.d.				
Na ₂ O	0.00	—			
K ₂ O	0.00	—			
F	n.d.				
Cl	n.d.				
S	< 0.01	—		< 0.01	
SO ₃	n.d.				
Pb	0.03	0.02		0.03	
Cu	< 0.01	—		< 0.01	
H ₂ O ⁺	0.00	—			
H ₂ O ⁻	0.00				
	99.76				

Sp. gravity $^{20}_{4}C = 4.978$.

Qualitative spectrographic analysis: Ag +, Ga +, Sb[+], V[+].

to Alnö Island was laid down, the sediments were removed and the uncovered rock at the sea bottom investigated by a series of drillholes. They disclosed the presence of an alnöitic kimberlite brecciating the country rocks. In one of the recovered cores a few exceptionally large, rounded grains of ores were noticed (Pl. II, Fig. 1). As the drillcores were to be kept as documentary evidence, I could not remove enough material for a chemical analysis, but the senior chemist of the Swedish Geological Survey, Mrs Ann-Marie Asklund, licenciante of science, kindly undertook an X-ray examination of the largest of the grains, measuring 15 × 8 mm and located in the centre of the core at the surface of a fracture of the latter. Her assistant, B. M. Eriksson, using Cu/Ni-radiation, found the ore to be mainly magnetite with a cell edge of 8.415 Å. The titaniferous magnetite of Ulvö Islands, to the north of Alnö, has a cell edge of 8.42 Å, while pure Fe₂O₃ has 8.39 Å. A spectral analysis by another assistant, B. Rajandi, indicated a rather high Ti-content, at least several percent, and the usual trace elements Zr, V, Cr, Ni and some Co.

Mrs Asklund wrote that "to judge by the cell edge the titanium occurs in the magnetite phase. We have not been able to indicate the presence of any separate Fe₂TiO₄ phase with a cell edge of 8.39 Å (Ulvö-spinel)".

Analysis no. 7. Titaniferous magnetite.
Locality: In jacupirangitic ore at Stavsätt, Alnö Island. *Analyst:* T. Berggren.

	Weight %	Mol. prop. $\times 100$			Schematic composition (weight %)
		Mineral	Pyrite	Impurities	
SiO ₂	0.00	—			Magnetite 65.02
CO ₂	n.d.				Ilmenite 14.54
TiO ₂	7.57	9.47			Jacobsite 8.20
ZrO ₂	n.d.				Magnesianoferrite 6.07
P ₂ O ₅	n.d.				Maghemite 4.93
Al ₂ O ₃	0.88	0.86			Spinel 1.24
Cr ₂ O ₃	n.d.				100.00
Fe ₂ O ₃	59.37	37.18			
FeO	27.26	37.28	0.67		
MnO	2.49	3.51			
MgO	1.56	3.87			
CaO	0.04			0.07	
BaO	n.d.				
SrO	n.d.				
Na ₂ O	0.02			0.03	
K ₂ O	0.01			0.01	
F	n.d.				
Cl	n.d.				
S	0.43		1.37		
SO ₃	n.d.				
V ₂ O ₃	0.32	0.21			
Nb ₂ O ₅	0.07			0.03	
H ₂ O ⁺	0.07	0.39			
H ₂ O ⁻	0.00				
— O = S	100.09	98.96	0.91	0.14	= 100.01 % weight
	0.20				
	99.89				

 Sp. gravity $^{20}_{4}C = 4.871$.

Qualitative spectrographic analysis: Ag +, Ga +, Sb [+].

Ilmenite

Ilmenite occurs in the sövite and carbonatitic dikes as the ultimate product of the carbonatization of perovskite, or as an earlier crystallized constituent, which may derive either from the parental magma of the carbonatites, kimberlites or melilite basalts, or from the alteration of ankeritic titanium-rich carbonatitic rocks. In the kimberlite dikes rich in calcite ilmenite is occasionally found in fairly large, generally badly crystallized or quite irregular, sometimes spongy grains of up to 15 mm diameter. From such a dike south-east of Bullås a sample of ilmenite was isolated and the impurities, mainly phlogopite and calcite, removed. The chemical composition is given by analysis no. 8, which is rather similar to those published of the ilmenites of Yakutian kimberlites (29, p. 124–125 and 24, p. 88), the main difference being a somewhat higher FeO and correspondingly lower MgO of the Alnö mineral.

*Analysis no. 8. Ilmenite in kimberlite dike at Bullås.**Analyst: H. von Eckermann.*

	Weight %	Mol. prop. × 100	Schematic composition (weight %)	
TiO ₂	50.08	62.68	(TiO ₂) _{50.08} (Fe,Mg,Mn)O _{39.41}	89.49
FeO	32.51	45.25	(Fe,Mg,Mn)O _{1.11} (Fe ₂ O ₃) _{1.07}	2.18
MgO	7.30	18.13	Fe ₂ O ₃	7.94
MnO	0.71	1.00		
Fe ₂ O ₃	9.01	5.64		99.61
	99.61			

Qualitative arc-spectrogram: Nb +, V +, Cr[+], Ni[+].

Specific gravity $^{20}_{4}C = 4.684$.*Haematite*

Haematite has been observed in some kimberlite dikes of high oxidation ratio and in 1–3 mm “kidney-shaped” knobs in the contact zones of the barite veins. A qualitative analysis by the present author shows, besides iron, some manganese and traces of titanium. Specific gravity: 5.296–5.306.

Periclase, brucite

Periclase occurs rarely in calcitic carbonatites (alvikites), but not in the sövite. The dikes have probably originally been dolomitic and the mineral is, in consequence, metamorphic. From an alvikite dike intersecting the sövite dike-breccia south of the western farm at Stolpås 1½ gram of periclase was recovered. Its character had previously been confirmed by staining a polished sample of the carbonatite with silver nitrate. The mineral occurs in small colourless cubic crystals. The specific gravity was found to be 3.668. The refractive index in sodium light: 1.754 ± 0.003 suggests a slight iron contamination. This was also confirmed by an analysis, made by G. K. Almström: MgO 97.10 % and FeO 2.56 %.

Brucite is very seldom found in the Alnö carbonatites. It has never been observed in the alvikitic deep-seated dikes, but in a few cases in the immediate proximity of the sövite contacts. One would have expected it to form in the dikes by hydration of the periclase, as the temperature of the dike magma must have been well below the 650°C limit of Yoder's experiment (36). Either very little water vapour was present or its quantity in comparison to the carbonic acid insignificant.

Chrome-spinel

I have not been able to prove the presence of pure chromite in the Alnö alkaline rocks, but I have found in kimberlites black, nicely crystallized small octahedral minerals, which were fairly rich in Cr according to microchemical tests. An attempt to isolate enough material for a complete chemical analysis failed, and a complete qualitative micro-chemical analysis was made instead. It showed the presence of a dominant content of alumina, large amounts of iron oxides and magnesia, an apparently fairly large amount of chromium oxide and traces of Ti and Ni. Roughly, this seems to agree with the composition of the chrome-spinels of Siberian kimberlites (cf. 29, p. 119).

Anatase

A. G. Högbom observed in carbonatite dikes at Långörsholmen Island small deep-blue birefringent crystals of an unknown mineral (18, p. 247). At this locality, however, they occur only occasionally as single crystals. Brögger, when comparing his Fen rocks with Alnö suggested that the mineral might be anatase. I found the same mineral in a rare type of olivine-(serpentine)-melilite alnöite (9e, analysis no. 74, p. 106) and in several beforstic and alvikitic dike rocks (9e, analyses no. 76, 91, 92 and 105). The mineral occurs in small crystals of "fused" appearance and commonly octahedral in aspect. It is optically negative and uniaxial. An earlier attempt to determine the birefringence failed, but a microchemical analysis left no doubt about the Ti content (9e, p. 100). From the beforstic dike at Bänkåsviken, which contains 1.2% of the blue anatase, I later succeeded in separating 1.2 gram of the mineral, which was analysed at my own laboratory. It was found to be almost pure TiO_2 with 0.17% Fe_2O_3 and <0.10% CaO, the latter probably in minute inclusions of calcite. Optical properties: $\omega = 2.559$, $\varepsilon = 2.487$, $\delta = 0.072$. Specific gravity: 3.847. Pleochroism: ω (deep blue) $>$ ε (blue-gray).

Baddeleyite

Baddeleyite was reported by Hussak (17) to occur in the Alnö rocks. According to von Eckermann (9b), however, it is likely that Hussak mistook melanitic garnet for baddeleyite.

The perovskite-pyrochlore series*Perovskite*

Perovskite occurs in all alnöitic, kimberlitic and carbonatitic dike rocks, but only exceptionally in sövites. In many kimberlites and carbonatite dikes the perovskite is partly altered into ilmenite and calcite. The largest amount of fresh perovskite is generally found in alnöites and dolomitic-ankeritic carbonatites. From a beforstic dike at the shore of the straits between Alnö Island and the mainland a sample of about 4 grams was recovered and analysed, analysis no. 9. The colour of the mineral is generally brownish yellow and in thin section almost colourless. It is slightly pleochroitic, $\gamma > \alpha$. The analysis indicates a very slight tendency of the perovskite towards a "knopitic" and "dysanalytic" composition. Lower refractive indices, observed in perovskite in thin sections from other dikes, indicate locally even greater percentages of rare earths and niobium. Accordingly, a more extensive analytical research would probably disclose a series of intermediate stages from perovskite to dysanalyte and knopite.

The composition of the perovskite is rather similar to the one of the Yakutian kimberlite pipe "Polyarnaya" (29, p. 130). Its rare earth content is probably largely responsible for the rare earth content of the kimberlites within the Alnö Region, which occasionally reaches about one per cent, as for instance in dikes underneath the foundations of the new Alnö bridge.

Dysanalyte

Within the central sövite body north of the Alnö Island dysanalyte occurs in the sövite at the small reef Prickskär. It is evenly distributed throughout the rock to-

Analysis no. 9. Perovskite.

Locality: Beforsite dike at Alvik. *Analyst:* G. K. Almström.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O)	
SiO ₂	0.12	0.20	Si	0.022
Al ₂ O ₃	0.08	0.08	Al	0.017
TiO ₂	58.16	72.79	Ti	7.930
Fe ₂ O ₃	n.d.		Nb	0.049
FeO	2.17	3.02	Fe ⁺²	0.327
MgO	0.02	0.05	Mg	0.005
CaO	39.05	69.63	Ca	7.509
Nb ₂ O ₅	0.21	0.09	Ce,La	0.109
(Ce,La) ₂ O ₃	0.27	0.20		
H ₂ O ⁺	0.08	0.44		
H ₂ O ⁻	0.10			
	100.26			

Composition: (Ca,Mg,Fe⁺²,(Ce,La))_{7.95}(Si,Al,Ti,Nb)_{8.02}O₂₄.

$n_{Na} = 2.376 \pm 0.003$. Spec. gravity $\frac{20}{4}^{\circ}C = 3.991$.

gether with small crystals of phlogopite and titaniferous magnetite. The mineral occurs as nicely crystallized cubes and is megascopically of a very dark brownish, almost black and sometimes bluish black colour, and in thin sections dark brown, isotropic and partly opaque. It is slightly radioactive. As shown by analysis no. 10 the dysanalyte contains substantial quantities of Ta₂O₅, cerium and rare earth metals—by the chemist calculated as CeO₂ on the basis of a spectrogram showing a predominance of cerium. This dysanalyte constitutes, accordingly, a transition to knopite.

This is also the case of another dysanalyte sampled from one of two boulders, pushed up from the sea by the ice onto Stugholmen, a small island north of Alnö within the central sövite body. The mineral paragenesis of the sövite is the same as that of Prickskär, but while the dysanalyte of the latter is homogeneous, this one is mostly of a zonal structure and carries numerous minute inclusions of phlogopitic mica and unidentifiable microlites, which could not be removed from the sample before analysis. This may explain, for one thing, the high silica content of analysis no. 11*a*. The mineral is in patches nearly opaque, the small crystals isotropic, but the larger ones weakly birefringent and lamellarly twinned. In some crystals birefringent and isotropic zones alternate. The crystal forms are not as perfect as in the dysanalyte of analysis no. 10. This may be due to the inclusions and to the uranium content, which makes it strongly radioactive. When calculating the ions on the basis of 24 (O), the ensuing formula does not agree with the general one of perovskite minerals. This is discussed later in connection with the knopite analyses.

Another sample was prepared from the dysanalyte of the other boulder, where the mineral occurs in larger cubic crystals of a size up to 4 mm. The majority are homogeneous without inclusions, slightly birefringent and radioactive. The analysis, no. 11*b*, shows a greater amount of cerium and rare earths, by the chemist calculated as CeO₂, and may be termed a more pronounced knopitic type of dysanalyte than those of analyses nos. 10 and 11*a*.

Evidently, the composition of the dysanalyte varies considerably. To judge by

Analysis no. 10. Dysanalyte.

Locality: In sövite at Pricksjär reef north of Alnö Island. *Analyst:* T. Berggren (Na₂O checked by H. v. Eckermann).

	Weight, %	Mol. prop. × 100	Number of ions on the basis of 24(O)	
SiO ₂	0.28	0.48	Si	0.057
CO ₂	0.00	—	Ti	5.570
TiO ₂	37.80	47.31	Al	0.222
ZrO ₂	n.d.		Mg	0.115
P ₂ O ₅	n.d.		Ta	0.168
Al ₂ O ₃	0.96	0.94	Nb	1.685
Cr ₂ O ₃	n.d.		Fe ⁺²	1.052
Fe ₂ O ₃	tr.		Mn	0.045
FeO	6.40	8.91	Ca	6.260
MnO	0.27	0.38	Na,K	0.196
MgO	0.39	0.97	Ce,La	0.088
CaO	29.72	53.00	Th	0.004
BaO	n.d.			
SrO	n.d.			
Na ₂ O	0.51	0.82		
K ₂ O	0.01	0.01		
F	0.00	—		
Ce(La)O ₂	1.28	0.74		
ThO ₂	0.08	0.03		
U ₃ O ₈	< 0.01	—		
Nb ₂ O ₅	18.97	7.14		
Ta ₂ O ₅	3.13	0.71		
F	0.00	—		
H ₂ O ^{+105°}	0.23	1.28		
H ₂ O ^{-105°}	0.03			
	100.06			

U₃O₈ polarographically determined by G. Wingårdh.

Composition: (Si,Ti,Al,Mg,Nb,Ta)₇₈₂(Fe⁺²,Mn,Ca,Na,K,Ce(La),Th)₇₆₅O₂₄.

Qualitative arc-analysis: Y[+], Zr[+], P[+], Cu[+], As[-], Sn[-], Zn[-].

Sp. gravity: $\frac{20}{4}^{\circ}\text{C} = 4.231$. $n_{\text{Na}} = 2.334 \pm 0.003$.

analysis no. 11b, strontium seems to be dominant over barium, and in all three analyses sodium over potassium.

Dysanalyte also occurs in the carbonatite globules of the kimberlites (9n, p. 34; 9q, p. 482).

Knopite

The late Professor P. J. Holmquist's samples, put at my disposal by Professor Quensel, were collected from boulders on the island Långörsholmen, north of Alnö Island. The boulders do not exist any more. Part of them were sampled by members of an International Geological Excursion in 1910 and the rest was taken care of by the late preparator of the geological institution at Uppsala, A. R. Andersson, who for years did a brisk trade selling knopite crystals to mineralogical institutions and private collectors all over the world.

Analysis no. 11a. Knopitic Dysanalyte.

Locality: Boulders of sövite at Stugholmen, an island north of Alnö Island. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O)	
SiO ₂	5.26	8.76	Si	0.936
TiO ₂	56.88	71.19	Ti	7.620
ZrO ₂	0.14	0.17	Zr	0.018
Al ₂ O ₃	1.48	1.45	Al	0.310
FeO	5.35	7.45	Mg	0.335
MnO	1.10	1.55	Nb,Ta	0.436
MgO	1.26	3.13	Fe ⁺²	0.796
CaO	20.04	35.74	Mn	0.166
SrO	0.03	0.03	Ca,Sr	3.823
Na ₂ O	0.35	0.57	Na	0.118
K ₂ O	0.11	0.12	K	0.026
Ce(La)O ₂	1.02	0.59	Ce,La	0.063
ThO ₂	0.24	0.09	Th,U	0.013
Nb ₂ O ₅ + Ta ₂ O ₅	5.64	2.04		
U ₃ O ₈	0.03	0.01		
Cu	< 0.01	—		
H ₂ O ^{+105°}	1.17	6.49		
100.10				

U₃O₈ polarographically determined by G. Wingårdh.
 Composition (Si,Zr,Ti,Al,Mg,Nb)_{9,65}(Fe⁺²,Mn,Ca,Sr,Na,K,Ta + Nb,Th,
 Ce)_{5,01}O₂₄.
 Sp.gravity: $\frac{20}{4}^{\circ}\text{C} = 4.077$. $n_{\text{Na}} = 2.311 - 2.342$.

The megascopic colour of the mineral is black to bluish black, in thin sections dark brown to opaque and indistinctly faintly birefringent. The crystals are partly cubo-octahedral or octahedral with rounded shiny corners, aptly described by Holmquist (14*b*, pp. 76, 77), and partly cubic with frequently occurring bulging cubic faces. The mineral was previously found only in the above-mentioned boulders and sparsely in sövite breccias on the mainland at Norrvik, north of Klingerfjärden bay, but was later discovered by the present author in the contact zone of the central sövite body and the surrounding fenite at the shore of the sea and recently in the sövite of shoals in the sea, now barely accessible at low water but submerged to a depth of 60–70 cm at the time of Högbom's and Holmquist's surveys. These shoals are distinguished by the strongest radioactivity within the alkaline area and the mineral paragenesis consists of knopite, pyrochlore, titaniferous magnetite, phlogopite and calcite (cf. 9*q*, p. 487 and map).

I seize the opportunity to correct an erroneous statement on page 733 in *Dana's System of Mineralogy, 1944*, Vol. I (6), where knopite is reported occurring in "contact metamorphosed limestone" at Alnö. No such limestone exists in the region, where all "limestones" are magmatically emplaced carbonatitic rocks: sövites, alvikites and beforites.

Two new analyses, nos. 12 and 13, were made from samples collected by Holmquist from different boulders, the former from octahedrons and the latter from cubic crystals. Both chemists gave the Ce and La contents calculated as CeO₂. In neither case was the large content of Holmquist's analysis, 6.81 % Ce₂O₃, confirmed. Further-

Analysis no. 11b. Knopitic Dysanalyte.

Locality: Boulders of sövite at Stugholmen, an island north of Alnö Island.

Analyst: G. K. Almström.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O)	
SiO ₂	0.44	0.73	Si	0.083
TiO ₂	51.04	63.88	Ti	7.310
ZrO ₂	0.10	0.08	Zr	0.009
CO ₂	0.00		Al	0.112
Al ₂ O ₃	0.50	0.49	Mg	0.128
Fe ₂ O ₃	n.d.		Nb	0.325
FeO	6.95	8.28	Ta	0.055
MnO	1.25	1.76	Fe ⁺²	0.948
MgO	0.25	1.12	Mn	0.202
CaO	29.19	52.06	Ca	5.960
SrO	0.04	0.04	Sr	0.004
BaO	tr.	—	Na	0.929
Na ₂ O	2.52	4.06	K	0.014
K ₂ O	0.06	0.06	Ce,La	0.113
Ce(La)O ₂	2.02	1.17	Th	0.014
ThO ₂	0.33	0.12	U	0.003
Nb ₂ O ₅	3.88	1.42		
Ta ₂ O ₅	1.10	0.24		
U ₃ O ₈	0.03	0.01		
F	0.10	0.53		
Cu	< 0.01	—		
H ₂ O ^{+105°}	0.25	1.39		
H ₂ O ^{-105°}	0.11			
	100.16			
- O = F	0.04			
	100.12			

Composition: (Si,Ti,Zr,Al,Mg,Nb,Ta)₈ 0₂(Fe⁺²,Mn,Ca,Sr,Na,K,Ce(La),Th)₈ 1₈(O,F)₂₄.
 Sp. gravity: $\frac{20}{4}C = 4.188$. $n_{Na} = 2.339 \pm 0.003$.

more, Holmquist seems to have overlooked the presence of Th, U, Nb and Ta, and his analyses are probably partly erroneous, but one has to take into consideration that the present methods of chemical analysis of rare elements and the use of spectrography were at the time (1894) still undeveloped. The samples of both analyses were radioactive. The octahedral knopite showed the strongest radiation, probably due to the high Th content.

The compositions of the two knopites, calculated on the basis of 24(O), are strikingly different. While that of the octahedral knopite of analysis no. 12 strongly resembles the one of the knopitic dysanalyte of analysis no. 11*a*, the cubic knopite of analysis no. 13 is normally "perovskitic". If expressed in the general perovskite formula, the calculated compositions would be: analysis no. 12 - A_{1.19}B_{0.63}O₃ and analysis no. 11*a* - A_{1.20}B_{0.69}O₃. On account of the above-mentioned errors in Holmquist's analyses, a corresponding reliable calculation of the composition of his octahedral knopite is not feasible, but a trial leads to A_{1.09}B_{0.82}O₃. An introduction of Nb and Ta in the analysis and a corresponding removal of parts of other components would, however,

Analysis no. 12. Knopite (Dysanalytic).

Locality: Professor P. J. Holmquist's collection at the University of Stockholm from boulders of sövite on Långörsholmen Island. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100		Number of ions on the basis of 24(O)
SiO ₂	3.98	6.63	Si	0.732
TiO ₂	58.00	72.59	Ti	8.025
ZrO ₂	0.25	0.20	Zr	0.022
CO ₂	0.00		Al	0.179
Al ₂ O ₃	0.63	0.62	Mg	0.365
FeO	4.82	6.71	Nb	0.194
MnO	1.64	2.31	Ta	0.011
CaO	18.49	32.97	Fe ⁺²	0.741
Na ₂ O	0.02	0.03	Mn	0.255
K ₂ O	0.15	0.16	Ca	3.650
Ce(La)O ₂	2.89	1.68	Na	0.007
ThO ₂	3.00	1.14	K	0.035
U ₃ O ₈	0.04	0.01	Ce,La	0.186
Nb ₂ O ₅	2.31	0.88	Th,U	0.129
Ta ₂ O ₅	0.23	0.05		
H ₂ O ^{+105°}	1.44	7.99		
H ₂ O ^{-105°}	0.28			
	99.70			

The U₃O₈ determined polarographically by G. Wingårdh.

Arc-spectrogram: Cu +, Pb[+], Y[+], As[-], Sn[-] and Zn[-].

Composition: (Si,Ti,Zr,Al,Mg,Nb,Ta)_{9.53}(Fe⁺²,Mn,Ca,Na,K,Ce(La),Th,U)_{5.00}O₂₄.

Sp. gravity: $\frac{20}{4}^{\circ}\text{C}$ 3.999–4.121. $n_{\text{Na}} = 2.368 \pm 0.005$ (average of 20 determinations).

move the composition of the mineral nearer to those of analyses nos. 12 and 11*a*. Holmquist was fully aware of the disagreement of his analyses with the perovskite formula, explaining it as secondary alterations of the knopites. Even if in very thin sections the knopites appear somewhat blotchy and a few microlites may be seen, the true explanation must be another one. Deer *et al.* (8, Vol. 5, pp. 48–52) recently gave a review of the present opinions of the structural and chemical deviations from the ideal cubic perovskite.

Analysis no. 13 of the cubic knopite agrees fairly well with one of Holmquist's corresponding analyses (14*b*, p. 73), quoted and calculated on the basis of 24(O) by Deer *et al.* (8, Vol. 5, p. 51). As both the analysts responsible for the new dysanalyte and knopite analyses are known as very skilled chemists serious errors must be considered out of question. The present investigation, in consequence, leads to the preliminary conclusion, that two different types of dysanalyte and knopite exist in the Alnö sövites, one of the normal perovskitic formula ABO₃ and one of the abnormal A_{1.80}B_{0.70}O₃. Evidently, these Alnö minerals ought to be much more thoroughly, systematically, structurally and chemically investigated.

Pyrochlore

Pyrochlore occurs sporadically in several of the sövite breccia dikes but has only been found in greater quantity in the about one metre wide central portion of a 3 to 4

Analysis no. 13. Knopite.
Locality: P. J. Holmquist's collection from boulders of sövite on Långörsholmen Island.

Analyst: G. K. Almström.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O)	
SiO ₂	0.06	0.10	Si	0.012
TiO ₂	52.16	65.96	Ti	7.730
ZrO ₂	0.10	0.08	Zr	0.008
CO ₂	0.00	—	Al	0.023
Al ₂ O ₃	0.10	0.10	Mg	0.161
FeO	3.65	3.69	Nb	0.206
MnO	0.66	0.93	Ta	0.007
MgO	0.57	1.41	Fe ⁺²	0.580
CaO	32.56	58.06	Mn	0.106
Na ₂ O	0.60	0.97	Ca	6.630
K ₂ O	0.16	0.17	Na	0.222
Ce(La)O ₂	5.10	2.96	K	0.039
ThO ₂	1.60	0.61	Ce,La	0.336
Nb ₂ O ₅	2.28	0.90	Th	0.070
Ta ₂ O ₅	0.12	0.03	U	0.003
U ₃ O ₈	0.04	0.01		
H ₂ O ^{+105°}	0.21	1.11		
H ₂ O ^{-105°}	0.10			
	100.07			

 Composition: (Si,Ti,Mg,Nb,Ta,Zr)_{8,15}(Fe⁺²,Mn,Ca,Na,K,Ce(La),Th)_{7,99}O₂₄.

 Sp. weight: ²⁰/₄C: 4.231 (average of 10 determinations).

 $n_{\text{Na}} = 2.318 \pm 0.003$ (average of 10 determinations).

metres wide dike running from south of Stavsätt to an outcrop north of Smedsgården. The average content is 0.56% pyrochlore or 0.39% Nb. Additional minerals are 1–2% titaniferous magnetite and some greenish phlogopite.

The mineral was also found in boulders on the island Långörsholmen by P. J. Holmquist, and his remaining samples at the University of Stockholm were kindly placed at my disposal by the late Professor Quensel. The original boulders went the same way as the earlier-mentioned knopite boulders, but the present author has found similar crystals in the sövite of the previously mentioned Sälskär shoals and on several of the islands within the central sövite body. Two analyses were made, one of pyrochlore from Stavsätt and the other from Holmquist's samples (no. 14, resp. no. 15). The author is indebted to AB Atomenergi for the determination of Th and U in two samples from Stavsätt:

	%ThO ₂	%U ₃ O ₈
Pyrochlore from centre of dike	2.31	0.03
Pyrochlore from the marginal part of pyrochlore-rich part of the dike	1.32	0.03

The crystals are more or less octahedral and occur from very small sizes up to 5 mm in diameter. The mineral grains are often rounded and metamict in the centre of the Stavsätt dike, while towards the margins the smaller crystals are strictly octahedral. The colour of the latter is a clear brown and of the metamict ones a dull brown. The

analysis of the Stavsätt pyrochlore does not agree very well with any of the analyses quoted by Van Der Veen from all over the world in his recent large work on pyrochlores (33, tables 2-5*a*). The closest approach seems to be an analysis, no. 38, of pyrochlore from the Khibina alkaline massive, published by Borodin and Nazarenko (4).

Dr Van Der Veen, whom I supplied with a sample of the pyrochlore, wrote me as follows:

"The following observations were made in vertically reflected light. The etch pattern (with concentrated HBF_4) resembled that given by Barsanov (1957) for mendelejevite, euxenite and ampangabeite (cf. resp. plate IV, Fig. 1, 2 and plate VIII, Fig. 1). Differences in etching between areas of higher reflectivity (often somewhat less etched) and other areas were only weak, while some areas of higher reflectivity were more strongly etched. Some of these areas showed after etching a typical trigonal pattern of insertions (cleavages of fersmite in statu nacendi?), see photo 5-27.

The pyrochlore is almost totally metamict. After heating the specimen for one hour to 1000°C an X-ray pattern was observable of a pyrochlore phase (a_0 = about 3.89 \AA) and a fersmite phase.

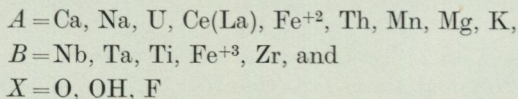
The reflectivity varies between 11.3 and 14.3 (mean 12.1). The micro-hardness of the areas with higher reflectivity varies between 636 and 662 V.H.N. while that of the areas with lower reflectivity varies between 571 and 590 V.H.N. (mean 582). (Vickers Hardness Numbers; load = 100 grams.)"

In the last chapter of his pyrochlore paper Dr. Van Der Veen (33) discusses the $\text{Nb}_2\text{O}_5/\text{Ta}_2\text{O}_5$ ratios of pyrochlores and betafites taken from the literature or analysed by himself. He remarks that the old analyses of P. J. Holmquist (14*a*) are probably not reliable for these elements, but that his own investigation points to a high and sometimes extremely high ratio for pyrochlores from carbonatites, while those from feldspar pegmatites, albitites etc. have a low ratio. As shown by analyses no. 14 and 15 of this paper his conclusion is amply verified in the case of the Alnö pyrochlores.

Neither of the new analyses nos. 14 or 15 of Holmquist's samples agrees very well with his own analyses, quoted by Van Der Veen as nos. 12 and 15. No. 14 contains less Ce + La and much more Ti and Th, and no. 15 lacks Zr and has less alkalis, iron and fluorine. The differences are in the last case too big to be due solely to previous analytical errors. Probably several different sövite boulders were sampled and the pyrochlore from two of them analysed, while the remaining samples were left with the misleading statement that they came from the same sampling. The high potassium contents of Holmquist's analyses of his own samples bring his pyrochlore nearer the koppite of the Fen sövite (Norway).

While the pyrochlore of analysis no. 14 lacked inclusions, that of analysis no. 15 was marginally defiled by minute microlite needles, which were found to be wollastonite, and as such deducted from the original analysis. The determination may, however, be questionable. As the chemist had given only total iron, calculated as FeO, a new determination of both ferric and ferrous iron was made on a remaining part of the sample by Aaremäe, and the original analysis corrected accordingly.

When calculating the composition according to the general formula $A_2B_2X_7$, where



the A-ion group of both analyses is found deficient. This is, for instance, also the case

Analysis no. 14. Pyrochlore.

Locality: Marginal part of pyrochlore-rich sövite dike between Stavsätt and Smedsgården.
Analyst: R. Blix.

	Weight %	Mol. prop. × 100	Atomic ratios on the basis of 2(Nb,Ta,Ti,Zr,Fe ⁺³)	
SiO ₂	0.00	—		
CO ₂	0.00	—		
Al ₂ O ₃	0.00	—		
CaO	17.01	30.33	Ca	1.006
Na ₂ O	3.33	5.37	Na	0.356
K ₂ O	0.26	0.28	K	0.019
ThO ₂	1.32	0.50	Th	0.018
FeO	0.24	0.33	Fe ⁺²	0.011
MnO	0.30	0.42	Mn	0.014
MgO	0.58	1.44	Mg	0.048
Ce(La)O ₂	0.16	0.09	Ce(La)	0.003
Nb ₂ O ₅	61.87	23.83	Nb } Ta }	1.580
Ta ₂ O ₅	0.10	0.02		
TiO ₂	6.06	7.59	Ti	0.252
ZrO ₂	2.55	2.07	Zr	0.068
Fe ₂ O ₃	2.40	1.50	Fe ⁺³	0.100
U ₃ O ₈	0.03	—		—
F	2.75	14.47	F	0.479
H ₂ O ^{+105°}	2.13	11.82	H ₂ O	0.390
H ₂ O ^{-105°}	0.28	—	O	6.000
	101.37			
- O = F	1.16			
	100.21			

Composition expressed in general formula: $A_{1.48}B_{2.00}(O,F,H_2O)_{6.87}$.
 Sp. gravity $^{20^\circ}\text{C} = 4.230$. $n_{\text{Na}} = 1.990 \pm 0.005$.

of the pyrochlore from the Mbeya carbonatite (Tanganyika), analysed by Van Der Veen (33, p. 75).

The pyrochlore of analysis no. 14 is fairly strongly radioactive; that of analysis no. 15 less so. The radioactivity of pyrochlore added to that of knopite in the sövites at Sälskär shoals probably accounts for the very strong local radiation (9l).

*Some remarks on the chemistry of the perovskite–dysanalyte–knopite–
pyrochlore minerals*

In Fig. 1 are plotted the atomic proportions of the essential components of the above-mentioned minerals. Comparing the minerals of analyses nos. 9, 10, 11b and 13, which have "perovskite type" structures with the general formula ABO_3 , the plotted "Ti+Zr+Si+Al" group is of equal size in the case of the perovskite, the dysanalyte no. 11b and the knopite no. 13, while it is smaller in the dysanalyte no. 10. On the other hand, the "Nb+La+Ta+Th" group is larger in the latter case while it is

Analysis no. 15. Pyrochlore.

Locality: Sövite boulders on Långörsholmen Island, collected by P. J. Holmquist 1862.
Analyst: T. Berggren. Iron content checked by A. Aaremäe.

	Weight %	Mol. prop. × 100	Atomic ratios on the basis of 2(Nb,Ta,Ti,Zr,Fe ⁺³)	
CO ₂	0.00	—		
CaO	18.84	33.60	Ca	1.225
Na ₂ O	1.74	2.81	Na	0.205
K ₂ O	0.02	0.02	K	0.001
ThO ₂	0.15	0.06	Th	0.002
FeO	0.40	0.56	Fe ⁺²	0.020
MnO	0.21	0.30	Mn	0.011
MgO	0.15	0.37	Mg	0.014
Ce(La)O ₂	3.69	2.14	Ce(La)	0.078
Nb ₂ O ₅	68.01	25.08	Nb	1.827
Ta ₂ O ₅	1.00	0.23	Ta	0.017
TiO ₂	1.63	2.04	Ti	0.076
ZrO ₂	tr.	—	Zr	—
Fe ₂ O ₃	1.74	1.09	Fe ⁺³	0.080
U ₃ O ₈	tr.	—	U	—
F	2.86	15.05	F	0.544
H ₂ O ^{+105°}	0.55	3.05	H ₂ O	0.110
H ₂ O ^{-105°}	0.10			
	101.09			
- O = F	1.20			
	99.89			

Composition expressed in general formula: $A_{1.56}B_{2.00}(O,F,H_2O)_{7.05}$.

Arc-spectrogram: Ba[+], Tl[+], W[+], Cu[-], Sb[-].

Sp. gravity $^{20^\circ}\text{C} = 4.248$. $n_{\text{Na}} = 2.102 \pm 0.005$.

considerably smaller and equal in the other three analyses. The calcium content reaches a maximum in the perovskite and is about equal in nos. 10, 11*b* and 13. A marked reciprocity of "Ti + Zr + Si + Al" and Ca is noticeable in the case of analyses 11*b* and 13.

The same reciprocity characterizes also the dysanalyte of analysis no. 11*a* and the knopite of analysis no. 12, which depart from the general perovskite formula, but in this case the "Ti + Zr + Si + Al" group reaches maximum and Ca minimum contents.

Turning finally to the pyrochlore analyses nos. 14 and 15, the reciprocity of the "Nb + La + Ta + Th" group and the "Ti + Zr" is almost perfect.

Phosphates

Apatite occurs abundantly in the sövites and constitutes most of the matrix in the sövite breccia boulders on Sälskär shoals (9*l*). Already Högbom proved (18, p. 152) that it is a fluor-apatite and that chlorine and carbonic acid are generally lacking. The present author believed this to be the case, too, until he got the first analysis, no. 16, from the sövite quarry at Smedsgården. He ought to have been warned,

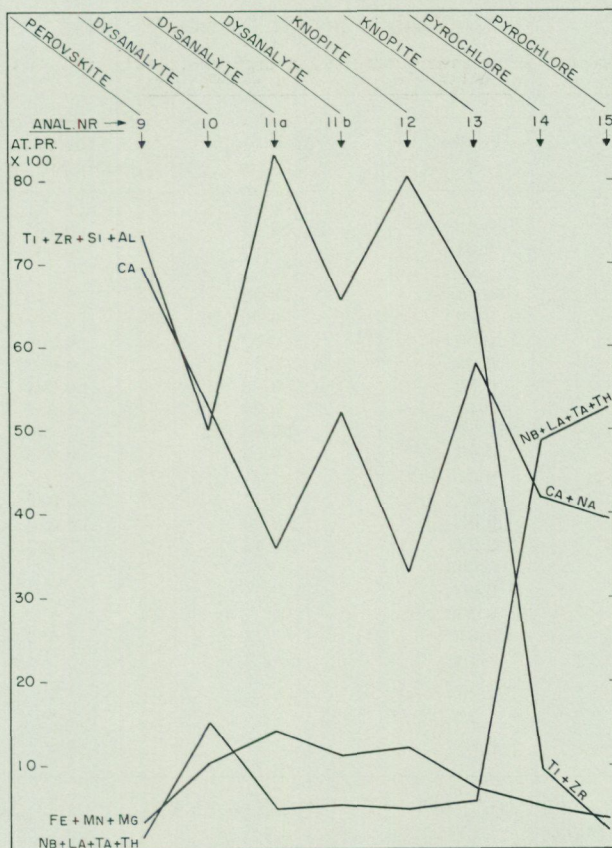


Fig. 1. Atomic proportions of the analyses of the perovskite-pyrochlore series.

however, by the occasionally observed twins in thin sections, which are believed to be a characteristic feature of apatites rich in carbonate (cf. Pl. V, Fig. 1). The apatite at Smedsgården is megascopically of a honey-yellow colour and contains a small amount of impurities, mainly calcite and microlites (pyroxene?). By a staining test the sample was proved to be free from calcite when sent to the chemist, who wrote me as follows: "Although the sample was very pure, I devoted great pains on examining it in a binocular microscope, grain by grain, and removing those containing microlites. The 0.20% unsolved probably represent minute, not observed microlites. Therefore, the sample must be considered extremely pure. There is, in consequence, no doubt of the SiO_2 , CO_2 and FeO contents being constitutional."

This being the case, the mineral is evidently an intermediate member of a series extending from apatite to wilkeite. Adopting the calculation of the formula on the basis of 10 atoms in the Ca group, suggested by Deer *et al.* (8, Vol. 5, p. 329), the result (P-group)_{5.94} (C-group)_{10.00} (F, OH-group)_{2.23} also agrees with an excess in the last group over the theoretical value of 2.00.

Profiting from the experience of Mr. Blix I undertook myself the analysis no. 17

*Analysis no. 16. Apatite.**Locality:* Limestone quarry at Smedsgården. *Analyst:* R. Blix.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 10(Al,Fe,Mn,Mg,Ca,Ba,Na,K)
SiO ₂	0.63	1.05	0.105
CO ₂	0.41	0.93	0.093
TiO ₂	n.d.		
P ₂ O ₅	40.65	28.62	5.740
Al ₂ O ₃	0.20	0.20	0.041
Fe ₂ O ₃	0.03	0.02	0.004
FeO	0.08	0.11	0.012
MnO	0.02	0.03	0.003
MgO	0.40	0.99	0.098
CaO	54.76	97.65	7.796
BaO	0.08	0.05	0.005
SrO	n.d.		
Na ₂ O	0.07	0.11	0.022
K ₂ O	0.08	0.09	0.019
F	2.93	15.42	1.547
Cl	< 0.005	—	
SO ₃	0.00	—	
Unsolved	0.20		
H ₂ O ^{+105°}	0.61		0.683
H ₂ O ^{-105°}	0.10		
	101.25		
— O = F	1.23		
	100.02		

Composition: (Si,P,C)_{5.94}(Al,Fe⁺²,Fe⁺³,Mn,Mg,Ca,Na,K)_{10.00}(F,OH)_{2.23} and (F,O,OH) = 26.53.

Sp. gravity $^{20}_{4}C = 3.221$ (average of 10 determinations).

$\omega_{550} = 1.634 \pm 0.003$ (average of 10 determinations).

$\varepsilon_{550} = 1.630 \pm 0.003$ (average of 10 determinations).

of an apatite from a sövite dike south-east of point 79 on the Alnö map (9e, Pl. 60). The apatite was noticed in a road-cutting, and the wider part of the dike north-west of the road was later exposed by digging.

Miss Berggren had previously tried to isolate the mineral by chemical means, but without real success. Her analysis suggested the atomic composition: P₅₂(Mg₄₇Fe₁₀Ca₉₈(Si, Al)₅₆O₃₉₆ or P(Mg, Fe, Ca)₃(Si, Al)O₈. At my suggestion Miss Berggren looked for and found CO₂ to enter the composition of the mineral, and in my Alnö Memoir (9e, p. 126) it was suggested to be an unknown silico-phosphate. The mineral is distinguished by yellow-brownish colour and stronger refringence than normal apatite (cf. 9e, Pl. 53, Fig. 4). I succeeded in isolating it by mechanical means from an uncovered part of the dike, where it made up about 10 % of the rock. The mineral contains remarkably few solid impurities, mainly calcite, but is, on the other hand, somewhat zoned, the centres being more deeply brownish coloured than the margins. The grains of the analysed sample were handpicked under the microscope and their pureness checked both by staining and by ultraviolet light.

Analysis no. 17. Apatite.
Locality: Farm south-east of Bäräng, Alnö Island. *Analyst:* Harry von Eckermann.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 10(Al,Fe,Mn,Mg,Ca,Na,K)
SiO ₂	3.38	5.63	0.569
CO ₂	0.90	2.05	0.207
P ₂ O ₅	37.04	26.08	5.290
Al ₂ O ₃	0.10	0.10	0.021
Fe ₂ O ₃	0.51	0.32	0.064
FeO	0.11	0.15	0.015
MnO	0.07	0.10	0.010
MgO	0.00	—	
CaO	55.26	98.54	9.806
BaO	n.d.		
SrO	n.d.		
Na ₂ O	0.22	0.36	0.072
K ₂ O	0.01	0.01	0.002
F	2.96	15.58	1.555
H ₂ O ^{+105°}	0.58	3.22	0.643
H ₂ O ^{-105°}	0.11		
	101.25		
- O = F	1.22		
	100.03		

 Composition: (Si,C,P)_{6.07}(Al,Fe⁺³,Fe⁺²,Mn,Ca,Na,K)_{10.00}(F,OH)_{2.20} and (F,O,OH) = 26.61.

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.221$ (average of 10 determinations).

 $\omega_{550} = 1.634 \pm 0.003$ (average of 10 determinations).

 $\varepsilon_{550} = 1.630 \pm 0.003$ (average of 10 determinations).

The analysis (no. 17) proved the mineral to be, not an unknown silico-phosphate, but another intermediate member of the apatite-wilkeite series, with more constitutional SiO₂ and CO₂ and a greater fluorine content than in analysis no. 16. The formula, when calculated on the basis of ten atoms in the Ca-group, is rather similar to the one of the previous analysis: (P-group)_{6.13}(Ca-group)_{10.00}(F, OH-group)_{2.20}.

Finally a third analysis, no. 18, of the reddish apatite in the sövite of Stolpås disused quarry was made by R. Blix. This sövite breccia dike contains up to 27 % apatite—the greatest amount so far recorded at Alnö. Unfortunately this richest part of the dike is only about 0.50 m wide and not worth mining. The reddish colour of the mineral is due to very thin scales of haematite located in cleavages. They could only partially be removed during the preparation of the analysis sample. The rest of the mineral is free of impurities, but full of small vesicles filled with gas, which qualitatively was found to be mainly CO₂. They make the appraisal of the analysis rather difficult. In order to make a discernment of constitutional and trapped CO₂ feasible, 20 thin sections were made and the number of vesicles determined microscopically. The average value of this tedious work was found to be about 12 % of the volume of the mineral, the values of different sections varying from 6 % up to 15 %.

As preliminary tests indicated a great amount of constitutional carbonic acid, the mineral was only slightly pounded in a mortar, in order to remove most of the

*Analysis no. 18. Apatite, rich in SiO₂ and CO₂.**Locality:* Old sövite quarry south of Stolpås. *Analyst:* R. Blix.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 10(Ca,Sr,Ba,Mg,Fe,Mn,Al,Na,K)
SiO ₂	1.48	2.46	0.242
TiO ₂	0.03	0.04	0.004
CO ₂	11.30	25.68	1.653 (CO ₂ in vesicles: 3.92 w. %)
SO ₃	0.20	0.25	0.025
S	0.15	0.47	0.046
P ₂ O ₅	29.13	20.51	4.030
Fe ₂ O ₃	0.55	0.34	0.067
FeO	0.89	1.24	0.122
MgO	1.39	3.45	0.339
CaO	52.50	93.62	9.217
BaO	0.20	0.13	0.013
SrO ^a	0.021	0.02	0.002
Na ₂ O	0.18	0.29	0.057
K ₂ O	0.15	0.16	0.031
Al ₂ O ₃	0.39	0.38	0.075
(RE) ₂ O ₃	0.00	—	—
F	0.77	4.05	0.399
Cl	0.02	0.06	0.006
H ₂ O ^{+105°}	0.38	2.11	0.416
H ₂ O ^{-105°}	0.46	—	—
— O = F	100.19	—	—
	0.32	—	—
	99.87	—	—

^a Spectrogr. by S. Landergren.Composition: (Ti,Si,P,C,S)_{6,00}(Fe⁺²,Fe⁺³,Mn,Mg,Ca,Ba,Sr,Al,Na,K)_{10,00}(F,Cl,OH)_{0,82} and (F,Cl,O,OH) = 25.05.Specific gravity ^{20°C}/₄C = 3.018 (analysed sample) and = 3.154 (powdered sample). $\omega_{550} = 1.590 \pm 0.003$ (analysed sample). $\varepsilon_{550} = 1.593 \pm 0.003$ (analysed sample).

haematite, and analysed. Some of the Fe₂O₃ and by way of a guess about one third of the free carbonic acid, remained in the sample and are, in consequence, not integral parts of the apatite. The total carbonic acid content of the analysis was checked twice by the analyst. Calculating the formula on the basis of 10 atoms in the Ca-group, an amount of C, sufficient to raise the number of atoms in the P-group to 6, was added, which leaves 3.92 % (weight) vesicular CO₂. This is, of course, a very approximate value, but seems reasonable in view of the previously measured vesicular volume and the amount of carbonic acid supposed to have escaped during the preliminary crushing of the sample. As a corroborative evidence may serve the sp. gravity which was found to be as low as 3.018 in the case of the analysed sample, but 3.154 after this had been ground to powder and all vesicles drained.

