

SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C.

Avhandlingar och uppsatser.

N:o 467.

ÅRSBOK 38 (1944) N:o 9.

THE ALTERATION OF THE ROCKS
IN THE COPPER DEPOSIT AT
LAVER IN N. SWEDEN

BY

TORSTEN DU RIETZ

Pris 2.00 kronor

STOCKHOLM 1945
KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
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Introduction.

In a recent paper Ödman¹ gives an account of the geology of the Laver copper mine. The following summary of the general geology of the mine is chiefly taken from his description.

The chief bed-rocks at the Laver deposit consist of liparites, a banded tuff complex, and dykes of greenstone and granite porphyry. The ore bodies are classified as ore veins, breccia ores, and ore-bearing faults. The chief ore minerals are chalcopyrite and pyrrhotite. Disseminations of sphalerite are also present, but the percentage of zinc is not high.

The liparites occupy the north-eastern part of the mine and the banded complex the south-western part.

The liparite complex is fairly uniform. The fresh liparite is a dense lava with small phenocrysts of feldspar. Certain parts of the rock complex must be considered as agglomerates with large fragments of the same liparite. Some parts of the complex are built up of banded liparites similar to the banded tuff complex and are considered to be tuff layers within the liparitic lava. Recently a liparitic dyke rock was observed cutting the liparite.

Outside the mine dacitic and andesitic rock types were observed within the liparite areas.

The banded tuff complex is chiefly composed of felsitic, banded rocks of a liparitic composition. Some parts of the banded complex, particularly on the 130 m level close to the contact of the liparite complex, are developed as agglomerates and some parts as a fairly even-grained coarse oligoclase tuff.

The greenstone dykes sharply cut the liparite and the banded complex. They can often be followed both horizontally and vertically over a consider-

¹ Ödman, O., Geology of the copper deposit of Laver. S. G. U. Ser. C, N:o 452, 1943.

able distance. Smaller dykes frequently branch out from the thicker ones. The general dip of the dykes is steep. The primary character of the rock is blotted out by a strong alteration which will be described in detail below.

The granite porphyry dykes generally have a considerable width and distinctly cut the liparite, the banded complex, and some of the greenstone dykes. The granite porphyry generally cuts the ore bodies at sharp contacts. The dykes are often developed as composite dykes with a dark, basic component (composition almost tonalitic) in the central part. This rock type has sometimes dark pegmatite-like veins or schlieren, chiefly consisting of quartz, plagioclase, and hornblende. The granite porphyry dykes have generally well defined chilled contacts against the liparite.

Some of the greenstone dykes cut the granite porphyry as well as the ore. It is not possible to distinguish between the two formations of greenstone dykes by their petrographic appearance.

A large number of almost vertical faults displace the rocks and ores of the deposit. The larger faults have been followed throughout all the levels of the mine. The general strike is about north—south.

Among the ore veins those approximately following the contact between the liparite and the banded complex are the most conspicuous ones. The vein ore-bodies are often very rich. Chalcopyrite and pyrrhotite are the chief sulphides. They are generally fine-grained. Sometimes sphalerite may be common and sometimes arsenopyrite. Pyrite is not prominent. Molybdenite occurs at some places but it is fairly rare. Besides the massive sulphide veins, disseminations of ore minerals may be found and frequently there occur more or less parallel apophyses of ore veins.

The breccia ores are found within the liparite area as wide bodies, containing about the same sulphides as the ore veins. The ore type may be characterized as a liparite with disseminations of sulphides and brecciating sulphide veinlets (Fig. 1). The mineralization is often accompanied by certain skarn¹ minerals, mostly micas and garnet, generally appearing in brecciating veinlets. Together with the sulphides this type of skarn is referred to in the following as *biotite skarn breccias*. Sometimes the ore does not contain any skarn minerals, and, on the other hand, some skarn breccias may be rather poor in sulphides. The appearance of the breccias shows that the formation of the skarn minerals and the sulphides took place at about the same time, although the sulphide minerals crystallized later and thus may replace the skarn minerals. The late hydrothermal alteration of some skarn minerals, *e. g.* the chloritization of biotite and garnet, is somewhat later and probably closely succeeded the deposition of the sulphides.

The liparite as well as the banded tuff have partly been subjected to another form of alteration, mainly resulting in the formation of fairly dense and dark-coloured rocks characterized by metasomatic minerals such as sericite and

¹ The term «skarn» is here, with some deviation from generally accepted practice, used for metasomatically formed mineral masses rich in magnesium-iron-aluminium silicates and comparatively poor in lime silicates.

biotite. These skarn rocks will be described below as dense altered rocks. Also in this case the alteration is accompanied by the deposition of some ore minerals, although the metal contents are always lower than in the breccia ores. Between the two types of skarn rocks, *viz.* the biotite skarn breccias and the dense altered rocks, there exist all gradations.

The biotite skarn breccias.

In order to ascertain the chemical and mineralogical alterations of the rocks as closely as possible, a number of samples in different degrees of alteration have been chemically analysed. As some of the complex minerals of the skarn breccia, such as biotite, garnet, and also epidote, are difficult to classify only by the aid of mineralogical methods, a typical sample of each has also been analysed chemically. The minerals in question being almost identical in the different alteration products, the known composition of the main minerals has made it possible to ascertain the mineralogical composition of the analysed rocks and also to some degree to find out the most probable composition of the other minerals.

The biotite, Table 1, and garnet, Table 2, were picked out of material from a very coarse, skarn-rich ore to be described in detail on pp. 7—9. The epidote, Table 3, came from a pure epidote-quartz skarn.

Table 1. Biotite.

Analyst: A.-G. Hybbinette.

	a. Chemical analysis	b. Same with deduction of 10 % chlcrite		
	Weight %	Weight %	Mol. prop.	Mol. %
SiO ₂	32.05	32.8	5461	35.0
TiO ₂	0.22	0.25	31	0.2
Al ₂ O ₃	23.00	23.5	2305	14.8
FeO	25.15 ¹	26.0	3619	23.2
MnO	0.30	0.30	42	0.3
MgO	5.60	3.9	967	6.3
CaO	1.10 ²	1.0 ²	178	1.1
Na ₂ O	0.10	0.11	18	0.1
K ₂ O	7.50	8.4	892	5.7
H ₂ O + 105°	4.40	3.5	1943	12.5
H ₂ O — 105°	0.16			
F	0.22	0.24	126	0.8
CO ₂	< 0.05			
	99.80	100.00		100.0
Sp. gr.	3.12			

¹ All iron is counted as FeO. Fe₂O₃ is less than 0.3 %.

² The high content of CaO probably indicates some inclusions of epidote or prehnite.

Table 2. Garnet. Cross-cut 236, 130 m level.

Analyst: A.-G. Hybbinette.

