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**Chemical and petrographical studies on the ore-bearing
rocks of Central Sweden**

by

HJ. SJÖGREN, H. E. JOHANSSON and NAIMA SAHLBOM.

(With Plates 7—8.)

In connection with the preparatory work for the excursion C₄ of the XI international geological congress in Stockholm one of us (SJÖGREN) started a somewhat extensive chemical investigation of the ore-bearing rocks at several mines of Central Sweden. Later a collaboration with the second of the authors (JOHANSSON) was arranged; for the execution of the very important analytical part of the work we have been favoured with the skilful assistance of the third collaborator (NAIMA SAHLBOM).

The principal aim of our researches is a systematic chemical and microscopical investigation of the main types of quartz-felspar-rocks with which the more important iron ores of the ore-bearing province of Central Sweden occur connected. However, several analyses and other data will be given also of certain other types of rocks with which these ores likewise are intimately associated. For the purpose abundant collections of rock specimens have been brought together during excursions to all important districts of the ore province. The results will be published in a series of papers, the first of which is now brought out dealing with the southwesternmost district or Filipstad's Bergslag.

I. Filipstad's Bergslag.

The main geological features of this district and the situation of the ore fields which our researches embrace are represented on the map in fig. 1, which is a copy from TÖRNEBOHM'S »Geologisk Öfersiktskarta öfver Mellersta Sveriges Bergslag». The central part of the district is occupied by

Fig. 1. Geological sketch-map of Filipstad's Bergslag.
Scale of 1:250000.

an area of reddish salic gneiss — the »Horrsjö-gneiss«. This gneiss is almost entirely surrounded by areas of ore-bearing granulitic rocks, which for a very great part seem to belong to types rich in soda. On the eastern side the granulite formation is bordered by a strip of dark hälleflintas, farther eastwards succeeded by slates of the Saxå-Grythytte forma-

tion; on all other sides it is cut off by younger intrusives of the Filipstad granite.

All iron ore deposits of the district are confined to the granulitic rocks. Chiefly two ore types are represented: firstly ores of decided skarn ore type and secondly manganese ores (hausmannite and braunite), partly associated with a more or less quartzeous specular hematite, of a type that is not typically developed in any other ore district in Central Sweden. Within the *Persberg ore field*, which may be taken as including all the innumerable deposits crowded over the southeastern part of the granulite area, only deposits of the skarn ore type are met with. In the northwestern part of the district including the *Taberg*, *Nordmarksberg*, *Finnmossen* and several less important mining fields ores of the same type are greatly predominating; along with the skarn ores there are, however, also a few deposits of manganese ores, as for inst. at *Jakobsberg* and *Nordmarks Kittelgruva*. The northeastern part of the district, on the contrary, contains but few and less typical skarn ore deposits; its most important deposits are the peculiar manganese ores and hematites of the *Långban mining field*; a similar deposit is also found farther southwards at *Pajsberg*.

The Persberg ore field.

Skarn-bearing soda granulites. As appears from the map published by TÖRNEBOHM,¹ the Persberg ore field is chiefly built up of granulitic rocks interstratified with a great number of more or less continuous bands of skarn rocks, which often exhibit a very intricate serpent-like winding. These skarn-bearing granulites, so far as hitherto known, seem altogether to be decided soda-granulites, essentially composed of quartz and a plagioclase felspar very near to pure albite. At many places, especially in the environs of the

¹ Geognostisk beskrifning öfver Persbergets gruffält. S. G. U. Ser. C. No 14. 1875.

main mines which are grouped together in the so called "Odalfältet", the rocks are almost purely white in colour; farther away slightly reddish as well as grayish types are more common. The granulites are for the most part rather fine-grained and often present a more or less distinctly porphyritic appearance due to the development of larger irregular crystals of quartz and plagioclase scattered in a finely granular ground-mass; such phenocrystic grains may, however, in many cases be entirely lacking. Of femic constituents the granulites as a rule only contain a pale brownish or greenish mica; owing to its irregular distribution into small nests and stripes a regular foliation is seldom distinctly marked. — Three ana-

Analysis No 1. White soda granulite. Railway cutting N of the managers residence, Odalfältet, Persberg.

Analyst: G. NYBLÖM.¹

%	Mol.	Norm:	
SiO ₂ 80.28	132.91	Q 41.94	Average felspar: Or 3.1 Ab 94.2 An 2.7
TiO ₂ 15	19	Or 1.54	
Al ₂ O ₃ 11.35	11.11	Ab 50.45	
Fe ₂ O ₃ 07	04	An 1.74	
FeO 28	40	Al ₂ O ₃ 64	Acidity: $\frac{Q}{Q+F} = 43.8\%$
MnO 01		Σ sal. 96.31	
MgO 1.18	2.95		
CaO 35	63	MgSiO ₃ 2.96	Quant. Classif.: I:3:I:5 Westphalose
Na ₂ O 5.94	9.58	FeSiO ₃ 19	
K ₂ O 26	28	FeTiO ₃ 29	
P ₂ O ₅ . . . . . tr.	—	Fe ₃ O ₄ 10	
S 02	06	Apatite . . . . . —	
H ₂ O 42		FeS ₂ 04	
		Σ fem. 3.58	
100.31		99.89	

H₂O at 105° 0.03%. Sp. g. 2.64.

¹ In the tables of analyses published in this series of papers the first column contains the original analysis and the second column the corresponding

lyses of these granulites have been executed two of which were already published in the guide for the Congress excursion C₄, prepared by SJÖGREN.

The analysed specimen N:o 1 is fairly typical of the rocks outcropping along the borders of that big skarn deposit, which includes the principal iron mines as well as the large limestone masses of the Odalfält. It is a whitish, very salic rock containing scattered phenocrysts of quartz and felspar, rarely exceeding one *mm* in size; the fine-grained groundmass is finely speckled with light-brownish and greenish specks, here and there aggregated into more compact brownish patches suggesting the presence of cordierite.

The phenocrysts of quartz occur quite sparingly. Under the microscope traces of bipyramidal outlines are occasionally seen (Pl. 7, fig. 1) but as a rule the crystals are quite irregular in shape sometimes breaking up into granular aggregates. High power reveals innumerable rutile-like microlithic inclusions; some curious vermicular inclusions of albite reminding of myrmekitic intergrowths may also be noticed. The phenocrysts of albite are slightly more abundant; they show some tendency towards a tabular development, occasionally with penetration twinning (Pl. 7, fig. 2) just as in phenocrysts of true porphyries; their external contour, however, as is the general rule in the granulitic rocks of Central Sweden, is quite irregular, so that these »phenocrysts» at the first glance might be taken for included fragments rather than crystals grown *in situ*. They usually show but few and discontinuous twinning lamellæ or are often only simple

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molecular ratios; the third column gives the »norm» of the rock according to the American method of calculation; in the fourth column are calculated first the composition of the »average felspar» of the rock, that is the percentic ratios of the three felspar-forming molecules, and secondly — as an expression for the acidity of the rock — the percentic ratio of the quartz-forming silica molecules to the total of quartz- and felspar-forming molecules; finally the place (class, order, rang and subrang) and name of the rock in the American quantitative system are indicated.

twins; the polarization is not uniform, but somewhat patchy. Symmetrical extinctions up to 15° have been measured; an individual cut $\perp c$ and showing good P-cleavages extinguishes at about 12° in the centre and slightly more at the outer parts; hence the proportion of anorthite molecule cannot exceed the ratio An_7, Ab_{93} . At the utmost border of the crystals there are often irregular seams of a distinctly later growth which exhibit a most intricate structure of about that kind to which the german term »Schachbrettalbit» pertains. This structure seems to appear only in very pure albite feldspars just as the evidently quite analogous »moire-microcline» structure described by BRÜGGER and USSING characterizes one of the purest potash feldspars ever analysed.¹ Characteristic of the albitic phenocrysts is also a dusty appearance, which under high power is seen to be due to a staining with small irregular pores. Inclusions of small mica tablets are abundant. Occasional larger grains show an irregular micrographic intergrowth with quartz, a structure not uncommon in rocks of this character.

The groundmass is chiefly composed of more coarsely crystalline aggregates and networks of quartz, biotite and subordnately a »moire-structured» albite (Pl. 7, fig. 3), with interstices of extremely fine-grained masses, the individual graines of which do not as a rule attain 0.01 mm in size. In these interstitial masses a fine intergrowth between quartz and albite might be suspected; closer inspection, however, reveals that they are essentially intricately interpenetrating grains of a more or less distinctly moire-structured albite with only subordinate and usually well defined inclusions of quartz. The mica is a light-coloured yellowish biotite. Some larger patches of a greenish bleached and partly chloritized mica may be pseudomorphous after original cordierite, judging from their macroscopical appearance, but no fresh cordierite is present.

¹ N. V. USSING, Meddelelser om Grönland XIV (1894): 12.

Analysis N:o 2. Light-reddish soda granulite. Northern Alabama shaft, Persberg. Analyst: G. NYBLÖM.