The constitutional amount of CO₂ in the Stolpås apatite is greater than in any analysis found in the mineralogical literature. At a first look it would be tempting to ascribe most of the CO₂ of the analysis to calcitic contamination, but on further consideration a deduction of calcite would create a rather unlikely relation between the

remaining CaO and the P_2O_5 , viz. between the C- and P-groups. Furthermore, no calcite is observable microscopically. The apatite, no doubt, is an extreme carbonate apatite, but its calculated formula remains approximate, not only on account of the arbitrary allotment of C, but also of the low (F,Cl,OH)-group and (F,Cl,O,OH)-value.

The presence of the above-mentioned, in thin sections translucent, haematite scales in the cleavages of the apatite raises the question whether they originate from secondarily infiltrated iron-solutions or are primary components of the mineral, unstable and exsolved at lower temperature and (or) pressure. A careful microscopical study of their mode of occurrence makes me suggest the second alternative to be the most probable one. This means that the original composition of the apatite when first formed contained a larger percentage of iron oxide. I have previously published an analysis of a blue apatite from Mansjö Mountain, which contained constitutionally both CO_2 and Fe_2O_3 (9a, p. 203).

Thanks to their vesicular carbonic acid content the Alnö apatites weather more rapidly than normal apatites. In cooperation with the agricultural authorities of the county a comparison was made between the Stolpås apatite and an apatite concentrate from the iron ore, rich in phosphorus, of the Kiruna mines. Used as fertilizers the Alnö apatite was found to disintegrate about four times faster than the one which contained neither vesicular nor constitutional carbonic acid. The farmers of the southern part of Alnö Island where acid rocks prevail, have also for hundreds of years used apatite-rich sövite from the northern part to fertilize their fields.

Fluorite

Fluorite occurs profusely at the contacts between sövite and fenite, as well as in sövite, fenite and rheomorphic fenites. It is also found in both calcitic and ankeritic-dolomitic dikes and in ultra-potassic alkaline dikes, such as libernite and borengite. Generally it is of a purplish colour or colourless, but a peculiar series of fluorites of different colours occurs in the marginal parts of the barite veins. In the vein at Hartung at the very contact towards the adjoining gneiss-granite or fenite it is of the usual purple colour, its fluorescence being strongly violet. Within the marginal parts of the vein, however, it is honey-coloured not unlike scheelite, and displays a very weak pale-violet fluorescence. It shows seldom any crystal forms and has repeatedly been mistaken for scheelite by visiting mineralogists during the time the vein was uncovered.

The fluorite assemblage of the Pottäng vein is more complex. The purple mineral is found also here at the contacts, grown at right angles to them towards the vein as a 5–10 mm wide rim. The adjoining fenite is strongly metamorphosed and contains a mineral paragenesis not yet quite elucidated. The about 0.5 m wide marginal part of the vein presents a zoned structure, vividly marked by different colours of three sets of fluorite. In the outmost zone the mineral is brown, in the central zone pale brownish-yellow to clear yellow and in the inner zone green to greenish white. In ultraviolet light of short wavelength, 2.537 Å, the brown fluorite is pale violet or pink, the yellow mineral lemon-yellow and the green one dull-violet. In ultraviolet light of long wavelength, however, the first-named fluorite is yellowish-green, the second intensely golden-yellow and the third one greenish-yellow or yellowish-green. The present author has analysed the five different fluorites only qualitatively and

microchemically, without discovering any difference between them. Neither could any difference be seen by microscopical examination, and the optical data were all similar. X-ray spectrograms (Pl. VI, Fig. 1) show no difference between the four fluorites of the Pottäng vein. Believing that the difference could possibly derive from organic micro-compounds an analysis of NH_4 was performed, but none was found. Gradual changes in temperature and pressure during the formation of the vein may have influenced the colour of the fluorite. Structural "defects" and empty lattice sites may also have to be taken into consideration. The author hopes, however, to return to the problem in connection with the investigation of the mineralization and alteration of the adjoining fenites, and to have the four different coloured fluorites of Pottäng and the two of Hartung fully analysed, trace-elements included.

Framework silicates

Analyses have been made of potash feldspars, feldspar-pseudomorphs in the zone of max. hydration (9e, p. 29), nephelized feldspars, nephelines, altered nephelines, natrolite and cancrinites. Zeolites have not yet been analysed.

Orthoclase

Five analyses were made and are presented below in a series of rising barium content. At the farm Stömsta the orthoclase occurs together with nepheline, natrolite, calcite and titanite in fenite *in situ*. Carlsbad twins are dominant, but Baveno twins occur occasionally. When ready for analysis some calcite and titanite remained in the sample as minute inclusions. They were deducted from the original analysis, which is given as no. 19. Of the impurities 0.38 % (weight) is Fe_2O_3 , which probably accounts for a slight reddish opacity of the mineral.

The accessory minerals of the pegmatitic sövite at Stolpås are: aegirine-augite, soda-orthoclase, natrolite, apatite, melanite and mica. The barium content of the orthoclase was already noticed by Högbom, who published an analysis showing 10.62 % K_2O , 3.78 % Na_2O and 1.52 % BaO . The new analysis, no. 20, presents more potash but less soda and barium. Obviously, the composition varies considerably between different parts of the dike-like intrusion.

In the brecciating sövite of the small separate intrusion area at Båräng a brick-coloured reddish-brown orthoclase occurs in numerous fragments, deriving from the feldspathized wallrocks. The fragments are about even-grained, sharp-cornered and bounded by the partings of the feldspar. Microscopically, the mineral is permeated with minute scales, partly almost colourless but mostly reddish, due to iron pigmentation. A calculation, based on the analysis no. 21, points to a pyrophyllitic or leverieritic composition of the scales. A small amount of ore-dust impurities occurs, too. The present author has previously published a partial analysis of the orthoclase of the sövite-pegmatite at Båräng, which is almost identical with the alkalis and BaO of analysis no. 21, viz. 13.48 % K_2O , 1.11 % Na_2O , 0.72 % BaO and 0.05 % SrO (9e, p. 90).

A bluish-gray orthoclase, rich in barium, characterizes the cancrinite-juvite dike east of Hörningsholm (9e, p. 47). The mineral is nicely prismatic, generally with well developed faces towards the cancrinite and calcite, which occupy the interstices. A preliminary partial analysis, carried out by R. Blix, was published in 1948 (9e, p. 47), and the complete analysis is given as no. 22. Another analysis, no. 23, represents an

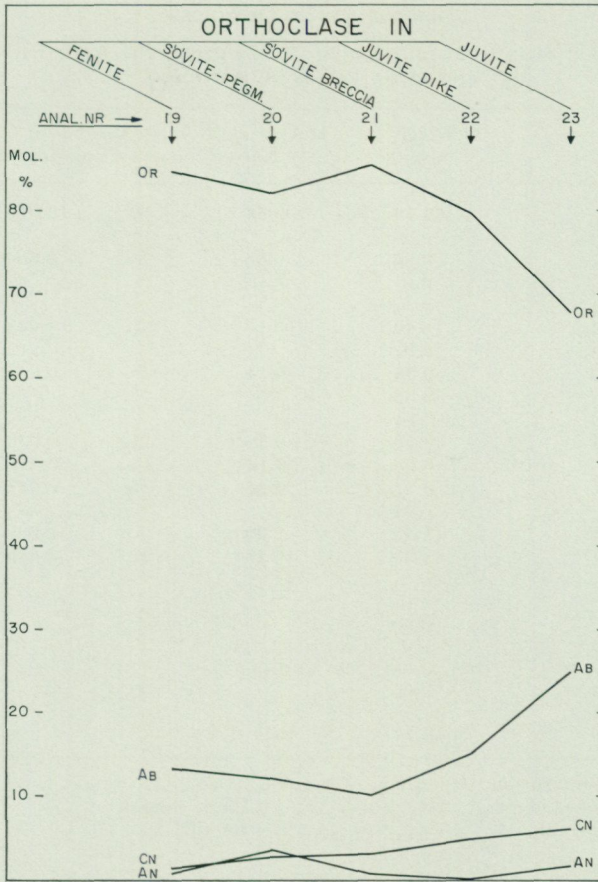


Fig. 2. Molecular proportions of orthoclases.

almost colourless soda-orthoclase rich in barium, isolated from a quarried block at Ås. A very small quantity of minute ore grains could not be removed before analysis. The mineral generally occurs as Carlsbader twins with nicely developed prismatic forms, but occasionally as Baveno twins. Examination of thin sections and microchemical analyses from other localities indicate the existence of apparently homogeneous orthoclases of still higher BaO-content than the 1.62 % of analysis no. 23. For instance, the partial analysis by N. Sahlbom of the soda-orthoclase of the fenite north of the barite vein at Pottäng showed 2.08 % BaO, 13.78 % K₂O and 0.66 % Na₂O, while I had estimated the BaO content to be about 2 % from microchemical tests. As the fenite also contains fluorite, the neighbourhood of the vein is probably the explanation of the increased BaO content (Pl. VII, Fig. 1).

The diagram, Fig. 2, illustrates the molecular proportions of the orthoclase, albite, anorthite and celsian components of analyses nos. 19-23. A proof of the very low content of fluorine is analysis no. 22. In consequence fluorine was not determined in the other analyses. The strontium content is also low, a maximum of 0.05 % SrO

Analysis no. 19. Orthoclase.

Locality: Fenite at Stömsta Farm. *Analyst:* T. Berggren, the oxidation ratio checked by A. Aaremäe.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 32(O)	
SiO ₂	64.19	106.88	Si	12.010
CO ₂	0.00	—		
TiO ₂	0.06	0.08	Ti	0.008
ZrO ₂	n.d.			
P ₂ O ₅	n.d.			
Al ₂ O ₃	18.49	18.14	Al	4.078
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃	0.38	0.24	Fe ⁺³	0.054
FeO	0.00	—		
MnO	< 0.01	—		
MgO	0.13	0.32	Mg	0.036
CaO	0.08	0.14	Ca	0.027
BaO	0.37	0.24	Ba	0.027
SrO	< 0.01	—		
Na ₂ O	1.48	2.39	Na	0.538
K ₂ O	14.39	15.28	K	3.480
F	n.d.			
Cl	n.d.			
S	0.00	—		
SO ₃	n.d.			
H ₂ O ^{+105°}	0.08	0.44		
H ₂ O ^{-105°}	0.09		Z _{16.15}	X _{4.10}
	99.74			

Composition: Or_{85.04}Ab_{12.53}Cn_{0.90}An_{0.39}Imp_{0.80} % weight.

Formula: Or_{86.02}Ab_{12.67}Cn_{0.91}An_{0.40} = 100 % weight.

Formula: Or_{84.65}Ab_{13.24}Cn_{1.33}An_{0.78} = 100 mol. %.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.568$.

$2V_{\text{Na}}$ (observed) = $-66^{\circ} \pm 1^{\circ}$; $2V_{\text{Na}}$ (calculated) = $-64^{\circ}54'$; $n_{\alpha\text{Na}} = 1.519 \pm 0.002$; $n_{\beta\text{Na}} = 1.524 \pm 0.002$; $n_{\gamma\text{Na}} = 1.526 \pm 0.002$; $\delta = 0.007$.

Analysis no. 20. Orthoclase.

Locality: Sövite-pegmatite at Stolpås. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 32(O)	
SiO ₂	62.90	104.73	Si	11.830
CO ₂	0.00	—		
TiO ₂	0.07	0.09	Ti	0.010
ZrO ₂	n.d.			
P ₂ O ₅	n.d.			
Al ₂ O ₃	18.48	18.13	Al	4.090
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃	0.42	0.26	Fe ⁺³	0.059
FeO	0.15	0.21	Fe ⁺²	0.024
MnO	0.01	0.01	Mn	0.001
MgO	0.07	0.17	Mg	0.019
CaO	0.52	0.93	Ca	0.105

Anal. no. 20 (cont.)

	Weight %	Mol. prop. × 100	Number of ions of the basis of 32(O)	
BaO	0.67	0.44	Ba	0.050
SrO	0.04	0.04	Sr	0.005
Na ₂ O	1.36	2.19	Na	0.494
K ₂ O(+ Rb ₂ O)	14.09	14.96	K(Rb)	3.380
F	n.d.			
H ₂ O ^{+105°}	1.04	5.77		
H ₂ O ^{-105°}	0.00		Z _{15,98} X _{4,08}	
	99.82			

 Composition: Or_{83,36}Ab_{11,45}Cn_{1,79}An_{1,75}Imp_{0,39} % weight.

 Formula: Or_{84,88}Ab_{11,56}Cn_{1,80}An_{1,76} = 100 % weight.

 Formula: Or_{81,93}Ab_{11,99}Cn_{2,63}An_{3,45} = 100 mol. %.

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.563$.

 $2 V_{\text{Na}}$ (observed) = $39^{\circ} \pm 1^{\circ}$; $2 V_{\text{Na}}$ (calculated) = $39^{\circ} 28'$; $n_{\alpha\text{Na}} =$
 1.5223 ± 0.0005 ; $n_{\beta\text{Na}} = 1.5278 \pm 0.0005$; $n_{\gamma\text{Na}} = 1.5285 \pm 0.0005$; $\delta = 0.0062$.

Analysis no. 21. Orthoclase.

Locality: Söвите breccia at Bäräng. Analyst: T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 32(O)	
SiO ₂	64.30	107.06	Si	12.020
CO ₂	0.00	—		
TiO ₂	0.06	0.08	Ti	0.009
ZrO ₂	0.00	—		
P ₂ O ₅	n.d.			
Al ₂ O ₃	18.37	18.02	Al	4.111
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃	0.94	0.59	Fe ⁺³	0.132
FeO	0.15	0.21	Fe ⁺²	0.024
MnO	0.00	—		
MgO	0.06	0.15	Mg	0.017
CaO	0.06	0.11	Ca	0.012
BaO	0.73	0.48	Ba	0.054
SrO	0.05	0.05	Sr	0.007
Na ₂ O	1.12	1.81	Na	0.404
K ₂ O	13.68	14.52	K	3.241
F	n.d.			
H ₂ O ^{+105°}	0.43	2.39		
H ₂ O ^{-105°}	0.12		Z _{16,27} X _{3,86}	
	100.07			

 Composition: Or_{80,82}Ab_{9,48}Cn_{1,96}Imp_{7,39} % weight.

 Formula: Or_{87,32}Ab_{10,24}Cn_{2,12}An_{0,32} = 100 % weight.

 Formula: Or_{85,56}Ab_{10,57}Cn_{3,12}An_{0,65} = 100 mol. %.

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.566$. Arc-spectrogram: Cu(-), Ga(-).

 $2 V_{\text{Na}}$ (observed) = $-55^{\circ} \pm 1^{\circ}$; $2 V_{\text{Na}}$ (calculated) = $-53^{\circ} 02'$; $n_{\alpha\text{Na}} =$
 1.520 ± 0.002 ; $n_{\beta\text{Na}} = 1.524 \pm 0.002$; $n_{\gamma\text{Na}} = 1.525 \pm 0.002$; $\delta = 0.005$.

*Analysis no. 22. Soda-orthoclase, rich in barium.**Locality:* Juvite dike east of Hörningsholm. *Analyst:* R. Blix.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 32(O)	
SiO ₂	63.46	105.66	Si	11.880
CO ₂	0.00	—		
TiO ₂	n.d.			
ZrO ₂	n.d.			
P ₂ O ₅	n.d.			
Al ₂ O ₃	18.49	18.14	Al	4.085
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃	0.50	0.31	Fe ⁺³	0.070
FeO	< 0.01	—		
MnO	n.d.			
MgO	< 0.01	—		
CaO	0.00	—		
BaO	1.22	0.80	Ba	0.090
SrO	0.05	0.05	Sr	0.006
Na ₂ O ^a	1.74	2.81	Na	0.632
K ₂ O ^b	13.67	14.51	K	3.260
F	< 0.01	—		
H ₂ O ^{+105°}	0.65	3.61		
H ₂ O ^{-105°}	0.13		Z _{15,97} X _{3,99}	
	99.91			

^a Average of 2 equal determinations.^b Average of 2 determinations, varying 0.04 %.Composition: Or_{80,76}Ab_{15,49}Cn_{4,69}Imp_{2,33} % weight.Formula: Or_{82,87}Ab_{13,88}Cn_{3,25} = 100 % weight.Formula: Or_{79,82}Ab_{15,49}Cn_{4,69} = 100 mol. %.Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.585$. $2 V_{\text{Na}}$ (observed) = $-68^{\circ} \pm 1^{\circ}$; $2 V_{\text{Na}}$ (calculated) = $-67^{\circ} 10'$; $n_{\alpha\text{NaZ}} = 1.520 \pm 0.002$; $n_{\beta\text{Na}} = 1.525 \pm 0.002$; $n_{\gamma\text{Na}} = 1.528 \pm 0.002$; $\delta = 0.008$.

having been recorded. The oxidation ratio, on the other hand, is very high, as shown by Fig. 26, even if the iron oxide percentage does not exceed 0.94 % Fe₂O₃ and 0.15 % FeO. In analysis no. 19 Fe⁺² is even totally lacking.

Optically, the orthoclases are generally homogeneous and no unmixing is observable, even on a microscopic scale.

Analyses illuminating the process of nephelinization

The concept of nephelinization was suggested by the present writer in lectures 1939–40, and in print 1942 and 1948 (9*d*, p. 3). Later he described the narrow zone of maximal hydration and turbidness of the feldspars, generally coinciding with the total disappearance of the quartz (9*l*, p. 29). In order to elucidate the chemical course of the process it was originally the aim of the author to analyse the primary minerals of the different pegmatitic, granitic and gneissous rocks surrounding the alkaline area as well as their alterations, intermediate stages and the finally resulting mineral assemblage. A start was made on the feldspars and four analyses were obtained, when the project had to be abandoned owing to want of financial support. Even if

Analysis no. 23. Soda-orthoclase, rich in barium.
Locality: Quarried block of juvite at Ås. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 32(O)	
SiO ₂	63.41	105.58	Si	11.775
CO ₂	tr.			
TiO ₂	0.10	0.13	Ti	0.015
ZrO ₂	0.00	—		
P ₂ O ₅	n.d.			
Al ₂ O ₃	19.03	18.67	Al	4.160
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃	0.40	0.25	Fe ⁺³	0.056
FeO	0.08	0.11	Fe ⁺²	0.012
MnO	0.02	0.05	Mn	0.007
MgO	0.02	0.05	Mg	0.006
CaO	0.17	0.30	Ca	0.033
BaO	1.62	1.06	Ba	0.118
SrO	0.03	0.03	Sr	0.003
Na ₂ O	2.84	4.58	Na	1.020
K ₂ O	11.91	12.64	K	2.842
F	n.d.			
H ₂ O ^{+105°}	0.32	1.78		
H ₂ O ^{-105°}	0.04		Z _{16.00} X _{4.04}	
	99.99			

 Composition: Or_{70.42}Ab_{24.00}Cn_{4.07}An_{0.84}Imp_{0.32} % weight.

 Formula: Or_{70.59}Ab_{24.16}Cn_{4.10}An_{0.85} = 100 % weight.

 Formula: Or_{67.91}Ab_{24.62}Cn_{5.86}An_{1.61} = 100 mol. %.

 Arc-spectrogram: Cu +, Ga +, P[+], Pb[+], Sn[+], V[+], As[-],
 Be -, Cd -, Cr -, Tl -, Zn -.

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.623$.

 $2 V_{\text{Na}}$ (observed) = $67^{\circ} \pm 1^{\circ}$; $2 V_{\text{Na}}$ (calculated) = $68^{\circ} 14'$; $n_{x\text{Na}} =$
 1.521 ± 0.002 ; $n_{\beta\text{Na}} = 1.527 \pm 0.002$; $n_{\gamma\text{Na}} = 1.529 \pm 0.002$; $\theta = 0.008$.

these analyses are quite insufficient to admit of any deductions whatever, they may serve to illustrate the complexity of the problem and induce somebody else with better economic and technical means at his disposal to tackle it.

For the sampling of the feldspars in question a special and rather tedious method had to be adopted. The rock-sample was cut up into $\frac{1}{2}$ –1 mm thin slabs which were ground and polished until they were transparent. Larger feldspar grains, apparently of similar state of alteration, were then removed, crushed and examined microscopically. The samples were finally accepted for analysis when observable impurities, such as calcite, quartz and ores, had been picked out, and they are believed to have represented within small limits of error the pseudomorphs.

The first analysis of this short series is of pseudomorphs in the above-mentioned zone of maximal hydration of the fenite west of Smedsgården. They are characterized by opacity caused by innumerable small scales, partly colourless, partly yellow or reddish. All attempts to determine optically their evidently varying compositions failed. I have tried instead to distribute the numerical values of analysis no. 24 between hydrated sheet minerals in order to form an idea of what kind of minerals could be represented in the feldspar-pseudomorph, starting from the unproved as-

*Analysis no. 24. Feldspar-pseudomorph.**Locality:* Zone of maximal hydration of the fenite west of Smedsgården. *Analyst:* R. Blix.

	Weight %	Mol. prop. × 100	Schematic composition		
			Mol. %	Weight % ^b	
SiO ₂	42.02	69.96	Sericite ^a	36.75	43.69
CO ₂	0.00	—	Natrolite	15.97	14.73
TiO ₂	0.04	0.05	Edingtonite	1.29	1.19
ZrO ₂	n.d.		Scolezite	32.77	27.31
P ₂ O ₅	n.d.		Pyrophyllite	5.90	6.10
Al ₂ O ₃	33.37	32.74	Boehmite	6.36	6.42
Cr ₂ O ₃	n.d.		Brucite	0.96	0.56
Fe ₂ O ₃	0.80	0.50		100.00	100.00
FeO	0.20	0.28			
MnO	0.006	0.009			
MgO	0.21	0.52			
CaO	3.85	6.87			
BaO	0.25	0.16			
SrO	0.082	0.08			
Na ₂ O	2.36	3.81			
K ₂ O	7.23	7.68			
F	n.d.				
H ₂ O ^{+105°}	8.01	44.46			
H ₂ O ^{-105°}	1.80				
	100.23				

^a Includes Fe₂O₃, replacing Al₂O₃.^b Impurities TiO₂ + MnO = 0.05 % weight, but 0.02 % H₂O wanting.Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.269$ (average of 20 determinations).

sumption that sericite and natrolite were the first to form. Calculations, starting from this or other hypotheses, may of course lead to quite different results, especially as one has to keep in mind that the analysed sample is not a single crystal, but an average of hundreds, chosen at random. As a coincidence may be taken the agreement of the measured specific gravity, 2.569 (average of 20 determinations) and the one calculated for the assumed paragenesis, 2.568. The combination of hydrous minerals, chosen by the author, may not be the best one and the recalculated combination has, of course, no verified equivalence, except in the case of the emerging nepheline, illustrated by analysis no. 25.

This next step in the process of nephelinization begins by the forming of shadowy crystal boundaries of apparent nepheline habit, enclosing scaly hydrated sheet-minerals. The microphoto, Pl. VIII, Fig. 1, illustrates how the nepheline is emerging out of the feldspar when the zone of maximal hydration is moving further away from the fenitizing carbonate intrusion. The two analyses, nos. 25 and 26, were made from samples, both taken near Stömsta—the first one about 10 metres from the maximal hydration zone, the second one about 15 metres closer to the alkaline centre. They show a rising amount of nepheline and a decreasing one of hydrated minerals nearer to the sövite-contact, especially of the potassic and calcic ones. Interesting is the comparatively great barium percentage by comparison with that of the metamorphosed original oligoclase of the gneiss-granite, in which the highest value so far

Analysis no. 25. Nephelinized feldspar.
Locality: Fenite, south-east of Stömsta, Alnö Island. *Analyst:* R. Blix.

	Weight %	Mol. prop. × 100	Schematic composition		
				Mol. %	Weight % ^b
SiO ₂	41.46	69.03	Nepheline	39.17 ^c	44.99
CO ₂	0.00		Natrolite	9.70	8.49
TiO ₂	0.11	0.13	Sericite	22.74 ^a	23.85
ZrO ₂	n.d.		Edingtonite	0.86	0.75
P ₂ O ₅	n.d.		Scolezite	21.75	16.96
Al ₂ O ₃	32.43	31.81	Pyrophyllite	2.12	2.03
Cr ₂ O ₃	n.d.		Boehmite	2.49	2.38
Fe ₂ O ₃	1.26	0.79	Brucite	1.17	0.55
FeO	0.23	0.32		100.00	100.00
MnO	0.02	0.03			
MgO	0.37	0.92			
CaO	2.39	4.26			
BaO	0.17	0.11			
SrO	0.041	0.04			
Na ₂ O	9.50	15.32			
K ₂ O	5.50	5.84			
H ₂ O ^{+105°}	5.10	28.53			
H ₂ O ^{-105°}	1.22				
	99.80				

^a Includes Fe₂O₃, replacing Al₂O₃.

^b Impurities: TiO₂ + FeO + MnO = 0.36 % weight.

^c The refraction measurement of the nepheline is rather uncertain on account of turbidness.

$\omega_{\text{Na}} = 1.540 \pm 0.005$.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.698$ (average of 20 determinations).

recorded is 0.06 %. It seems strange that barium could be carried such a long distance through solid rock by the metamorphosing gases and liquids emanating from the sövite. Possibly, fluorine was an important carrier but unfortunately its content was not determined in the analyses nos. 24–26. Probably, the barium does not occur at all as edingtonite, used by the author when recalculating the analyses, but the almost perfect agreement between actual analytic contents and schematic mineral-combinations was only obtained on this assumption.

The turbidness of the pseudomorph of analysis no. 26 is not only caused by hydrated sheet-minerals but also by swarms of not oriented tiny microlites of unknown character. In spite of the turbidness the nepheline contained a few fairly clear spots, where the refraction could be measured, although the numerical values are but approximate. They are so, too, in the case of analysis no. 27, where the schematic calculations of mineral constituents leads to a content of about 77 % nepheline. In this case the nepheline has clearly developed crystal boundaries, is centrally translucent and marginally interlaced with scaly microlites. The latter could no more be identified than those of the previously analysed pseudomorphs (Pl. IX, Fig. 1).

Another puzzling feature is the SrO content, which, although low, clearly shows a tendency to decrease towards the sövite contact. The fluorine is of about the same order as that of the orthoclases (analysis no. 27). The oxidation ratio (Fig. 26) drops

*Analysis no. 26. Nephelized feldspar.**Locality:* Fenite, north-east of Stömsta. *Analyst:* R. Blix.

	Weight %	Mol. prop. × 100	Schematic composition	
			Mol. %	Weight % ^b
SiO ₂	44.29	73.74	Nepheline ^{a,c}	73.16
CO ₂	0.00		Sericite ^a	6.47
TiO ₂	0.09	0.11	Edingtonite	1.00
ZrO ₂	n.d.		Scolezite	6.86
P ₂ O ₅	n.d.		Pyrophyllite	11.84
Al ₂ O ₃	32.10	31.49	Microlites	0.47
Cr ₂ O ₃	n.d.		(Pyroxene)	
Fe ₂ O ₃	0.71	0.45		100.00
FeO	0.20	0.28		99.80
MnO	0.003	—		
MgO	0.10	0.25		
CaO	0.97	1.73		
BaO	0.37	0.24		
SrO	0.023	0.02		
Na ₂ O	11.25	18.15		
K ₂ O	7.27	7.71		
SO ₃				
H ₂ O ^{+105°}	1.85	10.28		
H ₂ O ^{-105°}	0.80			
	100.03			

^a Includes Fe₂O₃, replacing Al₂O₃.^b Impurities: TiO₂ + FeO = 0.17 % weight, probably distributed over most of the schematic minerals.^c The refraction measurement of the nepheline uncertain on account of turbidness. $\omega_{\text{Na}} = 1.537 \pm 0.005$. $\epsilon_{\text{Na}} = 1.541 \pm 0.005$.Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.589$ (average of 20 determinations).*Analysis no. 27. Nephelized feldspar.**Locality:* East of Ås Village in the fenite between sövite and rheomorphic fenite (juvite).*Analyst:* Harry von Eckermann.

	Weight %	Mol. prop. × 100	Schematic composition	
			Mol. %	Weight % ^b
SiO ₂	42.35	70.51	Nepheline ^c	81.83
CO ₂	0.00		Natrolite	8.12
TiO ₂	tr.		Sericite ^a	5.00
ZrO ₂	n.d.		Edingtonite	0.49
P ₂ O ₅	n.d.		Scolezite	2.89
Al ₂ O ₃	33.88	33.24	Pyrophyllite	1.67
Cr ₂ O ₃	n.d.			100.00
Fe ₂ O ₃	0.32	0.20		100.00
FeO	0.09	0.13		
MnO	< 0.01	—		
MgO	< 0.01	—		

Anal. no. 27 (cont.)

	Weight %	Mol. prop. × 100
CaO	0.41	0.74
BaO	0.15	0.10
SrO	< 0.01	—
Na ₂ O	15.03	24.24
K ₂ O	6.12	6.50
F	0.12	0.63
H ₂ O ^{+105°}	1.54	8.53
H ₂ O ^{-105°}	0.10	
	100.11	

^a Includes part of Fe₂O₃, replacing Al₂O₃.

^b Impurities: part of Fe₂O₃ + FeO = 0.29 % weight. Not observable in thin sections. The fluorine is not included in the calculation of schematic components.

^c The refraction measurements of the nepheline uncertain on account of turbidness.

$\omega_{\text{Na}} = 1.538 \pm 0.005$.

$\epsilon_{\text{Na}} = 1.534 \pm 0.005$.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.698$ (average of 20 determinations).

towards the sövite contact—a phenomenon contrary to expectation. Generally, the CO₂ in the vicinity of the contact ought to increase on account of the CO₂ of the fenite reaction “CaCO₃ + SiO₂ → CaSiO₃ + CO₂” being added to that of the sövite magma. The short series of analyses may, however, not allow any general conclusions and the decreasing oxidation ratio may, therefore, be accidental.

The molecular proportions of the essential oxide components of analyses nos. 24–27 have been plotted in Fig. 3. The diagram illustrates how the contents of SiO₂, (Al, Fe)₂O₃ and K₂O vary within very narrow limits while H₂O decreases rapidly and Na₂O increases in an approximate proportion of Na₂O:H₂O=2:1 at increasing distance from the zone of maximum hydration. Analysis no. 27 differs from the following nepheline analysis no. 28 merely by less water and correspondingly more RO and Na₂O.

Nepheline and nepheline pseudomorphs

Nepheline occurring in melteigite west of Hörningsholm is represented by analysis no. 28. The mineral paragenesis of the melteigite comprises roughly 58 % aegirine-augite, 36 % nepheline, 3 % melanite, 2 % calcite and 1 % wollastonite. Occasionally small yellow grains of cancrinite may be found. The rock sample, from which the nepheline was isolated, did not contain any visible cancrinite, neither megascopically nor microscopically. The nepheline is slightly turbid and of a very weak pinkish shade. The turbidness is due, partly to minute blades, fibrous microlites and very small rounded grains of partly higher refringency than that of the nepheline and of the two other impurities. By a micro-staining test the grains were found to be calcite. The refringency of the scaly microlites was found to be below 1.5, indicating natrolite, while that of the fibrous ones seemed to be about 1.6 and the mineral, in consequence, supposed to be wollastonite.

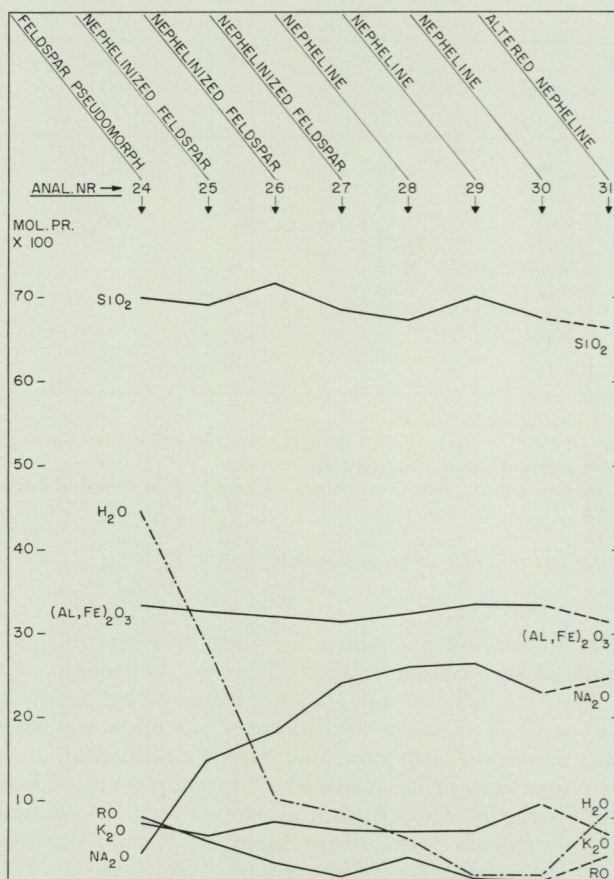


Fig. 3. Diagram of the molecular proportions of the major constituents, illustrating the process of nephelization.

The nepheline crystals were nicely formed and allowed an accurate separation from the other minerals of the paragenesis. No attempt was made, however, to remove the above-mentioned impurities from the ultimate sample before analysis. Instead the author tried by calculation to isolate the composition of the nepheline by allotments to natrolite, wollastonite and calcite. The results, recorded together with the analysis, are in fairly good agreement with a microscopical determination of the volume of the impurities. The presence of Cl and SO₃ indicate that some cancrinitic impurities may also occur, although not visible in thin sections. To my regret the calculation also fails to account for $\frac{3}{4}$ (weight) of the constitutional water.

A second nepheline analysis was made from unusually nepheline-rich ijolite east of Ås village, the mineral paragenesis being 70 % nepheline and 30 % aegirine-augite. The nepheline is in this case quite transparent without any foreign inclusions whatever. It is also nicely crystallized and the separation presented no problems. The analysis, no. 29, is rather similar to the nepheline from Iivaara, published by Lehi-

Analysis no. 28. Nepheline.
Locality: Melteigite between Hörningsholm and Nacka, Alnö Island. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Composition		
				Mol. %	Weight %
SiO ₂	40.62	67.63	Nepheline	92.56	94.02
CO ₂	0.44	1.00	Natrolite	3.69	2.49
TiO ₂	0.06	0.08	Wollastonite	2.28	2.48
ZrO ₂	n.d.		Calcite	1.47	1.01
P ₂ O ₅	n.d.			100.00	100.00
Al ₂ O ₃	32.38	31.76			
Cr ₂ O ₃	n.d.		<i>Number of ions on the basis of 32(O) of the nepheline</i>		
Fe ₂ O ₃	0.86	0.54	(Si + Ti + Al + Fe ⁺³) = 15.98		
FeO	0.15	0.21	(Na + K) = 8.08		
MnO	0.07	0.10	<i>Not included in the calculations</i>		
MgO	0.00	—	Cl	0.23 % weight	
CaO	1.54	2.75	SO ₃	0.15 % weight	
BaO	0.00	—	H ₂ O	0.78 % weight	
SrO	0.00	—	<i>Composition of "pure" nepheline</i>		
Na ₂ O	16.10	25.97		Mol. %	Weight %
K ₂ O	6.09	6.47	Ne	79.89	77.87
SO ₃	0.15	0.19	Kp	20.11	22.13
Cl	0.23	0.65			
H ₂ O ^{+105°}	1.03	5.72			
H ₂ O ^{-105°}	0.20				
— O = Cl	99.92				
	0.05				
	99.87				

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.606$ (average of 10 determinations).

 $\omega_{\text{Na}} = 1.544 \pm 0.002$ (average of 10 determinations).

 $\epsilon_{\text{Na}} = 1.539 \pm 0.002$ (average of 10 determinations).

järvi (24), but the normative percentage of SiO₂ is somewhat higher. There is a slight difference in refraction values, which may be due to the Ba–Sr content.

In the modes of the nepheline–soda-orthoclase rocks the allotments of Na and K to these minerals from the rock analyses were based on average optical determinations of series of thin slides. They were of necessity rather approximate, and some resulted in somewhat dubious Ne/Kp ratios with the amount of Ne suspiciously low. In order to test my method of calculation a sample was prepared of the nicely crystallized and very pure nepheline from the juvite between Näset and Hörningsholm. The rock had been previously analysed (9e, anal. no. 24, p. 50) and the composition of the nepheline estimated at "ne₇₄ab₂₆". Unfortunately, the sample used for the rock analysis had been consumed and new specimens were collected, avoiding as far as possible those rich in cancrinite. The analysis, no. 30, did not confirm my previous microscopical determination, but rather sustained some of the dubious Ne/Kp ratios.

Having read Bannister and Hey's paper of 1931 (1) I discussed the possibility of an error with the analyst, Dr. Almström, and we made sure that the remaining part

*Analysis no. 29. Nepheline.**Locality:* Ijolite at Ås village, Alnö Island. *Analyst:* Harry von Eckermann.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 32(O)	
SiO ₂	42.06	70.03	8.170	} 15.98
CO ₂	0.00	—		
TiO ₂	tr.			
ZrO ₂	n.d.			
P ₂ O ₅	n.d.			
Al ₂ O ₃	33.46	32.82	7.660	
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃	1.06	0.66	0.154	
FeO	tr.			} 7.79
MnO	tr.			
MgO	0.00	—		
CaO	0.21	0.38	0.045	
BaO	0.15	0.10	0.012	
SrO	0.05	0.05	0.006	
Na ₂ O	16.37	26.41	6.188	
K ₂ O	6.16	6.54	1.539	
F	n.d.			
Cl	n.d.			
S	0.00	—		
SO ₃	n.d.			
H ₂ O ^{+105°}	0.15	0.83		
H ₂ O ^{-105°}	0.17			
	99.84			

Normative composition:	Mol. %	Weight %
Ne	78.43	77.11
Ks	19.34	21.01
Q	2.23	1.88
	100.00	100.00

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.635$ (average of 10 determinations). $w_{\text{Na}} = 1.546 \pm 0.002$ (average of 10 determinations). $\epsilon_{\text{Na}} = 1.543 \pm 0.002$ (average of 10 determinations).

of the sample was quite pure and homogeneous without any inclusions whatever, whereupon a duplicate analysis was made, which in every respect confirmed the correctness of the previous one. Shortly after Dr. Almström's untimely death I received a letter from Professor Tilley, who doubted the correctness of the Kp-contents of 30 % and more in the modes of five of my syenitic rock analyses (9e, nos. 23, 26, 52, 54 and 57). At the same time I got a reprint of his paper on the nepheline parageneses (31). Since then much work has been done to shed light upon the structure and chemistry of the nepheline group of minerals and an excellent review was recently given by Deer *et al.* (8, Vol. 4). As this Alnö nepheline does not show any signs of unmixing in nepheline and kalsilite even at the strongest magnification, it remains in the light of present knowledge an anachronism and I have been in two minds about publishing the analysis. Of the correctness I am convinced and there may, of course, exist an invisible crypto-unmixing. That the analysis does not fit in with my estimate from the rock-analysis does not imply that the latter must be wrong, as the

Analysis no. 30. Nepheline.

Locality: Juvite between Näset and Hörningsholm, Alnö Island.
Analyst: G. K. Almström. (Average of two almost identical analyses.)

	Weight %	Mol. prop. × 100	Nepheline	Impurities	Number of ions on the basis of 32(O) of the nepheline
SiO ₂	40.57	67.55	67.55		8.039
CO ₂	0.10	0.18		0.18	
TiO ₂	tr.				
ZrO ₂	n.d.				
P ₂ O ₅	n.d.				
Al ₂ O ₃	33.16	32.53	32.53		7.742
Cr ₂ O ₃	n.d.				
Fe ₂ O ₃	1.51	0.95	0.95		0.214
FeO	0.07	0.10		0.10	
MnO	tr.				
MgO	0.00	—			
CaO	0.10	0.18		0.18	
BaO	0.11	0.07	0.07		0.008
SrO	0.01	0.01	0.01		0.001
Na ₂ O	14.25	22.99	22.99		5.472
K ₂ O	9.80	10.40	10.40		2.475
F	n.d.				
Cl	n.d.				
S	0.07	0.22		0.22	
H ₂ O ^{+105°}	0.21	1.17		(Weight of impurities	
H ₂ O ^{-105°}	0.22			0.34 %)	
	100.18				

Normative composition: Mol. % Weight %

Q	0.40	0.37
Ne	64.40	66.55
Ks	35.30	33.08

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.648$ (average of 10 determinations).

$\omega_{\text{Na}} = 1.547 \pm 0.002$ (average of 10 determinations).

$\epsilon_{\text{Na}} = 1.543 \pm 0.002$ (average of 10 determinations).

“mobilized” rheomorphic Alnö-fenites show great variations sometimes only a few feet apart.

A few words may be said about my interpretation of the analysis (no. 30). It can be calculated either as a combination of nepheline, some natrolite and impurities, or as nepheline and impurities. In the first case the water is included in the calculation and the number of ions of the slightly less amount of nepheline is altered to $(\text{Si} + \text{Al} + \text{Fe}^{+3}) = 15.92$, $(\text{Na} + \text{K} + \text{Ba} + \text{Sr}) = 7.92$. The impurities may be calculated as calcite + pyrite, but as neither was visible in the sample in thin slides, they probably represent a slight cancrinitization of the nepheline.

I am sorry that I could not at the time afford analyses of the nephelines of the above-mentioned analysed rocks, as they could have thrown more light on the problem of excess potassium content. An X-ray investigation could, maybe, also have solved the problem, if an ultramicroscopic exsolution of kalsilite occurs.

*Analysis no. 31. Altered nepheline.**Locality:* Melanite-ijolite, east of Hartung village. *Analyst:* R. Blix.

	Weight %	Mol. prop. × 100	Probable mineral combination		Impurity (Weight %)
			Mol. %	Weight %	
SiO ₂	39.88	66.40	Nepheline	43.79	46.26
CO ₂	1.70	3.86	Natrolite	19.07	15.27
TiO ₂	0.06	0.08	Cancrinite	36.81	37.71
ZrO ₂	n.d.				
P ₂ O ₅	n.d.		Haematite	99.67	99.24
Al ₂ O ₃	31.86	31.25			0.76
Cr ₂ O ₃	n.d.		<i>Normative composition of nepheline</i>		
Fe ₂ O ₃	0.76	0.48		Mol. %	Weight %
FeO	0.31	0.43	Q	0.75	0.72
MnO	0.01	0.01	Ne	88.09	76.99
MgO	0.16	0.40	Ks	11.16	22.29
CaO	1.62	2.89		100.00	100.00
BaO	0.07	0.05			
SrO	0.003	—			
Na ₂ O	15.28	24.65			
K ₂ O	6.06	6.43			
F	n.d.				
Cl	n.d.				
S	n.d.				
SO ₃	0.10	0.13			
H ₂ O ^{+105°}	1.50	8.33			
H ₂ O ^{-105°}	0.77				
	100.14				

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.478$ (average of 20 determinations).

Nepheline alters easily, as illustrated by Fig. 4, Pl. 20 of my Alnö memoir (9e) showing fresh nepheline changing into fibrous natrolite along a fracture in ijolitic rock. In the melanite ijolite, east of Hartung village, the nepheline, although retaining its original, sharply defined crystal form, is megascopically of a grayish colour and microscopically turbid. The CaO and CO₂ contents made me suspect the presence of calcite as impurity, although none could be found in the thin slides. Staining of a couple of slides confirmed the absence of carbonate. Minute red translucent scales, located in partings of the crystals, are evidently haematite. The turbidness is, however, caused by a network of colourless microlites and tiny scales, suspected to be cancrinite and natrolite. This was confirmed by analysis no. 31, which can be recalculated with great exactitude into nepheline, natrolite, cancrinite and the haematitic impurity. As the ijolite borders on a sövitic brecciating dike, containing some pyrite crystals, the alteration of the nepheline is probably due to magmatic or postmagmatic sulphurous carbonic gases circulating through the dike.

Another interesting alteration of nepheline was already observed by Högbom (18, p. 138) and further described by the present author (9e, p. 55). It is best observed in the ijolite south and south-west of Hörningsholm where large crystals occur, megascopically of peculiar grayish colour and in some cases of a bluish shade. A collection was made of the pseudomorphs and all those of bluish tint were picked out for ana-

Analysis no. 32. Pseudomorph of nepheline.

Locality: Ijolite south-west of Hörningsholm, Alnö Island. *Analyst:* N. Sahlbom. (Average of two analyses.)

	Weight %	Mol. prop. × 100	Possible mineral combination		
				Mol. %	Weight %
SiO ₂	32.90	54.73	Cancrinite	81.21	79.04
CO ₂	3.59	8.16	Haüyne	8.65	9.61
TiO ₂	tr.	—	Nosean	10.14	11.35
ZrO ₂	n.d.				
P ₂ O ₅	n.d.			100.00	100.00
Al ₂ O ₃	26.50	26.00			
Cr ₂ O ₃	n.d.				
Fe ₂ O ₃	1.42	0.89			
FeO	0.12	0.17			
MnO	0.01	0.01			
MgO	0.10	0.22			
CaO	5.42	9.67			
BaO	0.02	0.01			
SrO	0.005	—			
Na ₂ O	17.54	28.29			
K ₂ O	3.62	3.84			
F	n.d.				
Cl	0.04	0.14			
S	n.d.				
SO ₃	5.53	6.91			
H ₂ O ^{+105°}	3.11	17.26			
H ₂ O ^{-105°}	0.20				
	100.12				

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.401$ (average of 20 determinations).

lysis no. 32. Microscopically, the turbidness was found to be due to larger radiating, scaly microlites and smaller acicular or "stumpy" microlites. Besides, the crystals in cross section were more or less distinctly zoned and less turbid centrally. Were it not for the still preserved hexagonal crystal forms and the occurrence towards the margins of the ijolite body of increasingly fresh, unaltered nephelines, the original composition of the pseudomorphs would have remained obscure. The analysis of the assembled collection of megascopically uniform pseudomorphs of sizes from 4 to 8 mm, confirms their intricate composition. Assuming that all the nepheline is gone, that the CO₂, Cl and part of the SO₃ is bound to cancrinite, and the remaining lime and part of the SO₃ to haüyne, the author—by trial and error—, has attained a combination of cancrinite, haüyne and nosean. This mixture of hexagonal and cubic minerals does not seem very credible, but it gives certainly a notion of the complexity of the alteration of the nepheline. Calcite can be ruled out as impurity, as definitely proved by staining. An X-ray investigation would probably have thrown more light on the problem.