	Weight %	Mol. prop.	Mol. %	
SiO ₂	35.95	5986	41.5	Almandite 58.3 mol. %
TiO ₂	0.13	16	0.1	
Al ₂ O ₃	21.05	2065	14.3	Spessartite 25.9 »
FeO	25.67	3573	24.8	
MnO	11.28	1590	11.0	Grossularite 13.2 »
MgO	0.64	159	1.1	
CaO	4.50	802	5.6	Pyrope 2.6 »
Na ₂ O	0.19	31	0.2	
K ₂ O	< 0.02			
H ₂ O + 105°	0.28	155	1.1	
H ₂ O — 105°	0.06			
F	< 0.05			
CO ₂	0.21	48	0.3	
	99.96		100.0	100.0

(The content of Fe₂O₃ is less than 0.4 %)
 Sp. gr. 4.11.
 Lattice dimension a₀ = 11.51 Å. (O. Alvfeldt).
 N_{Na} = 1.829 ± 0.001 (T. Krokström).

The refraction indices of the biotite are $n_\gamma = n_\beta = 1.637 \pm 0.002$ (T. Krokström). The pleochroism is strong with γ bluish green with brownish tinge and α greenish yellow (to grayish yellow). $n_\gamma - n_\alpha = 0.054$.

The biotite is intergrown with a chlorite that is very similar and almost as strong in colour though somewhat more greenish. This chlorite is evidently a mineral intermediate in composition between prochlorite and delessite. The refraction indices are $n_\gamma = 1.608 \pm 0.001$, and $n_\alpha = 1.604 \pm 1.001$. $2V$ is about 35° (T. Krokström). $n_\gamma - n_\alpha$ averages 0.003. The birefringence has bluish gray anomalous colours, in certain spots almost changing into anomalous brownish yellow (with very low birefringence). The composition is estimated to be: SiO₂ 27 %, Al₂O₃ 20 %, FeO 19½ %, MgO 21 % and H₂O 12½ %.

The biotite is a mineral with extreme contents of Al₂O₃ and FeO and nevertheless with a low content of TiO₂. The very low content of Fe₂O₃ explains the green colour of the biotite.

The epidote is megascopically yellowish green and in thin section pale green with weak pleochroism. It was not possible to get rid of some of the quartz as it was poikiloblastically intergrown with the epidote. The epidote skarn also contained a little chlorite and calcite. In the altered rocks of Laver epidote is generally intergrown with the other skarn minerals as rather small grains. Also in other cases in the mine it seems to have the same colour and birefringence. It is, however, often partly intergrown with orthite in biotite and thus causes pleochroic halos in the latter.

Table 3. Epidote. Drift 25, 50 m level.

Analyst: A.-G. Hybbinette.

	a	b. Same with deduction of 8 % quartz (poikiloblastic inclusions)		
	Weight %	Weight %	Mol. prop.	Mol. %
SiO ₂	42.67	37.8	6294	42.8
TiO ₂	0.11	0.12	15	0.1
Al ₂ O ₃	22.60	24.6	2413	16.4
Fe ₂ O ₃	10.58	11.6	727	4.9
FeO	0.75	0.82	114	0.8
MnO	0.17	0.19	27	0.2
MgO	0.14	0.15	37	0.3
CaO	20.92	22.8	4066	27.7
SrO	0.076 ¹	0.08	8	0.1
Na ₂ O	0.08	0.09	15	0.1
K ₂ O	< 0.10			
H ₂ O > 105°	1.60	1.75	971	6.6
H ₂ O < 105°	0.17			
F	< 0.03			
	99.87	100.00		100.0
Sp. gr.	3.28			

Refraction indices, Na-light: $N_{\alpha} = 1.726 \pm 0.002$, $N_{\beta} = 1.743 \pm 0.002$.
 $N_{\gamma} - N_{\alpha} = 0.030$, $2 V_{\alpha} = 70^{\circ}$.

¹ Analyst: S. Henriksson.

The source of the biotite and the garnet analysed above is a copper ore extraordinarily rich in skarn minerals. Samples of the ore as well as the skarn have been analysed and will be quoted below, Table 4. The sulphides are principally chalcopyrite and pyrrhotite with some sphalerite. The skarn minerals are biotite (predominating), garnet, chlorite (prochlorite-delessite), epidote, muscovite-sericite, and a few grains of a dark-green spinel, probably an iron-rich pleonast. A recrystallized plagioclase may also be looked upon as a skarn mineral as it is intergrown with the other minerals as roundish grains of the same general size. It is an intermediate plagioclase of labradoritic to andesinic composition. As there is generally some original sodic plagioclase preserved in the rock, the average composition of the feldspar will be about oligoclase. The feldspar content of the rock is very irregularly distributed and the size of the individuals varies from the very small grains of original albite to the larger clusters of the more calcic, secondary plagioclases. The secondary plagioclase is also easily transformed and it is generally missing in the hydrothermally altered rocks.

Both the ore and the biotite skarn show a fairly irregular distribution of the minerals and a varying size of grain. The average size of the minerals as

Table 4. Micaceous copper ore. Cross-cut 236, 130 level.

Analyst: A.-G. Hybbinette.

	A. Copper ore.		B. Biotite skarn.	
	Weight %	Mol. prop.	Weight %	Mol. prop.
SiO ₂	45.83	7631	33.70	5611
TiO ₂	0.12	15	0.18	23
Al ₂ O ₃	16.70	1638	24.00	2354
Fe (total)	13.15	2355	17.02	3048
MnO	0.93	131	0.58	82
MgO	3.82	947	4.45	1104
CaO	2.53	451	1.16	207
BaO	0.03	2	0.05	3
Na ₂ O	2.19	353	0.28	45
K ₂ O	3.27	347	6.75	717
Cu	2.55	401	0.35	55
Zn	0.59	90	0.45	69
S	3.92	1223	0.73	228
P ₂ O ₅	0.15	11	0.32	23
H ₂ O +	2.30	1277	4.88	2709
H ₂ O -	0.09		0.14	
	98.17		95.04	
O ₂ for Fe	2.68		4.79	
	100.85		99.83	
Sp. gr.	2.98 (O. Alvfeldt)			
Actual mineral composition. Weight %				
Quartz		11		2.5
Plagioclase (average oligoclase)		25		2
Muscovite-sericite		0.2		8
Biotite		36		71
Chlorite		9		8
Garnet		5		2
Epidote		1.5		1
Prehnite		1		0.1
Spinel		0.5		2
Magnetite		tr.		0.5
Hematite				0.1
Pyrrhotite		1.9		0.2
Marcasite		0.6		0.3
Chalcopyrite		7.4		1
Sphalerite		0.9		0.7
Tourmaline		tr.		tr.
Zircon		tr.		tr.
		100.0 %		100.0 %

established in thin sections is: garnet 3 mm, biotite 1.5 mm, porphyric plagioclases 0.6 mm, prehnite and chlorite 0.5 mm, spinel 0.4 mm, apatite 0.3 mm, and epidote 0.1 mm. The remnants of feldspar-quartz matrix have partly preserved the grain-size of the liparite groundmass. The analysed ore sample has more remnants than the analysed skarn. The skarn minerals often show spots with recrystallized quartz grains.