%	Mol.	Norm:	
SiO ₂ 78.25	129.55	Q 37.08	Average felspar:
TiO ₂ 19	24	Or 1.96	Or 2.9
Al ₂ O ₃ 12.27	12.01	Ab 53.76	Ab 93.9
Fe ₂ O ₃ 05	03	An 1.74	An 3.2
FeO 57	81	Al ₂ O ₃ 84	
MnO 01		Σ sal. 95.38	Acidity:
MgO 1.22	3.05		$\frac{Q}{Q+F}$ 39.2%
CaO 35	63	MgSiO ₃ 3.06	
Na ₂ O 6.33	10.21	FeSiO ₃ 68	Quant. Classif.:
K ₂ O 33	35	FeTiO ₃ 36	I:3:I:5
P ₂ O ₅ . . . . . tr.	—	Fe ₃ O ₄ 07	Westphalose
S 02	06	Apatite . . . . . —	
H ₂ O 60		FeS ₂ 04	
		Σ fem. 4.21	
100.19		99.59	

H₂O at 105° 0.08%. Sp. g. 2.64.

This rock, although almost exactly agreeing with the preceding in chemical composition, is of a considerably different aspect and structure. Macroscopically only some irregularly distributed dark greenish stripes of micaceous matter are discernible in the uniform, pale reddish, dense-looking rock mass. Under the microscope the latter dissolves into an even-grained granulitic mixture of quartz and albite with the average size of the quartz grains amounting to 0.03 à 0.05 mm. The albite grains show indistinct twinning. A few larger grains of albite and quartz rarely exceeding 0.1 à 0.2 mm in size may be observed but otherwise porphyritic structure is practically absent. The biotite is always more or less bleached and chloritized under development of abundant small crystals of anatase- and brookite-like aspect which also occur independently spread through the whole rock mass.

*Analysis N:o 3. White soda granulite. Southern side of Hög-
berget, Persberg. Analyst: NAIMA SAHLBOM.*

%	Mol.	Norm:	
SiO ₂ 79.85	132.20	Q 41.64	Average felspar:
TiO ₂ 22	28	Or 1.78	Or 3.2
Al ₂ O ₃ 12.09	11.83	Ab. 50.71	Ab. 95.3
Fe ₂ O ₃ 11	07	An. 82	An. 1.5
FeO 14	21	Al ₂ O ₃ 1.63	
MnO 01		Σ sal. 96.58	Acidity:
MgO 1.20	3.00		$\frac{Q}{Q+F}$ 43.8
CaO 23	41	MgSiO ₃ 3.01	
Na ₂ O 5.97	9.62	FeTiO ₃ 32	Quant. Classif.:
K ₂ O 30	32	Fe ₂ O ₃ 11	I : 3 : I : 5
P ₂ O ₅ 05	(12)	TiO ₂ 05	Westphalose
H ₂ O 40		Apatite 12	
		Σ fem. 3.61	
	100.57	100.19	

A sugar-like almost snow-white rock with irregular branching nests of micaceous matter drawn out in the direction of foliation. The microscopical structure (Pl. 7, fig. 4) perfectly agrees with that of the preceding type. The colour of the mica is extremely feeble. Small prisms of a very feebly coloured tourmaline are frequently present in the micaceous portions. Rounded as well as prismatic grains of a TiO₂-mineral, chiefly rutile, are fairly abundant. No apatite accounts for the P₂O₅ of the analysis but abundant small rounded grains of a somewhat zircon-like character may be of some other kind of phosphatic mineral.

The close agreement between the published analyses of these otherwise somewhat diverging varieties from different localities points to a remarkably good chemical constancy of the Persberg granulites. Their most conspicuous chemical feature is the extremely sodic character, which in combination

with the rather high acidity places the rocks in the extreme westphalose subrang of the american quantitative classification. Another feature of interest is the high percentage of magnesia as compared with the very feeble amount of iron. This relation manifests itself in the almost phlogopitic character of the mica constituent; in regard of the very low potash content of the rocks it may also be concluded that this mica must contain a notable amount of soda. — The extremely sodic character of the Persberg granulites is also illustrated in two older analyses long ago executed by the well known swedish chemist SVANBERG, which may be quoted here for the sake of completeness¹:

	I.	II.
SiO ₂	77.93	74.95
Al ₂ O ₃	13.19	11.73
Fe ₂ O ₃	59	1.60
MgO	22	1.32
CaO	1.22	50
Na ₂ O	5.93	6.49
K ₂ O	08	35
Ign.	26	21
	99.42	97.15

I. Light reddish »hällfinta«, Persberg; II. Slightly more dark-coloured variety, ibdm.

In this connection some brief petrographical notices may be given also of certain other types of rocks which are characteristic for the Persberg ore field.

Skarn-banded soda granulites. In the Persberg ore field pyroxene- and amphibole- bearing varieties of soda granulites are almost entirely confined to the immediate borders of some of the skarn deposits. In such border phases the pyroxene usually displays a marked tendency to segregate into separate more or less sharply defined bands and lumps, which in their rather capricious schlieren-like distribution and

¹ Förh. vid Skand. Naturf.-mötet i Stockh. 1842, p. 525.

usually vere sinuous course give a very instructive reproduction on a small scale of the singularities which characterize the skarn rocks of this ore field as a whole in their geological appearance and relations to the bordering soda granulites. This is especially well illustrated in the rocks exposed at the entrance of the old Tilas' adit, on the eastern side of Högberget (fig. 2). The light-coloured component of

Fig. 2. Skarn-banded soda granulite from Tilas' adit, Högberget, Persberg.
Nat. size.

these very variegated rocks is a pale-reddish or whitish albite granulite closely agreeing, in structure and composition, with the above described soda granulite from the Alabama shaft excepting the heterogeneous dilution with small grains of a greenish pyroxene instead of biotite; an unusually high amount of zircon is also noticeable. The more dark-coloured skarn-like portions consist of more or less compact finely granular masses of a greenish pyroxene impregnated with grains

of magnetite; the latter are often surrounded by seams of a yellow-brownish orthite-epidote, which also occurs in larger compact segregations. The pyroxene is of a rather vivid colour and marked pleochroism in greenish and yellowish tints with more deep-coloured borders; the angle $c:c$ was measured to 49° in the centre of a grain and seems to increase in the border seams. The rather vivid greenish colour, the high extinction angle and a marked dispersion of the bisectrices probably indicate a not inconsiderable proportion of a soda pyroxene molecule in the pyroxene of these border rocks which, so far as known is not indicated in the pyroxene of the more compact skarn deposits. — At other places as for inst. along the northern side of the Krangrufve layer very fine-grained whitish green transition rocks are met with, which consist of a more homogeneous intermixture of a feebly coloured pyroxene with albite and a small quantity of quartz.

Cordierite-bearing soda granulites. A mineral which is of very wide-spread occurrence in the Persberg soda granulites is *cordierite*. This mineral, however, does not occur as a uniformly distributed constituent but usually appears in the shape of rounded nodules and patches of brownish or greenish colour and greasy lustre. At some places, as for inst. on the western side of Bertilsviken, there is a tendency to interbanding between light-coloured layers of typical soda granulite and more dark-coloured layers rich in cordierite. The cordierite is drawn out in fine light-brownish stripes in the direction of foliation. It is perfectly fresh with marked yellowish pleochroism; it usually appears in poikilitic intergrowth with some quartz, forming larger elongated individuals, which show an approximately uniform orientation in the different stripes. Between the stripes of cordierite are whitish stripes of soda granulite as well as grayish stripes essentially containing quartz and a yellowish biotite; with the latter are associated some flakes of muscovite, a mineral otherwise very rarely met with in the Persberg rocks.

Cordierite-gedrite-rocks. At several places in the ore field but most abundantly at the old silver and copper mines on the northern side of Getön a peculiar type of rock is met with, which is essentially composed of flinty-looking cordierite crowded with radiated groups, usually about one cm in diameter, of a brown-grayish fibrous gedrite. The gedrite is of a pale coloured and feebly pleochroic, optically positive variety, probably of a moderate FeO-percentage. The cordierite is in the usual spongy intergrowth with a variable amount of quartz. Through interstitial granular masses of albite and quartz transitions to cordierite-bearing soda granulites are

<i>Analysis No 4. Quartz-cordierite-gedrite-rock. Northern side of Getön, Persberg. Analyst: NAIMA SAHLBOM.</i>		<i>Quartz-gedrite-rock. Flogberget, Dalecarlia. Analyst: R. MAUZELIUS</i>	
SiO ₂	70.24		67.18
TiO ₂	15		10
Al ₂ O ₃	9.72		10.09
Fe ₂ O ₃	83		1.87
FeO	8.98		11.96
MnO	04		15
MgO	8.97		5.11
CaO	00		50
Na ₂ O	12		1.47
K ₂ O	13		65
P ₂ O ₅	01		01
S	—		01
H ₂ O	1.23		80
	100.42		99.90

performed. The chemical composition of the rock from Getön is shown in analysis no 4. For comparison an analysis of a related rock from Flogberget in southern Dalecarlia is also reproduced.¹ Chemically the two rocks chiefly differ in the relative proportions of MgO and FeO (MgO: (MgO + FeO) = resp. 64 and 43 %). The mineral composition of the Getö rock

¹ H. E. JOHANSSON. The Flogberget iron mines. Geol. För. Förh. Bd. 32 (1910) : 414.

may be calculated at about 20% cordierite, 40% gedrite and 40% quartz, while in the more ferrous Flogberg rock the cordierite is entirely replaced by the two other minerals.