The analysis no. 32 is, of course, not one of a single crystal, but the average of many, and a calculation of the actual mineralogical composition, in consequence, a hazard. For safety's sake two analyses were made of the sample, the differences

*Analysis no. 33. Natrolite.**Locality:* In sövite-pegmatite at Stolpås, Alnö Island. *Analyst:* G. K. Almström.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 80(O)	
SiO ₂	47.29	78.74	23.96	23.96
CO ₂	0.00			
TiO ₂	tr.			
ZrO ₂	n.d.			
P ₂ O ₅	n.d.			
Al ₂ O ₃	26.54	26.04	15.88	} 16.02
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃	0.37	0.23	0.14	
FeO	0.04	0.06	0.02	
MnO	tr.			
MgO	tr.			} 15.08
CaO	1.70	3.03	0.92	
BaO	n.d.			
SrO	n.d.			
Na ₂ O	14.07	22.70	13.85	
K ₂ O	0.41	0.44	0.29	
F	n.d.			
Cl	n.d.			
S	n.d.			
SO ₃	0.00	—		
H ₂ O ^{+105°}	9.52	52.84	16.12	16.12
H ₂ O ^{-105°}	1.62			
	101.56			

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.232$ (average of 20 determinations). $2 V_{\text{Na}}$ (observed) = $59^{\circ} \pm 1^{\circ}$. $2 V$ (calculated) = $60^{\circ}28'$. $n_{\alpha, \text{Na}} = 1.474 \pm 0.002$ (average of 10 determinations). $n_{\beta, \text{Na}} = 1.477 \pm 0.002$ (average of 10 determinations). $n_{\gamma, \text{Na}} = 1.486 \pm 0.002$ (average of 10 determinations).

in no case, except for water, exceeding 0.1%. Analysis no. 32 is the average of the duplicates. Pl. XI, Fig. 1 shows a microphoto of the pseudomorph.

The metamorphism may be explained by the central part of the ijolite body remaining fluid, or perhaps a semifluid crystal mush, percolated by late-magmatic gaseous emanations. Their sulphur content may have changed at times and this may account for the occurrence of both bluish and purely gray pseudomorphs. Sometimes the bluish tint is decidedly "patchy", reminding one of the irregular distribution of the blue colour of both haüynes and noseans. The gray pseudomorphs remain to be analysed. One may characterize the alteration of the nepheline as mainly a cancrinization.

The BaO and SrO content of the nepheline and its pseudomorphs seems to be rather low or wanting. The oxidation ratio reaches a maximum in the nephelines but seems to vary considerably in the pseudomorphs. In Fig. 3 the essential components are plotted in molecular proportions. The diagram illustrates the reciprocity of H₂O and Na₂O in analyses nos. 30 and 31 and the increase of water content in the pseudomorph, analysis no. 31.

Natrolite

Generally, natrolite occurs in the Alnö rocks only as red fibrous alteration product of nepheline, the red colour being due to minute grains or scales of hydrous iron oxide (goethite) or haematite. At one locality, however, more or less primary natrolite has been found, viz. in the sövite-pegmatite at Stolpås, where it even presents translucent, badly crystallized grains alternating with quite turbid ones. About 20 kg of rock was crushed before 5 grams of the former type were obtained for analysis no. 33. They were slightly pink, but the iron oxide pigmentation was rather slight and did not prevent the determination of the optic constants. A calculation of the number of ions based on the 80 oxygens of the anhydrous cell, according to the method used by Deer *et al.* agrees nicely with the first three analyses quoted by them (8, Vol. 4, p. 366). The soda is somewhat on the low side but compensated by a greater content of lime, indicating a mesolitic trend of the mineral. An attempt to measure the volume of the iron oxide impurity resulted in a quantity equal to about 0.20 % weight.

Cancrinite

Cancrinite occurs in small crystals as a primary mineral in the juvite and melanite-juvite rheomorphic rocks, where it constitutes up to 10 % of the minerals. Generally, it is nicely crystallized and free from impurities. It also occurs here and there, even in ijolites, as reaction rims between nepheline and calcite grains. The cancrinite is easily spotted on account of its strong yellow colour.

A seemingly almost pure cancrinite occurs in the pegmatitic juvite dike east of Hörningsholm, from which an analysis of barium-rich soda-orthoclase is given in this paper (analysis no. 22). The cancrinite was found to be of two kinds: one an almost homogeneous and slightly opaque type and another one more opaque, but translucent, and consisting of reaction rims enclosing minute calcite grains. The first one occurs in the centre of the dike, exhibits poorly developed crystal faces and is generally the last crystallized matrix surrounding the grayish-violet orthoclase crystals. It makes up about 20 % of the central part of the pegmatite and its composition is given by analysis no. 34. Calculations of the formula, based on the methods used by Deer *et al.* (8, Vol. 4, p. 311) and based both on the basis of 12(Si,Al) and 24(O) did not agree very well with those quoted by them. In the former case one gets $(\text{Si, Al})_{12.00}(\text{Fe}^{+3}, \text{Mn, Mg, Ca, Sr, Na, K})_{8.14}(\text{CS})_{1.56}$, the outcome of the second group being too high, and in the latter case the (Si,Al) group is much too low. The ratio $100 \text{ C} : (\text{C} + \text{S}) = 90.00$ agrees, however, with previous analyses of similar SO_3 -contents (cf. 8, p. 312, anal. no. 4). A comparison with the cancrinite formula, as written by the mineralogist, the late Professor Leon Borgström (3, p. 113–30) results in a better agreement. His conception postulated a three-part formula: $A = 3\text{Ne}$, 2Cc , $B = 3\text{Ne}$, $\text{Na}_2\text{CO}_3 \cdot 3\text{H}_2\text{O}$ and $E = 3\text{Ne} \cdot 2\text{CaSO}_4$ and the ratio $A + B : E = 12 : 1$. Conformably thereto, a calculation is given together with analysis no. 24, and leads to a $A + B : E$ ratio of 11.90. If, however a small percentage of natrolite—although not visible microscopically—is assumed to cause the very slight turbidness, a deduction of 0.43 % (weight) for natrolite raises the ratio to about 12.00.

The second type, "reaction-rim cancrinite", was analysed by Miss Berggren (analysis no. 35). It occurs in the juvite pegmatitic dike in the marginal primary calcite-juvite intrusion (cf. 9e, p. 47–48), bordering on the later central orthoclase-cancrinite intrusion. Inclusions of natrolite and calcite are the proximate cause of a turbidness, which

*Analysis no. 34. Cancrinite.**Locality:* Pegmatitic juvite dike south of Hörningsholm. *Analyst:* G. K. Almström.

	Weight %	Mol. prop. × 100	Cancrinite			Rest
			A	B	E	
SiO ₂	34.33	57.16	24.54	27.72	4.50	
CO ₂	5.83	13.25	8.18	5.07		
TiO ₂	tr.					
ZrO ₂	n.d.					
P ₂ O ₅	n.d.					
Al ₂ O ₃	28.99	28.44	12.16	13.86	2.33	0.09
Cr ₂ O ₃	n.d.					
Fe ₃ O ₃ (total Fe)	0.35	0.22	0.10	0.12		
FeO	n.d.					
MnO	0.04	0.06	0.06			
MgO	0.07	0.17	0.17			
CaO	5.25	9.36	7.83		1.53	
BaO	tr.					
SrO	0.12	0.12	0.12			
Na ₂ O	20.64	33.29	12.12	18.86	2.31	
K ₂ O	0.34	0.36	0.15	0.19	0.02	
F	tr.					
Cl	tr.					
S	n.d.					
SO ₃	1.23	1.53			1.53	
H ₂ O ^{+105°}	2.78	15.27		15.21		0.06
H ₂ O ^{-105°}	0.82					
	100.79	Mol. pr.	65.43	81.03	12.22	0.15
		Mol. pr.	A + B : E = 11.99			

Sp. gravity $^{20}_{4}C = 2.491$ (average of 10 determinations). $\omega_{Na} = 1.516 \pm 0.001$ (average of 10 determinations). $\epsilon_{Na} = 1.498 \pm 0.001$ (average of 10 determinations). $\delta = 0.018$.

prevents any reliable determination of the refractive indices. When preparing the sample the impurities were not removed, but the approximate percentage in weight of calcite grains, determined geometrically by the measuring of a series of stained thin sections, was deducted when calculating the composition of the mineral, analysis no. 35.

The formula was first calculated according to Borgström's conception, which is also presented together with the analysis, and shows a remarkably good agreement with the microscopically determined and deducted natrolite and calcite percentages, as well as with the A + B : E ratio equalling 12.20. A calculation on the basis of (Si,Al) = 12 and on 24(O) of the cancrinite component gave the same results as the corresponding calculations of analysis no. 34, viz. a too high (Ca,Na etc.) group value, respectively a too low (Si,Al) group value. The SO₃ percentage is lower and the water higher in the marginal reaction-rim cancrinite than in the central primary mineral. Attention is called to the great amount of natrolite in the former and to the rather small content in the homogeneous cancrinite. It almost looks as if natrolite should be an intermediate stage of the reaction: nepheline + calcite + SO₃ + Cl = cancrinite. On the other hand, as pointed out earlier and discussed by the author (9*e*, p. 48), no retrograde split-

Analysis no. 35. Cancrinite with natrolite and calcite.
Locality: In pegmatitic juvite dike south of Hörningsholm. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Cancrinite			Natrolite	Calcite	Rest	
			A	B	E				
SiO ₂	35.50	59.11	15.70	23.88	3.20	16.40		-0.07	
CO ₂	6.10	13.86	5.10	3.98			4.78		
TiO ₂	0.00	—							
ZrO ₂	n.d.								
P ₂ O ₅	0.00	—							
Al ₂ O ₃	27.17	26.63	7.79	11.82	1.59	5.45		-0.01	
Cr ₂ O ₃	n.d.								
Fe ₂ O ₃ (total Fe)	0.35	0.22	0.07	0.12	0.01	0.02			
FeO	n.d.								
MnO	0.03	0.04	0.04						
MgO	0.05	0.12	0.09		0.03				
CaO	5.96	10.63	4.88		1.02		4.78	-0.05	
BaO	tr.								
SrO	0.11	0.11	0.09		0.02				
Na ₂ O	18.90	30.49	7.77	15.78	1.59	5.40		-0.01	
K ₂ O	0.33	0.35	0.08	0.18	0.01	0.07		+0.01	
F	n.d.								
Cl	tr.								
S	n.d.								
SO ₃	0.86	1.07			1.07				
H ₂ O ^{+105*}	4.42	24.53		11.94		10.94		+1.65	
H ₂ O ^{-105*}	0.25								
	100.03	Mol.pr.	41.61	67.70	8.54	38.28	9.56	+1.52	
		Mol.pr. A + B : E =	12.80						

Weight %: Cancrinite 74.40

Natrolite 20.83

Calcite 4.77

100.00

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.432$ (average of 20 determinations).

ting of the cancrinite into nepheline and calcite has been observed in the Alnö rocks.

Noteworthy is the dominance of SrO over BaO in the cancrinites, the latter occurring merely as traces. The oxidation ratio could not be calculated from the analyses of the two chemists, as both calculated the total iron as Fe₂O₃. I asked Dr. Almström for a check on the FeO content of analysis no. 34, but as I did not receive it before his death I undertook one myself. I found but traces, and the oxidation ratio of the Alnö cancrinites may, therefore, preliminarily be taken to be about 100%. Both types of cancrinite are shown by Pl. X, Fig. 2.

Ortho- and Ring silicates

Titanite (Sphene)

Titanite occurs frequently in the fenites at, and close to, the sövite contacts, but is seldom found within the sövite itself. Intermixed with melanitic garnet it is found

west of Ås Jetty in the contact between fenite "in situ" and the rheomorphic ijolite south of the contact. As the two minerals are of the same colour they can hardly be distinguished from each other except in thin slides. Titanite is also a frequent component of the rheomorphic rocks themselves (cf. 9e, p. 51) and occurs at about 3½% in the ijolite body east of Hörningsholm, from which a sample was isolated for analysis no. 36.

The mineral is reddish-brown and slightly pleochroic with $\gamma > \beta > \alpha$. Isolated twins occur occasionally. Although generally nicely crystallized the titanite contained minute grains of carbonate as well as darker zones with dusty precipitates of magnetite. In order not to risk any oxidation error the sample was not ground fine enough to remove the impurities, but carbonate was deducted from the original analysis on the basis of a CO₂-determination and a staining test. The excess of iron remains in the analyses and is clearly demonstrated by the calculation of ions on the basis of 20(O) which results in a Ti-group somewhat above 4.00.

The determination of the optical values were carried out on titanites of two different slides, choosing optically homogeneous crystals. In zoned titanites the axial angle was observed to vary from about 38° in the marginal zone to about 33° in the centre, indicating an increase of Ti towards the centre. As only a single analysis was made it remains uncertain whether the Ce₂O₃ is a regular feature of the Alnö titanites or not.

Garnets

The garnets of the Alnö rocks contain without exception unusually high titanium percentages. Some of them may be termed hydro-garnets. Seven analyses have been made from different occurrences and the lowest Ti-content is 3.45% in analysis no. 37. The mineral occurs in the melanite-ijolite of a road-cutting west of Näset. It is, like most Alnö garnets, zoned, and the colour varies from brownish-yellow in the centre to yellow at the margins. The refringence increases towards the centre and one measurement is given together with the analysis. The garnet of analysis no. 37 contained minute calcitic grains, which were not removed from the sample but the corresponding calcite deducted from the original analysis. The yellow marginal parts of the crystals are occasionally birefringent. About 45.5% of the Ti-content has been placed in the Y-group, substituting for Fe⁺³. Garnet occurs frequently in the fenite close to the contact, and is generally fairly rich in titanium, as for instance to the north of the big sövite dike at Stavsätt, exemplified by analysis no. 38. The mineral may be termed a melanitic andradite. It is nicely crystallized and apparently free from inclusions of any kind, but strongly zoned with a dark brown centre and a honey-yellow slightly birefringent rim. The values of specific gravity and refraction, given with the analysis, are, in consequence, average ones. Of some interest is the fairly large alkali content.

The garnet in the juvite west of Näset has on account of its titanium content been termed a melanite (analysis no. 39). It is conspicuously rich in constitutional water and may in consequence be designated a hydro-melanite. Minute inclusions of calcite were left in the sample, prepared for analysis, in order to avoid oxidation by grinding. As the analyst did not determine the CO₂-content a supplementary analysis was carried out by Aaremäe. The formula based on 24(O) shows an excess of RO-components.

According to Deer *et al.* (8, Vol. 1, p. 104) the name hydrogrossular is applied to minerals with a composition between grossular and hibschite, and minerals of this compositional range have also been called hydrogarnets. The present analysis shows

Analysis no. 36. Titanite (sphene).
Locality: In ijolite east of Hörningsholm. *Analyst:* R. Blix (F by A. Aaremäe).

	Weight %	Mol. prop. × 100	Number of ions on the basis of 20(F, OH, O)
SiO ₂	30.82	51.32	4.032
CO ₂	0.00	—	
TiO ₂	35.02	43.83	3.440
ZrO ₂	n.d.		
P ₂ O ₅	n.d.		
Al ₂ O ₃	2.59	2.54	0.398
Cr ₂ O ₃	n.d.		
Fe ₂ O ₃	2.83	1.77	0.227
FeO	0.56	0.78	0.060
MnO	0.17	0.24	0.019
MgO	0.19	0.47	0.037
CaO	26.55	47.35	3.735
BaO	n.d.		
SrO	n.d.		
Na ₂ O	0.45	0.73	0.115
K ₂ O	0.15	0.16	0.025
F	0.11	0.58	0.046
Cl	n.d.		
S	n.d.		
SO ₃	n.d.		
Ce ₂ O ₃	0.18	0.06	0.010
H ₂ O ^{+105°}	0.06	0.33	0.099
H ₂ O ^{-105°}	0.18		
	99.86		

 Composition: Si_{4.03}(Ti,Al,Fe^{+2,+3},Mg)_{4.16}(Ca,Mn,Na,K,Ce)_{3.91}(F,OH,O)_{20.00}.

 Sp. gravity₄^{20°C} = 3.486 – 3.496.

 $2 V_{Na}$ (observed) = 1) + 37° ± 1°, 2) + 35° ± 1°.

 $2 V_{Na}$ (calculated) = 1) + 36°4', 2) + 34°29'.

$$\left. \begin{array}{l} n_{\alpha Na} = 1) 1.922, 2) 1.904 \\ n_{\beta Na} = 1) 1.929, 2) 1.912 \\ n_{\gamma Na} = 1) 1.999, 2) 2.002 \end{array} \right\} \text{all } \pm 0.001.$$

that the term "hydrogarnet" may be extended to include also minerals with a composition between melanite (andradite) and hibschite. Replacing Al₂O₃ by Fe₂O₃ the analysis is very similar to the hydrogrossular of Buffelsfontein (8, Vol. 1, p. 105). There exist, however, intermediary compositions between hydro-grossularites and hydro-melanites, as shown by analysis no. 40 of a garnet from the central part of the juvite body west of Näset, somewhat richer in TiO₂, considerably richer in Al₂O₃ and much poorer in Fe₂O₃. The analysis is given, recalculated by the chemist, Dr. Blix, to 100 %, and the H₂O^{-105°} and a small amount of calcitic impurities, corresponding to 0.20 % CO₂, deducted. After a discussion with him about the composition of the garnet, he undertook its calculation, starting with the ion contents recalculated to 100 % and the ion quota × 10⁴, presented together with the analysis. He wrote me as follows:

"The ion quota table (cf. analysis no. 40) shows that the O⁻²/Si⁺⁴ is 4.05. Within the limits of analytical error, the Si⁺⁴ content is, in consequence, sufficient for the

*Analysis no. 37. Titaniferous andradite.**Locality:* Melanite-ijolite in road-cutting west of Näset. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O)		
			X	Y	Z
SiO ₂	35.49	59.09			5.780
CO ₂	0.00	—			
TiO ₂	3.45	4.31		0.200	0.220
ZrO ₂	n.d.				
P ₂ O ₅	n.d.				
Al ₂ O ₃	7.63	7.49		1.463	
Cr ₂ O ₃	n.d.				
Fe ₂ O ₃	19.11	11.97		2.339	
FeO	3.28	4.57	0.446		
MnO	0.68	0.96	0.094		
MgO	1.23	3.05	0.298		
CaO	28.00	49.93	4.880		
BaO	n.d.				
SrO	n.d.				
Na ₂ O	0.88	1.42	0.276		
K ₂ O	0.20	0.21	0.041		
F	0.07	0.37			
Cl	0.05	0.14			
S	n.d.				
SO ₃	n.d.				
H ₂ O ^{+105°}	0.15	0.83			
H ₂ O ^{-105°}	0.04				
	100.26		6.035	4.002	6.000

Composition: $X_{3.01}Y_{2.00}Z_{3.00}O_{12.00}$.

Arc-spectrogram: V +, Cu[+], Ga[+], Pb[+], Sb[+], Ta[+], (Ag, Ba, Co, Cr, Sc, Sn).

Sp. gravity $_{4}^{20^{\circ}\text{C}} = 3.758$. $n_{\text{Na}} = 1.882$ (margin) — 1.890–1.906 (central part of mineral).

establishing of the SiO_4^{-4} , which does not prevent that some Ti^{+4} or, preferably, Al^{+3} is added in order to obtain the ratio $\text{O}^{-2}/\text{Si}^{+4} + \text{Al}^{+3} = 4.00$. The bivalent ions, and to a less degree the trivalent plus Ti^{+4} , are in excess of the garnet formula. If one lets Fe^{+2} and Mn^{+2} reduce Ti^{+5} to Ti^{+3} simultaneously with their oxidation to Fe^{+3} and Mn^{+3} (cf. Oxid. reduct. Table, analysis no. 40) the sum of the bivalent ions will be almost exactly that of Si^{+4} , but on the other hand $\text{R}^{+3} + \text{Ti}^{+4}$ will be much too high. If, however, from the bivalent ions are deducted $\frac{3}{12}$ of the hydroxyl ions and from the trivalent $\frac{2}{12}$ of the hydroxyl ions according to the formula $\text{R}_3^{\text{II}}\text{R}_2^{\text{III}}(\text{OH})_{12}$ we get a better formula. Even now the amount of R^{+2} exceeds somewhat that of R^{+3} which must be due to some bivalent ions, especially Mg^{+2} , being 6-coordinated instead of 8-coordinated in the crystal structure. (About titaniferous andradites cf. O. Zedlitz, 37 and 38, who rather "unprejudicedly" juggles with the ions.) In this case moving a part of the Mg^{+2} to R^{+3} will suffice and gives an acceptable formula: 40 % of $\text{Mg}^{+2} = 0.4 \times 592 = 237$ is added to R^{+3} and 60 % = 355 remains as R^{+2} . Accordingly:

Analysis no. 38. Melanitic andradite.
Locality: In fenite close to the sövite dike contact at Stavsätt. *Analyst:* G. K. Almström.

	Weight %	Mol. prop. × 100	Atomic proportions		
			X	Y	Z
SiO ₂	36.20	60.27			60.27
CO ₂	0.00	—			
TiO ₂	4.10	5.13		5.13	
ZrO ₂	n.d.				
P ₂ O ₅	n.d.				
Al ₂ O ₃	6.08	5.96		10.59	
Cr ₂ O ₃	tr.				
Fe ₂ O ₃	20.25	12.68		25.36	
FeO	2.13	2.97	2.97		
MnO	0.37	0.52	0.52		
MgO	2.82	6.99	6.99		
CaO	26.12	46.58	46.58		
BaO	0.03	0.02	0.02		
SrO	< 0.005	—			
Na ₂ O	1.21	1.95	3.90		
K ₂ O	0.29	0.31	0.62		
F	0.05	0.26			
Cl	n.d.				
S	n.d.				
SO ₃	n.d.				
H ₂ O ^{+105°}	0.16	0.89			
H ₂ O ^{-105°}	0.14				
	99.95		61.60	41.08	60.27

 Composition: $X_{3.00}Y_{2.00}Z_{3.00}O_{12.00}$.

 Sp. gravity $_{4}^{20^{\circ}\text{C}} = 3.752$ (average of 14 determinations).

 $n_{\text{Na}} = 1.901$ (average of 29 determinations).

Cell edge = 12.09 Å, determined by Dr. O. Gabrielson, Mineral. dept. "Riksmuseum".

Si ⁺⁴ + Al ⁺³	= 5935	Si ⁺⁴ + Al ⁺³	= 594
R ⁺³	= 3930	3/2 R ⁺³	= 590
R ⁺²	= 5895	R ⁺²	= 590
O ⁻²	= 23740	O ⁻²	= 2374

Formula (since $\text{Si}^{+4} + \text{Al}^{+3}/\text{OH}^{-} = 4.95 = \sim 5$): $20[\text{X}_3\text{Y}_2(\text{ZO}_4)_3] + 1[\text{X}_3\text{Y}_2(\text{OH})_{12}] = \text{X}_{63}\text{Y}_{42}(\text{ZO}_4)_{60}(\text{OH})_{12} = \text{X}_{21}\text{Y}_{14}(\text{ZO}_4)_{20}(\text{OH})_4$, where $\text{X} = \text{Fe}^{+2} + \text{Mn}^{+2} + \text{Mg}^{+2} + \text{Ba}^{+2} + \text{Sr}^{+2} + \text{Ca}^{+2} + \text{Na}^{+} + \text{K}^{+}$; $\text{Y} = \text{Ti}^{+4} + \text{Fe}^{+3} + \text{Al}^{+3} + \text{Mg}^{+2}$ and $\text{Z} = \text{Si}^{+4} + \text{Al}^{+3}$."

Mr Blix' detailed calculation of the analysis confirms, in consequence, the existence of a hydro-melanite, an equivalent of the previously known hydro-grossular.

The melanites, occurring in sövites, contain generally very little constitutional water and are also very nicely crystallized, usually as dodecahedrons but also as trapezohedrons and combinations of several forms. Analysis no. 41 represents such a melanite of fairly high titanium content. The mineral is megascopically almost black and only slightly zonal. The comparatively large amount of alumina and low one of ferric oxide reminds one of analysis no. 38, indicating a grossularitic trend.

The highest titanium contents, however, are found in the garnets in melteigitic

Analysis no. 39. Hydro-melanite.

Locality: In juvite west of Näset. *Analyst:* G. K. Almström (CO₂ by Aaremäe).

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O)		
			X	Y	Z
SiO ₂	32.33	53.83			5.363
CO ₂	0.50	0.91			
TiO ₂	6.08	7.61		0.759	
ZrO ₂	n.d.				
P ₂ O ₅	n.d.				
Al ₂ O ₃	2.26	2.22		0.442	
Cr ₂ O ₃	tr.				
Fe ₂ O ₃	22.45	14.06		2.809	
FeO	2.14	2.98	0.296		
MnO	0.30	0.40	0.040		
MgO	2.02	5.01	0.500		
CaO	29.94	53.39	5.210		
BaO	n.d.				
SrO	n.d.				
Na ₂ O	0.15	0.24	0.048		
K ₂ O	0.39	0.41	0.082		
F	n.d.				
Cl	n.d.				
S	n.d.				
SO ₃	n.d.				
H ₂ O ^{+105°}	1.38	7.66			OH/4:0.383
H ₂ O ^{-105°}	0.28				
	100.22		6.176	4.01	5.746

Composition: $X_{6.16}Y_{4.01}(Z,OH/4)_{5.75}O_{24}$.

Impurities: 1.14 % weight of calcite.

Sp. gravity $\frac{20}{4}^{\circ}C = 3.778$ (calcite not deducted, average of 20 crystals).

$n_{Na} = 1.909$ (average of 20 zonal crystals).

rocks west of Hörningsholm and north of Pottäng, where the mineral may be termed schorlomite. Two analyses, nos. 42 and 43, were made by different chemists. The minerals were isolated from samples collected about 100 metres apart. The nicely formed crystals were practically free from inclusions and very pure samples could be prepared for analysis. The mineral is megascopically almost black and microscopically a very dark, barely translucent brown. The chemical composition is rather similar to that of the Finnish "iivaarite" from Kusamo, the main difference being slightly more Fe₂O₃ and slightly less CaO. This applies to the analysis of Zedlitz (8, Vol. I, p. 91), published in 1935 as well as partly to an analysis by Mauno Lehighjärvi in his unpublished thesis for a licenciate of science degree, communicated privately to the present author in 1957 and reading as follows:

	%
SiO ₂	27.67
TiO ₂	14.20
Al ₂ O ₃	3.05

Analysis no. 40. Hydro-melanite

Locality: In the central part of the juvite body, west of Näset. Analyst: R. Blix.

	Weight %	Mol. prop. × 100	Ion-content (%)	Ion quota × 10 ⁴	Oxidation- reduction re-calculation
SiO ₂	35.17	58.56	OH ⁻ 2.04	1,200	OH ⁻ 1,200
CO ₂	0.00	—	Si ⁺⁴ 16.43	5,855	Si ⁺⁴ 5,855
TiO ₂	7.40	9.26	Ti ⁺⁴ 4.44	927	Ti ⁺⁴ 353
ZrO ₂	n.d.		Al ⁺³ 2.97	1,101	Ti ⁺³ 574
P ₂ O ₅	n.d.		Fe ⁺³ 10.86	1,945	Al ⁺³ 1,101
Al ₂ O ₃	5.62	5.51	Fe ⁺² 2.86	512	Fe ⁺³ 2,457
Cr ₂ O ₃	n.d.		Mn ⁺² 0.34	62	Mn ⁺³ 62
Fe ₂ O ₃	15.53	9.73	Mg ⁺² 1.44	592	Fe ⁺² 0
FeO	3.68	5.12	Ba ⁺² 0.05	4	Mg ⁺² 592
MnO	0.44	0.62	Sr ⁺² 0.06	7	Ba ⁺² 4
MgO	2.38	5.90	Ca ⁺² 19.39	4,838	Sr ⁺² 7
CaO	27.13	48.38	Na ⁺ 0.74	322	Ca ⁺² 4,838
BaO	0.06	0.04	K ⁺ 0.37	95	Na ⁺ 322
SrO	0.07	0.07	O ⁻² 38.01	23,740	K ⁺ 95
Na ₂ O	1.00	1.61	100.00		O ⁻² 23,740
K ₂ O	0.44	0.47			
F	n.d.				
Cl	n.d.				
S	n.d.				
SO ₃	n.d.				
H ₂ O ^{+105°}	1.08	6.00			
	100.00				

Calculated by the analyst

 Formula: $X_{21}Y_{14}(ZO_4)_{20}(OH)_4$, where
 $X = Fe^{+2} + Mn^{+2} + Mg^{+2} + Ba^{+2} +$
 $Sr^{+2} + Ca^{+2} + Na^+ + K^+$
 $Y = Ti^{+4} + Fe^{+3} + Al^{+3} + Mg^{+2}$
 $Z = Si^{+4} + Al^{+3}$

 Sp. gravity $\frac{20}{4}^{\circ}C = 3.781$ (before deduction of 0.46 weight % calcite).

 $n_{Na} = 1.911$ (average of 20 crystals).

	%	
Fe ₂ O ₃	19.28	
FeO	3.62	$n = 1.97$
MnO	0.22	$G = 3.752$
MgO	tr.	$a_0 = 12.138 \pm 0.006 \text{ \AA}$
CaO	31.08	
Na ₂ O	0.62	
K ₂ O	0.20	
H ₂ O ⁻	0.00	
Ign.	0.11	
	100.05	

The specific gravity of the Alnö schorlomite, analysis 43, is considerably greater than for this iivaarite, which is probably explained by its much higher total iron content and the two percent more TiO₂.

The barium and strontium contents were only determined in 5 of the analyses and showed weights of max. 0.06 % BaO and max. 0.07 % SrO. Barium is dominant in three analyses; strontium is lacking in one case, and slightly dominant in two analyses.

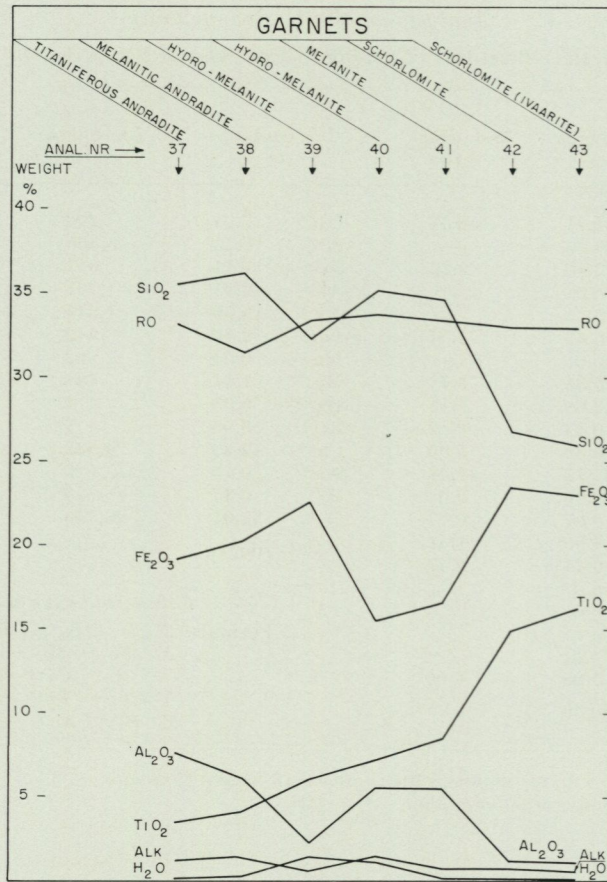


Fig. 4. Diagram of the weight % of the major components of the garnets.

Vanadium is probably present in all melanites. Almström found only traces in the schorlomite at Pottäng, but a later spectrogram of another sample from the same locality showed 0.14 % V_2O_3 . Arc-spectrograms indicate vanadium contents of about 0.10 %.

The oxidation ratios of the garnets range from 0.72 to 0.90, the two maximum values occurring in melanite close to the sövite-fenite contact and in the rheomorphic juvite (cf. Fig. 27).

In Fig. 4 the essential components are plotted in weight percentages. The diagram illustrates the reciprocity of SiO_2 and Fe_2O_3 , of Fe_2O_3 and Al_2O_3 and also (the hydro-melanite of analysis no. 39 excepted) of TiO_2 on the one hand and SiO_2 and Al_2O_3 on the other. This confirms that titanium increases principally at the expense of silicon (cf. 16, p. 784).

In the diagram, Fig. 5, the principal Niggli values are plotted. They indicate a pronounced reciprocity of "si" and "fm" in all garnets of a TiO_2 content above 4 %, viz. analyses nos. 38 to 43. In the last three analyses of very large titanium contents,

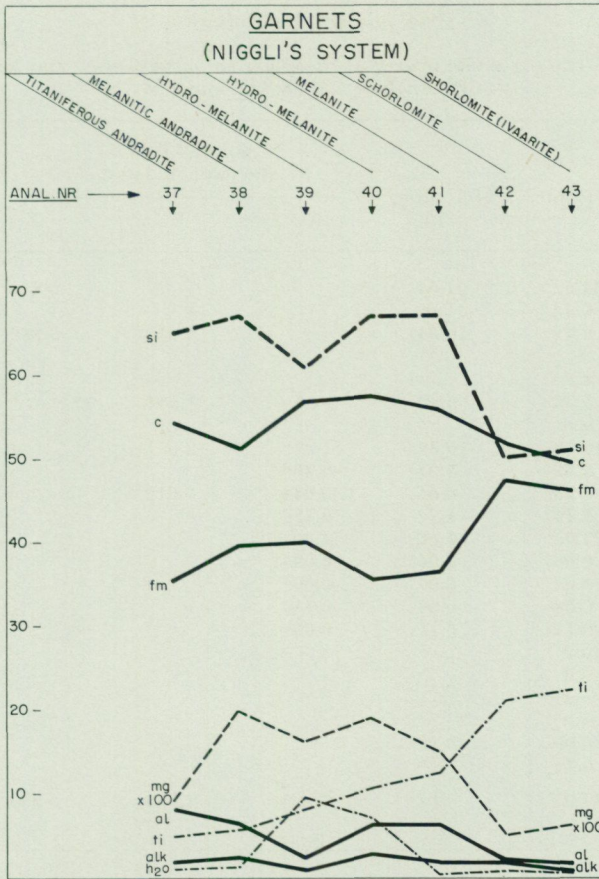


Fig. 5. The *Niggli* values of the garnets.

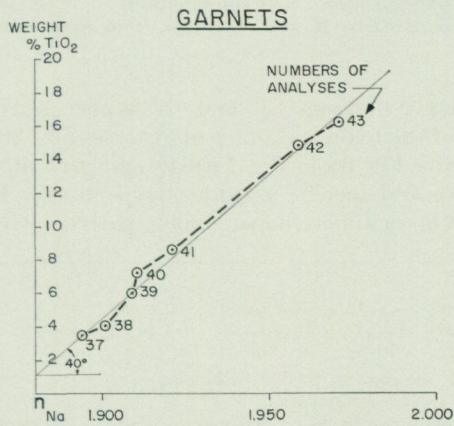


Fig. 6. Variation of refractive index of garnet with weight % TiO₂.

*Analysis no. 41. Melanite.**Locality:* The big sövite quarry at Smedsgården, now disused and filled-in.*Analyst:* Naima Sahlbom.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O)			Calcite
			X	Y	Z	
SiO ₂	34.62	57.64			5.690	
CO ₂	0.46	1.05				1.05
TiO ₂	8.42	10.54		0.814	0.246	
ZrO ₂	tr.					
P ₂ O ₅	n.d.					
Al ₂ O ₃	5.53	5.43		1.081		
Cr ₂ O ₃	n.d.					
Fe ₂ O ₃	16.59	10.39		2.051		
FeO	3.62	5.04	0.496			
MnO	0.43	0.61	0.048	0.012		
MgO	1.74	4.82		0.426		
CaO	27.51	49.06	4.801			1.05
BaO	0.06	0.04	0.004			
SrO	0.07	0.07	0.007			
Na ₂ O	0.58	0.94	0.186			
K ₂ O	0.14	0.15	0.030			
F	n.d.					
Cl	n.d.					
S	n.d.					
SO ₃	n.d.					
H ₂ O ^{+105°}	0.06	0.33				
H ₂ O ^{-105°}	0.14					
	99.97		5.998	3.958	5.936	(1.05 % weight)

Composition: $X_{3.00}Y_{2.00}Z_{3.00}O_{24}$.Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.768 - 3.783$ (including calcitic impurity). $n_{\text{Na}} = 1.921$ (average of 20 crystals).

Crystal forms: Perfect dodecahedrons and combinations with octahedrons.

Cell edge = 12.112 Å, calculated by H. v. Eckermann from spectrogram taken by Franz Raaz.

nos. 41 to 43, a reciprocity between "si" and "ti" is also clearly demonstrated, but it disappears in the case of the hydromelanites of analyses nos. 39 and 40.

Finally, in the diagrams Fig. 6 and Fig. 7 the weight percentages of TiO₂ are plotted against the refringences and specific gravities, respectively. The resulting plots are in both cases scattered in an almost linear sloping pattern, which allows the drawing

Composition, 24(O)-basis: $X_{3.00}Y_{1.95}Z_{3.00}O_{12.00}$.Composition, at. proport.: $X_{3.00}Y_{1.95}Z_{3.00}O_{12.00}$.

Arc-spectrogr.: Cu +, Ga +, Pb +, V +, Sb[+], Ta[+].

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.893$ (average of 10 determinations). $n_{\text{Na}} = 1.959$ (average of 10 determinations).

Cell edge = 12.168 Å, calculated by H. v. Eckermann from spectrogram taken by Prof. Franz Raaz.

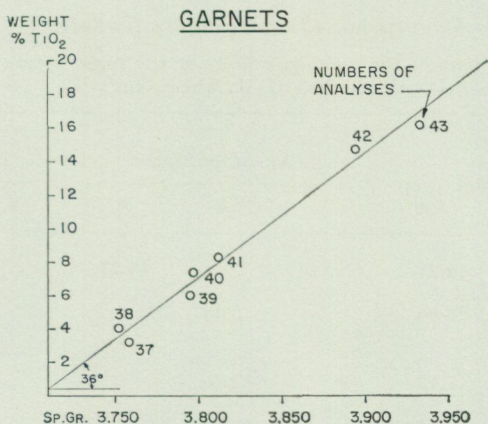


Fig. 7. Variation of specific gravity of garnet with weight % TiO₂.

of an average curve: a straight line. In Fig. 10 this line inclines at an angle of 40° to the "refringence-axis". This is exactly the same angle obtained by redrawing the corresponding line of Howie's and Woolley's Fig. 1a in the scales used in the Fig. 6 of this paper (16, p. 780). The result of the two authors' recently published work on the

Analysis no. 42. Schorlomite.

Locality: In melteigite west of Hörningsholm, Alnö Island. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	At. proportions			Number of ions on the basis of 24(O)		
			X	Y	Z	X	Y	Z
SiO ₂	26.80	44.62			44.62			4.627
CO ₂	0.00	—						
TiO ₂	14.83	18.56		5.28	13.28		0.552	1.373
ZrO ₂	tr.							
P ₂ O ₅	0.00	—						
Al ₂ O ₃	1.12	1.10		2.20			0.232	
Cr ₂ O ₃	n.d.							
Fe ₂ O ₃	23.53	14.74		29.48			3.058	
FeO	6.80	9.47	9.47			0.983		
MnO	0.45	0.63		0.63			0.065	
MgO	1.02	2.53		2.55		0.263		
CaO	24.64	43.94	43.94			4.557		
BaO	0.06	0.04	0.04			0.004		
SrO	0.00	—						
Na ₂ O	0.39	0.63		1.25		0.131		
K ₂ O	0.32	0.31	0.66			0.068		
F	0.00	—						
Cl	0.04	0.11						
S	n.d.							
SO ₃	n.d.							
H ₂ O ^{+105°}	0.10	0.56						
H ₂ O ^{-105°}	0.06							
	100.16		57.91	37.59	57.90	6.006	3.907	6.000

*Analysis no. 43. Schorlomite (iivaarite).**Locality:* In central part of the melteigite body at the road-cutting north of Pottäng.*Analyst:* G. K. Almström.

	Weight %	Mol. prop. × 100	At. proportions			Number of ions on the basis of 24(O)		
			X	Y	Z	X	Y	Z
SiO ₂	25.99	43.27			43.27			4.504
CO ₂	0.00	—						
TiO ₂	16.21	20.29		6.44		0.616		1.496
ZrO ₂	n.d.							
P ₂ O ₅	n.d.							
Al ₂ O ₃	1.15	1.13		2.26		0.236		
Cr ₂ O ₃	tr.							
Fe ₂ O ₃	23.01	14.41		28.82		3.000		
FeO	6.36	8.35	8.35			0.869		
MnO	0.39	0.55	0.01	0.54		0.057		
MgO	0.94	2.33	2.33			0.243		
CaO	25.20	44.94	44.94			4.678		
BaO	0.05	0.03	0.03			0.003		
SrO	< 0.005	—						
Na ₂ O	0.31	0.50	1.00			0.104		
K ₂ O	0.22	0.23	0.46			0.048		
F	n.d.							
Cl	tr.							
S	n.d.							
SO ₃	n.d.							
V ₂ O ₃	tr.							
H ₂ O ^{+105°}	0.12	0.67						
H ₂ O ^{-105°}	0.16							
	100.11		57.12	38.06	43.27	5.945	3.909	6.000

Composition, at. prop.: $X_{3.00}Y_{2.00}Z_{3.00}O_{12.00}$.Composition, 24(O)-basis: $X_{2.97}Y_{1.96}Z_{3.00}O_{12.00}$.Sp. gravity $^{20}_{4}C = 3.932$ (average of 10 determinations). $n_{Na} = 1.971$ (average of 10 determinations).

titanian garnets agrees therefore in this respect (TiO₂: n_{γ} ratio) with my own, and this in spite of their garnets being compiled from widely scattered localities while mine are all from Alnö Island.

In the diagram Fig. 7 the averaging straight line is inclined about 36° to the "specific gravity axis". If the analysis no. 9 is discarded in Howie's and Woolley's plotting of the wt. % TiO₂ against the specific gravity a fairly satisfying straight line could be drawn through the remaining scattered plots, which, transferred to the scale of my Fig. 7, would give an angle only slightly larger than 36° (cf. 16, p. 788, Fig. 1*b*).

Olivine and serpentine

Olivines occur in sövites, in jacupirangitic ores, in alvikite and beforosite dike rocks and in kimberlites. In the sövitic dikes at Stavsätt and Stolpås a graphic intergrowth of calcite and olivine occurs frequently, Pl. XVI, Fig. 1. It was noticed by Högbom

Analysis no. 44. Forsterite.
Locality: In kimberlite dike between Hartung and Närsta, Alnö Island.

Analyst: Harry von Eckermann.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 4(O)	Atomic ratio	
SiO ₂	40.82	67.97	0.999	Mg	90.3
CO ₂	0.00	—		Fe	9.7
TiO ₂	0.08	0.10	0.002		
ZrO ₂	n.d.				
P ₂ O ₅	n.d.				
Al ₂ O ₃	tr.				
Cr ₂ O ₃	0.06	0.04	0.001	} 2.001	
Fe ₂ O ₃	0.19	0.12	0.004		
FeO	9.43	13.13	0.193		
MnO	0.12	0.17	0.003		
MgO	49.32	122.32	1.798		
CaO	< 0.01				
BaO	tr.				
SrO	tr.				
Na ₂ O	0.00	—			
K ₂ O	0.00	—			
F	n.d.				
Cl	n.d.				
H ₂ O ^{+105°}	0.05				
H ₂ O ^{-105°}	0.06				
	100.13				

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.292$.

 $2 V_{\text{Na}}$ (observed) = $89^{\circ} \pm 1^{\circ}$; $2 V_{\text{Na}}$ (calculated) = $88^{\circ} 57'$; $n_{\alpha_{\text{Na}}} = 1.652 \pm 0.001$; $n_{\beta_{\text{Na}}} = 1.669 \pm 0.001$; $n_{\gamma_{\text{Na}}} = 1.687 \pm 0.001$.

in sövite outcropping on the small islands west-north-west of Hörningsholm and in the later disappeared knopite-bearing boulders at Långörsholmen Island. He believed the calcite to have "grown into" the olivine in a manner similar to that of quartz into orthoclase in granophyres (cf. 18, pp. 221–223). The true explanation of the formation of this symplectitic texture is probably the de-dolomitization of the previous ankeritic-dolomitic carbonate crystals. In each crystal the intergrown calcite and olivine constitute physically and optically one single homogeneous crystal each. At Stolpås I have even observed symplectitic twins with fresh olivine in the margins of the sövite dike and serpentinized olivine in the centre of the dike.

Generally, the more or less homogeneous olivine contains many inclusions of CO₂-filled vesicles, Pl. XVIII, Fig. 1, carbonates and ore-dust. Between Hartung and Närsta, however, when removing the overburden, a kimberlitic dike was found, which contains large, yellowish-green, nicely crystallized olivines of a length of up to 6 mm (cf. 9e, Pl. 58, dike dipping 69° NE). In thin sections the mineral proved quite homogeneous. The optical properties were determined on a isolated crystal of maximum size and agree with the chemical composition, analysis no. 44, which is not unlike those of Yakutian kimberlites (29, pp. 106–107). A still higher Fe⁺² percentage occurs in the olivine of a "jacupirangitic iron ore" at Stavsätt where the mineral is zonal with yellowish-green kernels and greenish-yellow rims but with badly

*Analysis no. 45. Forsterite.**Locality:* In jacupirangitic "iron ore" at Stavsätt, Alnö Island. *Analyst:* G. K. Almström.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 4(O)	Atomic ratio		
SiO ₂	40.26	67.05	1.001	Mg	88.16	
CO ₂	0.00	—		Fe	11.84	
TiO ₂	0.14	0.22	} 2.004			
ZrO ₂	n.d.					
P ₂ O ₅	n.d.					
Al ₂ O ₃	0.04	0.04		0.008		
Cr ₂ O ₃	0.05	0.03				
Fe ₂ O ₃	0.16	0.10				
FeO	11.11	15.47		0.231		
MnO	0.29	0.41		0.006		
MgO	46.45	115.20		1.725		
CaO	1.28	2.28		0.034		
BaO	0.005	—				
SrO	0.005	—				
Na ₂ O	0.00	—				
K ₂ O	0.00					
F	n.d.					
Cl	n.d.					
H ₂ O ^{+105°}	0.08	0.44				
H ₂ O ^{-105°}	0.21					
	100.08					

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.341$ (average of 20 determinations). $2 V_{\gamma\text{Na}}$ (observed) = $+88^{\circ}-89^{\circ} \pm 1^{\circ}$. $2 V_{\gamma\text{Na}}$ (calculated) = $+87^{\circ}13'-89^{\circ}38'$. $n_{\alpha\text{Na}} = 1.658-1.660 \pm 0.001$ (average of 20 determinations). $n_{\beta\text{Na}} = 1.673-1.675 \pm 0.001$ (average of 20 determinations). $n_{\gamma\text{Na}} = 1.690-1.691 \pm 0.001$ (average of 20 determinations).

developed crystals. The analysis, no. 45, expresses therefore the average composition, and the mineral is evidently a chrysolite. Notable is the comparatively large percentage of CaO. A beforstic dike rock south of Sunds Bruk on the mainland west of the Alnö island contains in its central part about 25% olivine together with calcitic carbonate. The olivine is quite homogeneous and of a greenish colour. The analysis, no. 46, indicates a chrysolitic composition.