Chalcopyrite, pyrrhotite, and sphalerite are mutually intergrown and brecciate the skarn minerals. Magnetite is brecciated by pyrrhotite and chlorite. Marcasite is typically developed as a secondary product in pyrrhotite.

The photo, fig. 2, shows the structure of a biotite skarn breccia.

The skarn minerals, now forming the largest part of the rock, are remarkably rich in divalent iron and alumina, and to a certain degree also in magnesia, as exemplified by the presence of garnet, biotite, epidote, sericite, chlorite, tourmaline, and spinel. The first stage of the metamorphism was also distinguished by an addition of some calcium, as exemplified by the formation of an intermediate plagioclase together with the skarn minerals, but this mineral was not so stable as the other secondary minerals and some altered rocks do not show any secondary feldspar at all. A small content of epidote is, however, always present. The ore-bearing rock has been formed by replacement volume by volume of an earlier liparite. A typical fresh liparite, analysed earlier (cf. O. Ödman, p. 13), had the following main composition: SiO_2 80.96, Al_2O_3 9.74, Fe_2O_3 0.37, FeO 1.14, CaO 0.76, K_2O 3.64, Na_2O 2.63 %.

It may be accepted as a typical representative though silica seems a little high and the alkali content in the average type might have equal quantities of sodium and potassium. A comparison between the ore analysis and the liparite discloses that the ore in the first place is characterized by an increase in divalent iron (even if the ore minerals are subtracted), alumina, magnesia, and to a certain degree also lime, as evidenced by the increase of the anorthite content of the feldspar. The proportion of the alkalies is not much altered though the potassium is now contained in the mica. The silica content of the rock has diminished.

Upon comparing the analysis of the biotite skarn with the liparite the strength of the alteration becomes even more apparent. The content of sodium is low, while the percentages of FeO , Al_2O_3 and MgO are still higher than in the ore, and the potassium has been much increased. Potassium-aluminium-magnesium-iron-minerals predominate in the skarn.

The rock type shown in Table 5 may be considered the normal type of the breccia ore. It has about the same minerals as the other one (Table 4), but the appearance of the rock is more quartzite-like. It has a smaller amount of skarn minerals, more quartz matrix, and smaller remnants of feldspar, but as the skarn-plagioclase is scarce the mean composition of the feldspar will be more sodic.

The average grain-size of the skarn minerals is: garnet 2 mm, biotite 0.6 mm, chlorite 0.4 mm, muscovite-sericite 0.2 mm, and recrystallized quartz (the

Table 5. Normal breccia ore type, rich in copper. Cross-cut 201, 130 m level.

Analyst: A.-G. Hybbinette,

		Mol. prop.	Actual mineral composition	
SiO ₂	54.20	9024	Quartz	38.0 % (weight %)
TiO ₂	0.13	16	Plagioclase	5.0
Al ₂ O ₃	11.60	1138	Sericite	10.0
Fe (total) ..,	14.30	2513	Biotite	15.0
MnO	0.69	97	Chlorite	10.0
MgO	2.43	603	Garnet	3.0
CaO	0.70	125	Epidote (orthitic)	1.2
BaO	0.01	1	Apatite	0.2
Na ₂ O	0.61 ¹	98	Tourmaline	0.1
K ₂ O	2.40 ¹	255	Magnetite	7.0
H ₂ O + 105°	2.45	1360	Chalcopyrite	9.0
H ₂ O — 105°	0.08		Pyrrhotite	1.0
S	4.66	1454	Sphalerite	0.4
F	0.02	11	Ni-Mo-Ag-sulphides	0.1
CO ₂	0.01	2	Marcasite	tr.
P ₂ O ₅	0.07	5		
Cu	3.10	488		100.0 %
Zn	0.25	38	Sp. gr. 2.99 (O. Alvfeldt)	
Ni	0.011	2		
Mo	0.0015	—		
Ag	0.0081 ²	1		
Au	0.000021 ¹	—		
Pb	< 0.01			
As	< 0.001			
Bi	< 0.005			
Se	< 0.005			
Te	< 0.005			
W	< 0.001			
Co	< 0.002			
Cl	< 0.01			
	97.75			
— O for F	0.01			
+ O for Fe	2.44			
	100.18			

¹ Analyst: L. Carlsson.² " : S. Johansson.

chief part of the quartz) 0.2 mm. The skarn minerals are thus not so coarse as in the rock described above.

The skarn minerals have the same high content of divalent iron, alumina and magnesia as the minerals of the biotite-rich ore described above, and they may be considered to be identical with the ones earlier described, *i. e.* the analysed biotite and garnet, the prochloritic-delessitic chlorite and a strongly

Table 6. Copper-rich breccia ore. Drift 201, 130 m level.

Analyst: A.-G. Hybbinette.

	Weight %	Mol. prop.	Actual mineral composition	
SiO ₂	46.94	7816	Quartz	22.0 %
TiO ₂	0.11	14	Plagioclase	27.0
Al ₂ O ₃	10.31	1011	Sericite	0.5
Fe (total)	13.77	2466	Biotite	18.0
MnO	0.51	72	Chlorite	3.0
MgO	2.11	523	Epidote	1.0
CaO	2.26	403	Apatite	0.1
BaO	0.01	1	Calcite	0.1
Na ₂ O	2.08 ¹	336	Magnetite	0.6
K ₂ O	1.82 ¹	193	Chalcopyrite	21.0
H ₂ O +	1.10	611	Pyrrhotite	5.0
H ₂ O -	0.10		Cubanite	0.6
S (total)	9.94	3100	Sphalerite	1.0
F	0.02	21	Ni-Mo-Ag-sulphides	0.1
P ₂ O ₅	0.04	3	Marcasite	tr.
CO ₂	0.07	16		
Cu	7.48	1177		100.0 %
Zn	0.68	104	Sp. gr. 3.04 (O. Alvfeldt)	
Ni	0.020	3		
Mo	0.025	3		
Ag	0.0137 ¹	1		
Au	0.00004 ²			
Pb	< 0.01			
Bi	< 0.005			
As	< 0.001			
Se	< 0.005			
Te	< 0.005			
W	< 0.001			
Co	< 0.002			
Cl	< 0.01			
	99.41			
- O for F	0.01			
+ O for Fe	0.93			
	100.33			

¹ Analyst: L. Carlsson.² " : S. Johansson.

greenish blue to violet (for ω) tourmaline. A remarkable content of magnetite distinguishes the rock last analysed. On the whole, magnetite is fairly common among the skarn-bearing rocks of Laver, though it is generally not so abundant as in the rock now analysed. This magnetite has often a very distinct cleavage, giving it a laminated appearance. Molybdenite was observed megascopically not far from where the sample was taken.