With respect to chemical composition as well as geological relations these interesting cordierite-gedrite rocks may be regarded as a special quartz type of skarn rocks; in fact such rocks have been recognized by us in all more important skarn ore districts as well as at several sulphide ore deposits of Central Sweden.

Cummingtonite skarn. Among the skarn masses of the Persberg ore field TÖRNEBOHM has distinguished between two mineralogical types, viz pyroxene skarn, partly rich in garnet (andradite), and amphibole skarn, always without admixed garnet. According to him the two types of skarn occur well separated from each other in a number of layers which were regarded as marking certain definite horizons in the stratified rock series of the ore field. While the garnet-bearing pyroxene skarn has attracted much interest, especially because of its mineralogical analogies with such lime-silicate masses usually rich in andradite which occur replacing limestone at many iron ore deposits of true contact ore districts, little attention has been bestowed on the amphibole skarn of Persberg. In this respect, however, the latter type of skarn also seems worth of some interest, as it is a fact that this amphibole skarn consists in part entirely of amphiboles free from lime, of the variety known as *cummingtonite* or *amphibole-anthophyllite*.

This type of amphibole skarn, which seems to be of rather frequent occurrence also in other skarn ore districts of Central Sweden, is macroscopically recognized by means of its characteristic greasy lustre and brown-grayish tint, which evidently is not developed in any true actinolite skarn; besides it has a more marked tendency to a long-fibrous development. It seems readily subjected to hydration and in many places is found only in a more or less advanced stage of alteration

into talc. Not improbably a good deal of the talc skarn found at several mines at Persberg may be traced back to original cummingtonite skarn. For testing the macroscopical diagnosis a fresh specimen of cummingtonite skarn has been analysed:

Analysis N:o 5. Cummingtonite skarn. SW of Storgruftan, Odalfältet, Persberg. Analyst: NAIMA SAHLBOM.

SiO ₂	50.99
TiO ₂	02
Al ₂ O ₃	3.78
Fe ₂ O ₃	85
FeO	21.70
MnO	18
MgO	18.61
CaO	00
Na ₂ O	24
K ₂ O	31
P ₂ O ₅	02
S	03
H ₂ O	<u>2.77</u>
	99.55

The analysed specimen is taken from an outcrop on the southwestern side of the open cut of Storgruftan. It is a very dense, heavy rock with scarcely perceptible fibrous fracture and the usual brown-grayish colour. Under the microscope it resolves into a fine felt of apparently colourless amphibole needles with no high birefringence and an extinction c:c amounting to about 19°. Notwithstanding the considerable amount of water shown in the analysis no talc can be seen. — Chemically this type of skarn is evidently most nearly related to the cordierite-gedrite rocks previously described and in fact usually appears in association with cordierite-bearing rocks. On the other hand a derivation from original limestone or dolomite can scarcely be assumed in the case of this kind of skarn rocks.

»Granitoid» soda granulites. Along the eastern border of the area occupied by the skarn- and ore-bearing, fine-grained soda granulites another type of soda rocks are met with which were distinguished by TÖRNEBOHM under the name of »granular curites» and later also as »granitic porphyroids». These rocks may be characterized merely as highly porphyritic phases of the Persberg soda granulites, in which the porphyritic crystals of albite and quartz have developed in very great abundance so as to become more or less predominating over the granulitic groundmass. Hence the rocks present a more coarse-grained gneissose or sometimes almost granitic appearance.

The most massive granite-looking varieties are met with in the islands Storön and Elgön in lake Yngen. A specimen of the rock from Elgön is speckled with fine-grained reddish and more coarsely granular grayish patches; in addition also some irregularly distributed femic patches chiefly containing a fibrous amphibole may be discriminated. Under the microscope the grayish patches are seen to consist of thickly aggregated crystals of albite and quartz with subordinate interstices of a granular albite-quartz-mass crowded with clusters of fibrous amphibole. The quartz grains when surrounded by groundmass frequently show good idiomorphic outlines although often distorted under development of strain shadows. The albite crystals are quantitatively predominating and reach a size of 2—3 mm. Symmetrical extinctions of up to 15° and extinctions $\perp c$ of 17°—18° point to a molecular ratio of about $An_6 Ab_{94}$ with only slight indications of any zonal structure. »Moire» structure is not developed. Abundant small rounded inclusions of quartz are invariably present. Occasional crystals exhibit a beautiful micrographic intergrowth with quartz (Pl. 7, fig. 5—6). The reddish fine-grained portions of the rock chiefly consist of granulitic aggregates of albite and quartz, the latter always subordinate in quantity and sometimes almost lacking; phenocrysts are only sparingly or not

at all developed in these portions. The amphibole is of a faintly coloured actinolitic variety (a yellowish to greenish, to pale-bluish) with a fine parting $\parallel$ 001; in other specimens of the rock it is replaced by radiated groups of an almost colourless (megascopically brownish) strongly polarizing variety, no doubt a cummingtonite, sometimes associated with cordierite. — An analysis of this type of granulite, which is not immediately connected with any ore deposits has not been executed, but its mineralogical composition points to a somewhat less acid phase of the same type of soda rocks as is represented in the ore-bearing granulites of the Persberg ore field.

The Nordmark ore field.

The iron ore deposits at Nordmarksberg occur in a large body of pyroxene-amphibole-skarn and associated crystalline dolomite which is surrounded by granulitic rocks. The granulite so far as can be judged from the few existing outcrops is a whitish to grayish easily crumbling soda granulite usually with marked porphyritic development. In its megascopical appearance it closely agrees with the whitish soda granulites at Persberg; its mica constituent however is mostly of a somewhat deeper colour and the brownish patches of cordierite so common in the Persberg rocks are not seen at Nordmarksberg. The close correspondency also in chemical composition is proved by the analysis no 6 which chiefly differs in the slightly lower acidity and the marked content of FeO.

The analysed specimen, which is taken from the underground workings, is of a somewhat darker brownish gray colour and a more compact appearance as compared with the rock in the surface outcrops but otherwise it is of the same character. It contains fairly numerous phenocrysts of bluish gray quartz up to 2 mm in size and less abundant but often larger ones of striated feldspar (Pl. 8, fig. 8). They are

Analysis No 6. Grayish soda granulite from the drive, Ormen
länge, at 260 m level. Nordmarksberg.

Analyst: NAIMA SAHLBOM.

%		Mol.	Norm:			
SiO ₂	76.62	126.85	Q	36.28	Average felspar: Or . . . . . 6.2 Ab . . . . . 90.6 An 3.2	
TiO ₂	15	19	Or	3.62		
Al ₂ O ₃	13.20	12.92	Ab	49.69		
Fe ₂ O ₃	08	05	An	1.85		
FeO	1.16	1.67	Al ₂ O ₃	2.22	Acidity: $\frac{Q}{Q+F}$ 39.7	
MnO	04		Σ sal. 93.66			
MgO	1.41	3.52	MgSiO ₃	3.54		
CaO	49	87				
Na ₂ O	5.85	9.43				
K ₂ O	61	65	FeTiO ₃	28	Quant. classif.: I:3:I:5 <i>Westphalosc</i>	
P ₂ O ₅	09		Fe ₃ O ₄	12		
H ₂ O	25		Apatite	21		
			6.04			
99.95			99.70			

embedded in a fine-grained indistinctly laminated groundmass stained with black mica stripes. Under the microscope some of the quartz crystals show fairly idiomorphic outlines although often flattened in the direction of foliation; they are thickly stained with the common hair-like inclusions. The albite crystals present the usual dusty appearance and irregular twinning and are filled up with mica tablets; symmetrical extinctions at least up to 16° and extinctions of 14° ⊥ a point to a molecular ratio about An₄ Ab₉₆. The groundmass is a fairly uniform mixtura of polyhedral grains of albite and quartz, the latter averaging 0.03 mm in size; occasionally there is a rough approximation towards a radiated micrographic intergrowth. In the larger albite grains of the groundmass moire twinning is well developed. The mica is a brownish not distinctly biaxial biotite. Very subordinately a rather markedly pleochroic gedrite-like amphibole is also

present; it appears in long slender prisms which break up into aggregated fibres with distinctly oblique extinction. The minor constituents include rutile, a scaly iron ore and occasional larger prisms as well as abundant small rounded grains of zircon and perhaps also some zircon-like phosphate; certainly the few grains of apatite that can be detected in the slide cannot account for the whole content of P_2O_5 shown by the analysis. A few clusters of zinkblende also have been recognized in the slide.

The Finnmosse ore field.