The olivine of the beautiful intergrowth with calcite at Stolpås was also analysed and found to be a chrysolite of still higher Fe content (analysis no. 47). While in every single crystal the olivine appeared physically and optically uniform the specific gravity and the optical properties changed gradually somewhat in the direction towards the centre of the sövite dike. The analysis, therefore, expresses the average composition of a series of samples, taken at right angles to the strike of the dike. For every third part of the series a small quantity of olivine was isolated and thin sections prepared in order to illustrate the gradual changes.

In the diagram, Fig. 8, are plotted the specific gravities, the essential chemical compounds in weight percentages and the optical data. Unfortunately no arcspectrograms were taken of the olivines and their content of trace elements remains unknown with the exception of V found in traces in analyses nos. 46 and 47. Chro-

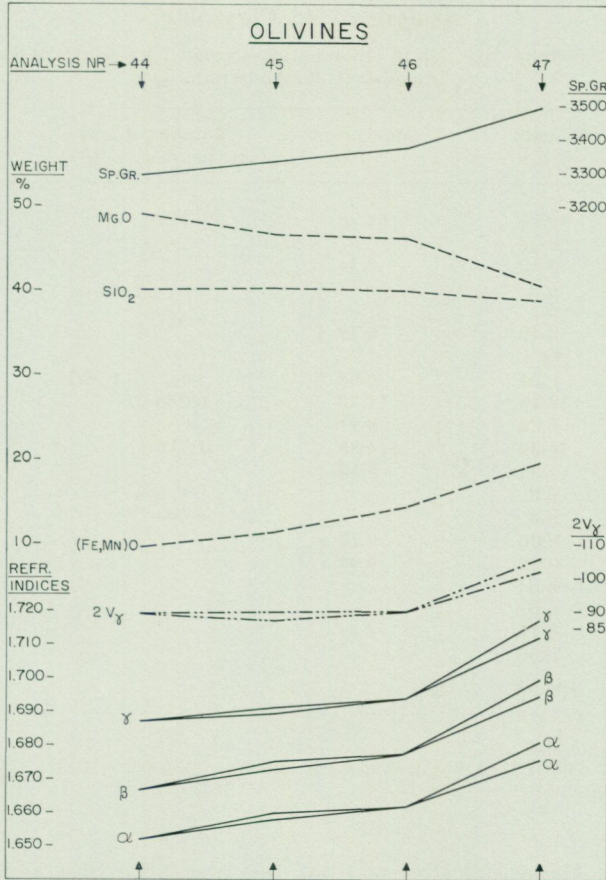


Fig. 8. Weight % of the major components of olivine and the corresponding refractive indices.

mium is present in small quantities in analyses 44 and 45, occurs as traces in analysis no. 46 and is lacking in analysis no. 47.

Olivine alters frequently into serpentine in the Alnö rocks. Occasionally the precipitation of ore dust accompanies the alteration, and carbonatization followed by exsolution of quartz occurs too (cf. 90, p. 398). Only one analysis, no. 48, was executed, the subject being an apparently homogeneous serpentine replacing olivine in jacupirangitic iron ore. No other alteration products, such as ore dust, carbonate or quartz were visible microscopically.

Chain silicates

Wollastonite

Wollastonite occurs frequently at the contacts between sövite and fenite and generally as enclosures within the feldspathized or nephelinized fenite in the immediate proximity of the contact. It generally contains some soda indicating a

*Analysis no. 46. Chrysolite.**Locality:* In beforite dike rich in olivine at coast road 1 km south of Sunds Bruk.*Analyst:* G. K. Almström.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 4(O)	Atomic ratio		
SiO ₂	40.11	66.78	0.999	Mg	86.9	
CO ₂	0.00	—		Fe	13.1	
TiO ₂	0.19	0.24	} 1.996			
ZrO ₂	n.d.					
V ₂ O ₃	tr.					
Al ₂ O ₃	0.12	0.12				
Cr ₂ O ₃	tr.	—				
Fe ₂ O ₃	0.51	0.32				
FeO	12.38	17.23	0.259			
MnO	0.08	0.11				
MgO	46.30	114.83	1.716			
CaO	0.08	0.10	} 0.004			
BaO	n.d.					
SrO	n.d.					
Na ₂ O	0.08	0.13				
K ₂ O	0.06	0.06				
F	n.d.					
Cl	n.d.					
H ₂ O ^{+105°}	0.11	0.61				
H ₂ O ^{-105°}	0.06					
	100.08					

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.377$.
 $2 V_{\text{Na}}$ (observed) = $90^{\circ} \pm 1^{\circ}$; $2 V_{\text{Na}}$ (calculated) = 90° ; $n_{\alpha\text{Na}} = 1.662 \pm 0.001$; $n_{\beta\text{Na}} = 1.678 \pm 0.001$;
 $n_{\gamma\text{Na}} = 1.694 \pm 0.001$.

pectolitic trend. Microscopically, pectolite has also been observed as a separate phase within the wollastonite, but only in minute patches of higher birefringence. My earlier suggestion of a slightly pectolitic composition of the wollastonite (9e, p. 125) has now been confirmed by a series of analyses. The textbooks do not mention any alteration of wollastonite into pectolite. It might in this case be a process of exsolution, triggered by temperature and (or) pressure. Analysis no. 47 gives the composition of wollastonite in fenite at the western contact of the large sövite dike east of Hartung.

P. J. Wyllie and J. L. Haas, when discussing the CaO-SiO₂-CO₂-H₂O system (34, p. 538) indicate "the possibility for coprecipitation of calcite and wollastonite through a significant temperature interval before the hydrated minerals are precipitated". They write: "Although wollastonite is not known in carbonatites themselves it does occur in the parageneses of carbonatite-alkalic rock complexes", quoting King and Sutherland 1960, Dawson 1962 and King 1965. The authors overlooked my Alnö memoir of 1948, where alvikitic coneshed dikes containing wollastonite are described (9e, p. 125, Pl. 54, Fig. 1). At professor Wyllie's request I published a reminder (9s, p. 2253), mentioning also the later discovery of a big boulder at Slädaviken, which consisted of only calcitic carbonate and up to 5 cm long wollastonite crystals. Any corresponding outcrop was, however, never found (Pl. XVIII, Fig. 2).

Analysis no. 47. Chrysolite.

Locality: In graphic intergrowth with calcite in sövite at Stolpås. Analyst: G. K. Almström.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 4(O)	Atomic ratio	
SiO ₂	38.80	64.60	0.998	Mg	79.02
CO ₂ (by H.v.E.)	0.00	—	} 1.990	Fe	20.98
TiO ₂	0.21	0.26			
ZrO ₂	0.00	—			
V ₂ O ₃	< 0.01	—			
Al ₂ O ₃	tr.	—			
Cr ₂ O ₃	0.00	—			
Fe ₂ O ₃	0.31	0.19			
FeO	19.11	26.60		0.411	
MnO	0.82	1.14		0.017	
MgO	40.39	100.17		1.547	
CaO	0.18	0.32	} 0.005		
BaO	0.02	0.01			
SrO	0.005	—			
Na ₂ O	0.00	—			
K ₂ O	0.00	—			
F	n.d.				
Cl	n.d.				
H ₂ O ^{+105°}	0.09	0.50			
H ₂ O ^{-105°}	0.32				
	100.26				

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.489-3.495$.

 $2 V_{\alpha\text{Na}}$ (observed) = $-87^{\circ}, -85^{\circ}, -85^{\circ} \pm 1^{\circ}$ (each angle the average of 5 determinations).

 $2 V_{\alpha\text{Na}}$ (calculated) = $-87^{\circ}41' - 84^{\circ}38' - 84^{\circ}36'$.

 $n_{\alpha\text{Na}} = 1.681-1.679-1.676 \pm 0.001$ (each figure the average of 5 determinations).

 $n_{\beta\text{Na}} = 1.700-1.700-1.695 \pm 0.001$ (each figure the average of 5 determinations).

 $n_{\gamma\text{Na}} = 1.718-1.718-1.713 \pm 0.001$ (each figure the average of 5 determinations).

At the eastern contact of the big sövite dike west of the Hartung village wollastonite occurs in well developed prismatic crystals in the fenite in immediate proximity to the contact. The central part of the mineral contains shadowy patches of somewhat higher birefringence. The analysis (no. 49) shows, however, that the schematically calculated percentage of pectolite is rather low. In the wollastonite of the above-mentioned boulder it is somewhat higher, as proved by analysis no. 50. This does not seem to have affected, though, the birefringence which is the same as in the previous case. Microscopically, the wollastonite appears to be quite homogeneous, although in patches somewhat turbid and no pectolitic "inclusions" of higher birefringence were observed.

In the big sövite quarry at Smedsgården (in 1967 abandoned and filled in) wollastonite was found, partly within the sövite, but close to the fenite contacts, and partly in the centre of the quarry. The former wollastonite occurred in a mineral paragenesis of calcite, phlogopite and diopsidic aegirine-augite while the latter was found in pure sövite carbonate. The analysis (no. 51) of the "contact-wollastonite" shows the highest apparent pectolite content recorded in this series of analyses, and microscopically patches of stronger birefringence were observed in the centre of the crystals, fading

*Analysis no. 48. Pseudomorph of olivine.**Locality:* In jacupirangitic iron-ore at Ås farm. *Analyst:* G. K. Almström.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 18(O,OH)	
SiO ₂	36.91	61.46	Si	4.705
CO ₂	n.d.			
TiO ₂	n.d.			
ZrO ₂	n.d.			
P ₂ O ₅	n.d.			
Al ₂ O ₃	1.01	0.99	Al	0.115
Cr ₂ O ₃	0.01	—		
Fe ₂ O ₃	7.24	4.53	Fe ⁺³	0.534
FeO	2.23	3.10	Fe ⁺²	0.179
MnO	0.25	0.35	Mn	0.020
MgO	36.93	91.59	Mg	5.290
CaO	2.07	3.69	Ca	0.213
BaO	< 0.005	—		
SrO	< 0.003	—		
Na ₂ O	0.09	0.15	Na	0.017
K ₂ O	0.04	0.04	K	0.005
F	n.d.			
Cl	n.d.			
H ₂ O ^{+105°}	13.15	72.99	OH	8.440
H ₂ O ^{-105°}	1.11			
	101.04			

Schematic average composition:

	Mol. %	Weight %
Greenalitic serpentine	84	91.13
Cronstedtitic amesite	16	
Quartz		8.00
Excess water		0.80
		99.93

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.693$ (average of 10 determinations).
 $n_{\gamma} = 1.579-1.590$ (range of 10 determinations).

towards the margins. As a separation of the wollastonite of normal and higher bi-refringence proved impossible the specific gravity of the whole crystals was determined. The resulting figure is rather low, which is partly due to the "pectolite" and partly to sparse vesicles filled with CO₂ and eliminated in the analytical sample by powdery grinding. The optical properties were determined on the marginal parts of the crystals and show fairly normal wollastonite values. An attempt to determine the axial angle of the central parts of the crystals failed on account of the turbidness. The birefringence could, however, be determined and its maximum value is given with the analysis.

The genesis of these "pectolitic" wollastonites is, of course, a problem, but I suggest that pectolite was first formed in the primary more water-rich gas-mixture at the contacts and then replaced by wollastonite when the water vapour and the

Analysis no. 49. Wollastonite.
Locality: In fenite at the contact west of Hartung village. *Analyst:* N. Sahlbom.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 18(O)	
SiO ₂	50.55	84.17	Si	5.860
CO ₂	n.d.			
TiO ₂	0.00	—		
ZrO ₂	n.d.			
P ₂ O ₅	0.00	—		
Al ₂ O ₃	0.43	0.42	Al	0.059
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃	0.08	0.05	Fe ⁺³	0.007
FeO	1.13	1.57	Fe ⁺²	0.108
MnO	0.73	1.03	Mn	0.071
MgO	0.14	0.35	Mg	0.025
CaO	46.29	81.70	Ca	5.750
BaO	0.05	0.03	Ba	0.002
SrO	0.005	—		
Na ₂ O	0.26	0.42	Na	0.058
K ₂ O	0.00	—		
F	0.00	—		
Cl	n.d.			
S				
SO ₃				
H ₂ O ^{+105°}	0.39	2.17	OH	0.302
H ₂ O ^{-105°}	0.00			
	100.05			

Schematic composition: 95.95 % weight wollastonite.
 2.80 % weight pectolite.
 1.25 % weight rest (0.95 RO + 0.30 H₂O).

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.871 - 2.922$.

$2 V_{\text{Na}}$ (observed) = $-42^{\circ} \pm 1^{\circ}$; $2 V_{\text{Na}}$ (calculated) = $-42^{\circ} 20'$; $n_{\alpha\text{Na}} = 1.622 \pm 0.001$; $n_{\beta\text{Na}} = 1.634 \pm 0.001$; $n_{\gamma\text{Na}} = 1.636 \pm 0.001$.

zone of maximum hydration moved further into the wall rocks, and CO₂ became the dominant gas. It remains strange that I have not been able to observe even at strong magnification any exsolution of pectolite in the case of the wollastonite of analysis no. 51.

In the wollastonite within the sövite, the analysis no. 52 shows a very small amount of both soda and water, and the mineral is quite homogeneous without any optically divergent patches. It occurs, however, only within an elongated streak of fine-grained sövite in the very middle of the great dike and resembles a secondary fissure intrusion. CO₂-filled vesicles are wanting.

Of the above-mentioned analyses, nos. 49 and 52 especially may serve as proofs of the correctness of Wyllie's and Haas's above-mentioned deduction of a coprecipitation of calcite and wollastonite.

Barium and strontium were only determined in analyses nos. 49 and 52. When present, barium is dominant, but evidently the occurrence of Ba and Sr is sporadic. The arc-spectrogram of analysis no. 50 is probably representative for all Alnö wolla-

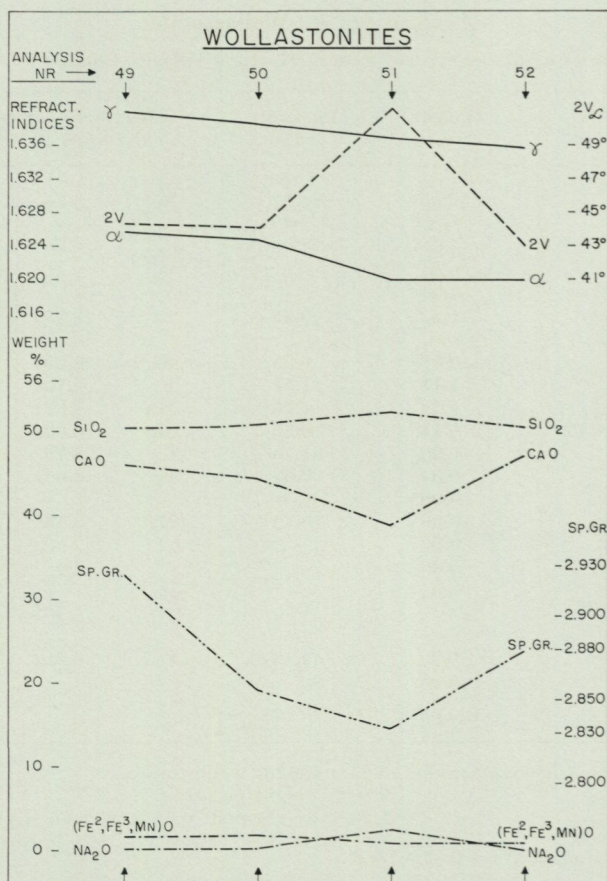


Fig. 9. The specific gravity, refractive indices, axial angles and major chemical components of the wollastonites.

stonites. Titanium is absent in all of them except the most "pectolitic" one of analysis no. 51 and it remains an unanswered question whether it accompanies the pectolitic "impurity" or the wollastonitic host-mineral.

Finally, the weight percentages of the essential minerals and the physical and optical properties of the analysed wollastonites are plotted in the diagram, Fig. 9.

Pyroxenes

A preliminary account of the chemistry of the pyroxenes and of their optical data was presented at the general meeting of the International Mineralogical Association at New Delhi in December 1964 and published in the IMA volume of the Mineralogical Society of India 1966 (9r). It comprised all analyses made at that time except one, which I considered dubious, but which has been rechecked since and is here given as no. 53. Three of the pyroxenes are from the disused and filled-in sövite

Analysis no. 50. Wollastonite.
Locality: In boulder at Slädaviken Bay. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 18(O)	
SiO ₂	51.38	85.55	Si	5.995
CO ₂	0.00	—		
TiO ₂	0.00	—		
ZrO ₂	n.d.			
P ₂ O ₅	0.00	—	Al	0.005
Al ₂ O ₃	0.56	0.55	Al	0.077
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃	0.60	0.38	Fe ⁺³	0.053
FeO	0.70	0.97	Fe ⁺²	0.068
MnO	0.69	0.97	Mn	0.068
MgO	0.33	0.82	Mg	0.057
CaO	44.41	79.19	Ca	5.550
BaO	n.d.			
SrO	n.d.			
Na ₂ O	0.52	0.84	Na	0.118
K ₂ O	0.00	—		
F	0.00	—		
Cu	0.01	—		
H ₂ O ^{+105°}	0.56	3.11		
H ₂ O ^{-105°}	0.21			
	99.97			

Schematic composition: Wollastonite 92.34 % weight.
 Pectolite 5.75 % weight.
 Pyrophyllite + water 1.91 % weight.
 100.00

Arc-spectrogram: Cd +, Bi[+], Pb[+], V[+], Zn[+], Ga -, Ni -, Ti -.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.858$.

$2 V_{\text{Na}}$ (observed) = $-41^{\circ} \pm 1^{\circ}$; $2 V_{\text{Na}}$ (calculated) = $-42^{\circ} 10'$; $n_{z\text{Na}} = 1.621 \pm 0.001$; $n_{\beta\text{Na}} = 1.633 \pm 0.001$; $n_{\gamma\text{Na}} = 1.635 \pm 0.001$.

Analysis no. 51. Wollastonite.
Locality: In sövite at Smedsgården, a now disused big quarry. *Analyst:* R. Blix.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 18(O)	
SiO ₂	52.72	87.78	Si	6.070
CO ₂	0.00	—		
TiO ₂	0.08	0.10	Ti	0.007
ZrO ₂	n.d.			
P ₂ O ₅	0.00			
Al ₂ O ₃	2.84	2.79	Al	0.386
Cr ₂ O ₃	n.d.			
Fe ₂ O ₃	0.16	0.10	Fe ⁺³	0.014
FeO	0.56	0.78	Fe ⁺²	0.053
MnO	0.25	0.35	Mn	0.024
MgO	0.34	0.84	Mg	0.058
CaO	39.12	69.76	Ca	4.850
BaO	n.d.			
SrO	n.d.			
Na ₂ O	2.38	3.84	Na	0.531

Anal. no. 51 (*cont.*)

	Weight %	Mol. prop. × 100	Number of ions on the basis of 18(O,OH)
K ₂ O	n.d.		
F	n.d.		
Cl			
H ₂ O ⁺¹⁰⁵	0.97	5.38	
H ₂ O ⁻¹⁰⁵	0.23		
	99.65		

Schematic composition: Wollastonite 72.60 % weight.
 Pectolite 25.55 % weight.
 Rest (1.56 SiO₂, 0.29 H₂O) 1.85 % weight.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.835$ (vesicles, pectolitic and other impurities included).
 $2 V_{\text{Na}}$ (observed) = $-50^{\circ} \pm 1^{\circ}$ (marginal part of 20 crystals, average figure).
 $2 V_{\text{Na}}$ (calculated) = $-49^{\circ}22'$.

$n_{\alpha\text{Na}} = 1.616 \pm 0.001$ (marginal part of 20 crystals, average figure).

$n_{\beta\text{Na}} = 1.630 \pm 0.001$ (marginal part of 20 crystals, average figure).

$n_{\gamma\text{Na}} = 1.633 \pm 0.001$ (marginal part of 20 crystals, average figure).

$\beta = 0.017$.

$\theta = 0.029 \pm 0.003$ (central parts of high birefringence).

Analysis no. 52. Wollastonite.

Locality: In sövite at Smedsgården farm. *Analyst:* N. Sahlbom.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 18(O)	
SiO ₂	51.22	85.28	Si	5.960
CO ₂	0.00	—		
TiO ₂	tr.			
ZrO ₂	n.d.			
P ₂ O ₅	n.d.			
Al ₂ O ₃	0.22	0.22	Al	0.040
Cr ₂ O ₃	n.d.		Al	0.001
Fe ₂ O ₃	0.08	0.05	Fe ⁺³	0.007
FeO	0.62	0.86	Fe ⁺²	0.060
MnO	0.04	0.06	Mn	0.004
MgO	0.08	0.20	Mg	0.014
CaO	47.61	84.90	Ca	5.933
BaO	0.00	—		
SrO	0.00	—		
Na ₂ O	0.04	0.07	Na	0.005
K ₂ O	0.00			
H ₂ O ⁺¹⁰⁵	0.05	0.28		
H ₂ O ⁻¹⁰⁵	0.11			
	100.07			

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.882$.
 $2 V_{\text{Na}}$ (observed) = $-42^{\circ} \pm 30'$; $2 V_{\text{Na}}$ (calculated) = $-41^{\circ}08'$; $n_{\alpha\text{Na}} = 1.616 \pm 0.001$; $n_{\beta\text{Na}} = 1.630 \pm 0.001$; $n_{\gamma\text{Na}} = 1.632 \pm 0.001$.

quarries south and north of the farm Smedsgården, one from the sövite south of the western Stolpås farm, one from the disused and filled-in sövite quarry south-west of Ås jetty, two from the sövite-pegmatite at W. Stolpås farm (of which one from the very contact towards the fenite) one from the ijolite quarry west of Hörningsholm, one from the sövite-nepheline fenite contact north of Släda farm, two from fenites south of Smedsgården and north-east of Alnö church, three from basic fenites west of Hörningsholm and north of the road to Ås jetty and one from jacupirangite at Ås farm.

Comments on the chemical composition

The pyroxenes are all more or less aegirine-augitic. The composition of monoclinic pyroxenes was expressed by Machatschki (25) by the general formula $XYZ_2(O,OH,F)_6$, where $X = Ca^{+2}, Na^{+1}, K^{+1}$; $Y = Mg^{+2}, Fe^{+2}, Fe^{+3}, Al^{+3}$ and $Z = Si^{+4}, Al^{+3}$. Schiebold (27) combined the two types XYZ_2O_6 with X-cations of eight-, respectively sixfold coordination only, into a general formula $X_mY_{2-m}((Si,Al)_2(O,OH,F)_6)$, where $X = Ca, Na, K, Mn$ ($n=8$) and $Y = Mg, Fe, Al, Ti, Mn$ ($n=6$). Finally Strunz (30) writes the general formula of augite $Ca_{6.5}Na_{0.5}Fe^{+2}Mg_6(Al,Fe^{+3},Ti)_2(Al_{1.5-3.5}Si_{14.5-12.5}O_{48})$,—aegirine-augite containing $NaFe^{3+}$.

When calculating the formulae of the Alnö pyroxenes one finds that they generally agree very nicely with both the general formula of Machatschki and that of Schiebold if $m=1$, and also with that of Strunz, except that the $Mg:Fe^{+2}$ ratio in several analyses exceeds its theoretical limit of 2:1. The calculation of the composition of the pyroxenes was in my IMA-paper based on the YZ -groups and the reason for this method of calculation is the previously mentioned uncertainty of the original oxidation ratio of the iron. As the analyses have been carried out by four different chemists I do not know if the grinding has been properly watched. The composition of each mineral given together with the analysis is in this paper, too, based on the same method of calculation. In fact, seven of the sixteen analyses show a small excess of the oxygen group.

The content of Al in the Y -group varies considerably and is lacking in 5 analyses. The variation in the Z -group is still more pronounced and reaches a maximum value

Table 1. Atomic percentages within each of the pyroxene-groups X, Y and Z.

Analysis no.	X	Y	Z
53	$((Na,K)_6Ca_{94})$	$(Ti_2Al_0(Fe^{tot},Mn)_{31}Mg_{67})$	$(Al_{18}Si_{82})$
54	$((Na,K)_8Ca_{92})$	$(Ti_3Al_8(Fe^{tot},Mn)_{27}Mg_{62})$	$(Al_{16}Si_{84})$
55	$((Na,K)_4Ca_{96})$	$(Ti_2Al_8(Fe^{tot},Mn)_{28}Mg_{62})$	$(Al_{14}Si_{86})$
56	$((Na,K)_8Ca_{92})$	$(Ti_2Al_2(Fe^{tot},Mn)_{32}Mg_{64})$	$(Al_{10}Si_{90})$
57	$((Na,K)_{11}Ca_{89})$	$(Ti_3Al_0(Fe^{tot},Mn)_{28}Mg_{69})$	(Al_9Si_{91})
58	$((Na,K)_{25}Ca_{75})$	$(Ti_2Al_2(Fe^{tot},Mn)_{66}Mg_{30})$	(Al_4Si_{96})
59	$((Na,K)_{22}Ca_{78})$	$(Ti_2Al_0(Fe^{tot},Mn)_{62}Mg_{36})$	(Al_6Si_{94})
60	$((Na,K)_{16}Ca_{84})$	$(Ti_2Al_2(Fe^{tot},Mn)_{45}Mg_{51})$	(Al_4Si_{96})
61	$((Na,K)_{13}Ca_{87})$	$(Ti_6Al_4(Fe^{tot},Mn)_{36}Mg_{54})$	$(Al_{14}Si_{86})$
62	$((Na,K)_{16}Ca_{84})$	$(Ti_4Al_2(Fe^{tot},Mn)_{50}Mg_{44})$	(Al_7Si_{93})
63	$((Na,K)_{34}Ca_{66})$	$(Ti_2Al_4(Fe^{tot},Mn)_{66}Mg_{28})$	(Al_4Si_{96})
64	$((Na,K)_{57}Ca_{43})$	$(Ti_2Al_6(Fe^{tot},Mn)_{72}Mg_{20})$	(Al_4Si_{96})
65	$((Na,K)_6Ca_{94})$	$(Ti_8Al_0(Fe^{tot},Mn)_{52}Mg_{40})$	$(Al_{21}Si_{79})$
66	$((Na,K)_{11}Ca_{89})$	$(Ti_6Al_6(Fe^{tot},Mn)_{34}Mg_{54})$	$(Al_{12}Si_{88})$
67	$((Na,K)_{14}Ca_{86})$	$(Ti_6Al_6(Fe^{tot},Mn)_{40}Mg_{48})$	$(Al_{15}Si_{85})$
68	$((Na,K)_8Ca_{92})$	$(Ti_6Al_8(Fe^{tot},Mn)_{36}Mg_{50})$	$(Al_{19}Si_{81})$

Table 2. Aegirine-augite analyses.
Numbers of ions on the basis of 6 oxygens.

	53	54	55	56	57	58
Si	1.665	1.713	1.750	1.810	1.830	1.919
Al	0.335	0.287	0.250	0.190	0.170	0.081
Fe ⁺³	—	—	—	—	—	—
Ti	0.023	0.035	0.027	0.028	0.027	0.017
Al	0.030	0.126	0.113	0.035	0.019	0.057
Fe ⁺³	0.190	0.191	0.186	0.191	0.152	0.274
Fe ⁺²	0.121	0.077	0.139	0.115	0.144	0.333
Mn	0.006	0.008	0.002	0.003	0.002	0.054
Mg	0.676	0.668	0.634	0.637	0.696	0.299
Ca	0.956	0.946	0.952	0.920	0.886	0.752
Na	0.048	0.046	0.068	0.065	0.088	0.256
K	0.011	0.026	0.013	0.013	0.023	0.013
	2.00	2.00	2.00	2.00	2.00	2.00
	1.04	1.10	1.10	1.01	1.04	1.03
	1.02	1.02	1.03	1.00	1.00	1.02
	59	60	61	62	63	64
Si	1.940	1.936	1.731	1.870	1.920	1.935
Al	0.060	0.064	0.269	0.130	0.080	0.065
Fe ⁺³	—	—	—	—	—	—
Ti	0.020	0.017	0.062	0.045	0.020	0.015
Al	0.097	0.034	0.058	0.102	0.045	0.076
Fe ⁺³	0.237	0.208	0.170	0.182	0.450	0.540
Fe ⁺²	0.349	0.208	0.118	0.303	0.154	0.174
Mn	0.043	0.018	0.016	0.026	0.053	0.034
Mg	0.365	0.691	0.543	0.432	0.267	0.205
Ca	0.692	0.830	0.873	0.836	0.654	0.427
Na	0.172	0.186	0.098	0.134	0.334	0.554
K	0.026	0.014	0.033	0.021	0.005	0.019
	2.00	2.00	2.00	2.00	2.00	2.00
	1.11	1.18	0.97	1.09	0.99	1.04
	0.89	1.03	1.00	0.99	0.99	1.00
	65	66	67	68		
Si	1.618	1.775	1.780	1.635		
Al	0.364	0.225	0.220	0.365	2.00	
Fe ⁺³	0.013	—	—	—		
Ti	0.140	0.052	0.086	0.065		
Al	—	0.058	0.012	0.027		
Fe ⁺³	0.250	0.156	0.198	0.164		
Fe ⁺²	0.174	0.172	0.205	0.193	0.96	
Mn	0.013	0.011	0.017	0.010		
Mg	0.533	0.554	0.458	0.504		
Ca	0.937	0.900	0.852	0.946		
Na	0.066	0.083	0.130	0.053	1.01	
K	0.005	0.026	0.045	0.006		

in the somewhat titaniferous augite of the jacupirangite, Al replacing Si to 21½%. This is an interesting replacement, as Strunz (30, p. 190) gives 25% as the theoretical, but still unproved, limit.

Table 1 gives the atomic ratios within each of the groups X, Y and Z, and Table 2 the ionic ratios, calculated on the basis of 6(F,Cl,OH,O) in order to facilitate a comparison with series of pyroxene analyses published lately by other authors, *exempli gratia* Deer *et al.* (8), Tylor and King (32), Yashina *et al.* (35), Kononova (22, 35), and Kukharensko *et al.* (23).

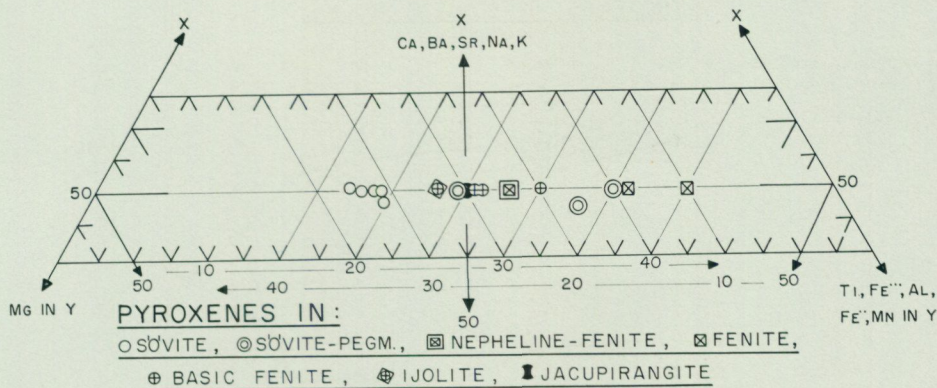


Fig. 10. X - (Mg in Y) - (Ti, Al, Fe³, Fe², Mn in Y) diagram of the pyroxenes.

Plotting the atomic percentages of the X and Y groups in the diagram, Fig. 10, gives an indication of the quality and reliability of the analyses. Theoretically, all the analyses should fall along the straight line "50-50", the size of the X-group being the same as the sum of the two components "Mg" and "Ti, Fe², Fe³, Mn, Al" of the Y-group. Only three analyses show any deviation from the theoretical 50%: a slight one in the case of the pyroxene, analysis no. 60, in sövite pegmatite, a very small one of the pyroxene, analysis no. 54, in sövite and a somewhat larger one of the pyroxene, analysis no. 59, in sövite-pegmatite. These aberrations may be due to an excess of free carbonic acid entrapped in minute vesicles during the crystallization of the minerals, and that, in consequence, too much CaO was calculated and deducted as calcite impurity from the original analysis. The diagram also illustrates the Mg-dominance in the pyroxenes of the sövites as compared with the sövite-pegmatites.

The diagrams Figs. 11 and 12 show the variations in weight of the principal components of the pyroxenes plotted against SiO₂ in sövitic and fenitic rocks respectively. A marked replacement reciprocity of total Fe, calculated as FeO, on one hand and MgO on the other is noticeable in the first-mentioned diagram, starting from analysis no. 55, while in the latter the replacement is almost perfect throughout the diagram. The same is apparent in the case of CaO versus alkalis. The aberration in diagram no. 11 is mainly due to analysis no. 54—the same one which in diagram no. 10 is noticeably displaced towards "X".

Plotting the analyses in atom ratios, Fig. no. 13, the reciprocity of Mg on one hand and Ti, Al, total Fe and Mn on the other is beautifully illustrated. The same applies to Si versus Al in "Z". Finally two diagrams have been drawn, nos. 14 and 15, where the "Niggli-values" fm, c, al and alk have been plotted against si, partly for pyroxenes in sövitic rocks and partly for those in rheomorphic fenite, fenites and jacupirangite. The first diagram shows a reciprocity from analysis no. 54 onwards of fm—c similar to the one of MgO—FeO of diagram, fig. no. 11, while in the second diagram the reciprocity is almost perfect up to analysis no. 63 but does not exist in the case of analysis no. 64, due to exceptionally high alk-percentage, viz. aegirinic composition of the pyroxene.

Seeking an explanation of the aberrations I also plotted the atomic oxidation ratios Fe³: Fe² + Fe³, given in diagram Fig. 28. No general connection between the irre-

PYROXENES IN SÖVITIC ROCKS

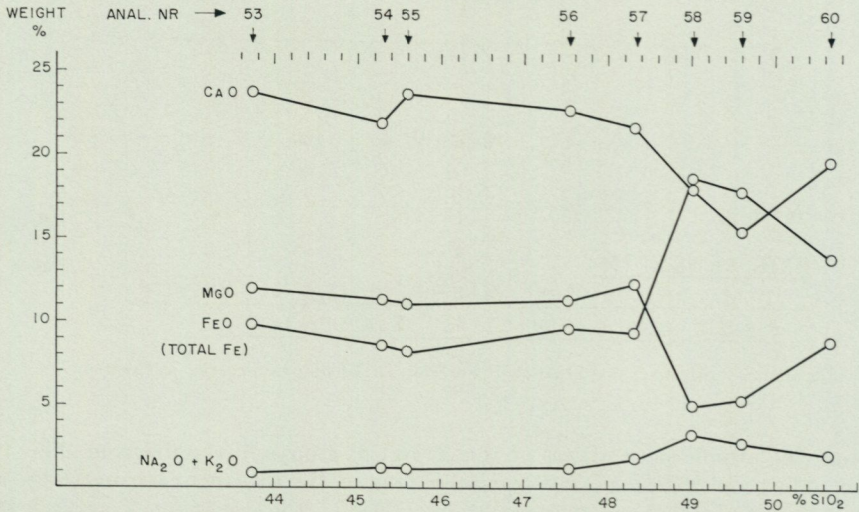


Fig. 11. The weight % of the major components of pyroxenes in sövitic rocks.

PYROXENES IN FENITIC ROCKS

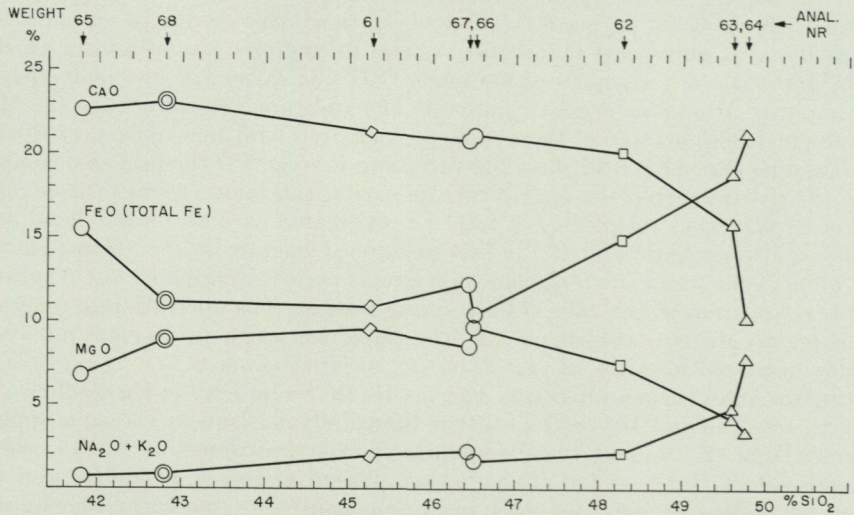


Fig. 12. The weight % of the major components of the pyroxenes in fenitic rocks.

gularities and the oxidation ratio can be traced from this diagram but it illustrates the great variation between pyroxenes of similar rocks. The ratios of pyroxenes from sövites range from 0.49 to 0.72, the sövite-pegmatites from 0.40 to 0.53, the fenites from 0.38 to 0.75 and the basic fenites from 0.47-0.61. The pyroxene of the ijolite has a ratio of 0.49 and that of jacupirangite a very similar of 0.47. Of these values, the

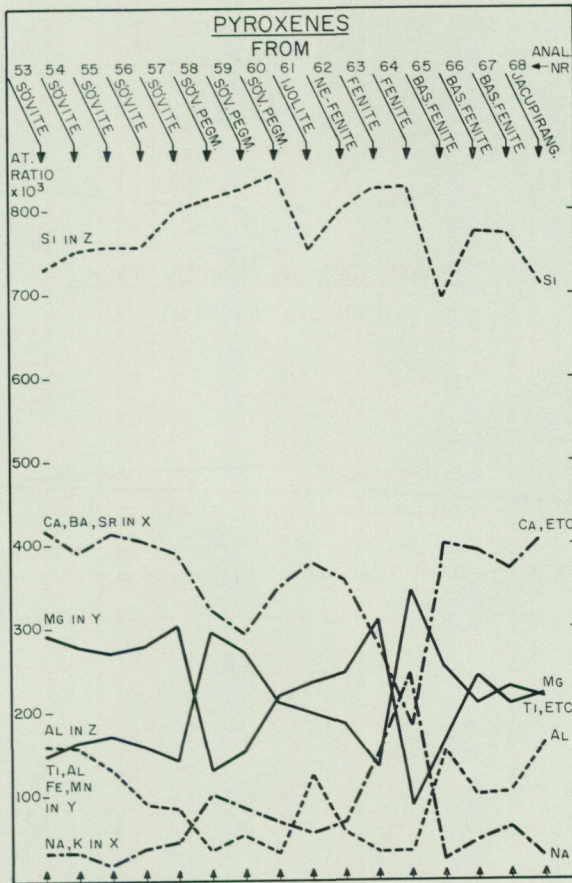


Fig. 13. The major atomic ratios of the pyroxenes.

highest ones, *i.e.* those for the aegirine-rich augites from the sövite-leucocratic fenite-contacts, are of special interest. They suggest a maximum oxidation reaction at these contacts, which may, perhaps, be explained by a corresponding maximum concentration of high-tension carbon dioxide resulting from an addition of the free CO_2 of the carbonatitic magma to the CO_2 set free by the basic fenitization reaction: $\text{CaCO}_3 + \text{SiO}_2 = \text{CaSiO}_3 + \text{CO}_2$. The lower oxidation ratios of the pyroxenes at the "sövite-basic fenite" contacts may, in consequence, be due to the absence of any remaining silica in the shape of quartz or in easily decomposed metasilicates, able to start a fenitization reaction. Therefore, the oxidation of these pyroxenes as well as of those at a distance from the contacts of the sövitic rocks must have been mainly governed by the local concentrations of CO_2 and the variations of CO_2 -pressure. However, there is one exception, the pyroxene of analysis no. 62 from the very contact between nephelinitized fenite and sövite, having a ratio of only 0.38. It may, perhaps, be explained by the dominantly nephelinitic-feldspathic composition of the fenite in question and the absence of quartz.

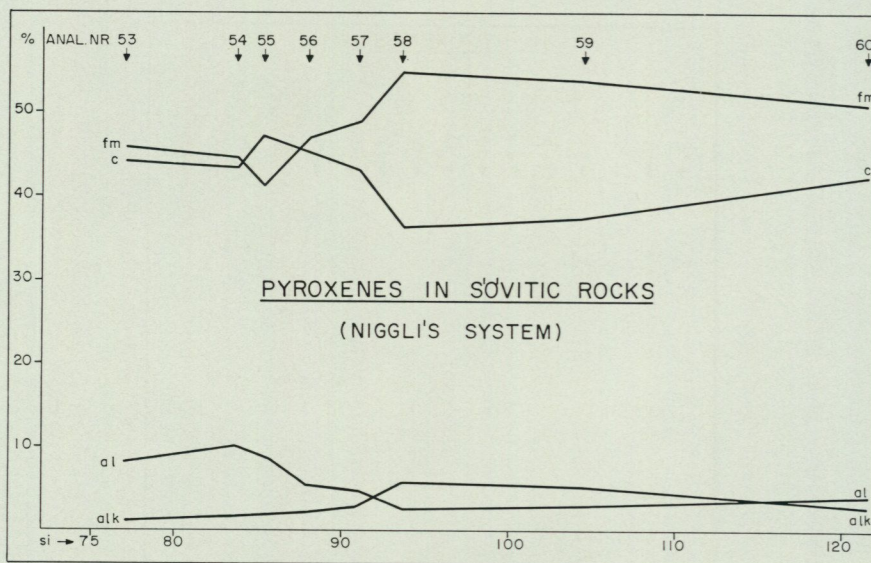


Fig. 14. The essential *Niggli* values of pyroxenes in sövitic rocks.

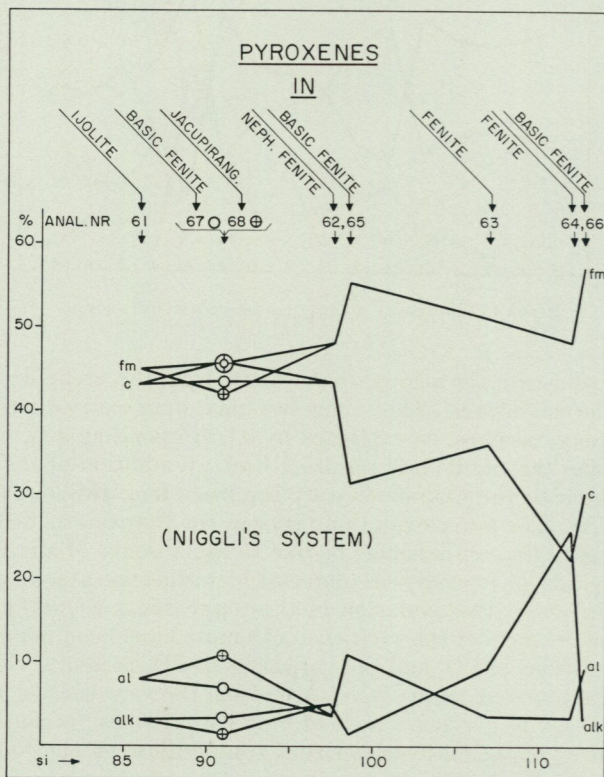


Fig. 15. The essential *Niggli* values of pyroxenes in fenitic rocks.

The titanium content of the pyroxenes varies a good deal. It is low in those of the feldspathic or nephelinic fenites, 0.47–0.60 %, but higher in those of the basic fenites where it reaches maximum values, 1.81–4.85 %. In the sövite the TiO_2 ranges from 0.79 to 1.23 % and in the sövite pegmatites from 0.60 to 0.94 %. The single analysis of pyroxene in juvite shows 2.16 % and that in jacupirangite 2.29 %.

The analysed minor constituents are few. The Cr_2O_3 content has been checked in three of the analyses and is generally small, 0.01 %. It is probably considerably higher in the pyroxenes of the basic igneous rocks: alnöites and kimberlites. The BaO and SrO contents were determined in 8 analyses and BaO was found to be max. 0.06 %, but was totally lacking in three analyses, while SrO did not exceed 0.01 % in one analysis and was wanting in six.

A fairly large amount of fluorine, 0.27 %, occurs in aegirine-augite in the sövite of the Smedsgården quarry, analysis no. 53, and 0.15 % in that of sövite-pegmatite, analysis no. 58, but ranges from traces to 0.09 % in 11 other analyses. It probably occurs in small amounts in the remaining 5 pyroxenes. Chlorine was determined in 10 analyses and ranges from 0.02 to 0.05 %. It seems to be present in all pyroxenes. ZrO_2 was looked for in 6 analyses. In one, no. 66, 0.15 % were found, in another, no. 56, 0.01 % and in four, zirconium was wanting. One may conclude, therefore, that it occurs occasionally. The same may be said about SO_3 , of which 0.08 % was found in one analysis (no. 66) out of three. To judge by the arc-spectrograms, vanadium is present in very small amounts in all pyroxenes, but may occasionally enter the composition in chemically determinable quantity, as for instance 0.10 % in analysis no. 59. As beryllium had been found by the present author to occur locally in the fenites, Miss Berggren looked in the pyroxene analysis no. 66 for BeO, but found none, although the arc-spectrogram indicated its presence.