In hand specimens the copper-rich breccia ore of Table 6 gives a chief impression of sulphide breccia, and the brecciating biotite skarn is not so striking in appearance. It belongs to the ore breccias which are poorest in skarn minerals, though there are others with a still smaller amount of skarn minerals and more preserved liparite matrix.

This rock is composed of a quartz-feldspar groundmass with remnants of porphyritic sodic plagioclase, often penetrated by later quartz. Together with the skarn and sulphide minerals there occur clusters of coarse, basic plagioclase, with a composition varying from basic oligoclase to labradorite. The feldspar of the liparite relics seems to be a plagioclase slightly below An₁₀, but the faint pink colour and the rock analysis indicate a fairly potassic albite. The average composition of all the plagioclase of the rock will be about An₃₀. The groundmass of the rock is granophyric to keratophyric.

The biotite of this rock is slightly paler than those described above, and judging from the rock analysis it will be poorer in alumina and richer in magnesia.

Table 7. Biotite-skarn breccia. Drift 8, 50 m level.

Analyst: Th. Berggren.

	Weight %	Mol. prop.	Actual mineral composition	
SiO ₂	65.69	10937	Quartz	43.0 %
TiO ₂	0.36	45	Plagioclase	17.0
Al ₂ O ₃	12.92	1267	Alkali feldspar	1.0
Fe ₂ O ₃	0.63	40	Sericite	1.3
FeO	9.01	1254	Biotite	18.0
MnO	0.42	59	Chlorite	10.0
MgO	3.06	759	Garnet	7.0
CaO	2.16	385	Epidote	1.2
SrO	0.01 ¹		Tourmaline	0.4
BaO	0.01	1	Apatite	0.4
Na ₂ O	1.32	213	Magnetite	0.2
K ₂ O	1.85	196	Pyrrhotite	0.1
H ₂ O +	1.61	894	Sphalerite	0.3
H ₂ O -	0.14		Molybdenite and chalcop- pyrite	0.1
P ₂ O ₅	0.19	13		
F	0.06	32		
CO ₂	0.01	2		100.0 %
S	0.13	41		
Cu	0.01	2	Sp. gr. 2.7 ⁸	
Zn	0.18	28		
Mo	0.03	4		
B ₂ O ₃	0.03 ²	4		
As	0.00			
	99.83			

¹ Analyst: S. Henriksson.

² K. G. Lindkvist.

The average grain-size of some of the minerals is: biotite 0.5 mm, porphyritic plagioclase 0.4 mm, and quartz-feldspar groundmass grains and sericite 0.1 mm.

A typical biotite-skarn breccia without any ore minerals has been analysed (Table 7). The rock is brecciated by veins of biotite, contains some secondary quartz, and carries large solitary grains of garnet. The average grain-size of the skarn minerals is a little smaller than in the rocks described above. Where the metasomatic alteration is very strong no primary feldspar remains. The feldspar is partly sodic plagioclase and alkali feldspar, forming a very fine-grained groundmass, and partly a more porphyritic labradorite-andesine feldspar. The biotite is brownish green to greenish yellow. It is partly altered to a strongly green chlorite. Both minerals are probably a little richer in iron than the minerals described earlier. The garnet is supposedly not so rich in manganese as the one analysed. A bluish tourmaline is locally abundant. The content of ore minerals is small. Sphalerite is relatively more prominent than the iron-copper-sulphides.

The analysis shows that the alteration has taken place with much addition of divalent iron and magnesia, and some alumina and lime. The content of potassium is somewhat low because of hydrothermal alteration with subtraction of some K_2O . Some Na_2O and silica have been carried away.

The analysed rock may be considered an average sample of skarn-brecciated liparite poor in sulphides.

A comparison between 8 different, typical skarn-brecciated liparites is given below.

The rocks of Table 8 are distinguished by a low content of feldspar and consequently a still lower amount of primary feldspar. Quartz is abundant

Table 8. Skarn-brecciated liparites. Volumetric percentage.

	a	b	c	d	e	f	g	h
Quartz	52	45	42	40	40	33	32	19
Feldspar	1	18		13	15		1	7
Sericite	3	1	2	0.1	0.3	5	5	2
Biotite	31	17	26	26	27	33	8	21
Chlorite	0.4	10	25	2.3	6	1	23	37
Garnet	8	6	1.5	5	0.1	17	25	5
Epidote (+ orthite)	0.1	1	0.5	6	3.2	0.2	0.3	0.1
Iron and copper sulphides	4	0.1	2	7	7.5	7	5	6.5
Sphalerite	0.4	0.3	0.2	0.4	0.5	1.6	0.3	1.4
Magnetite	tr.	0.1	tr.		0.3	1.8		
Tourmaline		1	0.3				0.3	1
Spinel						0.4		tr.
Apatite	0.1	0.4	0.5	0.2	0.1	tr.	0.1	
Zircon				tr.				
Calcite		0.1		tr.				

†2—450990. S. G. U. Ser. C. N:o 467. Du Riets.

and is chiefly a recrystallized, granular mineral. The percentage of biotite is always high, and sometimes also chlorite is abundant. The latter is formed at the expense of biotite or garnet. Garnet is generally present, though it is not so abundant as biotite. Epidote is a constant constituent, although to a very small amount, occurring as small grains. It is often an epidote-orthite. Among the typical skarn minerals tourmaline often appears. It is a greenish blue or bluish violet variety (in thin slices) occurring in relatively large grains. Sulphides and magnetite generally appear together with the skarn minerals. The apatite is a constant constituent, though it is always accessory. It may be considered a relic mineral; it is generally recrystallized.

Biotite generally appears as leafy aggregates or more or less long strings of small clusters of scales. It is sometimes intergrown with muscovite (sericite) and often with small grains of orthitic epidote with dark halos. The chloritization of the biotite is very irregular and may sometimes favour the small grains and sometimes the large ones. The garnet is reddish and forms up to one or two cm large grains. It is often poikiloblastic. The garnet is less chloritized than the biotite. The chlorite secondary after biotite is identical with that after garnet, generally being a strongly green delessite-prochlorite.

The quartz mostly appears as aggregates of grains of somewhat different sizes, though generally smaller than those of the biotite. The secondary, recrystallized quartz obliterates the groundmass and the feldspar seems to disappear, although it may partly remain as indistinct blurs.

The dense micaceous liparites.