The important skarn ore deposit at Finnmosse is accompanied by only small masses of skarn rock and in part borders directly on the surrounding granulitic rocks. At this mine outcrops are almost entirely wanting, and the following statements about the ore-bearing rocks are based chiefly upon a study of the material brought up into the dumps from the various underground workings. The rocks here observed are of a general gray or whitish gray colour and for the most part of a distinctly coarser appearance as compared with the granulites at Persberg and Nordmarksberg; porphyritic development seems to be lacking. As to their mineralogical and chemical constitution chiefly two types of granulites seem to be represented which, however, are not always easily distinguished only by their megascopic characters. One is a decided soda granulite entirely devoid of any potash feldspar but partly rich in a black mica and more or less gneissose in appearance. The other is more intermediate in character and contains soda plagioclase and microcline feldspar associated in about equal proportions or even with the latter distinctly predominating. According to personal communication from Mr O. BÄCKSTRÖM of Uppsala, who has recently undertaken an underground investigation of the mine, only rocks of the first type are observed close to the ore, while microcline-bearing rocks are met with at some distance in the foot-wall.

Analysis No 7. Gray soda granulite rich in biotite. Dump¹ at Finnmossen, parish of Nordmark. Analyst: NAIMA SAHLBOM.

%	Mol.	Norm:	
SiO ₂ 76.83	127.20	Q 40.36	Average felspar:
TiO ₂ 16	20	Or 11.39	Or 22.5
Al ₂ O ₃ 12.78	12.51	Ab 36.60	Ab 76.9
Fe ₂ O ₃ 35	22	An 30	An 0.6
FeO 1.22	1.78	Al ₂ O ₃ 3.48	
MnO 06		Σ sal. 92.13	Acidity:
MgO 1.95	4.87		$\frac{Q}{Q+F}$ 45.5
CaO 06	11	MgSiO ₃ 4.89	
Na ₂ O 4.31	6.95	FeSiO ₃ 1.80	
K ₂ O 1.92	2.04	FeTiO ₃ 30	Quant. classif:
P ₂ O ₅ . . . . . tr.		Fe ₃ O ₄ 51	I:3:I:4
H ₂ O 42		Apatite. . . . . tr.	Taurose
		Σ fem. 7.50	
100.06		99.63	

The analysed rock presents a whitish granulitic ground-mass thickly lined with elongated narrow stripes of black mica which mineral also occurs concentrated into occasional broader lenticular segregations of a more coarsely tabular development. No porphyritical grains of quartz and felspar can be detected. The whitish groundmass of the rock contains a granular mixture of quartz and albitic plagioclase crowded with abundant small nests of muscovite. The quartz is in grains of a somewhat variable size the average of which may be estimated at 0.1 mm; this coarseness of grains as well as other microscopical features characterizes the rock as a petrographic transition phase between the typical granulites and the more decidedly gneissose members of the ore-bearing formation. The plagioclase shows regular twinning,

¹ Mr. BÄCKSTRÖM who has examined the specimen analysed states that it is probably derived from the crosscut at 238 m level driven in towards the ore belt from the inclined shaft in the foot-wall.

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often with rather fine lamellæ. The measured extinction angles — about 16° max. $\perp$ 010 and $14^\circ \perp \alpha$ — would seem to point to a member slightly richer in the An-molecule than is consistent with the extremely small percentage of CaO shown by the analysis; the same extinctions, however, may also be found in a more purely albitic feldspar containing a certain proportion of the Or-molecule. Certainly the deep-brownish biotite of the rock, however abundant, and the subordinately associated muscovite cannot account for the whole potash content of the analysis and there are no indications of any second kind of feldspar. The minor constituents are abundant zircon, some rutile and occasional grains of a carbonate; neither iron ores nor apatite can be detected.

Analysis N:o 8. Light-grayish intermediate granulite. Dump at Finnmossen, parish of Nordmark. Analyst: NAIMA SAHLBOM.

%	Mol.	Norm:	
SiO ₂ 73.69	122.00	Q 28.30	Average feldspar:
TiO ₂ 36	45	Or 31.14	Or 46.9
Al ₂ O ₃ 13.57	13.28	Ab 31.85	Ab 51.0
Fe ₂ O ₃ 42	26	An 1.40	An 2.1
FeO 62	89	Al ₂ O ₃ 1.18	
MnO 02		Σ sal. 93.87	Acidity:
MgO 1.70	4.25		$\frac{Q}{Q+F}$ 30.5
CaO 36	64	MgSiO ₃ 4.27	
Na ₂ O 3.75	6.05	FeSiO ₃ 23	
K ₂ O 5.25	5.57	FeTiO ₃ 68	Quant. classif.:
P ₂ O ₅ 06	14	Fe ₃ O ₄ 61	I:4:I:3
H ₂ O 32		Ap 14	Liparose
		Σ fem. 5.93	
	100.12	99.80	

The external appearance of this fairly uniform even-grained light-grayish rock would suggest a common soda granulite. At microscopical examination it resolves into a mixture

of quartz, perthitic microcline, albitic plagioclase and chestnut-coloured mica. The size of the quartz grains is between 0.05 and 0.12 *mm* with occasional vein-like segregations chiefly containing a more coarsely granular quartz crowded with small inclusions of microcline. The microcline feldspar is in distinct excess over the plagioclase. It has a very fine cross-hair-twinning with rolling extinction and includes not abundant although fairly broad perthitic lamellæ; the whole appearance suggests an average proportion of the Ab-molecule of about 20%. The plagioclase is not frequently well twinned; sections cut $\perp a$ extinguish at 11° – 12° ; the maximal symmetrical extinction measured amounts to 16° . The biotite is of a more distinctly biaxial type than is the case in the rocks previously described and frequently includes prisms of rutile. Some flakes of muscovite are also present. Iron ore and apatite are lacking but grains of zircon or other zircon-like minerals are not rare.

So far as hitherto known, a similar intermediate sodiopotassic composition is not frequently met with in the typical granulitic rocks of Central Sweden while it seems to be rather characteristic of the more coarse-grained red salic gneisses of the ore-bearing formation. It should also be noted that in most alkaline granites of a similar composition the soda feldspar is almost entirely crystallized in the shape of a microperthite very rich in albite, while in the Finnmosse granulite it chiefly occurs in separate grains of albite associated with a microperthite rather poor in soda feldspar.

The Taberg ore field.

At Taberg no outcrops are found in the neighbourhood of the mines. The ore deposits as represented on the official map occur associated with limestone and considerable skarn rock in lenticular deposits interstratified with granulitic rocks. The granulites as seen in the dumps are whitish to grayish in colour and moderately fine to rather coarse in grain; por-

phyritic structure is not very conspicuous, or it is usually altogether lacking. The same association between typical soda granulites and microcline-bearing rocks of an intermediate or fairly potassic character, which has been described from Finn-mossen, also exists at Taberg. Rocks of both types frequently occur interbanded with narrow branching layers of skarn containing a black amphibole as well as some pyroxene and epidote. As the granulites in their essential chemical features evidently closely correspond with those at Finn-mossen, no analyses have been executed, but some brief microscopical observations of the types may be given.

Whitish amphibole-bearing soda granulites. This type of granulite consists of a saccharoid distinctly foliated mixture of quartz and albite with scattered blackish streaks and patches rich in hornblende. The mineral composition may be estimated at about 55 per cent of albite, 40 per cent of quartz and some few per cent of amphibole, titanite, zircon and calcite. The average size of the quartz grains amounts to 0.06 mm. The albite is not frequently twinned and then with few and broad lamellæ; symmetrical extinctions up to $-16\frac{1}{2}^{\circ}$ have been measured. The amphibole for the most part is of a rather pale-coloured variety with strong birefringence. Titanite, which mineral generally seems to be entirely lacking in the usual mica-bearing granulites of this ore district, is rather abundant in the present type forming rows of rounded grains. Grains of calcite occur scattered throughout the rock.

Gray gneissose binary soda granulites. Rather coarse-grained well foliated rocks of decidedly gneissose appearance, containing scattered not very conspicuous larger lath-shaped crystals of albite as well as rounded grains of quartz. The quartz grains of the »groundmass» measure about 0.15 mm as an average. The albite possesses excellent twinning but otherwise agrees in its optical properties with the albite of the preceding type. The micaceous laminae contain considerable muscovite associated

with a greenish bleached biotite rich in the usual needles of rutile. Rutile and zircon are the only minor constituents observed.

Light grayish microcline-albite-granulites. These rocks, as also is the case at Finnmossen, appear hardly distinguishable from the associated soda granulites only by megascopical characters. The slides examined show a granulitic mixture of quartz, perthitic microcline with fine cross-hair structure and a not very regularly twinned albite. The size of the quartz grains is about 0.08 mm. The microcline, on the whole, appears to be in some excess over the albite. The perthitically included soda felspar is largely segregated to the periphery of the microcline grains forming broad wedge-like patches.

The extinction angles of the plagioclase — up to 17° — 18° $\perp$ 010 and 14° — 15° $\perp$ α — indicate a fairly pure albitic member. Small flakes of an olive-coloured mica occur irregularly distributed through the rock. It is accompanied by abundant grains of epidote with frequent orthitic kernels as well as by small grains of zircon, a strongly pleochroic titanite and a little fluor spar. Curiously enough the feldspar constituents of the rock display a marked tendency to segregate into narrow veins, which often run quite across the general foliation of the rock but otherwise make no impression of secondary formations.