The specific gravities

Minute inclusions of carbonate and apatite, which on chemical and microgeometrical basis were deducted from the original analyses, remained in the sample at the measurements of specific gravities. In eight cases they amounted to 1.7–2.7 % while they were absent in the other eight. In all pyroxenes, however, minute gas-filled vesicles, observable in the thin slides at very high magnification, may have reduced the actual value. Further pulverizing of the samples by some of my chemists may also help to explain discrepancies between their specific gravity determinations and mine, as some of these vesicles could have been opened up and disappeared. Another reason for a number of varied values from even one and the same sample is due to the frequent and varying zoning of the pyroxenes. In my previous publication (9r, p. 134) I gave the average of 10–20 determinations. Since then I have made a new series of determinations, increasing the amount to 30 in some cases. The new values are given in Table no. 3, and the averages together with the analyses. In diagram, Fig. no. 17, the average specific gravities are plotted against the "total Fe: (Fe + Mn + Mg + Ca)" ratio. As pointed out in my previous paper (9r, p. 135) the pyroxenes of $Al > Fe^{+3}$ and those of $Fe^{+3} > Al$ apparently fell on two different curves. On account of the increased number of determinations of the specific gravity of each pyroxene and altered averages I am inclined to look upon it as nothing but a coincidence.

The optical data

Since I published my earlier optical data in a paper read at the I.M.A. symposium at New Delhi (9r) a new batch of thin slides was made from the very part of the rocks

Table 3. Specific gravities of the pyroxenes.

Analysis no.	Spec. gravity	Number of determinations	Range
53	3.327	5	3.326-3.328
54	3.329	30	3.273-3.460
55	3.325	15	3.327-3.331
56	3.337	20	3.330-3.348
57	3.332	30	3.328-3.341
58	3.522	30	3.421-3.562
59	3.508	12	3.488-3.518
60	3.416	30	3.389-3.473
61	3.381	15	3.369-3.390
62	3.460	25	3.394-3.479
63	3.515	15	3.502-3.520
64	3.589	12	3.584-3.606
65	3.439	20	3.409-3.442
66	3.371	15	3.368-3.380
67	3.410	12	3.396-3.419
68	3.441	12	3.435-3.447

Table 4. Optical data of the pyroxenes.

Analysis no.	n_γ	n_β	n_α	$n_\gamma - n_\alpha$	c/γ	2 V obs.	2 V calc.
53	1.730	1.707	1.701	0.029	-43°	+55°	+54°40'
54	1.725-1.731		1.694-1.701	0.029-0.033	-33° to -41°	+53° to +70°	+68°
55	1.732		1.701	0.031	-39°	+68°	+66°02'
56	1.732	1.711	1.701	0.031	-38°	+68°	+66°02'
57	1.724-1.730		1.696-1.699	0.031	-35°	+71° to +74°	+82°
58	1.748-1.751		1.718-1.721	0.028-0.033	-26° to -36°	+75° to +82°	+79°
59	1.742-1.755		1.710-1.720	0.032-0.035	-23° to -30°	+76° to +79°	+77°
60	1.731-1.738		1.707-1.710	0.025-0.028	-28° to -32°	+74° to +77°	+68°
61	1.745		1.715	0.030	-29°	+68°	+82°
62	1.740-1.766		1.706-1.730	0.028-0.034	-20° to -38°	+71° to +82°	+89°22'
63	1.768	1.748	1.731	0.037	-20°	+90°	+89°22'
64	1.794	1.777	1.750	0.044	-7° to -8°	-77°	-75°44'
65	1.742	1.720	1.710	0.032	-42°	+66°	+68°44'
66	1.739	1.722	1.714	0.025	-39°	+69°	+69°30'
67	1.735	1.713	1.704	0.031	-32°	+62°	+61°00'
68	1.743	1.723	1.717	0.026	-40°	+59°	+57°58'

from which the samples for analyses were prepared. In order to avoid errors caused by the rather strong colour of some of the pyroxenes the slides were ground to about half the normal thickness. From these very thin sections the axial angles and extinctions of the pyroxenes were determined. In the case of apparently homogeneous crystals the average obtained from each set of slides was taken to represent the optical data of the mineral in question. Six of the pyroxenes, however, proved to be of more or less zoned structure, the rims always being more aegirinic than the cores. In their case the minimum and maximum values were recorded.

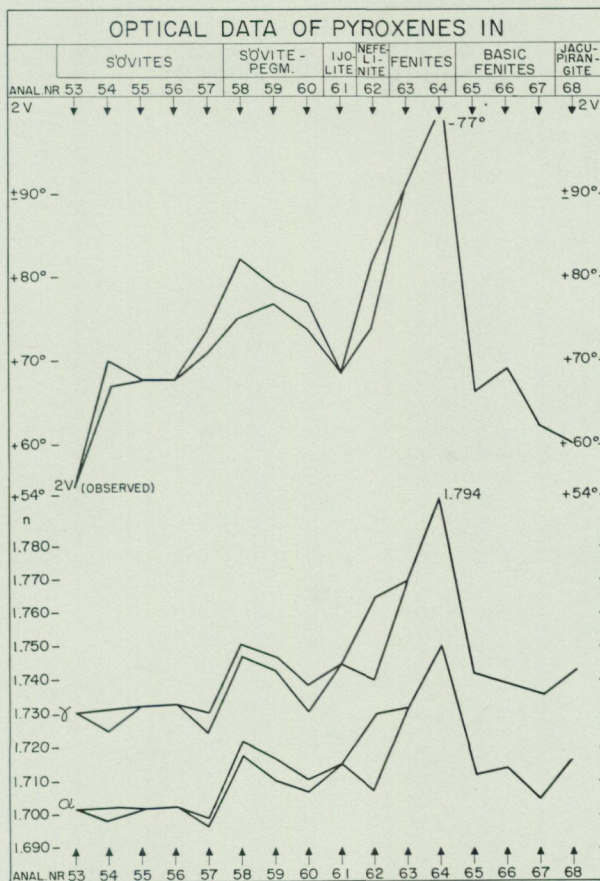


Fig. 16. Optical properties of pyroxenes.

The refractive indices were redetermined, this time using a 5-axis Leitz' universal stage. The refractions of the immersion liquids were carefully checked on a new Zeiss refractometer. The heterogeneity of the above-mentioned 6 pyroxenes (analyses no. 54, 57, 58, 59, 60 and 62) made a reliable determination of the refraction values difficult, for which reason only n_α and n_γ were recorded. The apparently homogeneous minerals allowed the determination of also n_β , which is believed to be fairly correct, although in a few cases vary narrow rims of slightly different refractions occurred.

The new optical data, which in some cases radically differ from those previously published are given in Table no. 4, and the axial angles and n_α and n_γ also in the diagram, Fig. 16. These data do not in parts agree very well with either Tröger-Larsen's diagram of "augites—augirine-augites—augirines", nor with the diagram of Deer *et al.* of the relation between the optical properties and the number of Fe^{+3} -ions per formula unit (8, Vol. 2, p. 87) or with their Sabine-diagram of the relationship between the optical properties and the chemical compositions of aegirine-augite minerals. This is probably due to several reasons, the most important being:

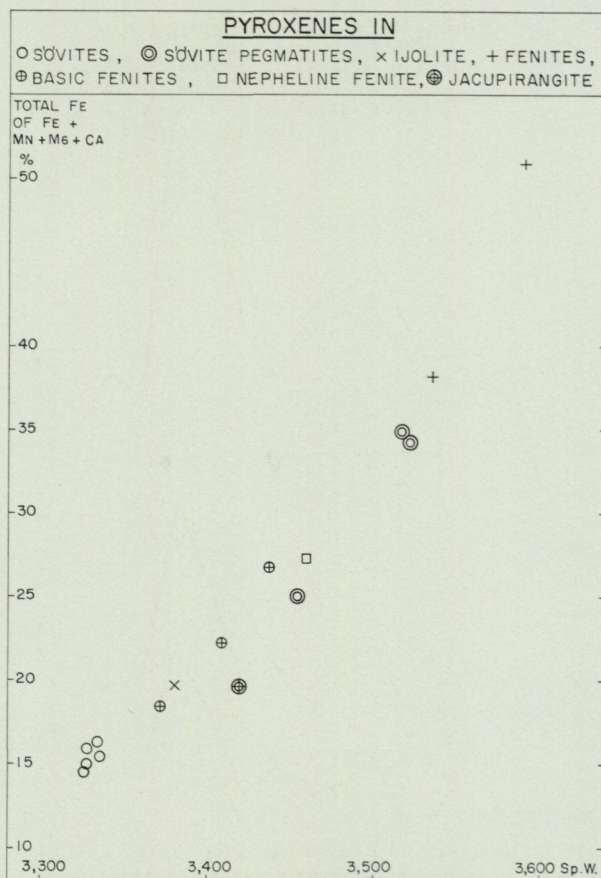


Fig. 17. Specific gravities of pyroxenes.

(1) the presence of inclusions of calcite and apatite in the thin sections of the pyroxenes and in the crystals or crystal fragments used in immersion determinations, but deducted from the analyses;

(2) the occurrence of TiO_2 in the pyroxenes in amounts varying from 0.47 to 4.85 %;

(3) the occurrence of small amounts of V_2O_3 and ZrO_2 in most analyses as well as various trace elements;

(4) the presence of various amounts of minute CO_2 -filled vesicles, especially numerous in the pyroxenes from extremely carbonatitic rocks;

(5) the more or less pronounced zoned structure of the majority of pyroxenes.

General comments

The present research has brought to light the great variability of the Alnö pyroxenes, from almost diopsidic and titaniferous aegirine-augites to strongly aegirinic ones. This wide spread of compositions seems to be duplicated in the case of the pyroxenes

Analysis no. 53. Aegirine-augite.

Locality: In sövite in the disused big quarry at Smedsgården. Analyst: G. K. Almström (CO₂ checked and F determined by H. v. E.).

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
SiO ₂	43.85	73.01			73.01	146.02
CO ₂	0.00	—				
TiO ₂	0.79	0.99		0.99		1.98
ZrO ₂	n.d.					
P ₂ O ₅	n.d.					
Al ₂ O ₃	8.15	8.00			16.00	24.00
Cr ₂ O ₃	< 0.01	—				
Fe ₂ O ₃	6.64	4.16		8.32		12.48
FeO	3.81	5.30		5.30		5.30
MnO	0.20	0.28		0.28		0.28
MgO	11.97	29.70		29.70		29.70
CaO	23.49	41.89	41.89			41.89
BaO	n.d.					
SrO	n.d.					
Na ₂ O	0.65	1.06	2.12			1.06
K ₂ O	0.23	0.25	0.50			0.25
F	0.27	1.42				1.42
Cl	0.04	0.11				0.11
H ₂ O ^{+105°}	0.12	0.61				1.34
H ₂ O ^{-105°}	0.06					
	100.27					
- O = F, Cl	0.13		44.51	44.59	89.01	265.83
	100.14					

Composition: $X_{1.000}Y_{1.002}Z_{2.000}(O,OH,F,Cl)_{5.973}$. Ratio: Mg:Fe:Ca = 37:18:45.

Sp. gravity $\frac{20}{4}^{\circ}C = 3.327$ (average of 5 determinations).

$2V_{550}$ (observed) = $55^{\circ} \pm 1^{\circ}$ (average of 5 determinations).

$2V_{\gamma}$ (calculated) = $54^{\circ}46'$ (average of 5 determinations).

$n_{\alpha 550} = 1.701 \pm 0.001$ (average of 5 determinations).

$n_{\beta 550} = 1.707 \pm 0.001$ (average of 5 determinations).

$n_{\gamma 550} = 1.730 \pm 0.001$ (average of 5 determinations).

$c/\gamma = -43^{\circ}$.

of the Russian alkaline Siberian rocks, as illustrated by the works of Kononova (22), Yashina *et al.* (35), and of those of the Kola peninsula, published by Kukharenko and coworkers (23), not to mention many other prominent Russian mineralogists. For other similar alkaline regions associated with carbonatites and kimberlites or ultrabasic rocks, as in eastern and southern Africa only random analyses seem to have been published, which do not illustrate the spread and chemical compositions and optical and physical properties within individual volcanic regions. An interesting collocation of the pyroxenes of the alkaline complexes of eastern Uganda was, however, recently published by Tylor and King (32). It contains only one pyroxene from fenite (syenitic with nepheline), which is not unlike my analysis no. 62 and three pyroxenes from carbonate-syenitic and carbonatite rocks, of which one from a pyroxene-apatite-carbonatite is the closest approach to the Alnö analysis no. 64, but all of which are considerably more acmitic than the Alnö minerals.

Analysis no. 54. Aegirine-augite.

Locality: In sövite dike at Smedsgården farm. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
SiO ₂	45.34	75.49			75.49	150.98
CO ₂	0.00	—				
TiO ₂	1.23	1.54		1.54		3.08
ZrO ₂	0.00	—				
P ₂ O ₅	0.00	—				
Al ₂ O ₃	9.36	9.18		3.56	14.80	27.54
Cr ₂ O ₃	n.d.					
Fe ₂ O ₃	6.74	4.22		8.44		12.66
FeO	2.48	3.45		3.45		3.45
MnO	0.18	0.25		0.25		0.25
MgO	11.25	27.90		27.90		27.90
CaO	21.98	39.19	39.19			39.19
BaO	0.00	—				
SrO	0.00	—				
Na ₂ O	0.64	1.03	2.06			1.03
K ₂ O	0.54	0.57	1.14			0.57
F	0.05	0.26				0.26
Cl	0.03	0.09				0.09
S	0.00	—				
SO ₃	0.00	—				
H ₂ O ^{+105°}	0.28	1.55				3.10
H ₂ O ^{-105°}	0.09					
	100.19		42.39	45.14	90.29	270.10
- O = F,Cl	0.03					
	100.16					

Composition: $X_{0.94}Y_{1.00}Z_{2.00}(O,OH,F,Cl)_{5.98}$. Ratio: Mg:Fe:Ca = 35:15:50.

Arc-spectrogram: Cu +, Ga +, Pb +, Be[+], V[+], Co[-], Sn[-], Zr -, Zn -.

Sp. gravity $^{20}_{4}C = 3.329$ (average of 10 determinations).

$2V_{550}$ (observed) = $66^{\circ} - 70^{\circ} \pm 1^{\circ}$ (20 determinations).

$n_{\alpha 550} = 1.698 - 1.701$ (20 determinations).

$n_{\beta} = \text{n.d.}$

$n_{\gamma 550} = 1.725 - 1.731$ (20 determinations).

$c/\gamma = -33^{\circ} - -41^{\circ}$ (20 determinations).

Analysis no. 55. Aegirine-augitic pyroxene.

Locality: In now disused sövite quarry at Ås Jetty. *Analyst:* Harry von Eckermann.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F)
			X	Y	Z	
SiO ₂	45.60	75.92			75.92	151.84
CO ₂	0.00	—				
TiO ₂	0.94	1.18		1.18		2.36
ZrO ₂	n.d.					
P ₂ O ₅	n.d.					
Al ₂ O ₃	8.01	7.86		3.40	12.32	23.58
Cr ₂ O ₃	0.01					
Fe ₂ O ₃	4.70	2.94		5.88		7.82
FeO	4.31	6.00		6.00		6.00
MnO	0.13	0.18		0.18		0.18
MgO	11.08	27.48		27.48		27.48
CaO	23.59	42.02	42.02			42.02
BaO	n.d.					

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F)
			X	Y	Z	
SrO	n.d.					
Na ₂ O	0.92	1.48	2.96			1.48
K ₂ O	0.27	0.29	0.58			0.29
F	0.09	0.47				0.47
Cl	n.d.					
H ₂ O ^{+105°}	0.16	0.89				0.89
H ₂ O ^{-105°}	0.12					
	99.93		45.56	44.12	88.24	264.41

Composition: $X_{1.03}Y_1Z_2(O,OH,F)_{5.92}$. Ratio: Mg:Fe:Ca = 34:15:51.

Sp. gravity $^{20}_4C = 3.325$ (average of 15 determinations).

$2V_{550}$ (observed) = $68^\circ \pm 1^\circ$ (average of 20 determinations).

$n_{\alpha 550} = 1.701 \pm 0.001$ (average of 20 determinations).

$n_{\beta} = \text{n.d.}$

$n_{\gamma 550} = 1.732 \pm 0.001$ (average of 20 determinations).

$c/\gamma = -39^\circ$ (average of 10 determinations).

Analysis no. 56. Aegirine-augitic pyroxene.

Locality: In a dike south of Stolpås farm. *Anlyst*: G. K. Almström (CO₂ checked by H. v. E.).

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
SiO ₂	47.52	79.12			79.12	158.24
CO ₂	0.00	—				
TiO ₂	0.93	1.16		1.16		2.32
ZrO ₂	0.01	0.01			0.01	0.02
P ₂ O ₅	< 0.01	< 0.01				
Al ₂ O ₃	5.01	4.92		1.26	8.58	14.76
Cr ₂ O ₃	< 0.01	—				
Fe ₂ O ₃	6.68	4.18		8.36		12.54
FeO	3.62	5.04		5.04		5.04
MnO	0.10	0.14		0.14		0.14
MgO	11.25	27.90		27.90		27.90
CaO	22.60	40.30	40.30			40.30
BaO	0.03	0.02				0.02
SrO	< 0.005	—				
Na ₂ O	0.91	1.47	2.94			1.47
K ₂ O	0.27	0.29	0.58			0.29
F	0.07	0.37				0.37
Cl	0.02	0.06				0.06
H ₂ O ^{+105°}	0.22	1.22				2.44
H ₂ O ^{-105°}	0.68					
	99.92		43.82	43.86	87.71	265.91

Composition: $X_{1.00}Y_{1.00}Z_{2.00}(O,OH,F,Cl)_{6.06}$. Ratio: Mg:Fe:Ca = 34:17:49.

Arc-spectrogram: Cu +, Zn +, Ag[+], Bi[+], Cd[+], Co[+], Cr[+], Ga[+], Ni[+], Sb[+], V[+].

Sp. gravity $^{20}_4C = 3.337$ (average of 20 determinations).

$2V_{550}$ (observed) = $68^\circ \pm 1^\circ$ (average of 20 determinations).

$2V$ (calculated) = $66^\circ 02'$.

$n_{\alpha 550} = 1.701 \pm 0.001$ (average of 20 determinations).

$n_{\beta 550} = 1.711 \pm 0.001$ (average of 30 determinations).

$n_{\gamma 550} = 1.732 \pm 0.001$ (average of 20 determinations).

$c/\gamma = -38^\circ$ (average of 15 determinations).

Analysis no. 57. Aegirine-augitic pyroxene.

Locality: In pyroxene-sövite in the big disused quarry at Smedsgården. *Analyst:* G. K. Almström (CO₂ and SrO checked by H. v. E.)

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH)
			X	Y	Z	
SiO ₂	48.26	80.35			80.35	160.70
CO ₂	0.00	—				
TiO ₂	0.94	1.18		1.18		2.36
ZrO ₂	n.d.					
P ₂ O ₅	n.d.					
Al ₂ O ₃	4.23	4.15			8.30	12.45
Cr ₂ O ₃	0.01					
Fe ₂ O ₃	5.33	3.34		6.27	0.41	10.02
FeO	4.56	6.35		6.35		6.35
MnO	0.07	0.10		0.10		0.10
MgO	12.35	30.63		30.63		30.63
CaO	21.82	38.89	38.89			38.89
BaO	0.00	—				
SrO	0.00					
Na ₂ O	1.19	1.92	3.84			1.92
K ₂ O	0.57	0.61	1.22			0.61
F	n.d.					
Cl	n.d.					
H ₂ O ^{+105°}	0.68	3.78				7.56
H ₂ O ^{-105°}	0.34					
	100.35		43.95	44.53	89.06	271.59

Composition: X_{0.99}Y_{1.00}Z_{2.00}(O,OH)_{6.10}. Ratio: Mg:Fe:Ca = 37:16:47.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.332$ (average of 20 determinations).

$2V_{550}$ (observed) = (71°) - 74° ± 1° (20 determinations).

$n_{\alpha 550} = (1.696) - 1.699 \pm 0.001$ (20 determinations).

$n_{\beta} = \text{n.d.}$

$n_{\gamma 550} = (1.724) - 1.730 \pm 0.001$ (20 determinations).

$c/\gamma = -35^{\circ}$ (10 determinations).

(Optical properties of narrow rims within parenthesis).

Analysis no. 58. Aegirine-augite.

Locality: In sövite-pegmatite at W. Stolpås. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
SiO ₂	49.05	81.67			81.67	163.34
CO ₂	0.00	—				
TiO ₂	0.60	0.75		0.75		1.50
ZrO ₂	0.00	—				
P ₂ O ₅	0.01					
Al ₂ O ₃	2.22	2.18		0.85	3.51	6.54
Cr ₂ O ₃	n.d.					
Fe ₂ O ₃	9.32	5.84		11.68		17.52
FeO	10.20	14.20		14.20		14.20
MnO	1.65	2.33		2.33		2.33
MgO	5.14	12.75		12.75		12.75
CaO	18.00	32.10	32.10			32.10
BaO	0.06	0.04	0.04			0.04
SrO	n.d.					
Na ₂ O	3.10	5.00	10.00			5.00
K ₂ O	0.20	0.21	0.42			0.21

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
F	0.15	0.79				0.79
Cl	0.03	0.09				0.09
S	0.00	—				
SO ₃	0.00	—				
H ₂ O ^{+105°}	0.21	1.17				2.34
H ₂ O ^{-105°}	0.20					
	100.14		42.56	42.56	85.18	258.75
- O = F,Cl	0.06					
	100.08					

Composition: $X_{1.00}Y_{1.00}Z_{2.00}(O,OH,F,Cl)$. Ratio: Mg:Fe:Ca = 18:37:45.

Arc-spectrogram: As +, Cd +, Cu +, Ga +, Ta +, V +.

Sp. gravity $\frac{20}{4}^{\circ}C = 3.522$ (average of 30 determinations).

$2V_{550}$ (observed) = $75^{\circ}-82^{\circ} \pm 1^{\circ}$ (20 determinations).

$n_{\alpha 550} = 1.718-1.721 \pm 0.001$ (20 determinations).

$n_{\beta} = \text{n.d.}$

$n_{\gamma 550} = 1.748-1.751 \pm 0.001$ (20 determinations).

$c/\gamma = -26^{\circ} - -36^{\circ}$ (20 determinations).

Analysis no. 59. Aegirine-augitic pyroxene.

Locality: In sövite-pegmatite at W. Stolpås farm. Analyst: T. Berggren.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH)
			X	Y	Z	
SiO ₂	49.60	82.58			82.58	165.16
CO ₂	0.00	—				
TiO ₂	0.69	0.86		0.86		1.72
ZrO ₂	n.d.	—				
P ₂ O ₅	0.00	—				
Al ₂ O ₃	2.69	2.64		0.35	4.93	7.92
V ₂ O ₃	0.10	0.07		0.14		0.21
Fe ₂ O ₃	8.04	5.04		10.08		15.12
FeO	10.70	14.89		14.89		14.89
MnO	1.32	1.86		1.86		1.86
MgO	6.28	15.58		15.58		15.58
CaO	16.54	29.49	29.49			29.49
BaO	n.d.	—				
SrO	n.d.	—				
Na ₂ O	2.25	3.63	7.26			3.63
K ₂ O	0.53	0.56	1.12			0.56
F	n.d.	—				
Cl	n.d.	—				
H ₂ O ^{+105°}	0.49	2.72				5.44
H ₂ O ^{-105°}	0.63					
	99.86		37.87	43.76	87.51	261.58

Composition: $X_{0.87}Y_{1.00}Z_{2.00}(O,OH)_{5.98}$. Ratio: Mg:Fe:Ca = 22:36:42.

Arc-spectrogram: Cu +, Ga +, Ta +, V +, Ni[+].

Sp. gravity $\frac{20}{4}^{\circ}C = 3.508$ (average of 20 determinations).

$2V_{550}$ (observed) = $76^{\circ}-79^{\circ} \pm 1^{\circ}$ (20 determinations).

$n_{\alpha 550} = 1.710-1.720 \pm 0.001$ (20 determinations).

$n_{\beta} = \text{n.d.}$

$n_{\gamma 550} = 1.742-1.755 \pm 0.001$ (20 determinations).

$c/\gamma = -23^{\circ} - -30^{\circ}$ (10 determinations).

Analysis no. 60. Aegirine-augitic pyroxene.

Locality: From the contact of the sövite-pegmatite east of the western farm at Stolpås.

Analyst: T. Berggren.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
SiO ₂	50.65	84.33			84.33	168.66
CO ₂	0.00	0.00				
TiO ₂	0.61	0.76		0.76		
ZrO ₂	0.00	—				
P ₂ O ₅	n.d.	—				
Al ₂ O ₃	2.18	2.14		1.03	3.25	6.42
Cr ₂ O ₃	n.d.	—				
Fe ₂ O ₃	8.15	5.10		10.20		15.30
FeO	6.51	9.06		9.06		9.06
MnO	0.55	0.78		0.78		0.78
MgO	8.85	21.95		21.95		21.95
CaO	19.56	34.89	34.89			34.89
BaO	0.00	—				
SrO	0.00	—				
Na ₂ O	1.83	2.95	5.90			2.95
K ₂ O	0.28	0.30	0.60			0.30
F	0.01	0.05				0.05
Cl	0.02	0.06				0.06
H ₂ O ^{+105°}	0.15	0.83				1.66
H ₂ O ^{-105°}	0.27	—				—
	99.62		41.39	43.78	87.58	262.08

Composition: $X_{0.95}Y_{1.00}Z_{2.00}(O,OH,F,Cl)_{6.02}$. Ratio: Mg:Fe:Ca = 29:25:46.

Arc-spectrogram: Cu +, Ga +, Ta +, V +, Ni[+], Se -.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.416$ (average of 30 determinations).

$2V_{550}$ (observed) = $74^{\circ}-77^{\circ}+1^{\circ}$ (20 determinations).

$n_{\alpha 550} = 1.707-1.710 \pm 0.001$ (20 determinations).

$n_{\beta} = \text{n.d.}$

$n_{\gamma 550} = 1.731-1.738 \pm 0.001$ (20 determinations).

$c/\gamma = -28^{\circ}-32^{\circ}$ (15 determinations).

Analysis no. 61. Aegirine-augitic pyroxene.

Locality: In ijolite at quarry east of Hörningsholm. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
SiO ₂	45.32	75.46			75.46	150.92
CO ₂	0.00	—				
TiO ₂	2.16	2.70		2.70		5.40
ZrO ₂	n.d.	—				
P ₂ O ₅	< 0.01	—				
Al ₂ O ₃	7.27	7.13		1.81	12.45	21.39
Cr ₂ O ₃	n.d.	—				
Fe ₂ O ₃	5.91	3.70		7.40		11.10
FeO	5.62	7.82		7.82		7.82
MnO	0.36	0.51		0.51		0.51
MgO	9.56	23.71		23.71		23.71
CaO	21.35	38.07	38.07			38.07
BaO	n.d.	—				
SrO	n.d.	—				
Na ₂ O	1.32	2.13	4.26			2.13

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
K ₂ O	0.68	0.72	1.44			0.72
F	0.06	0.32				0.32
Cl	0.05	0.14				0.14
H ₂ O ^{+105°}	0.28	1.55				3.10
H ₂ O ^{-105°}	0.08					
	100.02		43.77	43.95	87.91	265.33

Composition: $X_{0.996}Y_{1.000}Z_{2.000}(O,OH,F,Cl)_{6.037}$. Ratio: Mg:Fe:Ca = 31:30:49.

Arc-spectrogram: Cu +, As[+], Co[+], Ni[+], V[+], Sc -.

Sp. gravity $\frac{20}{4}^{\circ}C = 3.381$.

$2V_{550}$ (observed) = $68^{\circ} \pm 1^{\circ}$ (average of 20 determinations).

$n_{\alpha 550} = 1.715 \pm 0.001$ (average of 20 determinations).

$n_{\beta} = \text{n.d.}$

$n_{\gamma 550} = 1.745 \pm 0.001$ (average of 20 determinations).

$c/\gamma = -29^{\circ}$ (average of 15 determinations).

Analysis no. 62. Aegirine-augitic pyroxene.

Locality: From sövite contact with nepheline-fenite east of Stavsätt and north of Släda farms.

Analyst: T. Berggren.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH)
			X	Y	Z	
SiO ₂	48.35	80.50			80.50	161.00
CO ₂	0.00	—				
TiO ₂	1.55	1.94		1.94		3.88
ZrO ₂	n.d.					
P ₂ O ₅	0.00					
Al ₂ O ₃	3.27	3.21		0.56	5.86	9.63
Cr ₂ O ₃	n.d.					
Fe ₂ O ₃	6.26	3.92		7.84		11.76
FeO	9.39	13.07		13.07		13.07
MnO	0.80	1.13		1.13		1.13
MgO	7.53	18.68		18.68		18.68
CaO	20.16	35.95	35.95			35.95
BaO	n.d.					
SrO	n.d.					
Na ₂ O	1.85	2.98	5.96			2.98
K ₂ O	0.42	0.45	0.90			0.45
F	n.d.					
Cl	n.d.					
H ₂ O ^{+105°}	0.05	0.28				0.56
H ₂ O ^{-105°}	0.00					
	99.63		42.81	43.22	86.36	259.09

Composition: $X_{0.99}Y_{1.00}Z_{2.00}(O,OH)_{6.00}$. Ratio: Mg:Fe:Ca = 25:28:47.

Arc-spectrogram: Ga +, Ta +, V +, As[+], Cd[+], Cu[+].

Sp. gravity $\frac{20}{4}^{\circ}C = 3.460$ (average of 20 determinations).

$2V_{Na}$ (observed) = $74^{\circ} - 82^{\circ} \pm 1^{\circ}$ (25 determinations).

$n_{\alpha Na} = 1.706 - 1.730 \pm 0.001$ (20 determinations).

$n_{\beta} = \text{n.d.}$

$n_{\gamma Na} = 1.740 - 1.766 \pm 0.001$ (20 determinations).

$c/\gamma = -20^{\circ} - -38^{\circ}$ (20 determinations).

Analysis no. 63. Aegirine-augite.

Locality: In fenite south of Smedsgården. *Analyst:* G. K. Almström (CO₂ checked by H. v. E.).

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
SiO ₂	49.61	82.60			82.60	165.20
CO ₂	0.00	—				
TiO ₂	0.50	0.63		0.63		1.26
ZrO ₂	0.00	—				
V ₂ O ₃	0.09	0.06		0.12		0.18
Al ₂ O ₃	2.75	2.70		2.00	3.40	7.10
Cr ₂ O ₃	tr.	—				
Fe ₂ O ₃	15.49	9.70		19.40		29.10
FeO	4.90	6.82		6.82		6.82
MnO	1.62	2.28		2.28		2.28
MgO	4.64	11.51		11.51		11.51
CaO	15.80	28.17	28.17			28.17
BaO	< 0.005	—				
SrO	< 0.005	—				
Na ₂ O	4.46	7.19	14.38			7.19
K ₂ O	0.21	0.22	0.22			0.22
F	0.01	0.05				0.05
Cl	0.02	0.06				0.06
H ₂ O ^{+105°}	0.15	0.83				1.66
H ₂ O ^{-105°}	0.21	—				
	100.25		42.77	42.76	86.00	260.80

Composition: X_{1.00}Y_{0.99}Z_{2.00}(O,OH,F,Cl)_{3.03}. Ratio: Mg:Fe:Ca = 17:40:43.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.515$ (average of 15 determinations).

$2 V_{550}$ (observed) = $90^{\circ} \pm 1^{\circ}$ (average of 20 determinations).

$2 V_{\gamma}$ (calculated) = $89^{\circ} 22'$.

$n_{2550} = 1.731 \pm 0.001$ (average of 20 determinations).

$n_{\beta 550} = 1.748 \pm 0.001$ (average of 30 determinations).

$n_{\gamma 550} = 1.768 \pm 0.001$ (average of 20 determinations).

$c/\gamma = -20^{\circ}$ (average of 15 determinations).

Analysis no. 64. Aegirine-augite.

Locality: In quartz-syenitic fenite north-east of Alnö church. *Analyst:* R. Blix
(CO₂ determined by A. Aaremäe).

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH)
			X	Y	Z	
SiO ₂	49.75	82.83			82.83	165.66
CO ₂	0.00	—				
TiO ₂	0.47	0.59		0.59		1.18
ZrO ₂	n.d.	—				
P ₂ O ₅	n.d.	—				
Al ₂ O ₃	3.07	3.01		2.64	3.38	9.03
Cr ₂ O ₃	n.d.	—				
Fe ₂ O ₃	17.77	11.13		22.26		33.39
FeO	5.37	7.48		7.48		7.48
MnO	1.03	1.45		1.45		1.45
MgO	3.50	8.68		8.68		8.68
CaO	10.29	18.35	18.35			18.35
BaO	n.d.	—				
SrO	n.d.	—				
Na ₂ O	7.39	11.92	23.84			11.92

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH)
			X	Y	Z	
K ₂ O	0.39	0.41	0.82			0.41
F	n.d.					
Cl	n.d.					
H ₂ O ^{+105°}	0.97	5.38				10.76
H ₂ O ^{-105°}	0.17					
	100.17		43.01	43.10	86.21	268.31

Composition: $X_{0.99}Y_{1.00}Z_{2.00}(O,OH)_{6.22}$. Ratio: Mg:Fe:Ca = 15:53:32.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.589$ (average of 2 determinations).

$2V_{550}$ (observed) = -77° (average of 15 determinations).

$2V_{\alpha}$ (calculated) = $-75^{\circ}44'$.

$n_{\alpha 550} = 1.750 \pm 0.001$ (average of 15 determinations).

$n_{\beta 550} = 1.777 \pm 0.001$ (average of 20 determinations).

$n_{\gamma 550} = 1.794 \pm 0.001$ (average of 15 determinations).

$c/\alpha = 7^{\circ}-8^{\circ}$ (10 determinations).

Analysis no. 65. Aegirine-augite, rich in titanium.

Locality: In melteigite west of Hörningsholm. Analyst: Harry von Eckermann.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH)
			X	Y	Z	
SiO ₂	41.81	69.61			69.61	139.22
CO ₂	0.00	—				
TiO ₂	4.85	6.07		6.07		12.14
ZrO ₂	n.d.					
P ₂ O ₅	n.d.					
Al ₂ O ₃	7.99	7.84			15.68	23.52
Cr ₂ O ₃	tr.					
Fe ₂ O ₃	9.30	5.82		11.64		17.46
FeO	5.39	7.50		7.50		7.50
MnO	0.38	0.54		0.54		0.54
MgO	6.80	16.87		16.87		16.87
CaO	22.59	40.28	40.28			40.28
BaO	< 0.005	—				
SrO	< 0.005	—				
Na ₂ O	0.65	1.05	2.10			1.05
K ₂ O	0.11	0.11	0.22			0.11
F	tr.					
Cl	n.d.					
H ₂ O ^{+105°}	0.12	0.67				1.34
H ₂ O ^{-105°}	0.07					
	100.06		42.60	42.62	85.29	260.03

Composition: $X_{1.00}Y_{1.00}Z_{2.00}(O,OH)_{6.14}$. Ratio: Mg:Fe:Ca = 21:28:51.

Qualitative spectrogram: Bi+, Sn+, Tl+, As[+], Cd[+], Co[+], Cu[+], Ga[+], P[+], Pb[+], V[+], Zn[+].

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.439$ (average of 20 determinations).

$2V_{550}$ (observed) = $66^{\circ} \pm 1^{\circ}$ (average of 20 determinations).

$2V_{\gamma}$ (calculated) = $68^{\circ}44'$.

$n_{\alpha 550} = 1.710 \pm 0.001$ (average of 20 determinations).

$n_{\beta 550} = 1.720 \pm 0.001$ (average of 30 determinations).

$n_{\gamma 550} = 1.742 \pm 0.001$ (average of 20 determinations).

$c/\gamma = -42^{\circ}$ (average of 10 determinations).

Analysis no. 66. Aegirine-augitic pyroxene.

Locality: In pegmatitic malignite, west of Hörningsholm. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl,SO ₃)
			X	Y	Z	
SiO ₂	46.54	77.49			77.49	154.98
CO ₂	0.00	—				
TiO ₂	1.81	2.27		2.27		4.54
ZrO ₂	0.15	0.12			0.12	0.24
P ₂ O ₅	0.01	0.01				
Al ₂ O ₃	6.31	6.19		2.30	10.08	18.57
Cr ₂ O ₃	n.d.					
Fe ₂ O ₃	5.46	3.42		6.84		10.26
FeO	5.56	7.74		7.74		7.74
MnO	0.33	0.47		0.47		0.47
MgO	9.77	24.23		24.23		24.33
CaO	22.05	39.32	39.32			39.32
BaO	0.02	0.01	0.01			0.01
SrO	0.01	0.01	0.01			0.01
Na ₂ O	1.12	1.81	3.62			1.81
K ₂ O	0.53	0.56	1.12			0.56
F	0.02	0.11				0.11
Cl	0.04	0.11				0.11
SO ₃	0.08	0.10				0.30
BeO	0.00	—				
H ₂ O ^{+105°}	0.10	0.56				1.12
H ₂ O ^{-105°}	0.02					
	99.93		44.08	43.85	87.69	264.48

Composition: $X_{1.01}Y_{1.00}Z_{2.00}(O,OH,F,Cl,SO_3)_{6.05}$. Ratio: Mg:Fe:Ca = 31:19:50.

Arc-spectrogram: Be +, Ga +, Zn +, In[+], V[+], Cu[-], and (Ag, As, Au, Bi, Cd, Co, Cr, Ge, Hg, Li, Mo, Ni, Pb, Sb, Sc, Ta, Te, Th) all -.

Sp. gravity $^{20}_4C = 3.371$ (average of 15 determinations).

$2V_{550}$ (observed) = $69^\circ \pm 1^\circ$ (average of 15 determinations).

$2V_\gamma$ (calculated) = $69^\circ 30'$.

$n_{\alpha 550} = 1.714 \pm 0.001$ (average of 15 determinations).

$n_{\beta 550} = 1.722 \pm 0.001$ (average of 21 determinations).

$n_{\gamma 550} = 1.739 \pm 0.001$ (average of 15 determinations).

$c/\gamma = -39^\circ$ (average of 10 determinations).

Analysis no. 67. Aegirine-augitic pyroxene.

Locality: In malignite on the road to Ås Jetty. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
SiO ₂	46.43	77.31			77.31	154.62
CO ₂	0.00	—				
TiO ₂	2.19	2.74		2.74		5.48
ZrO ₂	n.d.					
P ₂ O ₅	n.d.					
Al ₂ O ₃	6.27	6.15		2.21	10.09	18.45
Cr ₂ O ₃	n.d.					
Fe ₂ O ₃	6.87	4.30		8.60		12.90
FeO	6.03	8.39		8.39		8.39
MnO	0.52	0.73		0.73		0.73
MgO	8.48	21.03		21.03		21.03
CaO	20.78	37.05	37.05			37.05
BaO	n.d.					
SrO	n.d.					
Na ₂ O	1.27	2.05	4.10			2.05
K ₂ O	0.92	0.98	1.96			0.98

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
F	0.04	0.21				0.21
Cl	0.05	0.14				0.14
H ₂ O ^{+105°}	0.28	1.55				3.10
H ₂ O ^{-105°}	0.06					
	100.19		43.11	43.70	87.40	265.13
- O = F,Cl	0.03					
	100.16					

Composition: $X_{0.99}Y_{1.00}Z_{2.00}(O,OH,F,Cl)_{6.06}$. Ratio: Mg:Fe:Ca = 28:23:49.

Arc-spectrogram: Ba +, Bi +, Co +, P +, Sn +, As [+], Be [+], Cr [+], Cu [-], Pb [+], Tl [+], V [+], Zn [+], Ga -.

Sp. gravity $^{20}_{4}C = 3.410$ (average of 10 determinations).

$2V_{550}$ (observed) = $62^{\circ} \pm 1^{\circ}$ (average of 10 determinations).

$2V$ (calculated) = $61^{\circ}00'$.

$n_{\alpha 550} = 1.704 \pm 0.001$ (average of 20 determinations).

$n_{\beta 550} = 1.713 \pm 0.001$ (average of 20 determinations).

$n_{\gamma 550} = 1.735 \pm 0.001$ (average of 20 determinations).

$c/\gamma = -32^{\circ}$ (average of 10 determinations).

Analysis no. 68. Aegirine-augitic pyroxene.

Locality: In jacupirangite at Ås, Alnö Island. Analyst: T. Berggren.

	Weight %	Mol. prop. × 100	At. proportions × 100			(O,OH,F,Cl)
			X	Y	Z	
SiO ₂	42.80	71.26			71.26	142.52
CO ₂	0.00	—				
TiO ₂	2.28	2.85		2.85		5.70
ZrO ₂	0.00	—				
P ₂ O ₅	0.00	—				
Al ₂ O ₃	9.86	9.67		3.00	16.34	29.01
Cr ₂ O ₃	n.d.	—				
Fe ₂ O ₃	5.68	3.56		7.12		10.68
FeO	6.05	8.42		8.42		8.42
MnO	0.29	0.41		0.41		0.41
MgO	8.87	22.00		22.00		22.00
CaO	23.14	41.26	41.26			41.26
BaO	0.02	0.01	0.01			0.01
SrO	0.00	—				
Na ₂ O	0.72	1.16		2.32		1.16
K ₂ O	0.13	0.14	0.28			0.14
F	0.07	0.37				0.37
Cl	0.03	0.09				0.09
H ₂ O ^{+105°}	0.10	0.56				1.12
H ₂ O ^{-105°}	0.20					
	100.24		43.87	43.80	87.60	262.89
- O = F,Cl	0.03					
	100.21					

Composition: $X_{1.00}Y_{1.00}Z_{2.00}(O,OH,F,Cl)_{6.01}$. Ratio: Mg:Fe:Ca = 28:20:52.

Arc-spectrogram: Cu +, Cr +, Ga +, Zn +, Pb [+], V [+], Bi -.

Sp. gravity $^{20}_{4}C = 3.420$ (average of 15 determinations).

$2V_{550}$ (observed) = $59^{\circ} \pm 1^{\circ}$ (average of 15 determinations).

$2V$ (calculated) = $57^{\circ}58'$.

$n_{\alpha 550} = 1.717 \pm 0.001$ (average of 10 determinations).

$n_{\beta 550} = 1.723 \pm 0.001$ (average of 20 determinations).

$n_{\gamma 550} = 1.743 \pm 0.001$ (average of 10 determinations).

$c/\gamma = -40^{\circ}$ (average of 5 determinations).

Pl. XVIII to Pl. XX illustrate a few of the analysed pyroxenes. All pyroxenes in the different rock series at Alnö are quite fresh and unaltered with one curious exception. Along a fissure running parallel with the strike of the big sövite dike at Smedsgården and in the very centre of the dike the pyroxene of a secondary pyroxenite-sövite intrusion is completely altered into carbonate, reddish goethite and magnetite. As shown by Pl. XXI, Fig. 1 the original crystal boundaries of the pyroxene are still recognizable. Probably the calcite with a small amount of barite filling the fissure is contemporaneous with the barite veins and a postmagmatic phenomenon responsible for the alteration of the pyroxene.

Amphiboles

Amphiboles occur rarely in the Alnö alkaline rocks. This is probably due to the dominance of carbonic acid and fluorine in the volcanic gases and a subordinate quantity of water vapour. Högbom found crystals of hornblende, rich in titanium, in a boulder of nepheline syenite and suspected that they were extraneous inclusions (18, p. 236). I have not succeeded in locating the boulder, nor have I found any amphiboles in the rheomorphic nepheline syenites. Högbom also observed big, more or less rounded, crystals of a darkbrown amphibole in the alnöite at the classic locality west of Näset, where the rock was first discovered. The original outcrop does not exist today, as it was removed when a new road was built along the northern coast of Alnö, but the alnöite is still visible in the road-cutting at a several metres lower level. The amphibole is here wanting. The same amphibole, however, occurs in the alnöite breccia at the road-cutting at Hovid, where it occurs together with fragments or rounded boulders of diabase, sandstone, quartzite, granite, sövitepegmatite etc.—all evidence of the then existing erosion products on an old rock surface. I quite agree with Högbom's suggestion that this amphibole, too, must be an extraneous inclusion, not belonging to the mineral paragenesis of the alnöite. This surmise is further supported by the amphibole lacking at an about 30 metres lower level, where the same alnöite dike was uncovered temporarily while laying down new water main-pipes. Even if the origin of the amphibole still remains obscure, the disappearance of the mineral at lower levels of the alnöite dikes, both at Näset and Hovid, suggests a genesis related to surface rocks eroded at the time of the alnöite intrusions.

The mineral was analysed, analysis no. 69, and was by me earlier believed to be barkevikitic hornblende (9e, p. 100). It was many years later analysed by Howie (15, p. 719), who on account of its titanium content referred it to the kaersutites, while I, on account of its relatively low titanium content and low birefringence prefer the term "kaersutitic amphibole". Howie's analysis and that of Miss Berggren are in parts identical, but the latter shows slightly more SiO_2 , MnO and MgO , considerably more Al_2O_3 , but less total iron and CaO and very much less constitutional water (0.32 % against 2.27 %). Howie only found traces of fluorine, while analysis no. 69 shows 0.11 % as well as some chlorine. Evidently, the volcanic gases, accompanying the alnöite intrusion, may not have been quite homogeneous or their composition may have changed during the intrusion and their metasomatic effect on the amphibole xenoliths differed within different parts of the breccia. But even if there are some discrepancies in their chemical compositions, the optical properties and specific gravities of the two samples examined by Howie and the present author agree within narrow limits.

Analysis no. 69. Kaersutitic amphibole.

 Locality: In alnöite at Hovid, Alnö Island. Analyst: T. Berggren (CO₂ checked by H. v. E.).

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F,Cl)	
SiO ₂	39.86	66.37	Si	5.885
CO ₂	0.00	—	Al	2.115
TiO ₂	2.94	3.68	Ti	0.327
ZrO ₂	0.00	—	Al	0.630
P ₂ O ₅	0.01	0.01	Fe ⁺³	0.460
Al ₂ O ₃	15.77	15.47	Fe ⁺²	0.704
Cr ₂ O ₃	n.d.	—	Mn	0.018
Fe ₂ O ₃	4.14	2.59	Mg	3.290
FeO	5.70	7.93	Ca	1.791
MnO	0.15	0.21	Ba	0.003
MgO	14.93	37.03	Sr	0.001
CaO	11.88	20.18	Na	0.590
BaO	0.04	0.03	K	0.380
SrO	0.01	0.01	OH	0.808
Na ₂ O	2.06	3.32	F	0.052
K ₂ O	2.02	2.14	Cl	0.008
F	0.11	0.58		
Cl	0.03	0.09		
H ₂ O ^{+105°}	0.32	1.78		
H ₂ O ^{-105°}	0.00	—		
	99.97			

 Composition: (Ca,Ba,Sr,Na,K)_{2.77}(Ti,Al,Fe⁺³,Fe⁺²,Mn,Mg)_{5.43}(Si,Al)_{8.00}(O,OH,F,Cl)_{24.00}.