The dense micaceous liparites are almost as finely granular as the liparites proper. It may therefore be hard to discern the separate minerals, though strings of mica and porphyritic grains appear here and there. Biotite, sulphides, magnetite, and garnet are thus often recognized. The completely transformed liparites are generally dark gray to greenish gray and may be granular or schistose. It is of course hard to discern if the primary rock has been a tuff or a lava. Agglomeratic structure may sometimes be recognized.

The colour of the rock varies according to the amount of micas and other secondary minerals formed. If the amount of secondary quartz is strong and the formation of mica not too high, the rock has a vitreous though rather dark appearance. If mica and epidote preponderate the rock will have a fairly dull appearance. As the biotite is generally somewhat porphyritic, it can be recognized megascopically as can also garnet, sulphides, magnetite, and tourmaline. The less altered liparites are grayish, brownish gray, or greenish gray. There are all stages of alteration with transitions toward the white, reddish, or light gray fresh liparites.

The slightly altered liparites still have a high content of feldspar, sodic plagioclase or microcline, each almost as prominent as quartz. The primary porphyritic feldspars are still preserved and the silicification is not particularly

pronounced. The composition of the plagioclase varies from albite to about andesine. It is evident that the anorthite component has been increased already by a slight metasomatic alteration of the rock. Oligoclase seems to be common in the ordinary altered rocks but the composition of the plagioclase may vary a good deal in the same rock. The slightly altered rocks always have some sericite and generally biotite, and often a little epidote concentrated in streaks. The latter is pistazitic and has about the same character as the one analysed (Table 3). It sometimes has a core of orthite, although this mineral generally forms small isolated grains in the biotite. The alteration being somewhat stronger, the sericite occurs as a fine network throughout the rock, the feldspars are attacked, and secondary quartz grains become more and more common. Garnet will appear and sulphides, principally pyrrhotite, sphalerite, and a little chalcopyrite, will be more common. Sometimes also other sulphides may be observed, such as arsenopyrite, pyrite, marcasite, galena and molybdenite. The potassic feldspar disappears and the plagioclase only occurs as relics, more or less pigmented and somewhat enriched in the anorthite molecule. It may also be completely substituted by quartz and sericite. The biotite appears as scattered porphyroblasts; it is often chloritized to a large extent. A bluish tourmaline frequently occurs and apatite always seems to be present. Generally the rocks have megascopically visible magnetite and microscopic grains of spinel, often enclosed in the biotite. Calcite as well as prehnite may locally occur in small quantities. The much altered rocks have about the following average volumetric composition: quartz 48 %, sericite 29 %, biotite 12 %, feldspar 4 %, chlorite 2,5 %, epidote (orthitic) 1 %, garnet 0,7 %, magnetite 0,6 %, pyrrhotite 0,4 %, sphalerite 0,3 %, apatite 0,2 %, chalcopyrite 0,1 %, tourmaline 0,1 %, spinel 0,1 % and zircon trace. The mineral

Table 9. Dense micaceous liparites. Volumetric percentage.

	a	b	c	d	e	f	g	h	i	f
Quartz	60	59	57	56	52	49	47	42	36	32
Feldspar			7	1	2.6			1	4	
Sericite	32	34	19	35	24	34	1	30	43	34
Biotite	7.2	3	12	6	10.5	15	46	25	16	31
Chlorite	0.1	0.3	1	1	0.3	0.1	1	0.4		2
Garnet	0.1		0.2	0.2	0.1		3	0.1	0.1	0.3
Epidote (+ orthite)	0.2	0.2	1	0.3	1.8	0.7	0.1	0.3	0.2	0.1
Iron and copper sulphides	} 0.3	1	2	tr.	} 8.7	0.2	1.3	0.3	0.1	
Sphalerite		0.1	0.1	0.1		0.1	0.4	0.1	0.1	0.1
Magnetite		2.3	0.5	0.4		0.6	0.1	0.3	0.1	0.1
Spinel					tr.	0.2		0.1	0.3	
Tourmaline		0.1	tr.					0.2		0.5
Apatite	0.1	tr.	0.1	tr.	tr.	0.1	0.1	0.2	0.1	0.1
Zircon	tr.	tr.				tr.	tr.	tr.		
Prehnite			0.1							

composition naturally varies much from case to case. The garnet is fairly irregularly distributed and so are also the magnetite and the sulphides.

In Table 9 above some typical, highly altered rocks have been arranged in order to facilitate a comparison.

The content of quartz and sericite is higher in these rocks than in the skarn-brecciated liparites. The content of feldspar is smaller and it is not possible to distinguish between secondary plagioclase enriched in lime or primary acid feldspar, this because of the even granularity of the fine-grained rocks. Nor is the content of garnet so prominent as in the skarn-brecciated liparites.

The slightly altered rocks with their dense quartz-feldspar matrix are difficult to measure quantitatively in rock slices, but the approximate average proportions of the minerals will be given as follows: quartz \geq acid plagioclase \geq potassic feldspar = biotite = sericite $>$ orthitic epidote $>$ sulphides \geq magnetite \geq chlorite \geq apatite = garnet = tourmaline $>$ zircon.

Table 10. Fine-grained micaceous liparite. Drift 201. 130 m level.
Analyst: Th. Berggren.

	Weight %	Mol. prop.	Actual mineral composition
SiO ₂	73.81	12289	Quartz 56 weight %
TiO ₂	0.26	33	Plagioclase (average
Al ₂ O ₃	11.87	1164	oligoclase) 1.8
Fe ₂ O ₃	1.82	114	Potassic feldspar 4
FeO	4.52	629	Sericite 20
MnO	0.05	7	Biotite 13
MgO	0.64	159	Chlorite 0.7
CaO	0.39	70	Garnet 0.2
SrO	0.002 ¹		Epidote 0.7
Na ₂ O	0.59	95	Prehnite 0.1
K ₂ O	3.50	372	Apatite 0.1
H ₂ O +	1.50	833	Magnetite 0.7
H ₂ O —	0.12		Chalcopyrite 1.4
Cu	0.49	77	Pyrrhotite 0.9
Zn	0.03	5	Sphalerite tr.
As	0.00		Tourmaline 0.4
S	0.89	278	Zircon tr.
P ₂ O ₅	0.05	4	
F	0.02	11	Sp. gr. 2.77 100.0 %
B ₂ O ₃	0.04 ²	5	
CO ₂	0.00		
	100.59		
— O for S	0.45		
	100.14		

¹ SrO: S. Henriksson.

² B₂O₃: K. G. Lindkvist.

The photos, figs. 3 and 4, show some structural variations of the altered liparites. Fig. 3 thus shows the ordinary, dense, micaceous liparite with a fine network of sericite and a porphyritic biotite which sometimes forms small stringers. Fig. 4 shows the micaceous liparite with a breccia-like appearance of the mica.

In order to closely elucidate the alteration and the chemical composition some typical, metasomatically altered liparites have been analysed chemically.