The Jakobsberg ore field.

The hausmannite deposits at Jakobsberg and some adjacent mines occur in a zone of crystalline limestones interstratified with reddish granulites. The granulite is best exposed at Backgrufvan, a small mine situated some hundred meters southwards of the Jakobsberg mine. The rock is reddish gray in colour with scattered grains of opalescent quartz standing out from the comparatively coarsely crystalline groundmass. Very characteristic of the rock is the tendency of its mica to segregate into branching nests and small veins

which often run quite obliquely to the general direction of foliation. The next analysis N:o 9 illustrates the decidedly potassic character of this kind of granulite.

Analysis N:o 9. Reddish potash granulite. Backgrufvan at Jakobsberg, parish of Nordmark. Analyst: NAIMA SAHLBOM.

%	Mol.	Norm:	
SiO ₂ 70.82	117.25	Q 21.91	Average felspar:
TiO ₂ 24	30	Or 52.14	Or 71.7
Al ₂ O ₃ 13.21	12.93	Ab 16.05	Ab 21.4
Fe ₂ O ₃ 1.04	65	An 63	An 0.9
FeO 2.08	} 3.04	Al ₂ O ₃ 33	
MnO 11		Σ sal. 91.06	Acidity:
MgO 1.66	4.15		$\frac{Q}{Q+F}$ 21.4
CaO 14	25	MgSiO ₃ 4.17	
Na ₂ O 1.89	3.04	FeSiO ₃ 2.77	
K ₂ O 8.79	9.33	FeTiO ₃ 46	Quant. classif.:
P ₂ O ₅ 01	(02)	Fe ₃ O ₄ 1.51	I:4:I:2
H ₂ O 43		Apatite 02	Omeose
		Σ fem. 8.93	
100.42		99.99	

Notwithstanding its comparatively low acidity this rock contains phenocrysts only of quartz, of a size between 0.25 and 1 mm. They frequently have fairly idiomorphic outlines and are stained with the usual hair-like inclusions. In the groundmass microcline is the predominating constituent. It is in grains of an average size of about 0.06 mm which show a fine cross-twinning and contain distinct, although not abundant perthitic spindles. At the junction of the individual grains of microcline small areas of a cloudy felspar which evidently is a plagioclase may be observed. A distinct lamination results from an alternation between purely feldspathic stripes and others containing a granular mixture of felspar and quartz in various proportions. In addition there are some

broader elongated stripes, evidently of a somewhat later growth, which consist essentially of a more coarsely crystalline quartz with subordinate small grains of microcline. The quartz of such coarse-grained segregations never contains the hair-like inclusions so characteristic for the proper phenocrysts. The abundant mica is a deeply olive-coloured biotite; in the larger nests of mica also flakes of muscovite often occur. Some more salic stripes of the rock are impregnated with small grains of hematite but otherwise the iron which it contains is entirely absorbed by the mica. Occasional rather large crystals of zircon and a few small grains of apatite may be noticed.

The Långban ore field.

Potash granulites on the southwestern side of the ore-bearing dolomite stock. The large irregular body of dolomite marble within which the ore deposits of the Långban mining field are included borders along its southwestern side on a belt of granulitic rocks which are chemically characterized by a highly potassic composition. These granulites are light coloured, usually in reddish tints, and rather fine-grained with a more or less conspicuously porphyritic appearance due to the development of larger quartz grains. They are sometimes traversed by networks of green silicates, chiefly pyroxene; at other places veins and irregular segregations of a dark coloured quartz heavily stained with hematite grains are of frequent occurrence. Two specimens of this kind of granulite have been analysed.

The analysed rock N:o 10 contains abundant lenticular grains and elongated stripes of opalescent quartz measuring up to 2 mm in breadth. The reddish or reddish gray groundmass shows an indistinct very fine banding which becomes well conspicuous on weathered surface. Microscopically this rock is of interest in showing a well marked sequence of crystallization. Of the megascopic quartz grains only a few small ones present the characters of crystals of early growth. The other are merely ill-defined

Analysis N:o 10. Red potash granulite. Lappåsen, on the southeastern side of Hyttsjön, Långban.

Analyst: NAIMA SAHLBOM.

%	Mol.	Norm:	
SiO ₃ 77.59	128.46	Q 41.09	Average feldspar:
TiO ₂ 17	21	Or 52.32	Or 94.6
Al ₂ O ₃ 11.61	11.36	Ab 2.29	Ab 4.4
Fe ₂ O ₃ 92	58	An + Ce 57	An + Ce 1.0
FeO 24	35	Al ₂ O ₃ 1.39	
MnO 01		Σ sal. 97.66	Acidity:
MgO 50	1.25		$\frac{Q}{Q+F}$ 42.7
CaO 10	20	MgSiO ₃ 1.26	
BaO 03		FeTiO ₃ 26	
Na ₂ O 27	44	Fe ₂ O ₃ 92	Quant. classif:
K ₂ O 8.82	9.36	TiO ₂ 03	I:3:I:1
P ₂ O ₅ . . . . . tr.	—	FeS ₂ 21	No name.
S 11	34	Apatite . . . . . tr.	
H ₂ O 11		Σ fem. 2.68	
100.48		100.34	

coarsely crystalline segregations in the groundmass, which make the impression of latest products of crystallization, just as the quartz masses in the centre of a zoned pegmatite dike (Pl. 8, fig. 11). No phenocrysts of feldspar are observable; they are substituted by abundant areas of somewhat coarsely crystalline aggregates of microcline. Most grains of microcline are twinned only after the albite law with few and broad, wedge-like lamellæ; not a trace of perthitic inclusions can be detected. The stripes of groundmass which are grown immediately upon the phenocrysts of quartz and phenocrystic aggregates of microcline, consist of a very finely granular mixture of microcline and quartz, the grains of the latter often falling below 0.01 mm; outwards from these centres the groundmass rapidly grows more coarse-grained and finally

grades into the above mentioned coarsely granular segregations. Of other constituents the rock contains innumerable small tables of hematite, irregular flakes of a greenish biotite, rather abundant grains of zircon, traces of orthite and occasional flakes of muscovite. The megascopical finely banded appearance is partly due to the distribution of the femic constituents into narrow sheets but chiefly to a general parallel arrangement of alternating coarse-grained and fine-grained portions of groundmass.

Analysis N:o 11. Light reddish potash granulite. Railway cutting 1.5 km S of Långbanshyttan station.

Analyst: NAIMA SAHLBOM.

%	Mol.	Norm:	
SiO ₂ 74.41	123.20	Q 37.44	Average felspar:
TiO ₂ 16	20	Or 47.28	Or 83.9
Al ₂ O ₃ 12.61	12.34	Ab 8.06	Ab 15.2
Fe ₂ O ₃ 2.86	1.79	An 50	An 0.9
FeO 18	26	Al ₂ O ₃ 2.22	
MnO 01		Σ sal. 95.50	Acidity:
MgO 36	90		$\frac{Q}{Q+F}$ 40.1
CaO 10	18	MgSiO ₃ 90	
Na ₂ O 95	1.53	FeTiO ₃ 30	Quant. classif.:
K ₂ O 7.97	8.46	Fe ₃ O ₄ 15	I:3:I:2
P ₂ O ₅ . . . . . tr.	—	Fe ₂ O ₃ 2.76	Magdeburgose
H ₂ O 41		Apatite . . . . . —	
		Σ fem. 4.11	
100.02		99.61	

This rock looks like a cataclastically deformed phase of the preceding type, with a sericitic lustre developed on the cleavage planes. It contains a few larger crystals of quartz and also some of microcline, more or less mashed and drawn out in the direction of foliation. In the groundmass thin stripes

of almost crypto-crystalline aggregates of microcline with undulous, occasionally somewhat radiating extinction alternate with other stripes consisting of a mixture of microcline and quartz of a more variable coarseness. Coarsely granular segregations of quartz with subordinate microcline, of the same character as described in the rock from Lappåsen, also occur in the present type; they show but faint indications of the mashing and rolling otherwise so strongly marked in the rock. The microcline possesses an indistinct irregular cross-twinning; notwithstanding the marked percentage of soda shown by the analysis neither perthitic inclusions nor grains of independent plagioclase can be detected. Muscovite and hematite both occur abundantly distributed in very fine stripes.

Micaceous and aluminous rocks associated with the ore-bearing dolomite. The immediate contact between the potash-granulites just described and the dolomite is not observed here. According to an observation on the shore of Hyttsjön the usual salic granulite when approaching to the contact appears to be replaced by more dark-coloured micaceous rocks poor in quartz but with irregular quartzey layers and segregations containing an altered cordierite as well as spongy patches of andalusite. Similar rocks are frequently met with in the mines intercalated in the ore-bearing dolomite. In composition they constitute a peculiar series varying from quartz-free biotite- and biotite-microcline rocks of an almost minette-like character to rather quartzose varieties usually rich in aluminous silicates. A good deal of what is called »skölar» in the mine is evidently nothing but micaceous rocks of this series in a more or less advanced stage of mechanical and chemical destruction. In fact the dolomite seems to be very intricately interpenetrated by a network of such rocks. In some cases it has been suggested from their geological mode of occurrence that they may once have been intruded into the dolomite in the fashion of true dike rocks which have later been destroyed by dynamic forces and fre-

quently torn into pieces included by the more plastic dolomite. These »sköls» have also been found to guide the ore deposits so that the deposits generally group around the »sköls».