Arc-spectrogram: As[+], Cd[+], Co[+], Ga[+], Ni[+], V[+], Bi[-], Ag, Au, Be, Ge, Hg, Ir, Mo, Nb, Pb, Pt, Sb, Sn, Ta, Th, and Tl all: -.

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.188$ (average of 5 determinations).

 $2 V_{\alpha 550}$ (observed) = $80^{\circ} \pm 1^{\circ}$ (average of 5 determinations on the universal stage).

 $2 V_{\alpha 550}$ (calculated) = $80^{\circ} 33' 40''$.

 $n_{\alpha 550} = 1.6692$ (determined from oriented and polished wedges).

 $n_{\beta 550} = 1.6785$ (determined from oriented and polished wedges).

 $n_{\gamma 550} = 1.6852$ (determined from oriented and polished wedges).

 $c/\gamma = 12^{\circ}$ (average of 5 determinations on the universal stage).

Barkevikitic hornblende, or perhaps kaersutite, is also found as a secondary product in cromaltite (melanite-jacupirangite), (9e, p. 61), but has not been analysed. Its optical data were found to be:

$$2 V_{\alpha 550} = 76^{\circ} \pm 1^{\circ}$$

$$n_{\alpha} = 1.673 \pm 0.003$$

$$n_{\gamma} = 1.696 \pm 0.003$$

$$\gamma/c = 6^{\circ}$$

Titaniferous hornblende is found as an essential mineral of jacupirangite at several localities. It occurs on the island Långörsholmen, north of Alnö, (9e, pp. 56, 62) in a dike. As it constitutes 27.6 % of the rock, the latter approaches a rock, which Brögger (2) in his classic description of Fen in Norway called "vibetoide". The mineral was

*Analysis no. 70. Titaniferous amphibole.**Locality:* In a vibetoid dike at Långörsholmen. *Analyst:* Harry von Eckermann.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(F,O,OH)	
SiO ₂	40.96	68.20	Si	6.104
CO ₂	0.00	—	Al	1.896
TiO ₂	2.44	3.05	Ti	0.273
ZrO ₂	n.d.		Al	0.714
P ₂ O ₅	n.d.		Fe ⁺³	0.412
Al ₂ O ₃	14.85	14.57	Fe ⁺²	1.135
Cr ₂ O ₃	tr.		Mn	0.008
Fe ₂ O ₃	3.67	2.30	Mg	2.442
FeO	9.10	12.67	Ca	2.163
MnO	0.06	0.09	Na	0.642
MgO	11.01	27.31	K	0.181
CaO	13.56	24.18	F	0.048
BaO	n.d.		OH	1.122
SrO	n.d.			
Na ₂ O	2.25	3.63		
K ₂ O	0.95	1.01		
F	0.10	0.53		
Cl	n.d.			
H ₂ O ^{+105°}	1.13	6.27		
H ₂ O ^{-105°}	0.02			
	100.10			

Composition: $((\text{Ca}_{2.16}(\text{Na}, \text{K})_{0.82})_{2.98}(\text{Ti}, \text{Fe}^{+2}, \text{Mn}, \text{Mg})_{3.86}(\text{Fe}^{+3}, \text{Al})_{1.12})_{4.98}(\text{Si}_{6.10}\text{Al}_{1.90})_{8.00}(\text{F}, \text{O}, \text{OH})_{24.00}$.

Sp. gravity $\frac{20^\circ\text{C}}{4} = 3.212$ (average of 4 determinations of the analysed sample).

$2 V_{\alpha 550}$ (observed) = $62^\circ - 77^\circ \pm 1^\circ$.

$n_{\alpha 550} = 1.670 - 1.679 \pm 0.003$ (20 determinations).

$n_{\gamma 550} = 1.684 - 1.696 \pm 0.003$ (20 determinations).

$n_{\gamma} - n_{\alpha} = 0.014 - 0.016$ (20 determinations).

$c/\gamma = 16^\circ - 21.5^\circ$ (10 determinations).

isolated and analysed by the author (analysis no. 70). It is, however, rather inhomogeneous and varies from the centre to the margins of the dikes. The analysis, is, in consequence, an average one representing amphiboles within the fairly large range of optical properties given together with the analysis. Actually Brögger discovered the presence of vibetoid at Alnö when receiving a sample from Högbom, who had overlooked it. Brögger did not analyse the amphibole of the Fen vibetoid, but calculated an approximate composition from the rock analysis (5, p. 80). In comparison the Alnö amphibole contains somewhat less silica, ferric iron and soda, but more alumina, potassium and water. Compared with the "kaersutite", analysis no. 69, the percentages of sodium and silica are somewhat higher and the ferrous iron and calcium very much so, while the titanium, alumina, ferric iron and potassium are a little lower and the magnesia almost 4%. The colour of the amphibole, analysis no. 70, grades from walnut-brown in the marginal parts of the dike to increasingly greenish towards the center. The absorption is throughout $\gamma > \beta > \alpha$, and the pleochroism: walnut brown or greenish-brown > greenish-brown > light-greenish-brown or green. As in the case of the amphibole from the alnöite breccia, analysis no. 69, the titanium

Analysis no. 71. Magnesioarfvedsonite.
Locality: Beforsitic dike south-east of Hovid. *Analyst:* G. K. Almström.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F)	
SiO ₂	52.10	86.75	Si	7.580
CO ₂	0.00	—	Al	0.325
TiO ₂	0.21	0.33	Fe ⁺³	0.095
ZrO ₂	n.d.		Ti	0.029
P ₂ O ₅	n.d.		Fe ⁺³	0.678
Al ₂ O ₃	1.90	1.86	Fe ⁺²	1.550
Cr ₂ O ₃	n.d.		Mn	0.037
Fe ₂ O ₃	7.05	4.42	Mg	2.585
FeO	12.74	17.73	Ca	0.305
MnO	0.31	0.42	Na	2.272
MgO	11.92	29.56	K	0.300
CaO	1.95	3.48	OH	1.215
BaO	n.d.		F	0.759
SrO	n.d.			
Na ₂ O	8.05	12.99		
K ₂ O	1.60	1.70		
F	1.65	8.68		
Cl	n.d.			
H ₂ O ^{+105°}	1.25	6.94		
H ₂ O ^{-105°}	0.20			
	100.93			
— O = F	0.59			
	100.34			

 Composition: (Ca,Na,K)_{2.88}(Fe⁺³,Fe⁺²,Mn,Mg,Ti)_{4.88}(Si,Al,Fe⁺³)_{8.00}(O,OH,F)_{24.00}.

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.199$ (average of 5 determinations).

 $2 V_{\alpha 550}$ (observed) = $\sim 8^{\circ}-12^{\circ}$ (20 determinations).

 $n_{\alpha 550} = \sim 1.656-1.662 \pm 0.001$ (20 determinations).

 $n_{\beta} = \text{n.d.}$
 $n_{\gamma 550} = \sim 1.668-1.673 \pm 0.001$ (20 determinations).

 $c/\gamma = \sim 10^{\circ}-14^{\circ}$ (10 determinations).

content seems me too low to justify the name "kaersutite". The dominance of CaO over MgO is also uncommon in kaersutites. The birefringence is rather low, which shows a barkevikitic trend. On the other hand, the percentages of ferrous iron and alumina are far too low for a barkevikitic classification.

Although amphiboles are rare in the intrusive Alnö rocks, a light-blue variety is occasionally found in biotite-alkalifeldspar dikes. In such a dike south-east of Hovid (9e, Fig. 2, Pl. 54) aggregations of small prismatic crystals were in my Alnö memoir suggested to be riebeckite, although the minute size of the crystals prevented any reliable optical determinations. I had the good fortune, however, to find later somewhat larger crystal clusters within the same dike with a few larger-sized crystals, too. I succeeded in separating a small quantity, sufficient for one analysis (no. 71) but not enough for a second checking. In this case I had to depart from the late Professor Aminoff's recommendation not to use heavy liquids. The larger-sized crystals permitted a determination of the optical properties. The analysis and optical data show that my previously suggested classification was erroneous, and that the mineral

is a magnesioarfvedsonite. The high magnesia content suggests an origin associated with the "de-dolomitization" of an originally beforstic (=dolomitic-ankeritic) carbonatite. While the specific gravity could be determined with exactitude, the small size of the crystals made the optical determinations difficult, and both extra thin sections of the carbonatite as well as two of the largest crystals were measured on the universal stage. I believe, however, that the true values lie within the limits, indicated together with the analysis. The dispersion is very strong, $r < v$, the absorption α , blue to greenish blue, β lavender blue to grayish or greenish blue and γ , blue-gray to almost colourless.

A similar light-blue amphibole also occurs occasionally within the fenite close to the sövite-contacts, and especially in originally albitic schistose parts of the fenite. It is not unlike eckermannite, but I have not been able to isolate enough material for analysis. The optical properties seem to vary within different parts of the fenites, probably on account of the heterogeneity of the fenitized gneiss-granite. In a private communication, A. R. Woolley has kindly given the results of an electrone probe analysis of such an amphibole in a sample of fenitized rock from Alnö in the collections of the Department of Mineralogy of the British Museum (Natural History). It showed a very small percentage of alumina and a very great one of lime—both features disproving an eckermannitic composition. The optical properties communicated by Woolley suggest instead a magnesioarfvedsonitic amphibole. This is also confirmed by my own investigations on similar amphiboles observed in the fenite west of Näset, which gave the following optical values: $n_{\alpha 550} = 1.65 - 1.67$, $n_{\gamma 550} = 1.66 - 1.68$, $2 V_{\gamma 550} = 20^\circ - 30^\circ$. As these values were only determined from thin sections of the rocks and as the crystals were very small, they are rather approximate.

A third type of amphibole may also be mentioned, even if it occurs in minute quantities and rather rarely. It has lately been observed in two thin sections of fenite from the "zone of maximum hydration" where the first signs of fenitization are observable in the shape of pyroxene rims around the quartz grains. Instead of pyroxene, amphibole rims have been formed. This phenomenon seems to be restricted to albitic mica schists, viz. more or less granitized sedimentary parts of the country rocks, and is probably due to local concentrations of water vapour or to abnormally high H_2O/CO_2 ratios of the penetrating volcanic gases. In the direction towards the sövite contact all amphibole disappears and is replaced by pyroxene. The amphibole seems to be a common hornblende, but any optical determinations or sampling of it was on account of its micro-size and scarcity impossible.

Sheet silicates

The mica group

In the Alnö alkaline rocks the mica minerals biotite, phlogopite and muscovite are present. The muscovite occurs in the feldspar- and probably also the nepheline-pseudomorphs. Only the biotite and phlogopite have been analysed. Other sheet silicates not analysed are chlorite, illite, talc and the rarely occurring apophyllite and prehnite. Serpentine, occurring as pseudomorphs of olivine, has already been discussed (p. 155, analysis no. 48) and the minerals of the montmorillonite group were briefly described by the present author in earlier papers 1954 (9*i*) and 1961 (9*k*). The composition of montmorillonite from gneiss-granite at a carbonatite contact was found to be: $(OH)_4Si_8(Al_{3.30}Mg_{0.40}Ca_{0.16}Na_{0.14})O_{20} + 2.02H_2O$.

Analysis no. 72. Biotite.

Locality: Sövite dike between Ås and Släda farms. Analyst: T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F,Cl)		Ratio Mg:Fe
SiO ₂	34.78	57.91	Si	5.480	0.82:1.00
CO ₂	0.00	—			
TiO ₂	3.20	4.01	Ti	0.140	8.00
ZrO ₂	n.d.				
P ₂ O ₅	0.01	0.01			
Al ₂ O ₃	12.80	12.56	Al	2.380	
Cr ₂ O ₃	n.d.		Ti	0.240	5.45
Fe ₂ O ₃	6.42	4.02	Fe ⁺³	0.381	
FeO	18.55	25.82	Fe ⁺²	2.447	
MnO	0.50	0.71	Mn	0.067	
MgO	9.84	24.41	Mg	2.310	1.87
CaO	1.04	1.86	Ca	0.176	
BaO	0.71	0.46	Ba	0.044	
SrO	n.d.				
Na ₂ O	0.56	0.90	Na	0.085	3.23
K ₂ O	7.76	8.24	K	1.560	
F	0.10	0.53	F	0.052	3.23
Cl	0.03	0.09	Cl	0.009	
H ₂ O ^{+105°}	3.02	16.76	OH	3.171	
H ₂ O ^{-105°}	0.90				
	100.22				
-O = F,Cl	0.05				
	100.17				

Arc-spectrogram: V +, Cu +, Ga +, Ag[+], Co[+], Li[+], Sb[+], Ta[+], Cr -, Cs -, Rb -, Sc -, Sn -.

 Composition: (K,Na,Ca,Ba)_{1.87}(Mg,Mn,Fe⁺²,Fe⁺³,Ti)_{5.45}(Si,Ti,Al)_{8.00}O_{22.12}(OH,F,Cl)_{1.88}.

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 3.060$ (average of 5 determinations).

 $2V_{\alpha 550}$ (observed) = $\approx 0^{\circ} - 6^{\circ} \pm 30'$.

 $n_{2550} = 1.602 \pm 0.001$ (average of 15 determinations).

 $n_{\beta 550} = \approx 1.666 \pm 0.001$ (average of 15 determinations).

 $n_{\gamma 550} = 1.666 \pm 0.001$ (average of 15 determinations).

If one adheres to the present usage of a Mg:Fe ratio below 2:1 being characteristic of biotite, this mineral seems to be rather rare in the Alnö rocks. Of the 11 analyses presented in this paper, only a single one represents a biotite. This biotite occurs in a fine-grained strongly micaceous sövite dike which from Släda farm runs in an easterly direction, passing south of Ås farm, the analysis being given as no. 72. The alkali content is rather low and of interest are the trace elements V, Cu and Ga. Högbom in his classic memoir of 1895 takes for granted that the micas of the sövites are "brown or darkgreen biotite" (18, p. 157) and I committed the same blunder in my memoir of 1948, although I should have known better. Take for instance my Table III A, B (9e, p. 73), where a re-calculation of the original complete analyses has shown that all "biotites" are phlogopites except the one numbered A-3, which is a pure biotite. The mica of the sövite at the great quarry at Smedsgården I also termed a biotite. The present analyses nos. 73, 76 and 78 all indicate a phlogopitic Mg:Fe

*Analysis no. 73. Phlogopite.**Locality:* In sövite at Smedsgården Quarry. *Analyst:* R. Blix.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F,Cl)		Ratio Mg:Fe
SiO ₂	38.40	63.94	Si	5.700	2.32:1.00
CO ₂	n.d.		Ti	0.135	
TiO ₂	2.40	3.00	Al	2.165	
ZrO ₂	n.d.		Ti	0.132	8.00
P ₂ O ₅	n.d.		Fe ⁺³	0.271	
Al ₂ O ₃	12.36	12.13	Fe ⁺²	1.345	
Cr ₂ O ₃	n.d.		Mn	0.046	5.54
Fe ₂ O ₃	2.43	1.52	Mg	3.745	
FeO	10.84	15.09	Ca	0.011	
MnO	0.37	0.52	Ba	0.020	1.98
MgO	16.94	42.01	Na	0.235	
CaO	0.07	0.13	K	1.712	
BaO	0.33	0.22	F	0.521	4.03
SrO	0.00	—	Cl	0.018	
Na ₂ O	0.82	1.32	Li	0.002	
K ₂ O	9.04	9.60	OH	3.490	
F	1.11	5.84			
Cl	0.07	0.20			
Li ₂ O ^a	0.0054	0.02			
H ₂ O ^{+105°}	3.52	19.54			
H ₂ O ^{-105°}	2.20				
	100.91				
- O = F,Cl	0.48				
	100.43				

^a Determined spectrographically.

Arc-spectrogram: Sn[+], Cu[+], Ag[-].

Composition: (K,Na,Ca,Ba)_{1.98}(Mg,Mn,Fe⁺²,Fe⁺³,Ti)_{5.54}(Si,Al,Ti)_{8.00}O_{19.98}(OH,F,Cl,Li)_{4.02}.Sp. gravity ²⁰C = 2.971 (average of 5 determinations).2 V_{zNa} (observed) = 0°-8° ± 30'.n_{zNa} = 1.586 ± 0.001 (average of 15 determinations).n_{βNa} = ~ 1.626-1.627 ± 0.001 (10 determinations).n_{γNa} = 1.627 ± 0.001 (average of 15 determinations).

ratio, although megascopically the mica of the first two analyses is almost black and in thin section deep brown while that of the third one is megascopically greenish-black and in thin section green. The barium content of all three is notable, especially in analysis no. 78. This is also the case of the biotite, analysis no. 72. The latter, as well as the phlogopites, mentioned above, also contain a fair amount of TiO₂, ranging from 1.30 to 3.20 %.

On the other hand the phlogopites of the sövite dike between Smedsgården and Släda farms, containing pyrochlore, are characterized by low TiO₂ percentages, 0.20-0.26 %, while the barium remains conspicuous. In the narrow part of the dike of the mineral paragenesis: 5-10 % pyrochlore, about the same amount of magnetite and mica and the rest carbonate, the phlogopite is green (analysis no. 79), while in the broad part close to Smedsgården it assumes a red colour, reminding of mangano-phyllite (analysis no. 80). The analysis, however, makes it clear that there is no

Analysis no. 74. Phlogopite.
Locality: In kimberlitic alnöite, east of Släda. *Analyst:* G. K. Almström.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F)		Ratio Mg : Fe
SiO ₂	36.60	60.94	Si	5.270	3.22:1.00
CO ₂	n.d.				
TiO ₂	4.26	5.33	Ti	0.152	8.00
ZrO ₂	n.d.				
P ₂ O ₅	n.d.				
Al ₂ O ₃	15.00	14.72	Al	2.578	5.70
Cr ₂ O ₃	tr.		Ti	0.316	
Fe ₂ O ₃	2.63	1.56	Fe ⁺³	0.289	
FeO	7.81	10.86	Fe ⁺²	0.950	
MnO	0.17	0.24	Mn	0.021	
MgO	18.98	47.07	Mg	4.120	1.99
CaO	tr.				
BaO	0.30	0.20	Ba	0.018	
SrO	0.005	—			
Na ₂ O	1.00	1.61	Na	0.281	
K ₂ O	9.12	9.68	K	1.688	
F	0.08	0.42	F	0.037	3.92
Cl	n.d.				
H ₂ O ^{+105°}	3.99	22.15	OH	3.880	
H ₂ O ^{-105°}	0.62				
	100.56				

 Composition: (K,Na,Ba)_{1.99}(Mg,Mn,Fe⁺²,Fe⁺³,Ti)_{5.70}(Si,Ti,Al)_{8.00}O_{20.08}(OH,F)_{3.92}.

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.816$ (average of 15 determinations).

 $2 V_{\alpha 550}$ (observed) = $0^{\circ} - 8^{\circ} \pm 1^{\circ}$.

 $n_{\alpha 550} = 1.582 \pm 0.001$ (average of 15 determinations).

 $n_{\beta 550} = \sim 1.627 \pm 0.001$ (average of 15 determinations).

 $n_{\gamma 550} = 1.627 \pm 0.001$ (average of 15 determinations).

Analysis no. 75. Phlogopite.
Locality: In alnöite west of Näset. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F,Cl)		Ratio Mg : Fe
SiO ₂	37.00	61.61	Si	5.520	3.69:1.00
CO ₂	0.00	—			
TiO ₂	4.27	5.34			8.00
ZrO ₂	0.00	—			
P ₂ O ₅	0.01	0.01			
Al ₂ O ₃	15.29	15.00	Al	2.480	6.08
Cr ₂ O ₃	n.d.		Al	0.210	
			Ti	0.438	
Fe ₂ O ₃	2.78	1.74	Fe ⁺³	0.312	
FeO	6.77	9.42	Fe ⁺²	0.844	
MnO	0.07	0.10	Mn	0.009	2.14
MgO	19.17	47.55	Mg	4.265	
CaO	0.28	0.50	Ca	0.045	
BaO	0.53	0.35	Ba	0.032	
SrO	n.d.				
Na ₂ O	1.02	1.65	Na	0.296	
K ₂ O	9.28	9.85	K	1.767	

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Anal. no. 75 (cont.)

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F,Cl)		Ratio Mg:Fe
F	0.08	0.42	F	0.038	} 2.41
Cl	0.03	0.09	Cl	0.008	
H ₂ O ^{+105°}	2.38	13.21	OH	2.365	
H ₂ O ^{-105°}	1.01				
	99.97				

Arc-spectrogram: Ag +, Cr +, Cu +, Ga +, Li[+], V[+], Co -, Cs -, Rb -, Sb -, Sc -, Sn -, Ta -.

Composition: (K,Na,Ca,Ba)_{2.14}(Mg,Mn,Fe⁺,Fe⁺,Ti,Al)_{6.10}(Si,Al)_{8.00}O_{21.59}(OH,F,Cl)_{2.41}.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.810$ (average of 5 determinations).

$2V_{\alpha 550}$ (observed) = $0^{\circ}-11^{\circ} \pm 1^{\circ}$ (15 determinations).

$n_{\alpha 550} = 1.590 \pm 0.001$ (average of 10 determinations).

$n_{\beta 550} \sim 1.629-1.632 \pm 0.001$ (15 determinations).

$n_{\gamma 550} = 1.629-1.632 \pm 0.001$ (15 determinations).

Analysis no. 76. Phlogopite.

Locality: In sövite at quarry north-east of Smedsgården. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F)		
SiO ₂	38.11	63.45	Si	5.820	} 7.98
CO ₂	n.d.				
TiO ₂	2.07	2.59			
ZrO ₂	n.d.				
P ₂ O ₅	n.d.				
Al ₂ O ₃	13.69	13.43	Al	2.180	} 6.36
Cr ₂ O ₃	n.d.		Ti	0.238	
			Al	0.202	
Fe ₂ O ₃	2.79	1.75	Fe ⁺	0.301	} 2.25
FeO	10.86	15.12	Fe ⁺	1.387	
MnO	0.40	0.56	Mn	0.051	
MgO	18.38	45.59	Mg	4.180	
CaO	0.03	0.05	Ca	0.005	} 2.25
BaO	0.19	0.12	Ba	0.011	
SrO	n.d.				} 1.11
Na ₂ O	0.68	1.10	Na	0.202	
K ₂ O	10.49	11.14	K	2.040	} 1.11
F	1.12	5.19	F	0.476	
Cl	n.d.				} 1.11
H ₂ O ^{+105°}	0.62	3.44	OH	0.632	
H ₂ O ^{-105°}	0.68				
	100.11				
-O = F	0.47				
	99.64				

Composition: (K,Na,Ca,Ba)_{2.35}(Mg,Mn,Fe⁺Fe⁺,Al,Ti)_{6.36}(Si,Al)_{8.00}O_{22.89}(OH,F)_{1.11}.

Determined spectrogr. by A. M. Johansson: V₂O₃ = 0.11 %.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.969$ (average of 5 determinations).

$2V_{\alpha \text{Na}}$ (observed) = $0^{\circ}-6^{\circ} \pm 1^{\circ}$ (15 determinations).

$n_{\alpha \text{Na}} = 1.582 \pm 0.001$ (15 determinations).

$n_{\beta \text{Na}} \sim 1.623-1.624 \pm 0.001$ (15 determinations).

$n_{\gamma \text{Na}} = 1.624 \pm 0.001$ (15 determinations).

Analysis no. 77. Phlogopite.

Locality: In beforosite at Bergforsen on the mainland north of Alnö Island.

Analyst: T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F,Cl)		Ratio Mg : Fe
SiO ₂	40.60	67.60	Si	5.900	5.53:1.00
CO ₂	0.00	—			
TiO ₂	3.32	4.16			
ZrO ₂	0.00	—			
P ₂ O ₅	n.d.	—			
Al ₂ O ₃	13.72	13.46	Al	2.100	8.00
			Ti	0.364	
Cr ₂ O ₃	n.d.	—	Al	0.255	6.16
Fe ₂ O ₃	1.94	1.22	Fe ⁺³	0.213	
FeO	4.33	6.03	Fe ⁺²	0.524	
MnO	0.04	0.06	Mn	0.005	
MgO	22.51	55.83	Mg	4.800	
CaO	0.32	0.57	Ca	0.050	2.01
BaO	0.23	0.15	Ba	0.013	
SrO	0.00	—			
Na ₂ O	0.81	1.31	Na	0.229	2.08
K ₂ O	9.25	9.82	K	1.716	
F	0.53	2.79	F	0.244	2.08
Cl	0.03	0.09	Cl	0.008	
H ₂ O ^{+105°}	1.88	10.44	OH	1.828	
H ₂ O ^{-105°}	0.50	—			
	100.01	—			
- O = F,Cl	0.24	—			
	99.77	—			

Arc-spectrogram: Be[+], Co[+], Cu[+], P[+], Sn[+], Cd[-], Pb[-], Bi[-], V[-], Ga - , Tl - , Zn - .

 Composition: (K,Na,Ca,Ba)_{2.01}(Mg,Mn,Fe⁺²,Fe⁺³,Al,Ti)_{6.16}(Si,Al)_{8.00}O_{21.92}(OH,F,Cl)_{2.08}.

 Sp. gravity $^{20}_{4}C = 2.788$ (average of 5 determinations).

 $2 V_{\alpha 550}$ (observed) = $0^{\circ} - 5^{\circ} \pm 30'$.

 $n_{\alpha 550} = 1.574 \pm 0.001$ (average of 15 determinations).

 $n_{\beta 550} = 1.613 \pm 0.001$ (average of 15 determinations).

 $n_{\gamma 550} = 1.613 \pm 0.001$ (average of 15 determinations).

question of any manganophyllite, even if the red phlogopite contains somewhat more manganese than the green one. I believe the higher Fe⁺³/Fe⁺² ratio to be mainly responsible for the change in colour. The mineral paragenesis of this part of the dike contains very little pyrochlore and magnetite, phlogopite being the dominant impurity of the sövite. The content of free-oxidizing CO₂, evidenced by vesicles in the carbonate, may have been still higher here than in the narrow part of the dike.

At Långörsholmen Högbom (18) claimed to have found manganophyllite, partly in boulders and partly in solid sövite rock at the northern point of the island. He also observed that the centres of the mica flakes were of a greenish-brown color with rims of red manganophyllite. At the 45° position with crossed nicols "the two minerals

Analysis no. 78. Phlogopite.

Locality: In sövite from drillhole at Smedsgården, Alnö Island. The sövite contains dysanalyte and (or) pyrochlore. *Analyst:* T. Berggren.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F,Cl)		Ratio Mg:Fe
SiO ₂	37.40	62.27	Si	5.480	6.34:1.00
CO ₂	n.d.				
TiO ₂	1.30	1.63			
ZrO ₂	n.d.				
P ₂ O ₅	n.d.				
Al ₂ O ₃	16.61	16.29	Al	2.520	8.00
			Ti	0.144	
Cr ₂ O ₃	n.d.		Al	0.340	6.38
Fe ₂ O ₃	3.33	2.09	Fe ⁺³	0.357	
FeO	3.65	5.08	Fe ⁺²	0.447	
MnO	0.10	0.14	Mn	0.012	
MgO	23.31	57.81	Mg	5.080	
CaO	0.13	0.23	Ca	0.020	2.09
BaO	0.55	0.36	Ba	0.032	
SrO	< 0.005	—			
Na ₂ O	1.46	2.36	Na	0.415	2.46
K ₂ O	8.69	9.23	K	1.625	
F	0.04	0.21	F,Cl	0.021	2.46
Cl	0.01	0.03			
H ₂ O ^{+105°}	2.47	13.71	OH	2.442	
H ₂ O ^{-105°}	0.82				
	99.87				

Composition: (Na,K,Ca,Ba)_{2.09}(Mg,Mn,Fe⁺²,Fe⁺³,Al,Ti)_{6.38}(Si,Al)_{8.00}O_{21.56}(OH,F,Cl)_{2.46}.

Arc-spectrogram: Sn[+], Ag[-], (Be, Bi, Cd, Ce, Cr, Ga, Ge, Ir, Li, Mo, Ni, Pb, Pt, Sb, Ta, Te, Th, Tl, V, W, Zn, Zr) -.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.786$ (average of 5 determinations).

$2 V_{\alpha\text{Na}}$ (observed) = $0^{\circ}-4^{\circ} \pm 30'$.

$n_{\alpha\text{Na}} = 1.550 \pm 0.001$ (average of 10 determinations).

$n_{\beta\text{Na}} = \sim 1.594 \pm 0.001$ (average of 10 determinations).

$n_{\gamma\text{Na}} = 1.594 \pm 0.001$ (average of 10 determinations).

showed the same absorption and colour and looked quite uniform" (18, p. 247). In my Alnö memoir (9e, pp. 69, 72) I already disclaimed this classification of the mica as erroneous. I based my opinion at that time partly on microchemical tests and partly on the absence of any coating of manganese oxide on weathered rock. My analysis no. 82 of red phlogopite from the knopite-bearing sövite at Prickskär Island had already strengthened my supposition. Dr. Blix' analysis no. 81 of the phlogopite from Högbom's own locality at the northern point of Långörsholmen Island furnished the ultimate proof. As the narrow red rims could not be removed from the sample, the analysis is in consequence an average of the phlogopite crystals, as is also the specific gravity. While the central greenish part of the crystals is uniaxial, the red rims are biaxial with $2 V = 4-5^{\circ}$. This small axial angle excludes any mangano-phyllitic composition. Evidently, increased oxidation of the iron is in this case, too, the cause of the red colour.

Nevertheless, in 1916 H. Hedström (12) published a partial analysis of a mangano-

Analysis no. 79. Green phlogopite.

Locality: In pyrochlore-bearing sövite at Smedsgården. Analyst: Harry von Eckermann.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F)		Ratio Mg:Fe
SiO ₂	40.32	67.13	Si	5.710	7.94:1.00
CO ₂	0.00	—			
TiO ₂	0.26	0.33	Ti	0.028	8.00
ZrO ₂	n.d.				
P ₂ O ₅	0.00				
Al ₂ O ₃	12.12	11.88	Al	2.023	5.86
Cr ₂ O ₃	n.d.				
Fe ₂ O ₃	3.46	2.17	Fe ⁺³	0.239	5.86
			Fe ⁺³	0.131	
FeO	2.96	4.12	Fe ⁺²	0.350	
MnO	0.12	0.17	Mn	0.015	5.360
MgO	25.36	62.90	Mg	5.360	
CaO	0.19	0.34	Ca	0.029	2.00
BaO	0.44	0.32	Ba	0.027	
SrO	< 0.005				2.00
Na ₂ O	0.16	0.46	Na	0.078	
K ₂ O	10.32	10.96	K	1.865	4.02
F	0.80	4.23	F	0.360	
Cl	n.d.				4.02
H ₂ O ^{+105°}	3.88	21.54	OH	3.660	
H ₂ O ^{-105°}	0.03				
	100.42				
- O = F	0.32				
	100.10				

Composition: (K,Na,Ca,B)_{2.00}(Mg,Mn,Fe⁺²,Fe⁺³)_{5.86}(Si,Ti,Al,Fe⁺³)_{8.00}O_{19.98}(OH,F)_{4.02}.
 Sp. gravity ^{20°C}/₄ = 2.799 (average of 5 determinations).

$2 V_{\alpha\text{Na}}$ (observed) = $0^\circ - 3^\circ \pm 30'$ (10 determinations).

$n_{\alpha\text{Na}} = 1.543 \pm 0.100$ (average of 10 determinations).

$n_{\beta\text{Na}} = 1.583 \pm 0.100$ (average of 10 determinations).

$n_{\gamma\text{Na}} = 1.583 \pm 0.100$ (average of 10 determinations).

phyllite alleged to be isolated from sövite from one of the now vanished sövite boulders at Långörsholmen. He had started on the analysis 20 years earlier, on a sample provided by Högbom, but without completing it. He restarted again in 1916 on what he claims was the remaining part of the original sample, which, however, proved insufficient for a complete analysis. He got 8.69 % Al₂O₃, 10.95 % Fe₂O₃, 7.62 % MnO and 16.12 % MgO. The alkalis were not determined. The low alumina and exceedingly high iron contents are unusual in previously known manganophyllites. The MnO content of the now published series of 83 analyses is generally rather small or even wanting. The maximal percentages are recorded in the case of the titaniferous magnetites, 2.94 % at Stavssätt and 2.91 % at Prickskär. The MnO of the knopite-dysanalyte series reaches 1.64 %, the pyrochlores merely 0.30 %, the garnets 0.68 % and the pyroxenes 1.65 %, but the average content of all these minerals is rather low. Neither do the carbonatitic rocks contain any notable amount of manganese. It is therefore curious that such a concentration of MnO could have taken place in the

Analysis no. 80. Red phlogopite.

Locality: In sövite dike east of Smedsgården. *Analyst:* R. Blix (CO₂ and H₂O by H. v. E.).

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F)		Calcite Mol. prop. × 100	Ratio Mg : Fe
SiO ₂	40.30	67.10	Si	5.895	0.71	5.43 : 1.00
CO ₂	0.31	0.71				
TiO ₂	0.20	0.25	Ti	0.022	8.00	
ZrO ₂	n.d.					
P ₂ O ₅	n.d.					
Al ₂ O ₃	8.52	8.36	Al	1.468		
Cr ₂ O ₃	n.d.					
Fe ₂ O ₃	5.57	3.49	Fe ⁺³	0.615	5.87	
FeO	3.19	4.44	Fe ⁺²	0.390		
MnO	0.42	0.59	Mn	0.052		
MgO	24.95	61.88	Mg	5.430	0.71	
CaO	0.79	1.41	Ca	0.061		
BaO	n.d.				2.02	
SrO	n.d.					
Na ₂ O	0.25	0.40	Na	0.070		
K ₂ O	10.17	10.80	K	1.895	4.11	
F	0.40	2.11	F	0.185		
Cl	n.d.					
H ₂ O ^{+105°}	4.03	22.39	OH	3.930		
H ₂ O ^{-105°}	1.26					
	100.36					
- O = F	0.17					
	100.19					

Composition: (K,Na,Ca)_{2.02}(Mg,Mn,Fe⁺²)_{5.87}(Si,Ti,Al,Fe⁺³)_{8.00}O_{19.88}(OH,F)_{4.11}.

Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.846$. Impurity: 0.71 % calcite.

$2 V_{\alpha\text{Na}}$ (observed) = $0^{\circ}-2^{\circ} \pm 30'$; $n_{\alpha\text{Na}} = 1.561 \pm 0.100$; $n_{\beta\text{Na}} = \sim 1.602 \pm 0.100$; $n_{\gamma\text{Na}} = 1.602 \pm 0.100$.

Analysis no. 81. Red phlogopite.

Locality: In sövite at Långörsholmen. *Analyst:* R. Blix (CO₂ checked by H. v. E.).

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F)		Ratio Mg : Fe	
SiO ₂	38.60	64.25	Si	5.530	7.55 : 1.00	
CO ₂	0.00					
TiO ₂	0.62	0.78	Ti	0.067	8.00	
ZrO ₂	n.d.					
P ₂ O ₅	n.d.					
Al ₂ O ₃	11.56	11.34	Al	1.952		
Cr ₂ O ₃	n.d.					
Fe ₂ O ₃	4.05	2.52	Fe ⁺³	0.451	5.65	
			Fe ⁺³	0.037		
FeO	1.86	2.59	Fe ⁺²	0.223		
MnO	0.23	0.32	Mn	0.027	5.360	
MgO	25.13	62.33	Mg	5.360		
CaO	1.31	2.34	Ca	0.199	2.00	
BaO	0.55	0.36	Ba	0.031		
SrO	n.d.					
Na ₂ O	0.11	0.18	Na	0.031		
K ₂ O	9.49	10.07	K	1.735		

Anal. no. 81 (cont.)

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F)		Ratio Mg : Fe
F	0.26	1.37	F	0.118	} 4.77
Cl	n.d.				
H ₂ O ^{+105°}	4.88	27.09	OH	4.654	
H ₂ O ^{-105°}	1.30				
	99.95				
- O = F	0.11				
	99.84				

 Composition: (K,Na,Ca,Ba)_{2.00}(Mg,Mn,Fe⁺²,Fe⁺³)_{5.65}(Si,Ti,Al,Fe⁺³)_{8.00}O_{19.23}(OH,F)_{4.77}.

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.769$ (average of 5 determinations).

 $2 V_{\alpha 550}$ (observed) = $4^{\circ}-5^{\circ} \pm 1^{\circ}$ in the marginal parts of the crystals, $0^{\circ}-1^{\circ} \pm 30'$ in the centre.

 $n_{\alpha 550} = 1.562 \pm 0.001.$
 $n_{\beta} = \text{n.d.}$
 $n_{\gamma 550} = 1.604 \pm 0.001.$

} Measured on the central parts of the crystals.

Analysis no. 82. Red phlogopite.

Locality: In knopite-bearing sövite, Prickskär Island. Analyst: Harry von Eckermann.

	Weight %	Mol. prop. × 100	Number of ions on the basis of 24(O,OH,F)		Ratio Mg : Fe
SiO ₂	40.90	68.10	Si	5.860	} 5.95 : 1.00
CO ₂	0.00	—			
TiO ₂	0.35	0.44	Ti	0.040	
ZrO ₂	n.d.				
P ₂ O ₅	0.00	—			} 8.00
Al ₂ O ₃	9.20	9.03	Al	1.556	
Cr ₂ O ₃	n.d.				
Fe ₂ O ₃	5.32	3.34	Fe ⁺³	0.544	} 5.93
			Fe ⁺³	0.032	
FeO	3.34	4.65	Fe ⁺²	0.404	
MnO	0.96	1.35	Mn	0.117	} 1.99
MgO	24.99	61.98	Mg	5.380	
CaO	0.28	0.50	Ca	0.043	} 4.10
BaO	< 0.01				
SrO	tr.				
Na ₂ O	0.31	0.50	Na	0.086	} 4.10
K ₂ O	10.21	10.84	K	1.866	
F	0.26	1.32	F	0.114	} 4.10
Cl	n.d.				
H ₂ O ^{+105°}	4.17	23.15	OH	3.985	
H ₂ O ^{-105°}	0.02				
	100.31				
- O = F	0.11				
	100.20				

 Composition: (K,Na,Ca,Ba)_{1.99}(Mg,Mn,Fe⁺²,Fe⁺³)_{5.93}(Si,Ti,Al,Fe⁺³)_{8.00}O_{19.90}(OH,F)_{4.10}.

 Sp. gravity $\frac{20}{4}^{\circ}\text{C} = 2.790$ (average of 5 determinations).

 $2 V_{\alpha \text{Na}}$ (observed) = $0^{\circ}-4^{\circ} \pm 30'$.

 $n_{\alpha \text{Na}} = 1.572 \pm 0.001.$
 $n_{\beta \text{Na}} = 1.614 \pm 0.001.$
 $n_{\gamma \text{Na}} = 1.614 \pm 0.001.$

 } Average of 10 determinations, measured on a crystal with $2 V_{\alpha} \sim 0^{\circ}$.

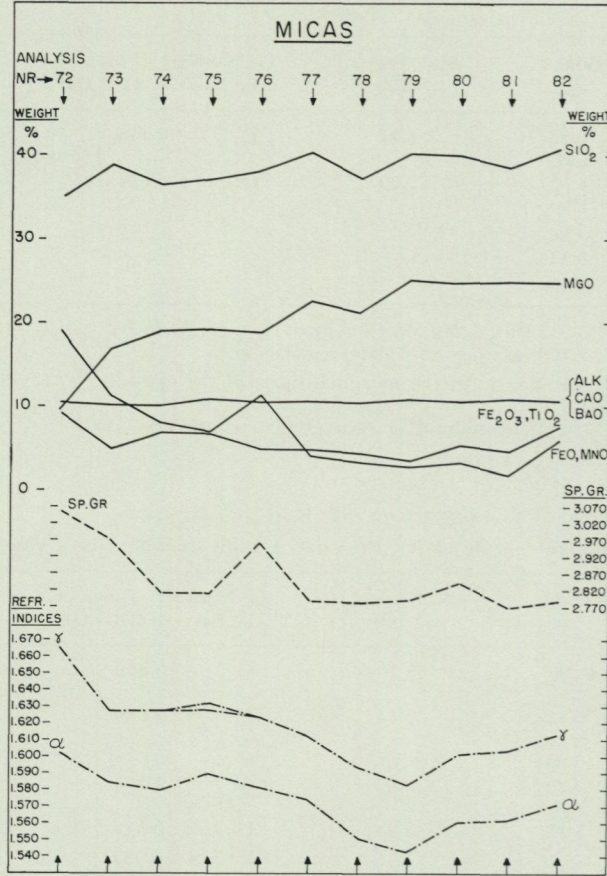


Fig. 18. The weight % of the major components, the specific gravity and refractive indices of micas.

phlogopite of sövite. If not a confusion of samples occurred after 20 years, the now-vanished boulder, from which the manganophyllite was claimed to have been isolated, must have been a freak, not representing the now observable rocks within the region.

Finally, a few words may be said about the micas of the melilite-basaltic alnöite. Both Högbom and the present author classified them as ordinary biotite and anomite in our respective memoirs. Winchell describes anomite as a "black mica, which is not unlike ordinary biotite but which has the optic plane normal to 010". Deer *et al.* mention the anomite under the heading "biotite" (8, Vol. 3, p. 70) but consider the use of the name superfluous in view of the mineral being equivalent to $2M_1$ polymorph (13a).

The big, macroporphyratically occurring mica crystals of up to 4 cm diameter were first investigated by Fr. Eichstädt at the University of Stockholm in 1884 (10, p. 194) and he found them to be anomites, which at that time were only known from three localities—in Siberia, the State of New York and Austria. Eichstädt had probably got his anomite from the classic locality west of Näset, where it was first discovered

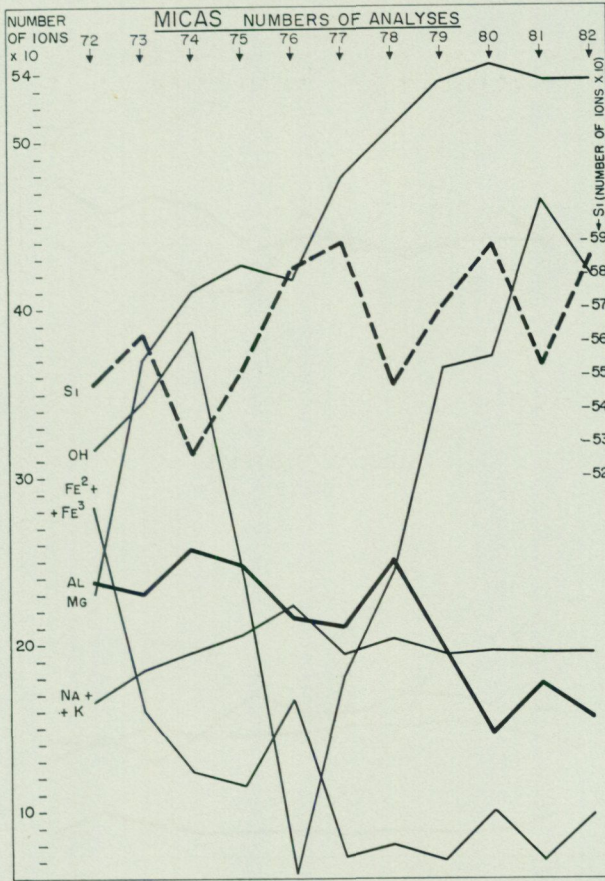


Fig. 19. The number of ions of the major components of micas.

by Törnebohm in 1882. Having isolated enough mica for analysis, I also repeated his investigation of its optical properties and confirmed the position of the optical plane being normal to 010. It came as a surprise to me that the succeeding analysis, no. 75, showed a phlogopitic and not a biotitic composition, the Mg:Fe ratio being 3.69:1. The "anomite" crystals proved to be somewhat zoned, the titanium content decreasing from a homogeneous large central part towards rather narrow rims of somewhat lower refraction. Some of the crystals have uniaxial centres and biaxial rims, but many crystals are also centrally biaxial.

In a kimberlite dike east of Släda farm, I also found "anomitic" mica of a more homogeneous kind. An analysis, no. 74, gives a rather similar chemical composition, the main differences being somewhat lower Mg- and somewhat higher Fe-contents, resulting in an decrease of the Mg:Fe ratio to 3.22:1. In other kimberlite dikes, as for instance at Hovid, I have found the optic axial plane to be generally parallel to (010), but occasionally perpendicular to (010). The two analyses, mentioned above, seem to show that the mica of the alnöites, previously generally accepted as "anomitic"

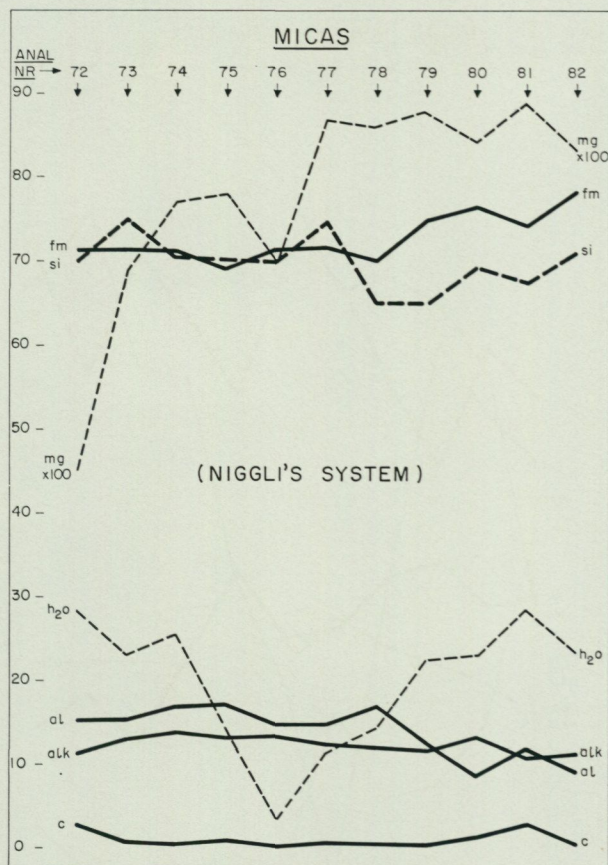


Fig. 20. *Niggli* values of micas.

ic" biotite, is in fact an "anomitic" phlogopite. The dark colour, which may have misled me as well as other mineralogists, is probably the result of the titanium content. The true biotite of analysis no. 72 is not "anomitic".