The analysed rock in Table 10 is a dense, dark, and quartzite-like liparite with solitary grains of feldspar. The sericitization of the groundmass often proceeded in streaks. Greenish biotite occurs as porphyroblasts. Close to the sulphides it is often altered to the ordinary bluish green chlorite. Small garnets are gathered here and there.

As seen by the analysis, most of the Na_2O is removed and the amount of calcium has not increased as compared with an unaltered liparite. The content of silica has not decreased very much and the addition of iron, alumina, and magnesia is not so prominent as in the skarn-brecciated rocks. The content of biotite and garnet is consequently not so high.

The average grain-size is small: biotite-chlorite-garnet 0.2 mm, epidote-quartz 0.1 mm, and sericite 0.05 mm.

The altered liparite of Table 11 has many relic parts and the formation of secondary biotite, sericite, and quartz is mostly concentrated in spots and streaks. The rock was originally a quartz-keratophyric liparite. The average

Table 11. Slightly altered liparite. Northern part of the A ore body about 74 m level. Analysis by the Boliden Laboratory, Boliden.

	Weight %	Mol. prop.	Actual mineral composition
SiO_2	64.10	10673	Quartz 29 weight %
TiO_2	0.05	6	Plagioclase 42
Al_2O_3	19.00	1864	(averaging oligoclase-
Fe_2O_3	0.30	19	andesine)
FeO	5.69	792	Potassic feldspar 1
FeS	0.42	48	Sericite 8
ZnS	0.16	16	Biotite 16
MgO	0.97	241	Chlorite 1
CaO	2.98	531	Epidote 1.2
Na_2O	3.53	569	Orthite 0.2
K_2O	2.10	223	Apatite 0.1
$\text{H}_2\text{O} +$	0.81	450	Spinel 0.4
$\text{H}_2\text{O} -$	0.19		Magnetite 0.4
	100.30		Pyrrhotite 0.4
			Sphalerite 0.2
			Chalcopyrite 0.1
Sp. gr.	2.71		Zircon tr.
			100.0 %

Table 12. Highly altered liparite. Cross-cut 228, 130 m level.
Analysis by the Boliden Laboratory, Boliden.

	Weight %	Mol. prop.	Actual mineral composition	
SiO ₂	69.70	11605	Quartz	50 weight %
TiO ₂	0.05	6	Sericite	30
Al ₂ O ₃	15.50	1521	Biotite	16
Fe ₂ O ₃	1.73	108	Chlorite	0.2
FeO	5.84	813	Epidote (orthitic)	1
FeS	0.23	26	Apatite	0.1
ZnS	0.25	25	Spinel	0.6
MgO	1.26	313	Magnetite	1.5
CaO	0.26	46	Pyrrhotite	0.2
Na ₂ O	0.18	29	Sphalerite	0.3
K ₂ O	4.08	433	Chalcopyrite	0.1
H ₂ O +	1.30	722	Zircon	tr.
H ₂ O -	0.16			
	100.54			100.0
Sp. gr.	2.80			

grain-size of the minerals is biotite-chlorite 0.2 mm, quartz-feldspar 0.1 mm, and epidote 0.05 mm.

The biotite of this rock has a brownish green colour and the chlorite is a green delessite. The feldspar in the remnants of the original rock is partly a sodic plagioclase and partly a potassic feldspar, but in the micaceous parts of the analysed sample a fairly basic plagioclase occurs. Epidote occurs as a fine pigment together with some magnetite and spinel.

To this rock has been added more iron, alumina, and magnesia than to the rock described above, notwithstanding the fact that it has more relics of the original rock. Lime must also have been added. Silica has probably not decreased. The high content of sodium is due to the fact that most of the plagioclase remains. Some of the potassic feldspar has been altered.

The analysed rock of Table 12 is strongly altered and it has therefore a high content of micas and more conspicuous grains of magnetite and spinel. The rock is fine-grained, almost sugary-grained with much quartz and is strongly sericitized with spots of porphyritic biotite of a dirty greenish, fairly strong colour. The magnetite is also porphyritic. Quartz and sericite are very fine-grained.

Chemically the rock is distinguished by a high Al-Fe-Mg-content and a fairly low content of sodium and calcium due to the complete alteration of the feldspar. The percentage of potassium is high.

Some skarn-bearing rocks with basic plagioclase may originally have been more dacitic than liparitic, though this is not always possible to ascertain

Table 13. Biotitized, dacitic liparite. Air-raid shelter.

Analysis by the Boliden Laboratory, Boliden.

	Weight %	Mol. prop.	Actual mineral composition	
SiO ₂	47.70	7942	Quartz	5 weight %
TiO ₂	0.75	94	Plagioclase	36
Al ₂ O ₃	21.70	1229	(average basic oligoclase)	
Fe ₂ O ₃	0.74	46	Microcline	1
FeO	7.44	1036	Sericite	0.1
FeS	0.21	24	Biotite	39
ZnS	0.12	12	Chlorite (penninite)	3
MgO	3.86	957	Epidote (orthitic)	9
CaO	7.44	1327	Titanite	1
Na ₂ O	3.00	484	Apatite	0.1
K ₂ O	3.76	399	Calcite	5.4
H ₂ O +	1.00	555	Pyrrhotite	0.3
H ₂ O —	0.14		Sphalerite	0.1
CO ₂	2.45	557	Chalcopyrite	tr.
	100.31			100.0 %
Sp. gr.	2.85			

owing to the complete recrystallization of the rocks. Two diamond drill hole sections within an altered liparite area have, however, shown ophitic rock texture which makes it appear probable that basic phases now and then occur within the otherwise fairly uniform liparitic rocks. The analysed rock of Table 13 is an example as it has an obvious porphyritic and ophitic texture, and it is quite evident that primarily the rock was more basic (calcic) than the ordinary liparite. Just as the composition of the liparite agrees fairly well with that of the normal granite porphyry of the region, this rock is very much like the basic granite porphyry (tonalite) chemically and mineralogically, although they belong to two different igneous epochs.

The original dacite has been very much biotitized, somewhat epidotized and invaded by calcite. The feldspar phenocrysts are chiefly plagioclase of a basic oligoclase composition. Its content of lime has been lowered by the formation of secondary epidote and calcite. There are also a few phenocrysts of microcline and antiperthitic plagioclase. Solitary aggregates of quartz indicate that there have also been phenocrysts of quartz.

The biotite is a little browner than in the altered liparites. Neither the biotite nor the chlorite are so rich in iron as the minerals of the ordinary dense altered liparites. The chlorite is an optically positive penninite.

The average grain-size of the rock is: plagioclase phenocrysts 0.2 mm, biotite, chlorite, calcite, and larger quartz grains 0.1 mm, and epidote 0.05 mm.