A series of analyses of these rocks were prepared for the Congress Guide of SJÖGREN and may be reproduced und discussed here together with some brief petrographical descriptions.

The biggest of these inclusions of silicate rocks in the dolomite is the »horse» of a dark, micaceous rock, which forms the footwall of the Norrbotten deposit and separates the same from the Storgruvve deposit. From the Båt-drive at 110 *m* level, which is the highest level, where it has been observed, it increases downward in size; at the Råms drive at 130 *m* level it is about 20 *m* and at the Botten drive at 150 *m* its width is more than 30 *m*. Some of the petrographical

Analysis N:o 12. Dark grayish andalusite- and cordierite-bearing mica-microcline-rock, Lesjöfors drive, at 150 m level, Långban. Analyst: G. NYBLÖM.

%	Mol.	Norm:
SiO ₂ 66.67	110.38	SiO ₂ 23.91
TiO ₂ 23	29	Or 40.99
Al ₂ O ₃ 18.01	17.62	Ab 7.14
Fe ₂ O ₃ 84	53	An 92
FeO 1.22	1.78	Al ₂ O ₃ 8.79
MnO 06		Σ sal. 86.75
MgO 3.54	8.85	MgSiO ₃ 8.89
CaO 21	38	FeSiO ₃ 1.15
Na ₂ O 84	1.35	FeTiO ₃ 44
K ₂ O 6.91	7.34	Fe ₃ O ₄ 1.22
P ₂ O ₅ 02	(05)	FeS ₂ 11
S 06	19	Apatite 05
H ₂ O 1.27		Σ fem 11.86
99.88		98.61

H₂O at 105° 0.12 %.

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variations shown in this horse are represented by the two
following analyses.

The rock N:o 12 presents a dark grayish compact mass with a
greenish and violet-brownish tint and a greasy lustre which at
once suggests a considerable proportion of aluminous silicates.
The main portion consists of a fairly coarse-grained mixture of a
slightly perthitic microcline and a chestnut-coloured mica. No
plagioclase can be seen but some quartz occurs intermixed in
small grains and rounded inclusions. Occasional flakes and
skeleton crystals of muscovite may also be noticed. This
groundmass includes abundant but small areas of entirely
altered cordierite as well as larger and more sharply segre-
gated areas of a fresh andalusite which attain a size of up
to 2 mm. The andalusite is in skeleton-like intergrowth with
much quartz and usually surrounded by borders of a coarsely
crystalline mixture of quartz and biotite. A few grains of
orthite, zircon and rutile complete the list of constituents.

*Analysis N:o 13. Micaceous contact facies of the »horse». Le-
sjöfors drive, at 150 m level, Långban. Analyst: G. NYBLÖM.*

%	Mol.	Norm:	
SiO ₂ 52.80	87.42	Or 39.80	Average felspar: Or : . . . . . 68.2 Ab . . . . . 18.4 An 18.4
TiO ₂ 42	53	Ab 10.94	
Al ₂ O ₃ 17.59	17.21	An 11.58	
Fe ₂ O ₃ 1.46	91	Al ₂ O ₃ 3.94	
FeO 2.27	3.15	Σ sal. 66.26	Quant. classif. II:5:II:2 Ciminoze.
MnO 35	49		
MgO 12.18	30.45	(MgFe) ₂ SiO ₄ . . 12.63	
CuO 2.39	4.27	(MgFe)SiO ₃ . . 15.55	
Na ₂ O 1.29	2.08	FeTiO ₃ 80	
K ₂ O 6.71	7.12	Fe ₃ O ₄ 2.12	
P ₂ O ₅ 05	(12)	FeS ₂ 04	
S 02	06	Apatite 12	
H ₂ O 2.84		Σ fem. 31.26	
100.37		97.52	

H₂O at 105° 0.28 %.

The chemical and mineralogical composition of the rock is essentially that of a common clay hornfels. At the contact against the dolomite as well as against the ore the horse, however, acquires a more micaceous, lamprophyric character and at the 130 *m* level and, moreover, at several other places it is bounded on the E by a thick sköl of essentially micaceous composition. An analysis (N:o 13) shows the composition of this contact facies of the horse.

In its chemical composition this rock may be well compared with certain special lamprophyric phases of syenitic rocks, as for instance the durbachite and the selagite, although still high in alumina and somewhat low in CaO. Unfortunately the original material for the analysis has been lost so that no further petrographical description can be given.

Analysis N:o 14. Dark gray cordierite-bearing mica-felspar-rock. Bjelke's shaft, at 150 m level, Långban.

Analyst: G. NYBLÖM.

	%	Mol.	Norm:	
SiO ₂	56.12	92.91	Q	3.63
TiO ₂	30	38	Or	46.45
Al ₂ O ₃	20.20	19.76	Ab	15.89
Fe ₂ O ₃	3.05	1.91	An	5.10
FeO	2.47	3.57	Al ₂ O ₃	6.75
MnO	10		Σ sal.	77.82
MgO	5.61	14.03	MgSiO ₃	14.08
CaO	1.05	1.88	FeSiO ₃	1.67
Na ₂ O	1.87	3.02	FeTiO ₃	1.57
K ₂ O	7.83	8.31	Fe ₃ O ₄	4.42
P ₂ O ₅	02	(05)	FeS ₂	04
S	02	06	Apatite	05
H ₂ O	1.35		Σ fem.	20.83
	99.99			98.65

Average felspar:

Or 67.9

Ab 24.6

An 7.5

Acidity:

$\frac{Q}{Q+F}$ 5.1

Quant. classif.:

II:5:II:2

Cimnosc.

H₂O at 105° 0.17 %.

Among the other »sköls» may here be mentioned only three, from which several smaller ramify. They are: *Storgrufveskölen* (Bruseortskölen), which may be traced 200 *m* and which generally has a dip to north but in some places is vertical; this sköl guides the deposits of Storgrufvan and Collegiegrufvan, which are situated above the sköl; The *Japan-sköl*, which stands vertically and has the Japan-deposit on the northern side, and the Norrbotten on the south side; The sköl of Collegiegrufvan bounds the ore-bearing field towards east; it has a dip to west and determines the pitch westward, common to all deposits in this ore field.

The two following analyses (N:o 14 and 15) are from some smaller »sköls» belonging to the system of the Storgrufveskölen.

The rock N:o 14 presents a dark greenish gray mass of a somewhat greasy lustre, in which nothing but some irregularly distributed grains of a dark coloured quartz can be megascopically distinguished. Microscopical examination reveals an intricate mixture of biotite and felspar which sweeps around irregularly distributed areas of a more or less altered cordierite usually crowded with inclusions of the other minerals. These areas frequently show the characteristic division into sector-shaped subareas due to twinning, as well as the well known yellowish pleochroic coronas around included grains of zircon. The mica is of a greenish brown not very deeply coloured — a almost colourless — but vividly polarizing variety. The predominant felspar is a microcline-perthite rather rich in perthitic inclusions suggesting an average amount of about 25–30 % Ab. A considerable amount of a cloudy not usually twinned plagioclase is also associated which frequently has myrmekitic seams developed at the borders towards the microcline. Of other constituents hematite occurs abundantly as well as a little zircon and apatite. No grains of quartz can be detected in the main portion of the rock; this mineral only occurs in the shape of occasional irregular larger grains

or coarsely granular aggregates, partly of an appearance suggesting foreign inclusions or relic elastic grains but in other cases holding inclusions of the other constituents. This quartz is invariably stained with abundant fine scales of hematite and may perhaps be of a similar nature as the well known deposits of ferruginous quartz which accompany the ore shoots of this mine.

In chemical respect the present rock may be said to unite the characters of a kind of lamprophyric rock with those of a common clay hornfels.

Analysis No 15. Cordierite-bearing quartz-mica rock? Smedje-drive, 150 m level, Långban. Analyst: G. NYBLÖM.

%	Mol.	Norm:
SiO ₂ 69.47	115.02	SiO ₂ 34.38
TiO ₂ 23	29	Or. 17.62
Al ₂ O ₃ 13.67	13.38	Ab 17.58
Fe ₂ O ₃ 1.35	84	An 3.59
FeO 2.47	} 3.52	Al ₂ O ₃ 5.72
MnO 06		Σ sal. 78.89
MgO 5.71	14.27	MgSiO ₃ 14.33
CaO 76	1.36	FeSiO ₃ 3.03
Na ₂ O 2.07	3.34	FeTiO ₃ 44
K ₂ O 2.97	3.15	Fe ₃ O ₄ 1.96
P ₂ O ₅ 03	(07)	FeS ₂ 11
S 06	19	Apatite 07
H ₂ O 1.11		19.94
99.96		98.83

H₂O at 105° 0.18 %.