Fig. 18 shows a diagram of the compositions by weight of the micas as well as of the two refractive indices γ and α and of the specific gravity. In virtually all analyses the percentage of $\text{Alk} + \text{CaO} + \text{BaO}$ is the same and the ensuing curve is an almost straight horizontal line slightly above 10%. If the number of ions are plotted, as in Fig. 19, a remarkable reciprocity between the Si and Al is noticeable and is emphasized by the two heavily drawn curves. This diagram also illustrates the increasing Mg- and decreasing Fe^{tot} -content of this series of analyses. The most important Niggli-values have also been plotted in the diagram, Fig. 20. A certain reciprocity between "al" on one hand and "alk" and "fm" on the other is shown by the curves. Finally, I have plotted γ against $\text{FeO} + 2(\text{Fe}_2\text{O}_3 + \text{TiO}_2)$ according to Heinrich's proposal (13*b*, 1946), and obtained in Fig. 21 a very good agreement with the corresponding curve, published by Deer *et al.* (8, Vol. 3, p. 48) and "showing that the effect of Fe^{+3}

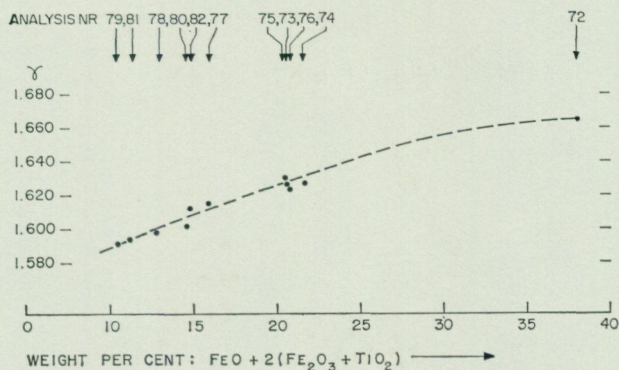


Fig. 21. The relationship between refractive index and chemical composition of micas.

and Ti on refractive index is greater than that of Fe^{+2} . This diagram may also be taken as a proof of the validity of the analyses. In two of the analyses, however, no. 76 and no. 77, the percentages of fluorine or water, or both of them, seem questionably low.

The trace elements of the phlogopites have been determined in 4 of the analyses by arc-spectrograms. In the phlogopite of analysis no. 78 only some Sn is present while 23 elements were looked for without success. Ag, Cr, Cu, Sn, Li and V seem to occur generally in the other analyses and in analysis no. 76 the V_2O_3 was found to amount to no less than 0.11%. BaO is throughout the analytical series dominant over SrO, which occurs in very small amounts or is totally missing. TiO_2 ranges from 0.20% in the red phlogopite at Smedsgården to 4.26%–4.27% in the alnöites east of Släda and west of Näset. An increase of the axial angle with rising titanium content is clearly indicated.

The oxidation ratios of biotite and phlogopite are generally low, below 0.30, but increase rapidly in sövites containing dysanlyte, knopite and pyrochlore. This is graphically shown by analyses nos. 78 to 82 in Fig. 29.

A short graphic representation of the analysed minerals

In order to show the mutual chemical relationship existing between the most important mineral groups, eight diagrams have been plotted.

The first "Ca–Mg–Fe(tot.)+Mn" diagram, Fig. 22, illustrates the Mg-dominance within the olivines, phlogopites, amphiboles and the majority of the pyroxenes. The olivines and the majority of the phlogopites occupy about the same space in the diagram. They are both the first two minerals to form at the silicification of the ankeritic-dolomitic carbonatite dikes. The second and third diagrams, Figs. 23 and 24, show the distribution of the minerals—magnetites and ilmenites excluded—calculated in Niggli values. The orthoclases and their pseudomorphs have in the latter figure been plotted in an enlarged triangle of the "al+alk" corner, while in Fig. 23 only the upper part of the complete diagram is represented, leaving out all the framework silicates. The "alk–al–c+fm" diagram, Fig. 23, illustrates the increasing alumina in the mineral series: pyrochlore → dysanlyte, knopite, perovskite, apatite →

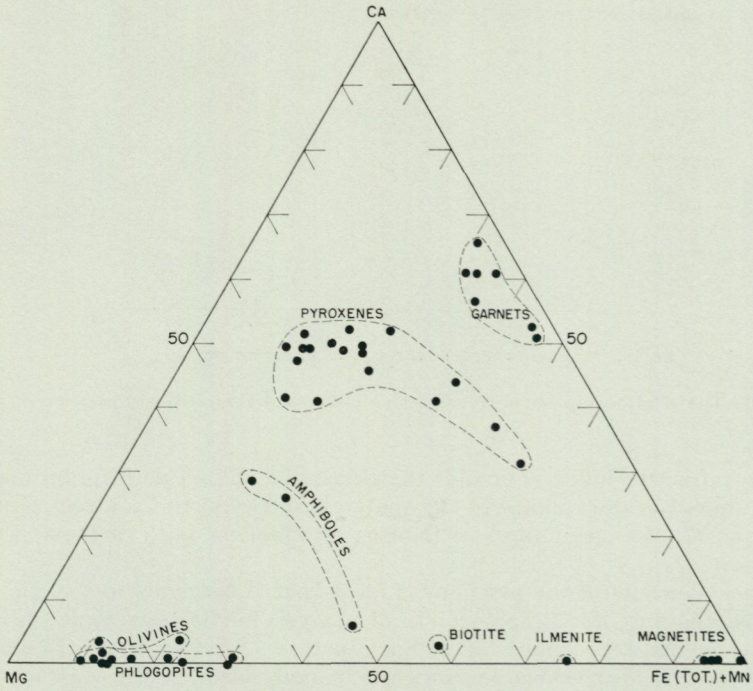


Fig. 22. Ca - Mg - (Fe_{tot} + Mn) diagram of the essential mineral groups.

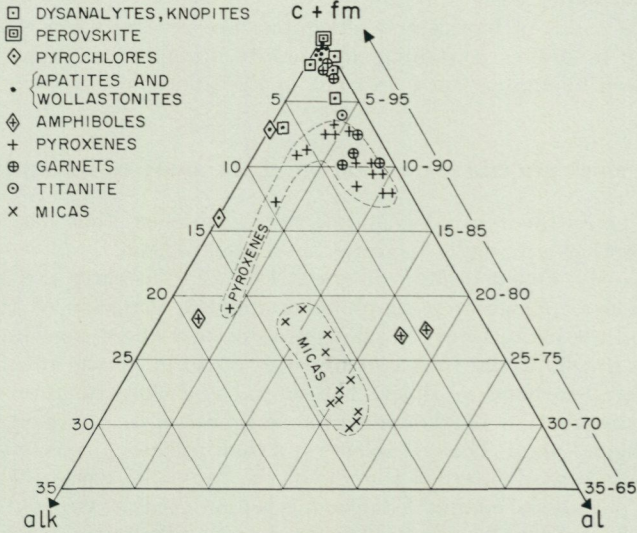


Fig. 23. (c + fm) - alk - al diagram of the Alnö minerals.

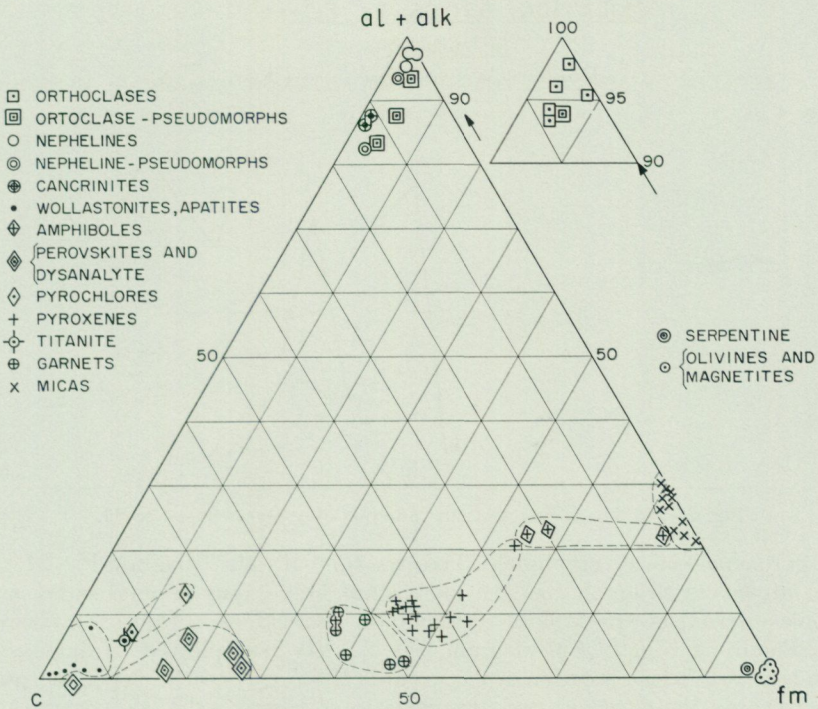


Fig. 24. (al + alk) - c - fm diagram of the Alnö minerals.

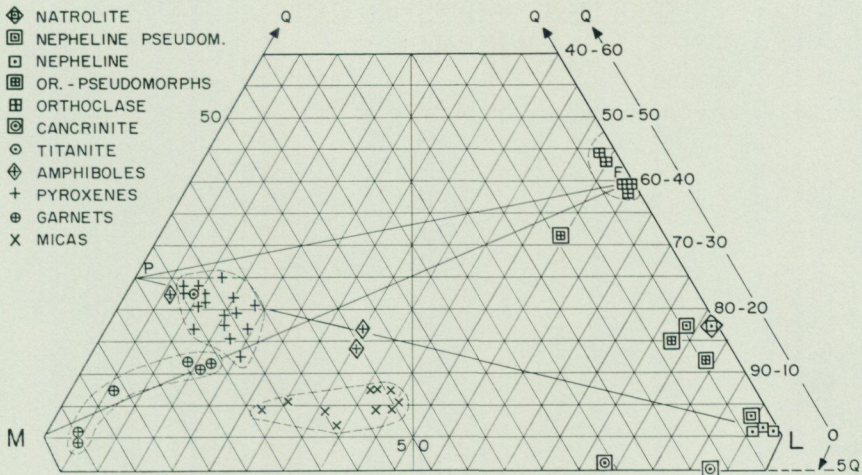


Fig. 25. Q - L - M Niggli diagram of the Alnö minerals.

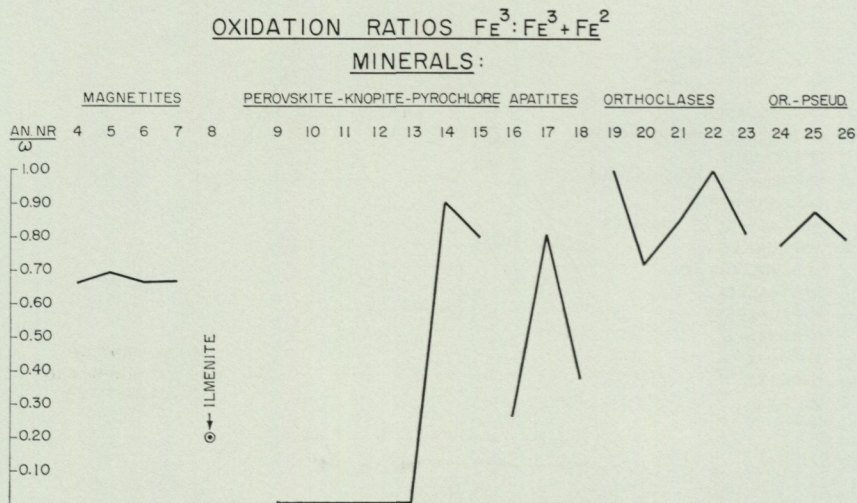


Fig. 26. Oxidation ratios of the minerals of analyses nos. 4 to 26.

garnet, pyroxene → mica → amphibole. The “c - fm - al + alk” diagram Fig. 24, on the other hand, serves to emphasize the increase of lime in the mineral series: mica → amphibole → pyroxene → perovskite, dysanalyte, pyrochlore → titanite → wollastonite, apatite. Finally, a Niggli QLM diagram, Fig. 25, has been plotted. It demonstrates the trends of orthoclase pseudomorphs towards the *L*-corner, the nepheline pseudomorphs towards the *Q*-corner and the cancrinites towards the *M*-corner, thereby emphasizing the independent formation of cancrinite, unconnected with the nephelization of the feldspars.

The last four diagrams, Figs. 26-29, give the oxidation ratios of the minerals, and have been referred to during the descriptions of the mineral groups.

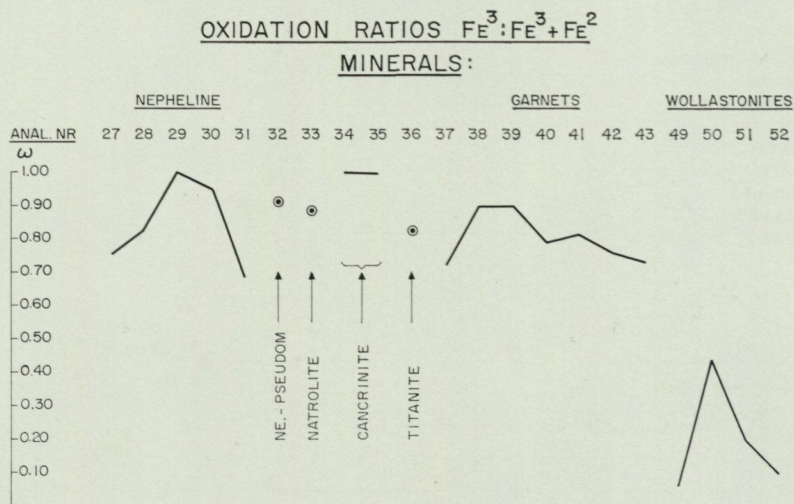


Fig. 27. Oxidation ratios of the minerals nos. 27 to 52.

OXIDATION RATIOS $Fe^3:Fe^3+Fe^2$

MINERALS :

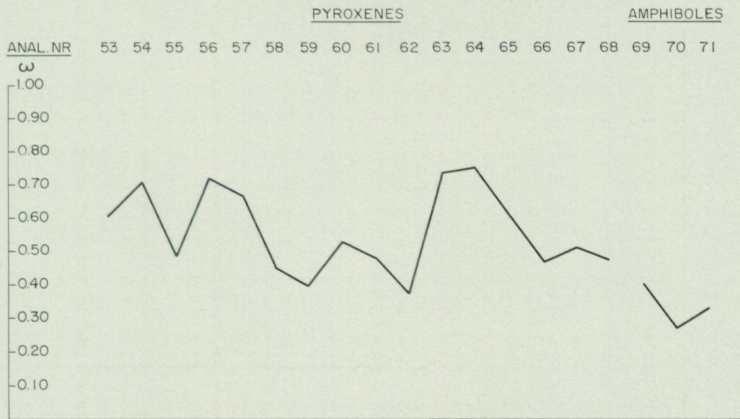


Fig. 28. Oxidation ratios of the pyroxenes and amphiboles.

OXIDATION RATIOS $Fe^3:Fe^3+Fe^2$

MICAS

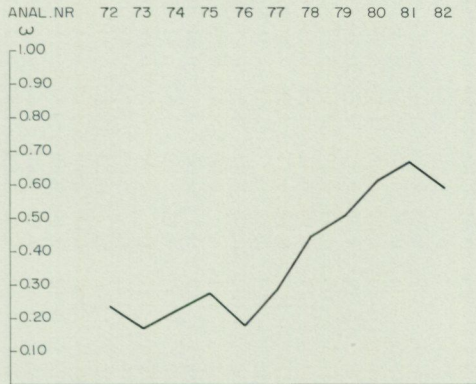


Fig. 29. Oxidation ratios of the micas.

Table 5. Niggli values of analyses nos. 16 to 82.

Analysis no.	al	fm	c	alk	si	qz	ti	mg	c/fm	k	ω	p	co ₂	h ₂ O	Q	L	M	π	γ	α	μ
16	0.2	1.2	98.4	0.2	1.1	-100	0.00	0.81	81.50	0.16	0.27	28.80	1.01	2.11	48.4	1.2	147.2	0.00	0.99	-1.02	0.01
17	0.1	8.3	91.1	0.5	5.2	-96	0.00	0.00	10.98	0.81	0.81	24.10	1.89	2.97	42.7	0.5	142.7	0.00	0.92	-0.91	0.00
18	0.4	5.4	93.7	0.5	2.5	-99	0.04	0.64	17.38	0.35	0.38	20.51	25.65	2.55	46.5	2.3	144.2	0.00	0.85	-1.00	0.03
19	48.7	2.4	1.3	47.6	287.5	+7	0.02	0.40	0.54	0.87	1.00	—	0.00	0.37	39.3	59.5	1.2	0.01	0.08	-1.23	3.70
20	51.1	2.5	4.0	42.4	295.5	+26	0.03	0.23	1.60	0.87	0.71	—	0.00	1.83	43.3	54.5	2.2	0.05	0.00	9.60	0.23
21	50.0	4.2	0.5	45.3	315.5	+34	0.06	0.10	0.12	0.89	0.85	—	0.00	0.67	44.1	53.4	2.5	0.01	0.00	10.20	0.10
22	49.0	1.6	2.5	46.9	286	-2	0.02	0.00	1.56	0.89	1.00	—	0.00	1.12	39.7	59.7	0.6	0.22	0.20	-0.60	0.00
23	49.2	1.8	3.7	45.3	278	-19	0.06	0.07	2.06	0.78	0.82	—	tr.	0.47	39.5	59.8	0.7	0.39	0.00	-11.60	0.07
24	61.6	3.4	13.4	21.7	131.5	-56	0.01	0.39	3.94	0.67	0.72	—	0.00	9.39	31.6	54.2	14.2	0.24	0.00	-0.94	0.39
25	52.7	4.8	7.3	35.2	114	-127	0.19	0.31	1.52	0.28	0.88	—	0.00	47.40	15.6	77.0	7.4	0.94	0.00	-11.89	0.31
26	51.8	2.5	3.3	42.4	121	-149	0.18	0.17	1.32	0.30	0.70	—	0.00	16.35	12.1	83.9	4.1	0.41	0.00	-60.10	0.17
27	50.8	0.8	1.3	47.1	108	-180	tr.	tr.	1.62	0.21	0.76	—	0.00	13.05	9.2	182.0	-91.2	0.01	0.00	-110.02	0.52
28	47.2	2.1	2.6	48.1	100	-192	0.10	0.00	1.24	0.17	0.83	—	0.00	8.50	0.8	95.8	3.4	0.00	0.55	-47.20	0.00
29	48.5	1.9	0.7	48.9	104	-191	tr.	0.90	0.37	0.20	1.00	—	0.00	1.23	0.4	98.5	1.4	0.00	0.27	-11.15	0.50
30	47.8	2.8	0.3	49.1	99.5	-152	tr.	0.00	0.11	0.31	0.95	—	0.27	1.72	1.3	96.0	2.7	0.00	0.01	-65.30	0.00
31	46.6	2.7	4.3	46.4	99	-197	0.13	0.22	1.59	0.21	0.69	—	5.76	11.08	1.0	95.5	3.5	0.02	0.60	-52.60	0.09
32	37.1	3.1	14.1	45.7	77	-187	tr.	0.09	4.56	0.12	0.91	—	11.65	20.65	4.8	77.9	17.3	0.00	0.82	-8.50	0.18
33	49.4	1.0	5.7	43.9	149	-127	tr.	0.00	5.70	0.02	0.89	—	n.d.	107.20	17.7	81.8	0.5	0.59	0.17	-210.00	0.00
34	39.3	1.0	13.1	46.6	79	-200	tr.	0.53	13.10	0.01	1.00	—	21.00	18.32	4.8	92.2	12.6	0.00	0.93	-11.91	0.04
35	39.9	1.1	11.1	47.89	81	-203	0.00	0.20	1.01	0.01	1.00	—	17.10	22.45	4.2	78.3	25.9	0.00	0.90	-13.94	-0.02
36	4.5	8.9	85.0	1.6	92.5	-13	84.10	0.09	9.55	0.18	0.82	—	0.00	0.59	22.2	9.3	68.5	0.48	0.90	0.69	0.01
37	8.2	35.5	54.6	1.7	65	-42	4.70	0.09	1.54	0.13	0.72	—	0.00	0.93	11.3	17.0	71.7	0.66	0.52	0.00	0.04
38	6.6	39.5	51.4	2.5	67	-43	5.64	0.20	1.45	0.14	0.90	—	0.00	0.98	10.6	15.5	73.9	0.45	0.55	0.01	0.09
39	2.4	39.9	56.9	0.8	61	-42	8.32	0.16	1.42	0.63	0.90	—	0.00	4.36	7.3	5.6	87.1	0.56	9.59	11.41	0.07
40	6.3	35.6	55.5	2.6	67	-43	10.63	0.19	1.76	0.23	0.79	—	0.00	6.89	10.3	15.2	74.5	0.42	0.59	0.01	0.09
41	6.3	36.4	56.0	1.3	67	-21	12.35	0.15	1.55	0.14	0.81	—	0.00	0.38	11.9	13.1	75.0	0.66	0.58	0.18	0.06
42	1.2	47.6	49.8	1.4	50	-55	21.04	0.05	1.05	0.46	0.76	—	0.00	0.63	0.8	4.7	96.1	0.00	0.51	-0.19	0.02
43	1.3	46.1	51.8	0.8	51	-52	22.15	0.06	1.12	0.32	0.73	—	0.00	0.77	0.9	4.1	95.0	0.24	0.53	-0.07	0.03
44	tr.	99.9	0.1	0.0	50	-50	0.00	0.90	0.00	0.00	0.00	—	0.00	0.03	0.0	0.0	100.0	0.00	0.00	0.00	0.90
45	0.0	98.3	1.7	0.0	50	-51	0.16	0.88	0.02	—	0.00	—	0.00	0.01	0.0	0.1	100.0	0.00	0.02	0.00	0.86
46	1.5	97.0	0.5	1.0	49	-55	0.14	0.89	0.01	0.32	0.04	—	0.00	0.06	1.0	4.9	96.1	0.20	0.00	-0.42	0.86
47	0.0	99.8	0.2	0.0	50	-50	0.16	0.78	0.00	—	—	—	0.00	0.01	0.0	0.0	100.0	0.00	0.00	0.00	0.78
48	0.9	95.5	3.4	0.2	55	-46	0.00	0.88	0.04	0.21	0.75	—	0.00	67.05	3.5	2.1	94.4	0.64	0.03	0.07	0.86
49	0.5	3.6	95.4	0.5	105	+3	0.00	0.10	26.45	0.00	0.06	—	n.d.	2.52	-27.2	1.5	71.3	0.00	0.97	1.05	0.01
50	0.7	4.1	94.2	1.0	100	-4	0.00	0.20	22.95	0.00	0.44	—	0.00	3.64	-26.3	2.2	71.5	0.00	0.96	0.97	0.01

51	3.5	2.8	88.9	4.8	114	+0	0.01	0.30	31.53	0.00	0.20	—	0.00	6.84	-27.0	9.4	63.6	0.00	0.97	0.97	0.01
52	0.3	1.4	98.2	0.1	98.5	-2	tr.	0.16	70.2	0.00	0.10	—	0.00	0.29	-24.5	0.6	74.9	0.50	0.99	0.96	0.00
53	8.4	46.0	44.2	1.4	77	-29	1.05	0.68	0.96	0.19	0.61	—	0.00	0.69	17.5	15.8	66.7	0.71	0.45	0.31	0.38
54	10.2	44.5	43.5	1.8	84	-23	1.67	0.70	0.98	0.39	0.71	—	0.00	1.72	20.6	18.4	61.0	0.70	0.44	0.41	0.28
55	8.6	43.5	46.0	1.9	83	-25	1.22	0.69	1.06	0.16	0.49	—	0.00	0.98	19.6	16.3	64.1	0.64	0.51	0.41	0.36
56	5.5	46.9	45.7	1.9	89	-19	1.35	0.67	0.91	0.16	0.72	—	0.00	2.46	20.7	11.4	67.9	0.49	0.45	0.71	0.35
57	4.7	49.0	43.5	2.8	90	-21	1.32	0.70	0.85	0.28	0.67	—	0.00	4.23	16.7	11.9	71.4	0.25	0.46	0.55	0.38
58	2.7	51.0	39.8	6.5	102	-10	0.98	0.31	0.78	0.04	0.45	—	0.00	1.45	22.5	7.7	69.8	0.00	0.44	0.74	0.55
59	3.3	53.9	37.5	5.3	105	-15	1.14	0.37	0.70	0.13	0.40	—	0.00	3.46	23.6	9.3	67.1	0.00	0.41	0.78	0.22
60	2.5	51.0	42.4	4.1	105	-38	0.92	0.52	0.89	0.10	0.53	—	0.00	1.01	23.8	7.0	69.2	0.00	0.46	0.85	0.28
61	8.1	45.0	43.6	3.3	86	-27	3.45	0.60	0.97	0.29	0.49	—	0.00	1.77	19.1	16.9	64.0	0.42	0.45	0.11	0.52
62	3.8	49.8	42.4	4.0	95	-21	2.28	0.44	0.85	0.02	0.38	—	0.00	0.33	20.3	11.3	68.4	0.00	0.46	0.56	0.24
63	3.4	51.1	36.0	9.5	106	-26	0.80	0.29	0.71	0.03	0.74	—	0.00	1.06	22.3	10.2	67.5	0.00	0.41	0.71	0.15
64	4.1	54.2	25.0	16.7	113	-42	0.81	0.28	0.46	0.03	0.75	—	0.00	7.31	25.1	11.8	63.1	0.00	0.32	0.75	0.19
65	9.1	42.6	46.9	1.4	81	-25	4.38	0.46	1.10	0.09	0.61	—	0.00	0.78	15.3	17.6	67.1	0.73	0.15	0.40	0.25
66	7.1	45.1	45.1	2.7	89	-22	2.63	0.62	1.00	0.16	0.47	—	0.00	0.64	19.2	15.0	65.8	0.45	0.48	0.49	0.33
67	7.3	45.6	43.6	3.5	91	-23	3.18	0.54	0.96	0.30	0.51	—	0.00	1.82	20.5	16.1	63.4	0.39	0.46	0.46	0.29
68	10.7	42.1	45.8	1.4	79	-27	3.20	0.58	0.92	0.11	0.47	—	0.00	0.73	12.1	20.7	67.2	0.77	0.47	0.32	0.31
69	16.9	55.0	22.1	6.0	73	-52	4.04	0.74	0.40	0.39	0.40	—	0.00	1.94	14.0	35.2	50.8	0.48	0.17	-0.56	0.62
70	18.4	57.6	19.9	4.1	74	-42	3.24	0.67	0.35	0.22	0.27	—	0.00	6.51	17.4	34.3	48.3	0.64	0.09	-0.34	0.61
71	2.5	73.7	4.6	19.2	113	-47	0.43	0.52	0.06	0.12	0.33	—	0.00	9.01	22.2	6.4	71.4	0.00	0.59	0.72	0.49
72	15.2	71.0	2.8	11.0	70	-74	4.77	0.45	0.39	0.90	0.24	—	0.00	28.40	6.7	40.0	53.3	0.16	-0.20	-1.24	0.46
73	15.4	71.4	0.4	12.8	75	-76	3.66	0.69	0.01	0.83	0.17	—	n.d.	23.15	7.3	41.6	51.1	0.09	-0.03	-1.21	0.71
74	17.0	71.1	0.2	11.7	71	-77	5.38	0.77	0.00	0.86	0.22	—	n.d.	25.55	7.1	43.2	49.7	0.19	-0.08	-1.33	0.83
75	17.0	68.9	1.0	13.1	70	-82	6.01	0.78	0.02	0.86	0.27	—	0.00	14.00	5.4	45.1	49.5	0.13	-0.04	-1.50	0.81
76	14.8	71.5	0.2	13.5	70	-84	4.68	0.70	0.00	0.91	0.18	—	n.d.	3.76	3.9	42.8	53.9	0.05	-0.02	-1.54	0.71
77	15.0	71.8	0.8	12.4	75	-75	4.74	0.87	0.01	0.88	0.29	—	0.00	11.65	7.5	40.6	51.9	0.10	-0.02	-1.50	0.74
78	17.1	70.2	0.6	12.1	65	-83	1.71	0.86	0.01	0.80	0.45	—	n.d.	14.28	4.5	45.1	50.4	0.17	-0.07	-1.60	0.92
79	12.5	75.0	0.6	11.9	65	-83	0.35	0.88	0.01	0.96	0.51	—	0.00	22.60	2.0	38.7	59.3	0.02	0.00	-1.23	0.88
80	8.7	76.5	1.5	13.3	70	-79	0.36	0.84	0.02	0.96	0.61	—	0.00	23.15	4.4	27.2	68.4	0.00	0.02	-0.60	0.83
81	11.9	74.3	2.9	10.9	68	-76	0.82	0.89	0.04	0.98	0.66	—	0.00	28.60	5.0	36.0	60.0	0.04	0.02	-1.00	0.87
82	9.4	78.3	0.5	11.8	71	-74	0.46	0.83	0.01	0.96	0.59	—	0.00	27.60	5.5	29.9	64.6	0.00	0.01	-0.65	0.82

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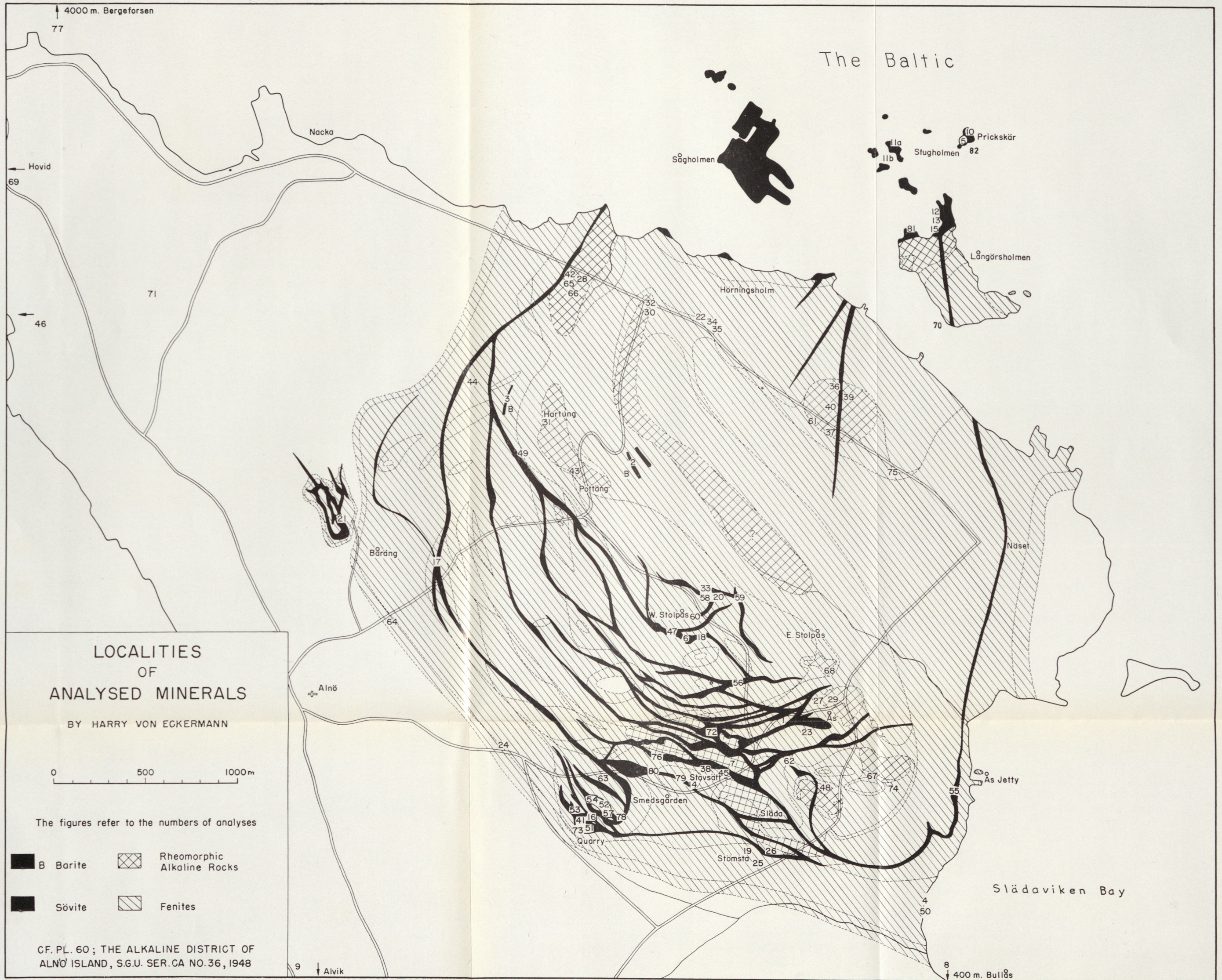
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Tryckt den 26 april 1974

Almqvist & Wiksell, Uppsala 1974



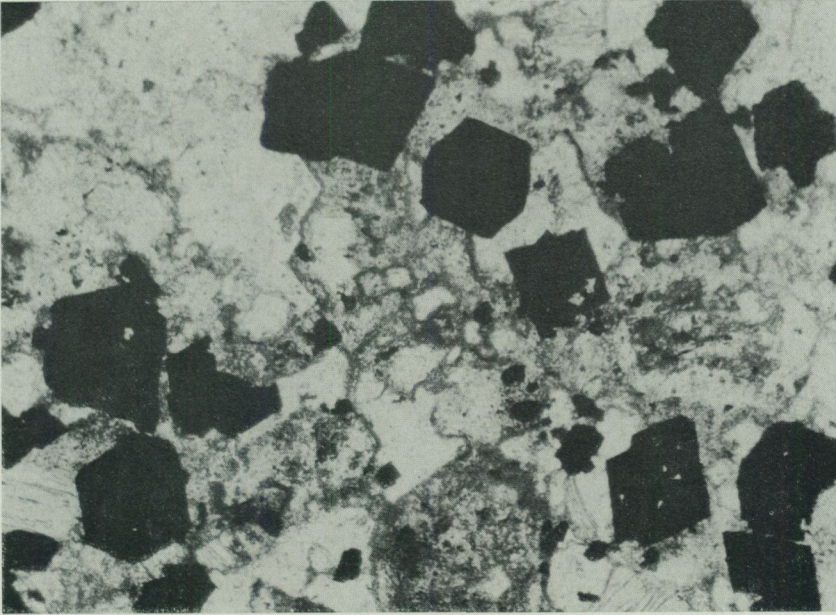


Fig. 1. Magnetite crystals in carbonatite. $\times 125$.

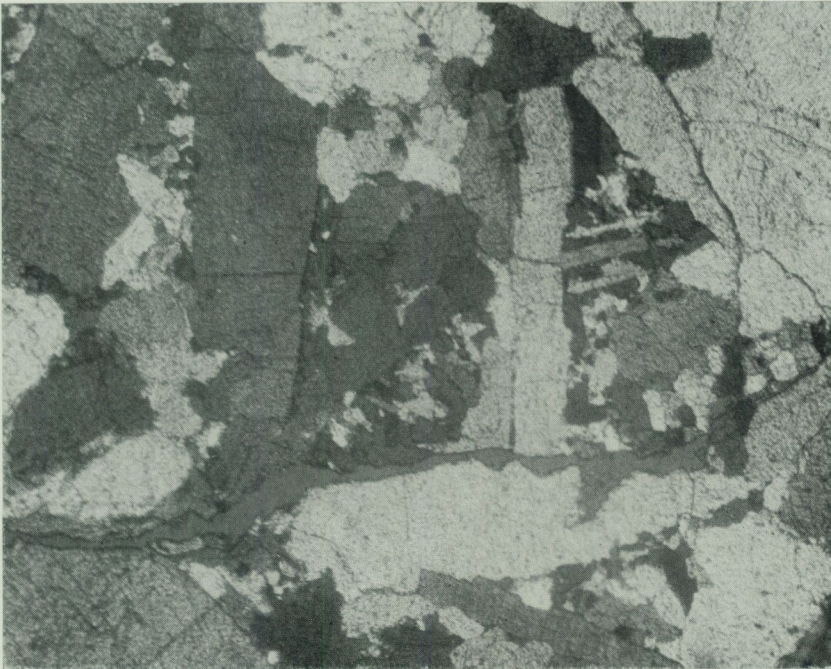


Fig. 2. Barite from the Hartung vein. $\times 30$. Analysis no. 3.

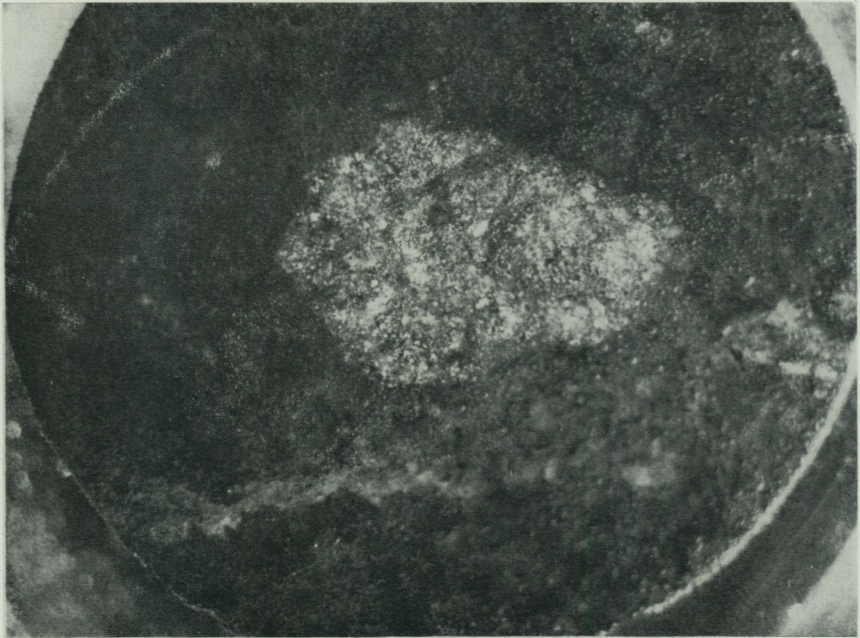


Fig. 1. Titaniferous magnetite in kimberlite dike. $\times 2$.

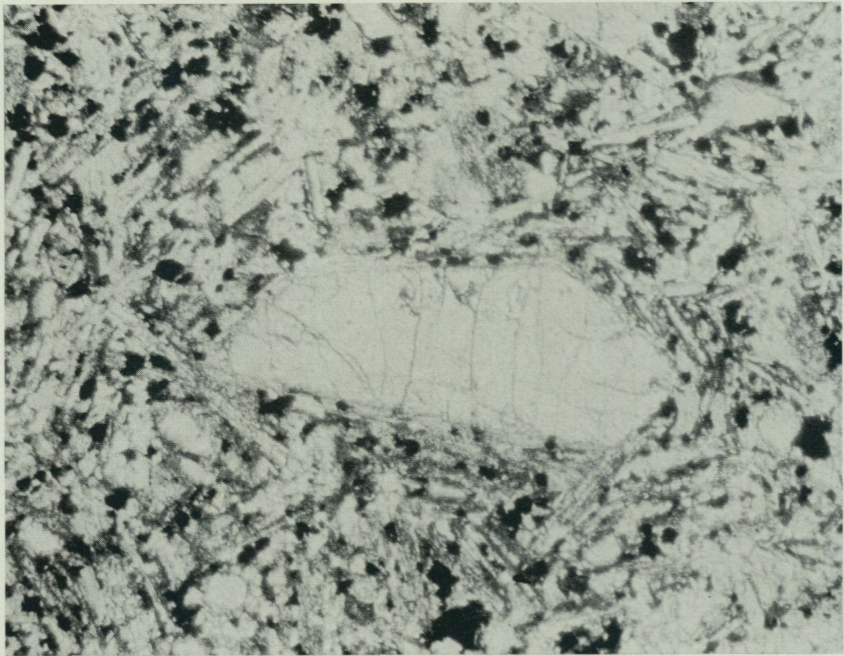


Fig. 2. Perovskite crystals (black and dark gray) in micaceous beforosite dike at Alvik. $\times 10$.
Analysis no. 9.



Fig. 1. Perovskite with ilmenite margins in phlogopite-sövite (lower left part of microphoto).
× 30.

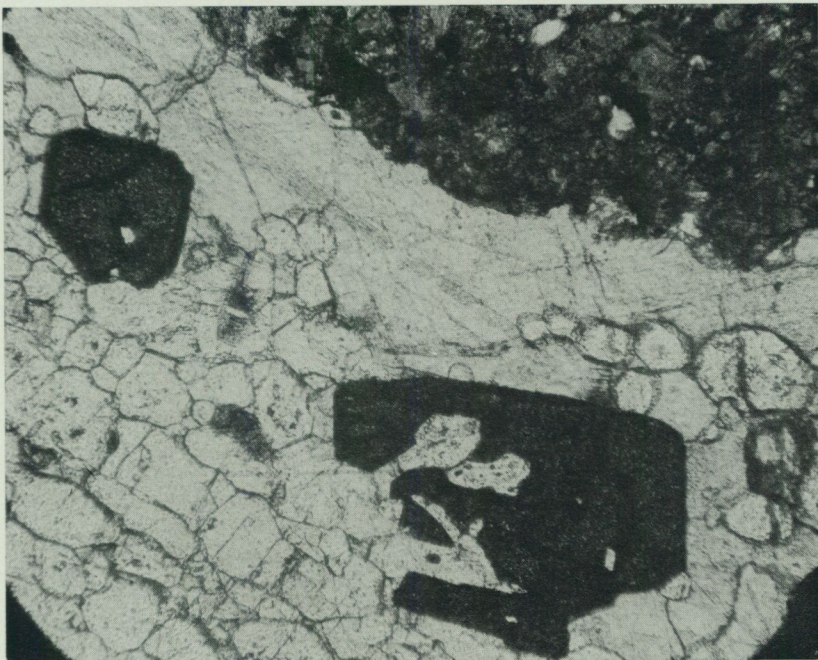


Fig. 2. Knopite (dark gray in upper left part of photo), analysis no. 12, and pyrochlore (dark gray in lower right corner of photo), analysis no. 15. To the upper right, red phlogopite (gray and black). × 65.

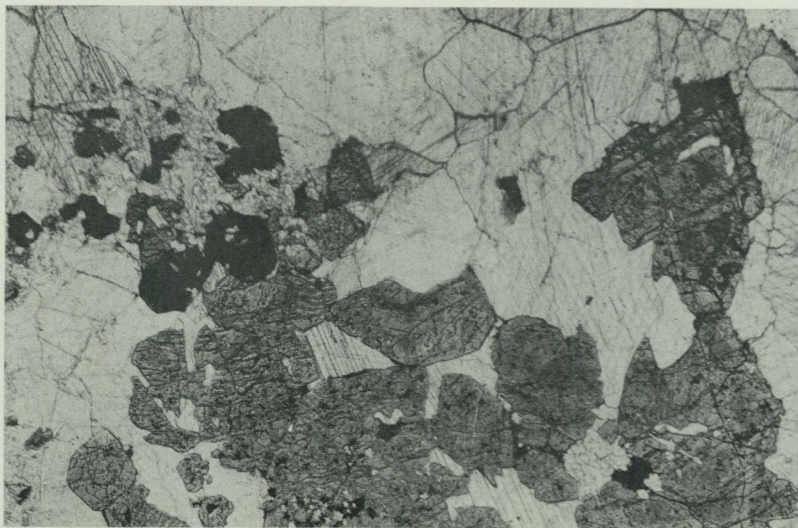


Fig. 1. Dysanalyte (black) in sövite, rich in serpentine (gray). $\times 30$. Analysis no. 11a.

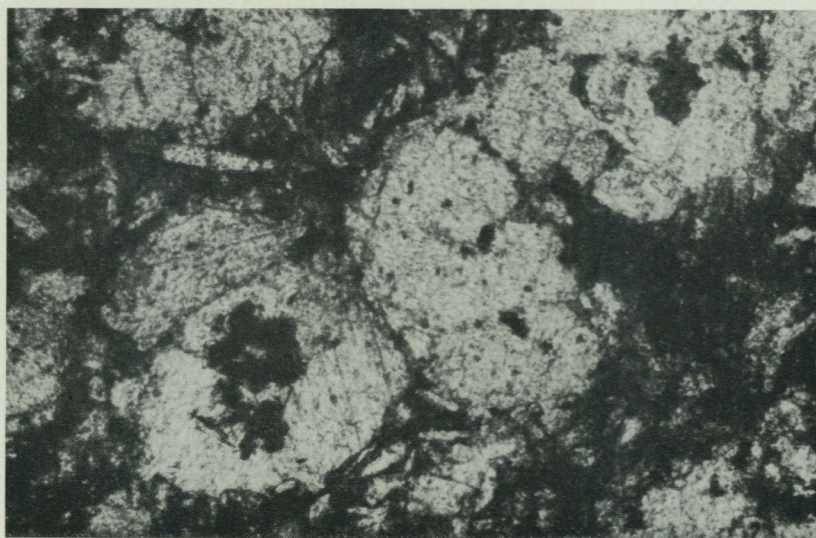


Fig. 2. Dysanalyte and knopite crystals in the centres of two carbonate globules in kimberlite dike, west of Hartung.

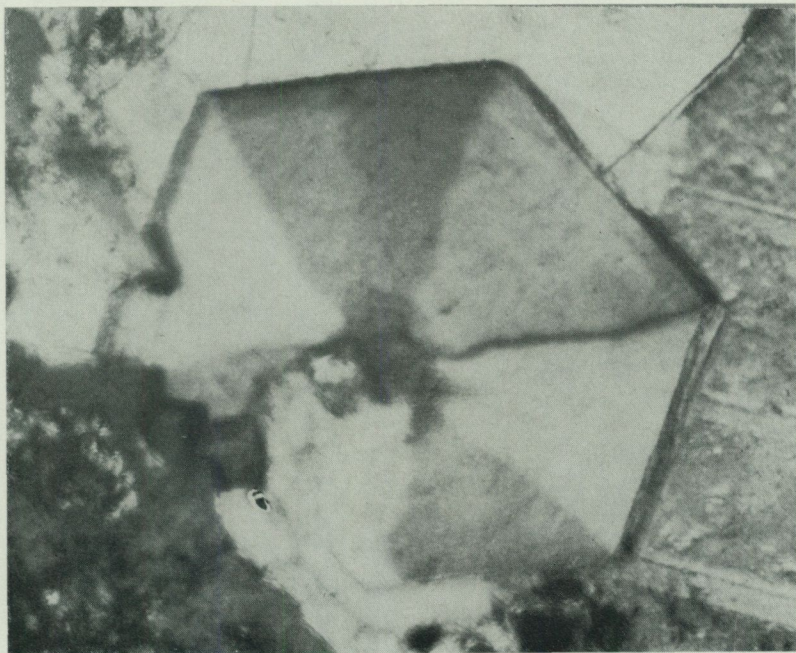


Fig. 1. Twinned apatite crystal close to Ås Jetty.