Chemically the rock is distinguished by an increased content of alumina, magnesia, potassium, and probably calcium. Silica and possibly sodium have decreased. The high percentage of biotite and low sericite content is due to the large addition of Al_2O_3 , MgO , and iron.

Compared with the biotite skarn-brecciated liparites the dense skarn-bearing rocks show certain differences. In the first place they are richer in quartz and sericite. They have less secondary "skarn" plagioclase and as a rule a lower content of garnet. The ore minerals, *i. e.* the sulphides, are very sparse in these rocks and the chloritization of the biotite is less frequent. Chemically the rocks are distinguished by a higher content of silica and relatively also alumina (the formation of sericite), while magnesia may be reduced and often also sodium and lime.

The dense altered rocks are fairly common within the mine area, but they have an irregular occurrence. They are often observed around certain greenstone dykes, around or between some faults (and ore-bearing faults), in some breccia ores, and around some ore veins, and in schistose areas.

The dense altered rocks often appear within the sulphide-bearing areas, though they do not indicate the richest deposits of the brecciated areas. The alteration has probably been a slow process, a successive transformation with but little sulphides and more sericitization than in the skarn- and ore brecciation. It seems to have preceded the ore deposition, but it has followed the same zones of weakness where a little later the more rapid process of brecciation and ore deposition followed.

The alteration of the rocks of the banded tuff complex.

In general the banded tuff complex is more sodic and the lime content of the rocks is on an average also higher than in the liparite complex. Petrographically the rock type may vary from a quartz-keratophyre to a dacite, but as some parts of the complex seem to be fairly clastic (cf. Ödman, p. 14), the composition of the rock may from the very beginning have been a little different from that of a genuine igneous rock. The general non-metamorphic rock type is, however, a dense and fairly acid rock consisting of chiefly albite or oligoclase with quartz and a little potassic feldspar. The size of the grains varies within different layers.

The alteration product has the same mineral components as the altered liparite, though the amount of the minerals may vary a little due to the slightly different primary composition of the rock. An analysis of a relatively fresh banded tuff (cf. Ödman, p. 14) gave the following main components: SiO_2 73.94, TiO_2 0.26, Al_2O_3 12.75, Fe_2O_3 0.53, FeO 3.54, MnO 0.04, CaO 1.30, MgO 0.01, Na_2O 4.95, K_2O 2.01, H_2O 0.10. It may be regarded as characteristic of the banded complex. The rock is thus a little richer in Na_2O , CaO , iron, and alumina than the ordinary liparite. The higher original percentage of lime has resulted in a generally higher content of lime-bearing min-

erals in the altered rock. The biotite as compared with the sericite may be relatively more frequent in the banded tuff skarn.

As the banded rock is often quite dense, it is fairly difficult to quantitatively decipher the minerals of the finer layers. Microscopically the secondary formation of sericite and biotite is visible as well as veins or clusters of secondary quartz. The garnet and epidote are often gathered in strings. That may occasionally also be the case with the opaque minerals. A bluish tourmaline is observed as solitary grains. Porphyritic grains of plagioclase still occur in the slightly altered rocks. It has probably been enriched in the anorthite component. When the alteration is strong, the feldspar disappears. The highly altered rocks have slightly porphyritic biotite and garnet (and tourmaline). The sericite and epidote are fine-grained. The sulphides are very irregularly distributed.

The biotite scales in the slightly altered banded tuff are on an average about 0.05 mm, but in the very much altered rocks it will average 0.2 mm. The colour of the mineral is rather dirty brown with pleochroism from greenish brown to greenish or grayish yellow.

As a secondary formation there occur large porphyroblasts of chlorite. The chloritization is associated with the crystallization of the sulphides. The colour of the mineral is always strong with a pleochroism between bluish green and grayish yellow. The birefringence is low with bluish gray anomalous colour, optically negative. It may sometimes change into anomalous brown interference colour (opt. positive).

The sericite appears as a fine network in the rock with a grain-size of about 0.02 mm. It may sometimes appear as large flakes just as the biotite.

In the slightly altered rocks garnet occurs in rather small grains (average size about 0.1 mm) but in the highly altered types the grains attain a size from 0.2 mm to 3 mm. The mineral is generally poikiloblastic and may contain zony interpositions. It mostly appears as continuous rows of grains. The garnet is less chloritized than the biotite.

The epidote is usually fine-grained. The composition is pistacitic, often with orthite. It is less abundant than in the agglomeratic rocks.

The tourmaline is of about the same grain-size as the biotite or garnet. The strong absorption colour is blue, violet gray, or bluish green. The mineral occurs as solitary grains.

The greenish spinel appears in the average size of 0.3 mm. It is often chloritized and may be surrounded by a margin of chlorite. The spinel is sometimes intergrown with epidote.

Hornblende, rutile, titanite, zircon, and more seldom fluorite and calcite appear sporadically.

Sulphides occur in great variation as to size, form, and quantity. Chalcopyrite, sphalerite, and pyrrhotite are often intergrown. They are frequently deposited within the garnet.

A common alteration product of a banded tuff rock has been analysed:

Table 14. Metasomatically altered banded tuff. Cross-cut 20, 50 m level.
Analysis by the Boliden Laboratory, Boliden.

	Weight %	Mol. prop.	Actual mineral composition	
SiO ₂	65.50	10906	Quartz	42.5 weight %
TiO ₂	0.38	48	Feldspar	1
Al ₂ O ₃	17.20	1687	Sericite	27
Fe ₂ O ₃	1.14	71	Biotite	27
FeO.....	7.76	1080	Chlorite	0.3
FeS.....	0.25	28	Garnet	0.6
ZnS.....	0.09	9	Epidote	0.3
MgO.....	1.28	318	Tourmaline	0.1
CaO.....	0.46	82	Spinel	0.1
Na ₂ O.....	0.53	86	Magnetite	0.6
K ₂ O.....	4.46	474	Pyrrhotite	0.3
H ₂ O +.....	1.30	722	Sphalerite	0.1
H ₂ O -.....	0.15		Chalcopyrite	tr.
			Zircon	tr.
	100.50			
Sp. gr.	2.80			100.0 %

The analysis of this rock (Table 14) does not differ very much from that of the metasomatically altered liparites and the mineral assembly is about the same. The high iron content indicates that the secondary minerals must be somewhat richer in iron than those described earlier. The biotite is a dark, greenish brown mineral and the chlorite is a dark green delessite-prochloite with bluish gray interference colour. Like many highly altered liparites this rock is short of lime-bearing minerals.