The original material of this analysis having been lost, no statements about its petrographical characters can be given. From the chemical analysis it may be concluded that the analyzed rock represents a phase of the present rock series in which the potash felspar has almost disappeared and which

approaches to certain types of quartzzy cordierite-rocks known from several other mines of Central Sweden.

The next analysis is from the *Japan-sköl*, the second of the main-sköls in the Långban-mine.

Analysis No 16. Dark coloured mica-microcline-rock. Working Japan. Bordering the ore deposit. Analyst: G. NYBLÖM.

%	Mol.	Norm:	
SiO ₂ 52.91	87.60	Or. 59.02	
TiO ₂ 12	15	Ab 7.90	
Al ₂ O ₃ 23.04	22.54	An 2.07	
Fe ₂ O ₃ 1.20	75	Nc. 8.23	
FeO 54	75	Al ₂ O ₃ 7.00	
MnO 19	27	Σ sal. 84.22	
MgO 6.37	15.92	Mg ₂ SiO ₄ 11.18	
CaO 78	1.40	FeTiO ₃ 23	
Na ₂ O 2.72	4.39	Fe ₂ O ₃ 04	
K ₂ O 9.95	10.56	Fe ₃ O ₄ 1.68	Quant-classif.:
P ₂ O ₅ 28	(66)	Apatite 66	II:5:1:2
S 09	28	FeS ₂ 17	Highwoodose.
H ₂ O 1.50		Σ fem. 13.96	
99.69		98.19	

H₂O at 105° 0.10 %.

It is a dark brownish gray hornfels-looking rock with a somewhat conchoidal fracture. Under the microscope it resolves into an uniform not very conspicuously foliated mixture of small grains of microcline and fine flakes of a very feebly coloured vividly polarizing yellowish mica with occasional purely micaceous patches. The minor constituents include abundant grains of TiO₂-minerals, chiefly rutile, and a considerable amount of apatite. The grains of microcline rarely exceed 0.03 mm in size. They show a rolling extinction, sometimes also distinct wedge-shaped lamellae according to the albite law, combined with very fine pericline lines. No perthitic inclusions can be detected, but there are subordinate

grains of a more cloudy feldspar of higher refraction which evidently is a plagioclase. The chemical composition of the rock is rather puzzling. In its general features it shows undeniable affinities to certain types of lamprophyric rocks, but the very high percentage of alumina is strange in a rock of this nature. It is evident that the large excess of Al_2O_3 resulting at the calculation of the norm of the rock cannot be accounted for by any mica normal in constitution as to the proportions between the olivine silicate and the aluminous molecules. For this reason a control of the analysis seemed desirable; however the new determinations by NAIMA SAHLBOM, viz 21.74 % Al_2O_3 and 6.60 % MgO , are in essential accordance with the original values. Unfortunately the fine grain of the rock scarcely allows of any separation of the mica for a more exact determination of its chemical constitution.

The genetical interpretation of the rock series now described and its relations to the associated dolomite and ore deposits as well as to the surrounding potash granulites certainly constitutes one of the many difficult problems connected with the geology of the ore-bearing formation of Central Sweden. Without further entering here on this question we only wish to accentuate the analogies which doubtless exist between these Långban rocks and certain other types of rocks which are of wide-spread occurrence in this ore-bearing formation. Thus the micaceous sköls-rocks at Långban evidently constitute equivalents of the peculiar mica rocks known as mica skölar or mica-skarn, which are seen at almost every mine in this province only excepting those in quartz-banded hematites. And the associated members rich in aluminous silicates have their analogies in a much varied series of aluminous rocks which in many ore districts occur in a characteristic association with the various types of ores.¹

¹ In a monograph on the Orijärvi ore-bearing region in Southwestern Finland (Bull. Comm. Geol. Finl. N:o 40) P. ESKOLA has recently given an important contribution to the knowledge of a series of aluminous rocks which evidently has much in common with the series of rocks here alluded to.

»Granular» rocks *N* of *Långbanshyttan*. In this connection a few notices may be bestowed also on certain peculiar rocks which occur along the railway northwards from *Långbanshyttan* station, on the eastern side of the main dolomite area. These rocks were in part mapped by TÖRNEBOHM in the same colour as the fine-grained granitic rocks which occur along the northeastern side of Hytt Lake, on the western side of the dolomite. One type is characterized by a quite massive aspect and the presence of very abundant small grains of quartz embedded in a white-greenish groundmass. Its megascopical appearance would suggest some porphyritic rock unusually rich in quartz phenocrysts. When examined microscopically these phenocrysts, however, prove to be entirely fragmental in shape (Pl. 8, fig. 12) with marked indications of mechanical grinding. They are surrounded by a fine-grained groundmass which in part consists of a fairly typical granulitic mixture of quartz and slightly perthitic microcline but otherwise appears to have resulted merely from a crushing of original larger grains of microcline and plagioclase. As feldic constituents the rock contains a considerable amount of a pale green pyroxene and of epidote.

Another associated type of these rocks includes more dark-coloured varieties which at the first glance appear to be composed of thickly crowded fragments and rounded grains of felspar and a dark-coloured quartz and thus might be taken for clastic graywackes. The microscopical appearance, however, scarcely allows of any other interpretation but that these rocks are derived from some more coarse-grained, granitoid rocks which have suffered from a special kind of cataclastic destruction. In this process all the biotite and most of the plagioclase of the original rock have been reduced to fine aggregates, while the quartz and the micropertthite have especially yielded larger somewhat oval-shaped pieces. Indications of a similar destruction have also been observed in the otherwise distinctly granitoid rocks on the northeastern side of Hytt Lake.

The Pajsberg ore field.

The Pajsberg deposits evidently constitute a southern continuation of the Långban ore formation and as to character and mode of occurrence of the ore agree in all essentials with the Långban deposits. Also in the character of the ore-bearing granulite there seems to be a close correspondency. Among the rocks which outcrop on the western side (in the footwall) of the ore-bearing dolomite at Pajsberg thus only decided potash rocks entirely destitute of any soda feldspar have been met with. One of the types observed is a light gray to reddish rock, which contains scattered large grains of quartz and has the mica distributed into an irregular network; in appearance and mineral composition it can scarcely be distinguished from the type of potash granulite which has been described and analyzed from Backgrufvan at Jakobsberg. Another associated type presents a uniform thinly laminated grayish mass without any larger grains; it is poorer in quartz and mica and essentially contains a slightly perthitic microcline intermixed with some epidote.

Concluding remarks.

All the above analyses of rocks from the Filipstad iron ore district are grouped together in the accompanying table. The nine analyses of granulites included are plotted in a triangular diagram (fig. 3) according to the proportions of the felspar-forming molecules $Or:Ab:An$ calculated from analyses.

A glance at this table and diagram is certainly suggestive in several respects. Thus it is a fact that almost every one of the analyses in this table is *rather strange in character and extreme in composition*. If these analyses be grouped in WASHINGTON's tables, they certainly largely will contribute to fill out »subrangs» now only poorly represented.

	1	2	3	6	7	8	9	10	11	16	13	14	12	15	4	5
SiO ₂	80.28	78.25	79.85	76.62	76.83	73.69	70.82	77.59	74.41	52.91	52.80	56.12	65.67	69.47	70.24	50.99
TiO ₂	15	19	22	15	16	36	24	17	16	12	42	30	23	23	15	02
Al ₂ O ₃	11.35	12.27	12.09	13.20	12.78	13.57	13.21	11.61	12.61	23.04	17.59	20.20	18.01	13.67	9.72	3.78
Fe ₂ O ₃	07	05	11	08	35	42	1.04	92	2.86	1.20	1.46	3.05	84	1.35	83	85
FeO	28	57	14	1.16	1.22	62	2.08	24	18	54	2.27	2.47	1.22	2.47	8.98	21.70
MnO	01	01	01	04	06	02	11	01	01	19	35	10	06	06	04	18
MnO	1.18	1.22	1.20	1.41	1.95	1.70	1.66	59	36	6.37	12.18	5.61	3.54	5.71	8.97	18.61
CaO	35	35	23	49	06	36	14	13	10	78	2.39	1.05	21	76	00	00
Na ₂ O	5.94	6.33	5.97	5.85	4.31	3.75	1.89	27	95	2.72	1.29	1.87	84	2.07	12	24
K ₂ O	26	33	30	61	1.92	5.25	8.79	8.82	7.97	9.95	6.71	7.83	6.91	2.97	13	31
H ₂ O ¹	42	60	40	25	42	32	43	11	41	1.50	2.84	1.35	1.27	1.11	1.23	2.77
P ₂ O ₅	tr.	tr.	05	09	tr.	06	01	tr.	tr.	28	05	02	02	03	01	02
S	02	02	—	n d.	tr.	06	01	11	—	09	02	02	06	06	—	03
Or	100.31	100.19	100.57	99.95	100.06	100.12	100.42	100.48	100.02	99.69	100.37	99.99	99.88	99.96	100.42	99.55
Ab	27	3.2	3.2	6.2	22.5	46.9	74.7	94.6	83.9							
An	94.2	93.9	95.4	90.6	76.9	51.0	24.4	4.4	15.2							
	3.1	2.9	1.4	3.2	0.6	2.1	0.9	1.0	0.9							