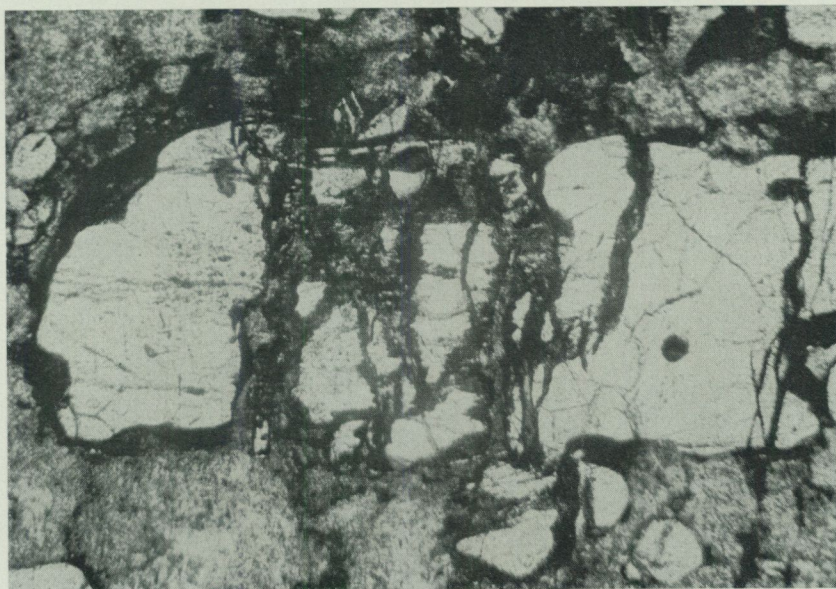


Fig. 2. Apatite crystals with haematite (translucent films) in the partings. $\times 12$. Analysis no. 18.

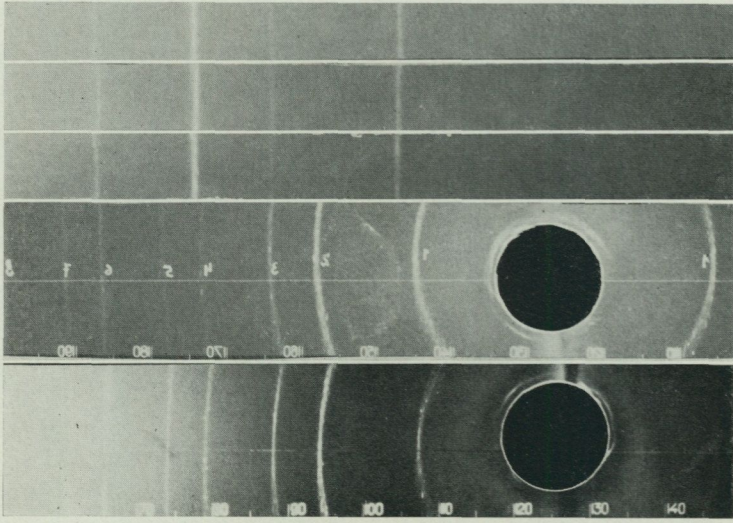


Fig. 1. X-ray spectrograms of brown, green and yellow fluorite (resp. *a*, *b*, and *c*), of normal violet fluorite of violet fluorescence (*d*) and of yellow fluorite of bright yellow fluorescence (*e*). The marginal parts of the barite vein at Pottäng.



Fig. 2. Orthoclase albite-twins (gray) in a matrix of cancrinite (white). Black crystals are aegirine-augite. $\times 30$. Analysis no. 23.



Fig. 1. Soda-orthoclase in calcitic fenite. $\times 16$. Analysis no. 19.



Fig. 1. Hydrated plagioclase beginning to recrystallize into nepheline (analysis no. 25) and perthitic orthoclase into soda-orthoclase (white). $\times 45$.



Fig. 1. Nephelinized feldspar. $\times 45$. Analysis no. 27.

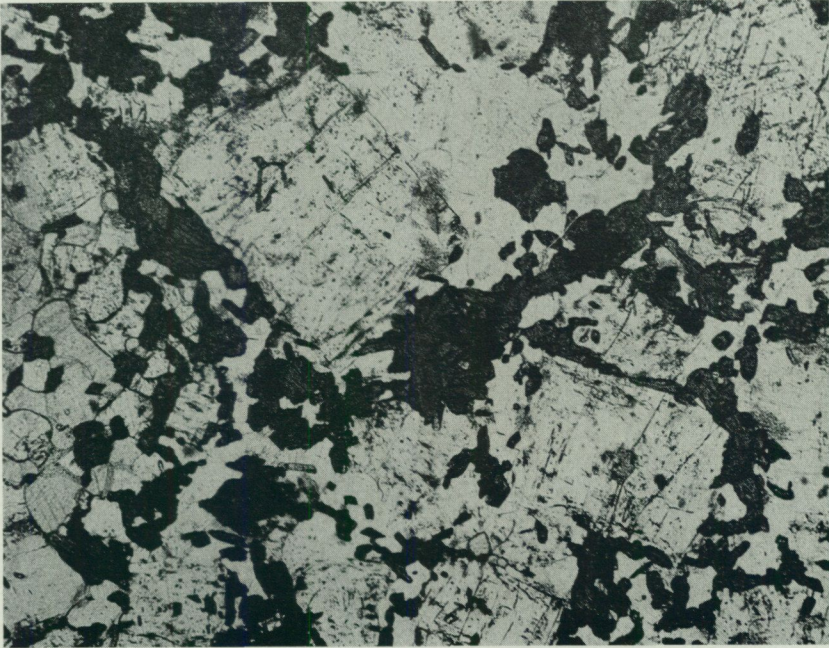


Fig. 2. Nepheline (white to light gray) in melteigite rich in cancrinite (white) and calcite (white with relief). Dark gray to black is aegirine-augite. $\times 40$. Analysis no. 29.

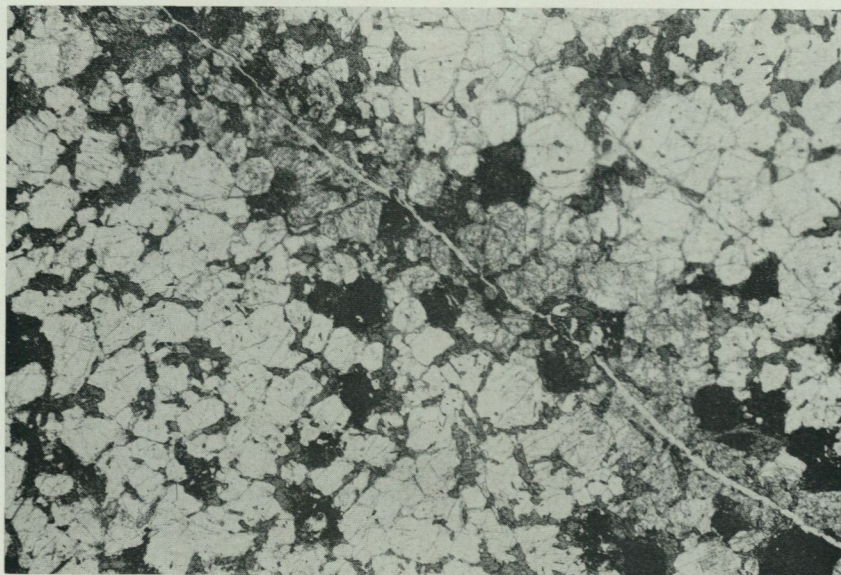


Fig. 1. Hydration of nepheline on both sides of a fissure in ijolite. $\times 10$. Analysis no. 31.

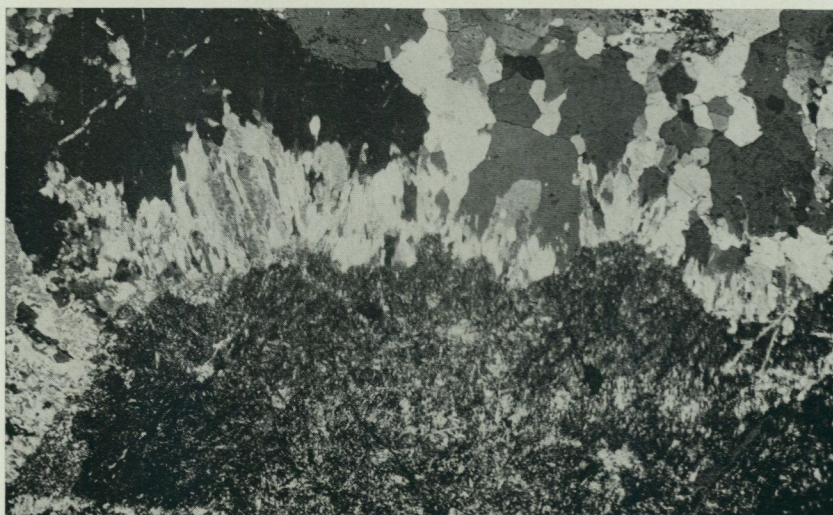


Fig. 2. Reaction rim of cancrinite between stained carbonate at the bottom of the picture and nepheline (black, gray and white) at the top. Crossed nicols. $\times 20$. Analysis of cancrinite no. 34.

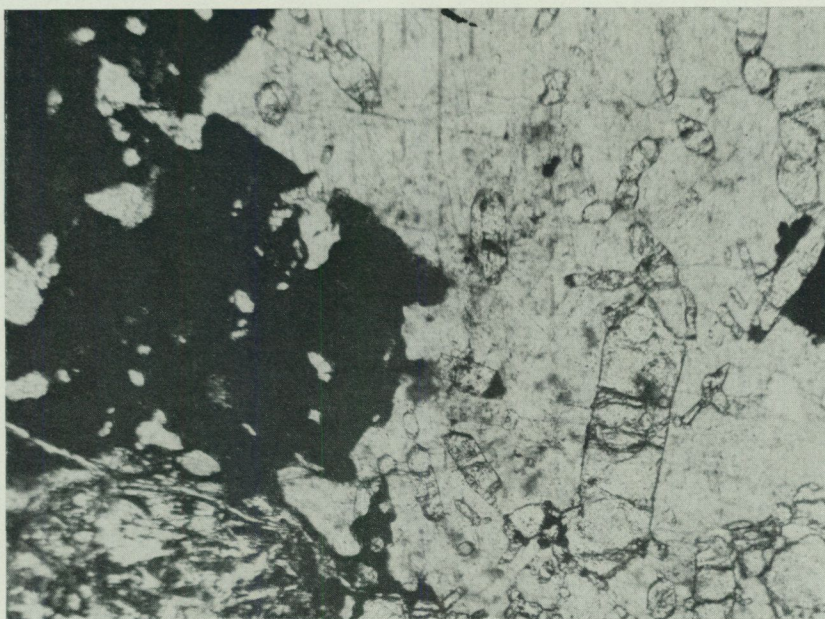


Fig. 1. Opaque, haüynized and sodalitized pseudomorph of nepheline in foyaite (black in picture). White parts of picture are soda-orthoclase with enclosed apatites. $\times 30$. Analysis of pseudomorph no. 32.

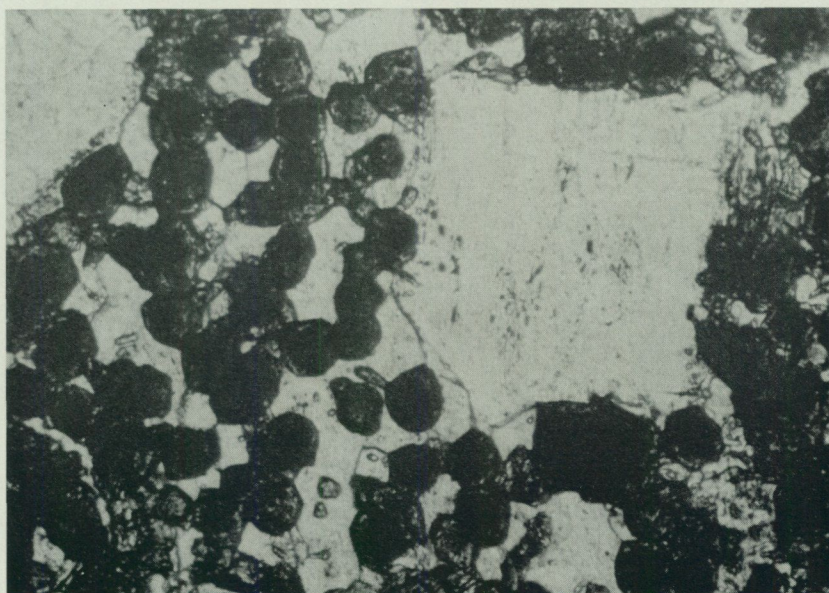


Fig. 2. Titaniferous andradite in ijolite (black to dark gray). Analysis no. 36. White is a nepheline crystal. Matrix: calcite and cancrinite. $\times 125$.



Fig. 1. Titanite (sphene) in sövite. To the left of the titanite aegirine-augite crystals. $\times 6$.
Analysis no. 36.



Fig. 1. Hydro-melanite in juvite. $\times 10$. Analysis no. 39. Within the garnet crystal are nephelines, slightly hydrated along partings.

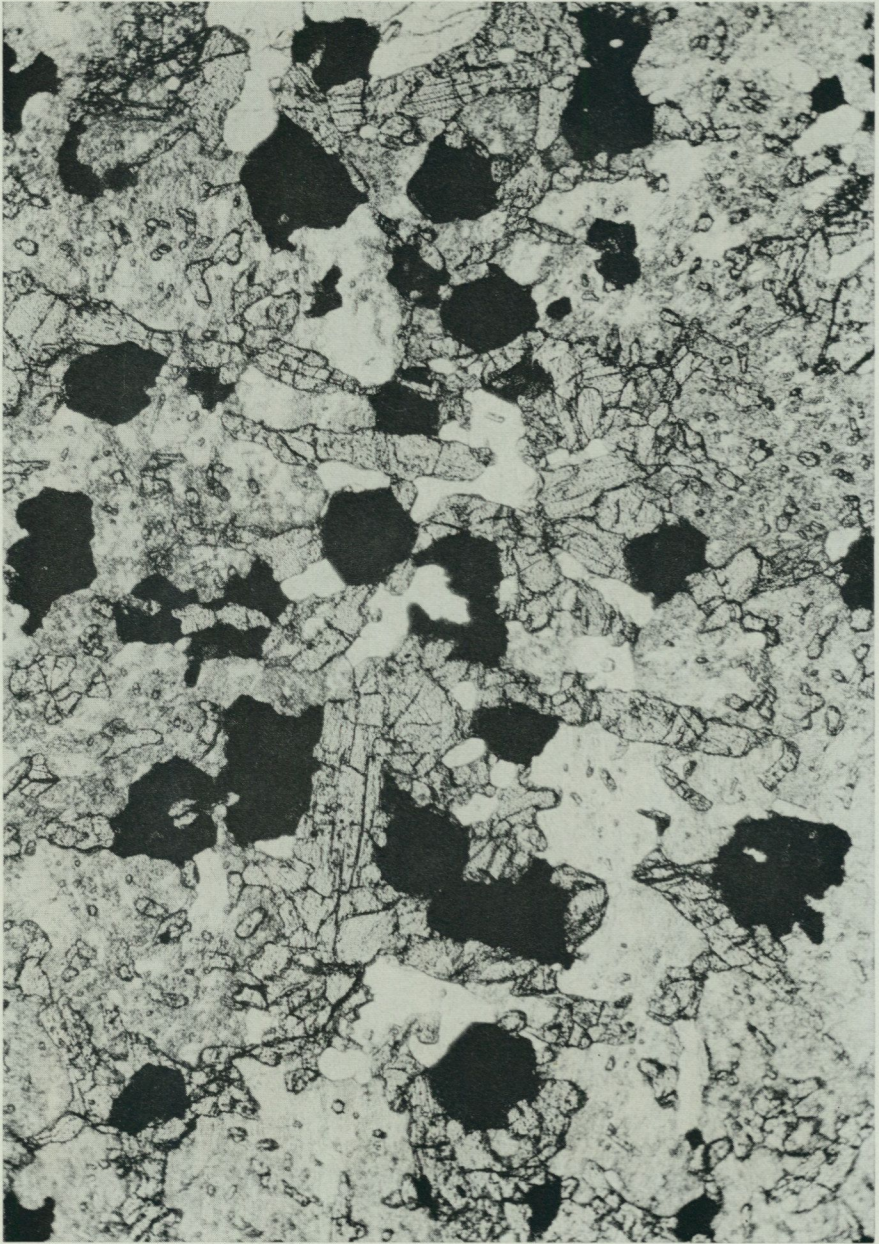


Fig. 1. Schorlomite crystals (black) in melteigite. Aegirine-augite gray with strong relief. Carbonate, light gray; nepheline, light gray or white. $\times 40$. Analysis of schorlomite no. 42.

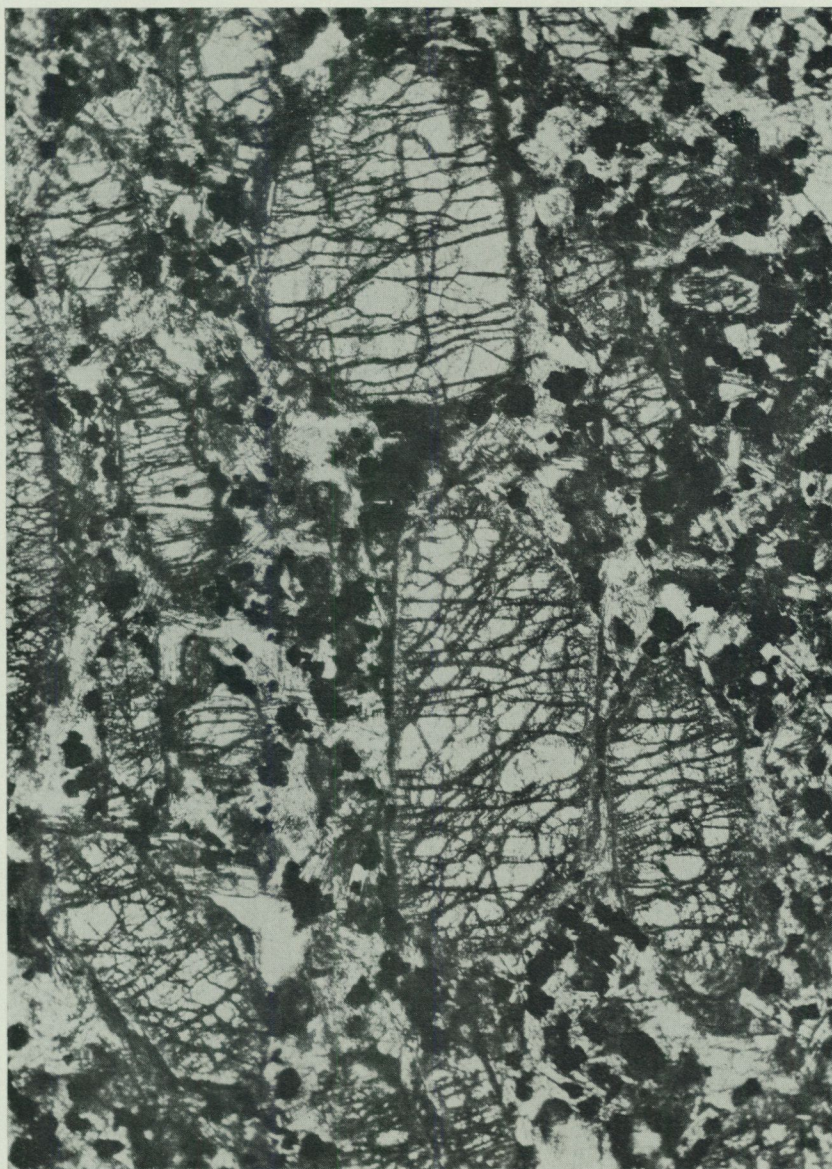


Fig. 1. Chrysolite in beforite (alnöitic). Carbonatized melilite appears gray; titanomagnetite, black. $\times 45$. Analysis of chrysolite no. 46.



Fig. 1. Twinned graphic intergrowth of chrysolite (black) and calcite (gray). $\times 42$. Analysis of chrysolite no. 47.

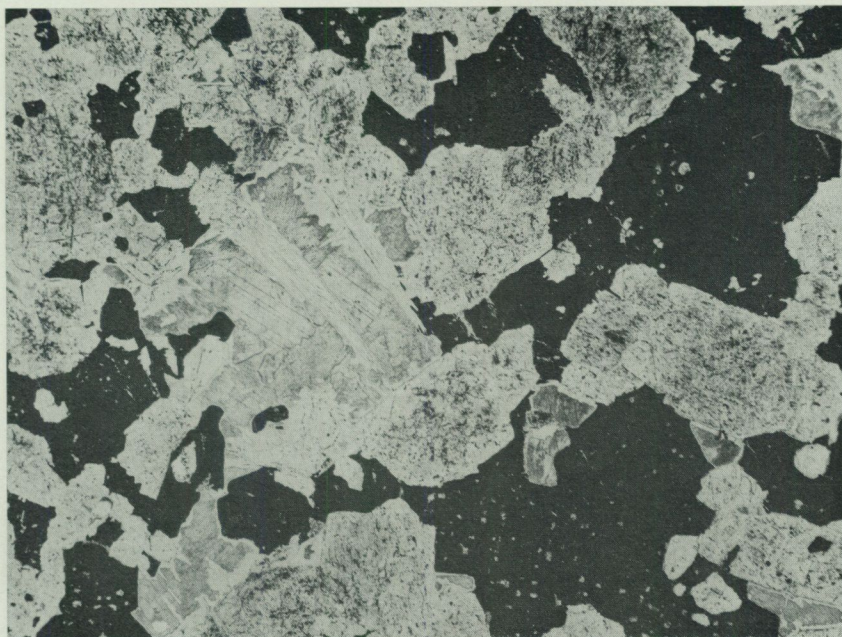


Fig. 1. Serpentine (dotted gray) in jacupirangitic peridotite rich in iron ore. Analysis of serpentine no. 48. Titaniferous magnetite, black. $\times 10$.



Fig. 2. Wollastonite in wollastonite-calcite boulder at Släda Bay. $\times 45$. Analysis of wollastonite no. 50.

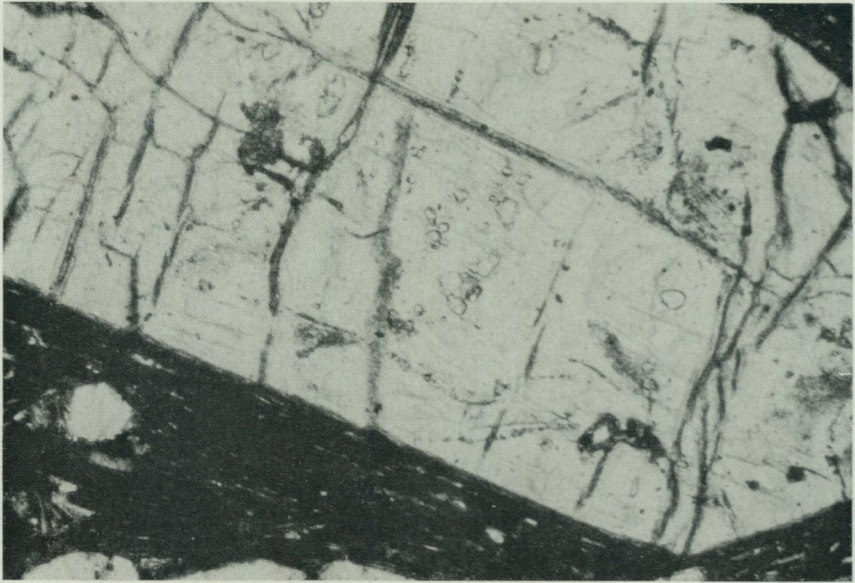


Fig. 1. Gas- and CO₂-filled vesicles in an olivine crystal. $\times 30$.

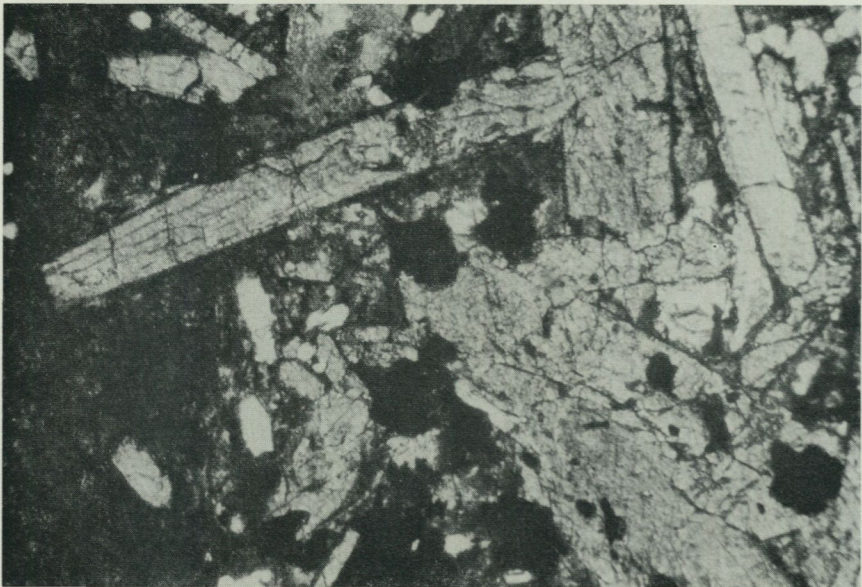


Fig. 2. Aegirine-augite in fenite south of Smedsgården. Pyroxene, gray; mica, dark gray; garnet, black. $\times 7$. Analysis of aegirine-augite no. 63.



Fig. 1. Aegirine-augite in sövite at Smedsgården. Pyroxene, mottled gray. $\times 8$. Analysis no. 53.

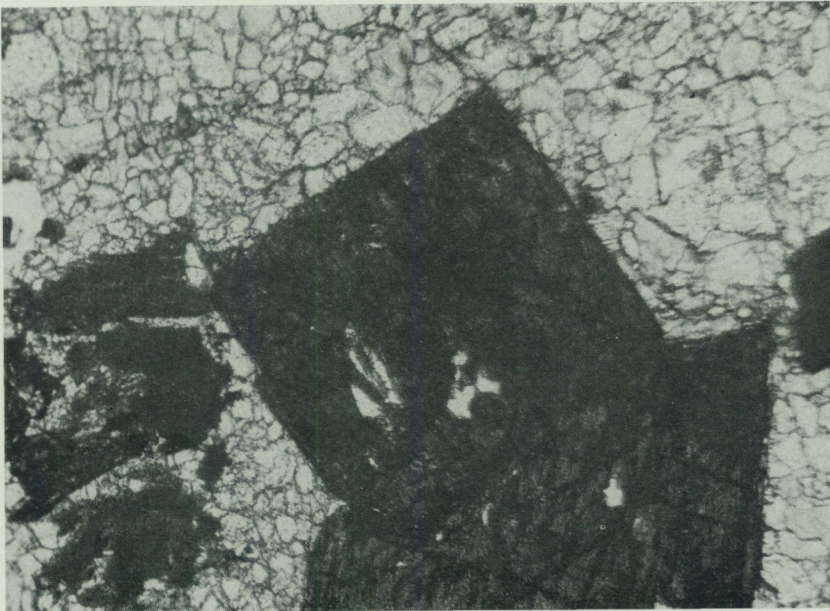


Fig. 2. Aegirine-augite in jacupirangite at Ås, rich in apatite. $\times 6$. Analysis of pyroxene no. 68.

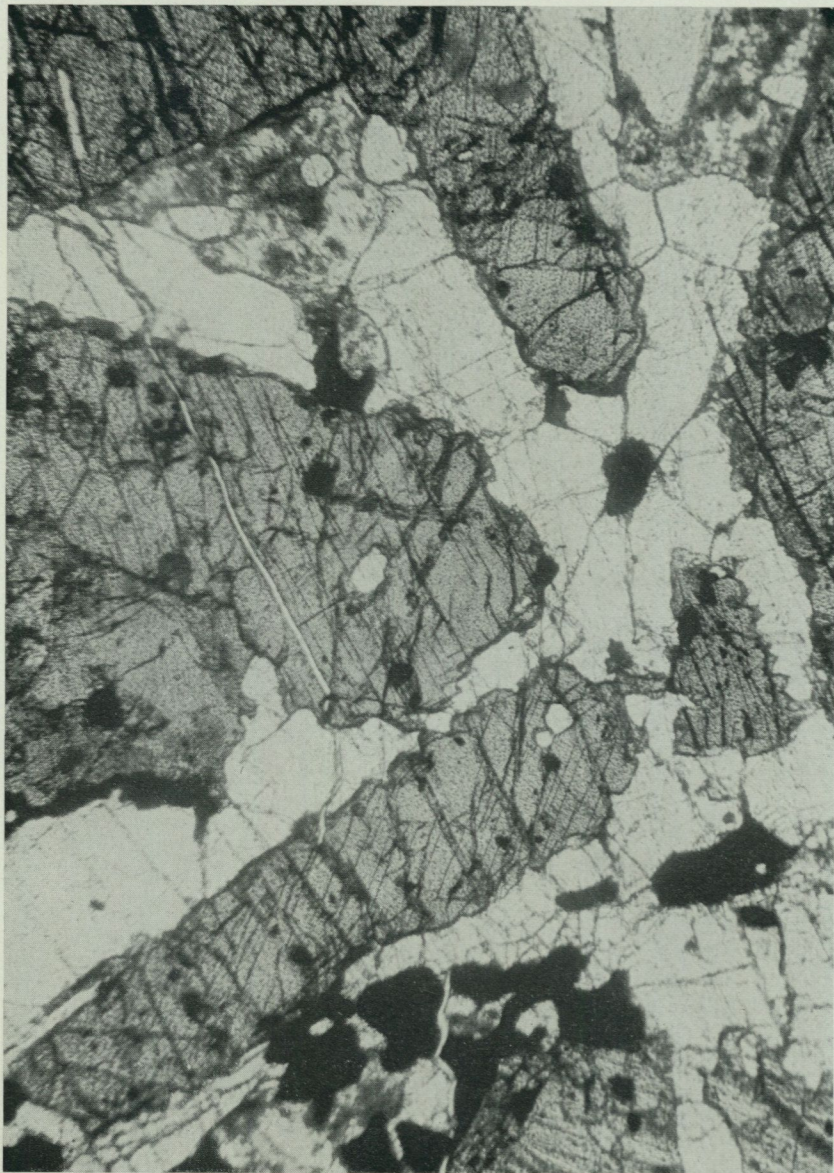


Fig. 1. Aegirine-augite, analysis no. 66, in pegmatitic malignite west of Hörningsholm. $\times 35$. Pyroxene, gray; apatite and nepheline, white. The black parts at the bottom of the picture are phlogopite. The black spot towards the pyroxene crystals are converging in a metamict radioactive dysanallyte or knopite crystal from which radiating cracks split the nepheline.

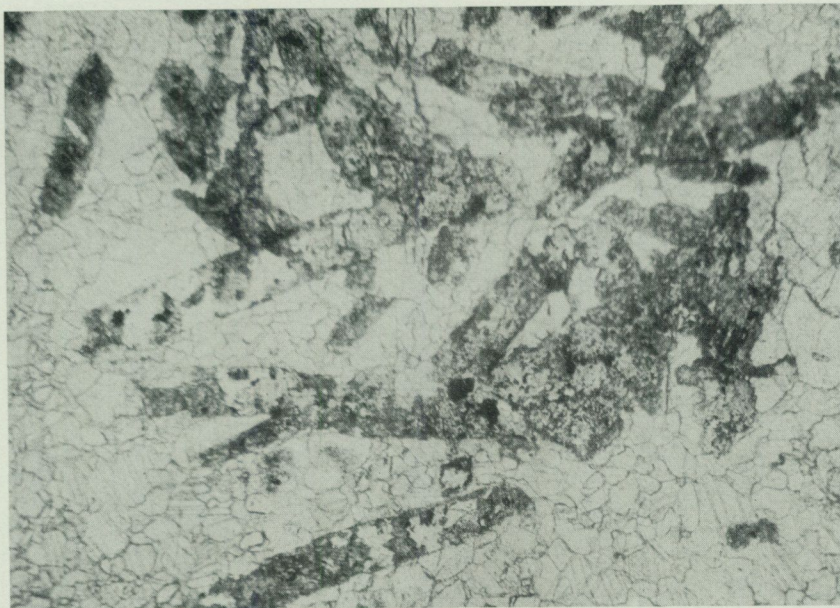


Fig. 1. Magnetite-goethite-carbonate pseudomorphs of pyroxene in sövite at Smedsgården quarry. $\times 35$.



Fig. 2. Titaniferous amphibole (gray), analysis no. 70, in vibetoides. Titaniferous magnetite appears black, and calcite white. $\times 14$.

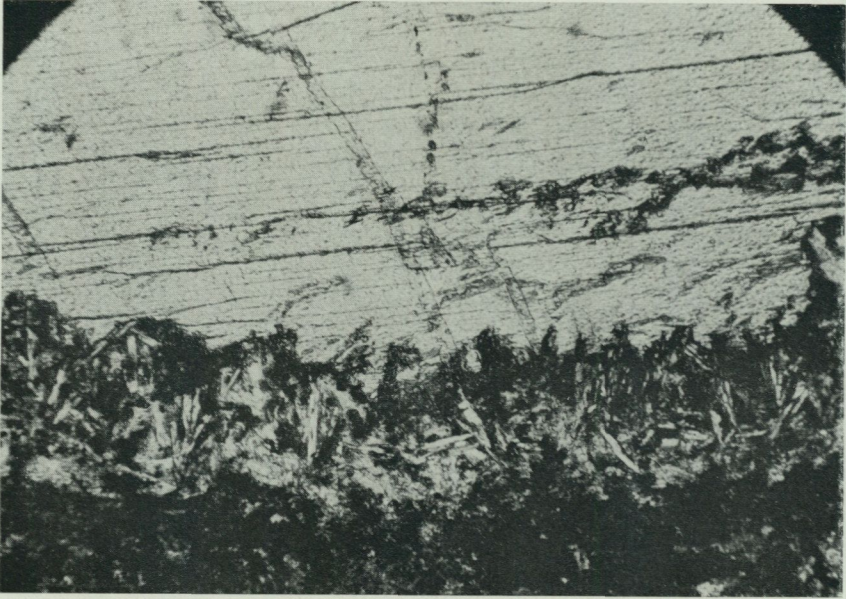


Fig. 1. Phlogopite reaction zone around titaniferous hornblende (kaersutitic). Analysis of amphibole no. 69. $\times 70$.

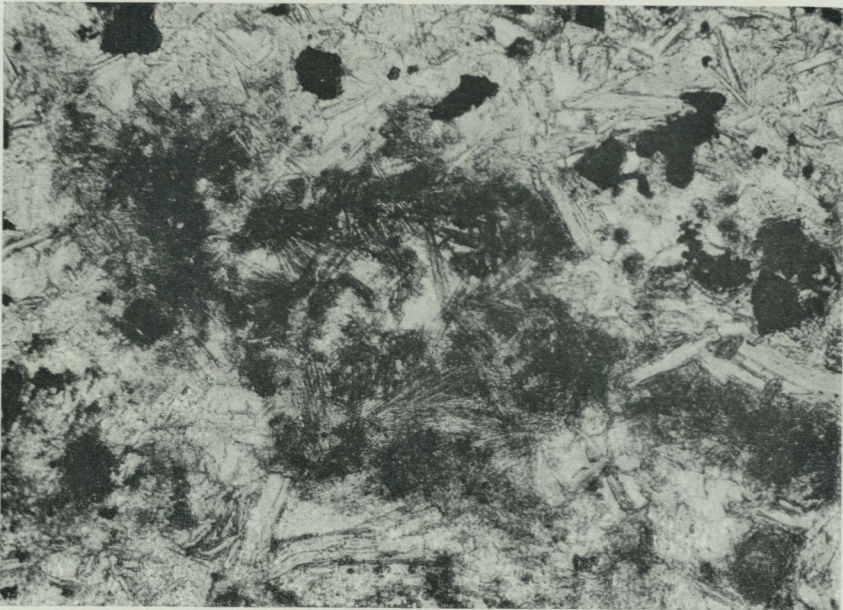


Fig. 2. Magnesianarfvedsonite (dark and light gray) (analysis no. 71) in beforsitic micaceous carbonatite dike. $\times 125$.

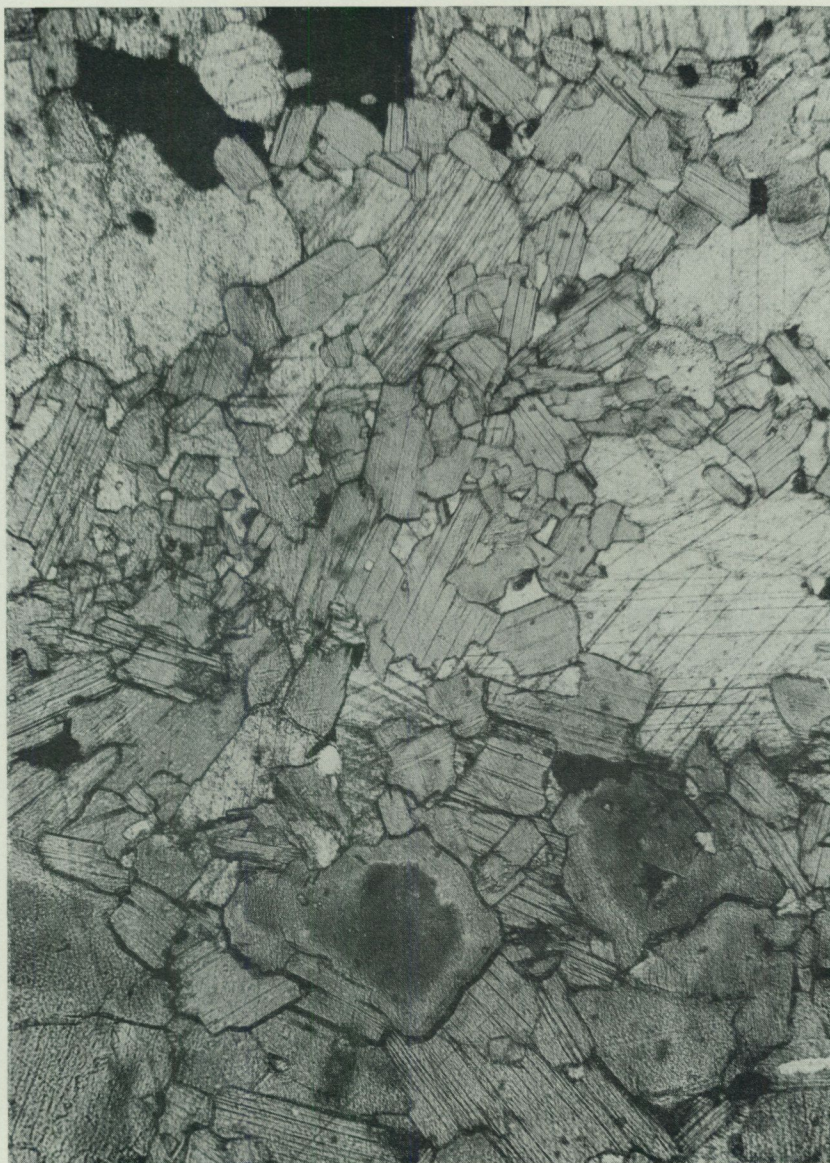


Fig. 1. Phlogopite in sövite, analysis no. 72. The picture from a detached boulder from the dike. $\times 37$.

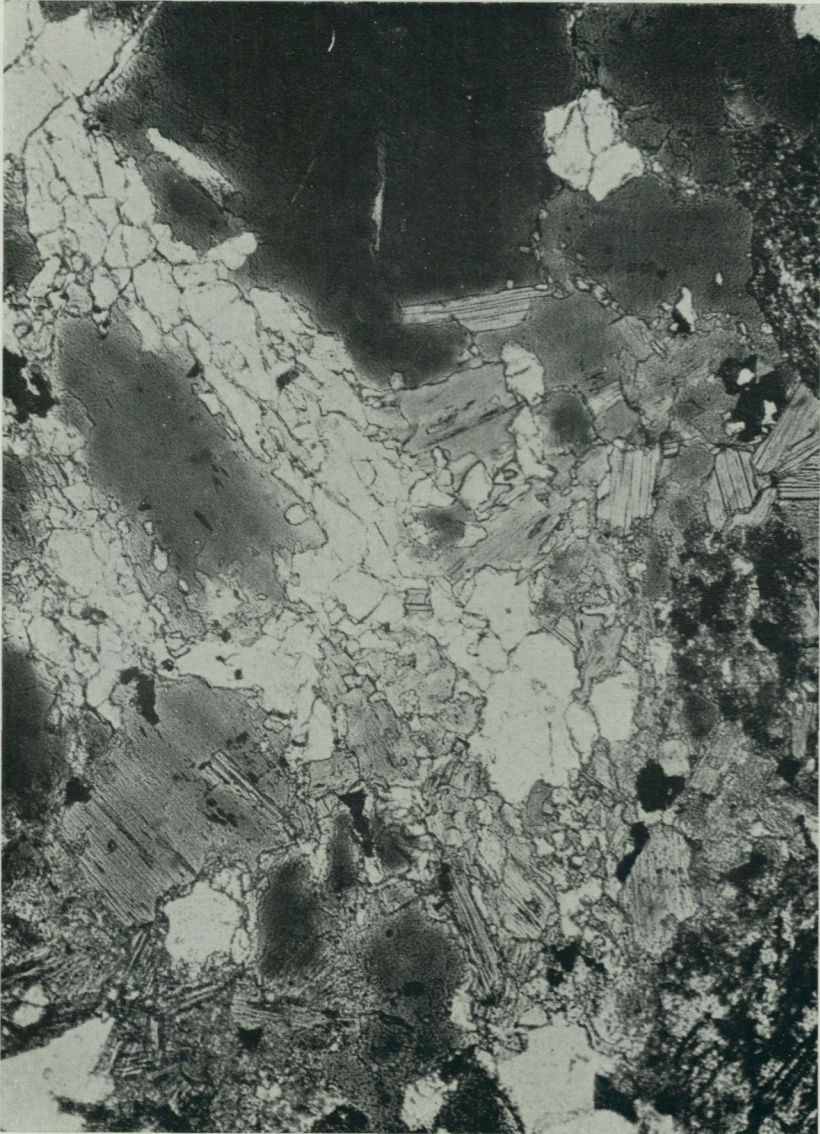


Fig. 1. Phlogopite in sövite at Smedsgården Quarry. Analysis no. 72. $\times 37$.

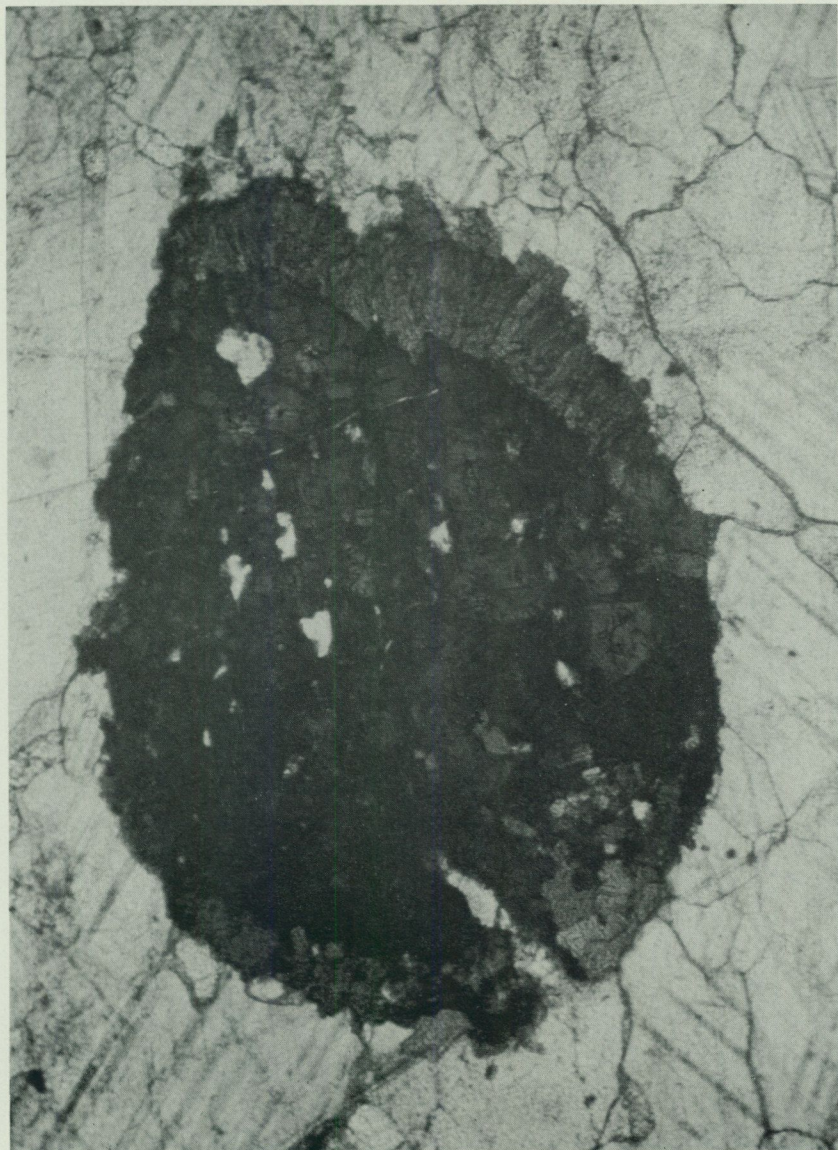


Fig. 1. Serpentine with rim of red phlogopite (analysis no. 81) in sövite at Långörsholmen. $\times 40$.