1. White soda granulite (westphalose), Odalfältet, Persberg; 2. Reddish soda granulite (westphalose), Odalfältet, Persberg; 3. White soda granulite (westphalose), Högberget, Persberg; 4. Gray soda granulite (westphalose), Nordmarksberg; 5. Gray micaceous soda granulite (taurose), Finnmosen; 6. Grayish intermediate granulite (liparose), Finnmosen; 7. Reddish potash granulite (omose), Jakobsberg; 8. Red potash granulite (S. R. 1 of alaskase), Lappasen, Långban; 9. Reddish potash granulite (magdeburgese), Långban; 10. Mica-microcline-rock (highwoodse), Japan, Långban; 11. Mica-rock (cimino), Lesjöfors drive, Långban; 12. Cordierite-bearing mica-felspar-rock (cimino), Bjelke's shaft, Långban; 13. Mica-microcline-rock with patches of andalusite and cordierite, Lesjöfors drive, Långban; 14. (probably a micaceous quartz-cordierite-rock), Smedje drive, Långban; 15. Quartz-cordierite-gedrite-rock, Getön, Persberg; 16. Cummingtonite-skarn, Odalfältet, Persberg.

¹ Incl. 0.03% BaO. ² All analyses made on samples dried at 105°.

A striking feature of all the granulites analyzed is their *very small percentage of CaO*. Certainly the iron bearing formation of this district seems to be one *practically destitute of the An-molecule* and from this point of view may really be called an alkaline formation. This feature may induce one

Fig. 3.

to some speculative suggestions. If we imagine a magma of this composition undergoing differentiation, then it is obvious that there must be very little chance for any part-magmas of gabbroidic or dioritic character to be formed. Would this be the true explanation of the fact that in the Filipstad district no amphibolitic rocks are seen interbanded with the granulites, while in other ore-bearing districts less extremely alcaic in character, as for instance the southern part of

Dalecarlia, such rocks occur interstratified with the granulites in almost every existing outcrop of rock? And what kind of rocks might be expected to result if the femic constituents of such a magma nevertheless should tend to differentiate?

It is a puzzling but indisputable fact that in the midst of these salic rocks, which are in themselves almost destitute of lime but at the same time are rather high in alcalies, masses of crystalline limestone and dolomite occur abruptly intercalated in great number, some of which also are of considerable dimensions. This fact is very suggestive for a broader discussion from a chemical point of view, which, however, may be reserved for a later publication.

As another interesting feature, the grouping of the granulites according to their proportions of potash and soda, should be observed. As illustrated in the diagram the analyzed rocks chiefly belong to three divisions, one very *extreme in soda*, another equally *extreme in potash* and a third more *intermediate* in character. In fact there are represented in this series of analyses in the same time some of the purest soda- as well as potash-rocks ever analysed. For a determination of the exact distribution within the district of the different types represented a detailed survey according to chemico-petrographical principles is needed; however, enough is already known to justify a general statement that rocks extreme either in soda or in potash occupy a very important part of the district.

Several years ago one of the authors pointed out that there seemed to exist a general parallelism in the iron-ore-bearing formation between the distribution of the different chemical types of granulites, that can be distinguished, and the distribution of the different types of ore¹. Thus the typical skarn ores were stated to occur chiefly in such zones of rocks that are rich in soda,

¹ H. E. JOHANSSON: Till frågan om de mellansvenska järnmalmernas bildningssätt. Geol. Förr. Förh. Bd 29 (1907).

while the quartzeous ores were said to be particularly associated with granulites of a decidedly potassic character. As to the rocks associated with manganiferous ores they were said to be probably also of a potassic character, although sufficient data for a definite statement were lacking at that time. If the distribution of the two main types of ore that are represented in the Filipstad district be considered from this point of view it cannot be denied that there is a good accordance with these general statements. Here the *close relationship between skarn ores and soda granulites is excellently manifested*, and no deposits of this type have been met with in the zones of extreme potash granulites. On the other hand it certainly is not a mere chance that *those granulites which accompany the main representatives of the type of manganese- or combined manganese- and hematite-ore, viz Långban, Pajsberg and Jakobsberg, have in all cases proved to be of an extremely potassic character*. This is a feature that we have now become acquainted with also with regard to a large number of manganiferous iron ore deposits in various other parts of the ore-bearing province.

Without entering at this place into any broader discussion of the genesis of the iron ore deposits we only wish to express the opinion that in the present district, as well as in other ore districts of Central Sweden, all available facts, geological as well as chemical, point to a *very intimate genetical connection between the ores and the accompanying quartz-felspar rocks*. In the case of the Filipstad district there is a special reason to emphasize this general conclusion. Thus it is well known that, especially on the part of certain foreign geologists who have had no personal experience of the true conditions of our iron-bearing formation, an opposite opinion has been advanced with special regard to the Persberg deposits. According to this opinion the source of the ore, just as in true contact ore districts, should be sought for in the intrusive granites which have invaded the district. In this respect,

however, we are fully convinced that no geologist who has had the opportunity of studying the conditions more closely at the place will leave this district with the slightest doubt that the granites have intruded long after the formation of the ore deposits and have no genetical connection at all with the iron ores.

Explanation of the plates 7—8.

Plate 7.

Fig. 1. Porphyritic soda granulite, Odalfältet, Persberg. 30 diameters, with analyzer. Bipyramidal phenocryst of quartz showing embayments of the surrounding fine-grained granulitic quartz-albite-groundmass. (P. 445.)

Fig. 2. The same rock, 30 diameters, with analyzer. A larger phenocryst of albite in the shape of a penetration twin is seen to border on the granulitic groundmass with quite irregular ragged outlines. This structural feature, which is so general a characteristic of porphyritic phases of the granulitic rocks, is thought to indicate a period of deformation in the process of structural development of these rocks during which an earlier generation of larger crystals have been mashed and reduced to fragments around which the fine-grained granulitic groundmass has crystallized. (P. 445.)

Fig. 3. The same rock, 150 diameters, with analyzer. A portion of the groundmass consisting of somewhat larger grains of quartz and moire-twinned albite which border on an area of very finely granular (polysomatic) albite. (P. 446.)

Fig. 4. Even-grained soda granulite, Högberget, Persberg. 60 diameters, with analyzer. Uniform granulitic intermixture of albite and quartz. (P. 448.)

Fig. 5. »Granitoid» soda granulite, Elgön, Persberg. 22 diameters, with analyzer. At the upper margin parts of a mashed phenocryst of quartz (white) and of another phenocryst of albite (dark) are visible. Along the lower margin a portion of granulitic albite-quartz-intermixture. In the centre a regular micrographic intergrowth of quartz and albite. The interstices are chiefly filled up with needles of amphibole and clusters of iron ore. (P. 455.)

Fig. 6. »Granitoid» soda granulite (cummingtonite- and cordierite-bearing variety), Elgön, Persberg. 60 diameters, with analyzer. An occasional area of a micrographic intergrowth of quartz and moire-twinned albite. (P. 455.)

Plate 8.

Fig. 7. The same rock as in fig. 5. 10 diameters, with analyzer. In the central part a group of closely aggregated larger crystals of

quartz and albite with narrow interstices chiefly filled up by a felt of amphibole needles. Marginal areas of a fine-grained quartz-albite-intermixture. (P. 455.)

Fig. 8. Porphyritic soda granulite, Nordmarksberg. 9 diameters, with analyzer. Irregularly distributed fragment-looking phenocrysts of quartz and albite embedded in a fine-grained groundmass of the same minerals. (P. 456.)

Fig. 9. Gneissose soda granulite, Taberg. 30 diameters, with analyzer. A more coarsely and unevenly granular intermixture of quartz and albite, the latter with regular and fine twinning lamellæ. (P. 462.)

Fig. 10. Potash granulite, Backgrufvan, Jakobsberg. 8 diameters, without analyzer. Illustrates the network-like distribution of the deep-coloured mica in the predominating granulitic quartz-microcline-mass. To the right an occasional phenocrystic individual of quartz. (P. 463.)

Fig. 11. Potash granulite, Lappåsen, Långban. 50 diameters, without analyzer. Illustrates the sequence of crystallization shown by this rock. At the lower margin a small phenocryst of quartz surrounded by areas of a partly very fine intermixture of quartz and microcline which further outwards passes into areas of more coarsely crystalline microcline almost free from quartz. From the latter areas rod-shaped crystals of microcline are seen to project into a central broader area of coarsely crystalline quartz stained with small inclusions of microcline. This quartz evidently constitutes the latest product of the crystallization process of the rock. The whole rock is stained with black grains of iron ore, chiefly hematite. (P. 466.)

Fig. 12. Quartz-porphyritic rock, N of Långbanshyttan. 10 diameters, with analyzer. Illustrates the strikingly fragmental character of the very abundant phenocryst-looking quartz grains of the rock. (P. 476.)

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