The agglomerates in the banded complex close to the ore veins are often strongly metasomatically altered. They have fragments of various rocks, which chiefly, however, are of a dacitic type, generally oligoclase porphyry, but with different textures, such as trachytic, ophitic, and porphyritic ones, indicating a somewhat varying basicity. Banded tuffs occur close by. The alteration is mostly a sprinkling of epidote and small flakes of biotite and scattered opaque minerals. Locally a greenish hornblende may be abundant. The skarn minerals are most common in the coarser part of the rock or close to the borders of the larger fragments. Some agglomerates have been epidotized, which has emphasized the appearance of the primary structure of the rock, but in certain spots the alteration is so strong that the rock is completely dark, generally due to a strong biotitization. Often the epidote is accumulated to form a rock consisting of almost only epidote and quartz. It has often a vivid green colour.

Table 15. Greenstone-like skarn-bearing agglomerate. Cross-cut 217, 130 m level.

Analyst: A.-G. Hybbinette.

	Weight %	Mol. prop.	Actual mineral composition	
SiO ₂	53.46	8901	Quartz	11 weight %
TiO ₂	0.68	85	Plagioclase	36
Al ₂ O ₃	17.42	1709	(average andesine)	
Fe ₂ O ₃	1.27	119	Potassic feldspar	1.3
FeO	8.94	1244	Sericite	1
MnO	0.32	45	Biotite	9
MgO	4.16	1032	Chlorite	0.7
CaO	7.43	1325	Hornblende	36.5
BaO	0.16	10	Epidote	2.4
Na ₂ O	3.10 ¹	500	Prehnite	0.3
K ₂ O	1.64 ¹	174	Apatite	0.5
Cu	< 0.03		Ilmenite	1
Zn	0.02	3	Pyrrhotite	0.2
S	0.10	31	Chalcopyrite +	
P ₂ O ₅	0.23	16	Sphalerite	0.1
H ₂ O +	1.10	611	Tourmaline	tr.
H ₂ O —	0.07			
B ₂ O ₃				100.0 %
	100.10		Sp. gr. 2.86 (O. Alvfeldt)	

¹ Analyst: S. Henriksson.

A strongly altered rock of peculiar character occurring at several places close to the ore veins will be described in detail. It appears as rather a lengthened band or sheet of a greenstone-like rock. Megascopically the rock is fairly skarn-like, similar to the biotitized greenstone dykes. Ore veins follow the border of the rock, which is slightly mineralized.

The rock consists of acid to intermediate plagioclase, green hornblende, biotite, quartz, and epidote as main minerals with varying amounts of chlorite, garnet, chalcopyrite, pyrrhotite, and some sphalerite. Apatite, orthite, and locally microcline and calcite are of an accessory nature. The hornblende occurs as sheaf-like porphyroblasts growing across the other minerals. The plagioclase, which varies between oligoclase and labradorite, may be quite predominating, but it is not so abundant in the most altered rock type. The latter carries abundant biotite and has some garnet and sulphides. The quartz appears as a secondary mineral. Structurally the rock looks like a porphyrite (*i. e.* a dacitic porphyrite), though with secondary minerals obscuring the structure.

At first the rock was considered a lava within the banded complex. But a closer microscopical study showed that it is very inhomogeneous and it is

now looked upon as an agglomerate, chiefly consisting of oligoclase porphyry fragments. The secondary skarn minerals have given it a greenstone-like appearance.

A typical sample of the rock has been analysed (Table 15).

The hornblende is a bluish green amphibole rich in alumina and iron. The axial angle is $2V_{\alpha} = 64^{\circ} \pm 2^{\circ}$, the refraction indices $\alpha = 1.661 \pm 0.003$, $\beta = 1.674 \pm 0.003$, $\gamma = 1.688 \pm 0.003$ (T. Krokström). The hornblende is probably of a secondary nature. The chlorite is a ripidolitic penninite.

This kind of rock has a mineral composition that is very similar to the biotitized greenstones, and as it has been observed close to cutting greenstone dykes, it is probable that it got its rather abnormal composition with an abundance of lime-bearing skarn minerals from solutions emanating from the greenstones during their late crystallizing stage.

■ The greenstone dykes.

The greenstone dykes are always so altered that it is difficult to recognize any primary textures. Particularly the borders and the ends of the dykes and many thin dykes are very much altered. It is, however, possible to discern a relatively fresh and not very greatly recrystallized rock in the inner parts of some large dykes. The rock is here a hornblende-dacite-porphyry or quartz-bearing porphyrite with solitary plagioclase phenocrysts in a somewhat ophitic groundmass. The rock has generally also solitary phenocrysts or amygdules of quartz. Even the groundmass has a little free quartz.

The following mineral composition is typical of the fresh greenstone: hornblende 45 %, plagioclase 40 %, biotite 9 %, quartz 4 %, epidote 1 %, ore grains 0.5 %, titanite 0.3 %, apatite 0.2 %, and some traces of microcline. A little chlorite is common as a secondary product and prehnite sometimes occurs. The rock has an ophitic or trachyto-ophitic groundmass, which is more or less confused by the re-crystallized bundles of hornblende. The plagioclase varies between labradorite and oligoclase. The hornblende has the following pleochroism: γ strong bluish green, β grassgreen, α greenish yellow, but with very much varying intensity. The biotite shows a comparatively light brown colour, indicating the mineral to be poorer in iron and richer in magnesia than the biotite of the skarn rocks described earlier. It may also have some trivalent iron.

Ödman's paper contains an analysis of a typical greenstone dyke. The rock was rather fresh, but somewhat biotitized. The analysis will be quoted here with the mineral composition calculated, Table 16.

At the borders the greenstones generally show the strongest alteration, and a quite different textural appearance has resulted. The biotitization has in most cases destroyed all structures, but sometimes groundmass relics are visible which are similar to the liparitic rocks. The rock is thus similar to a liparite overgrown with secondary minerals. This alteration of the ends and the borders

Table 16. Greenstone. Drift 140, W part of 90 m level.

Analyst: Th. Berggren.

	Weight %	Mol. prop.	Norm		Actual mineral composition
SiO ₂	50.53	8413	Or	10.57	Quartz 6 weight %
TiO ₂	0.84	105	Ab	20.97	Plagioclase 34
Al ₂ O ₃	15.70	1540	An	26.42	(about An ₄₀)
Fe ₂ O ₃	2.11	132			Hornblende 40
FeO	7.67	1068	Sal	57.96	Biotite 14
MnO	0.24	34			Epidote 4.4
MgO	7.46	1850	Di	14.96	Titanite 0.8
CaO	9.47	1689	Hy	13.77	Apatite 0.7
BaO	0.04	3	Ol	6.59	Ore minerals 0.1
Na ₂ O	2.50	403	Mt	3.01	Prehnite tr.
K ₂ O	1.81	192	Il	1.52	
P ₂ O ₅	0.32	23	Ap	0.67	
H ₂ O +	0.91	505	Fem	40.52	
H ₂ O -	0.14				
S	0.03	9	H ₂ O +	0.91	
	99.77			99.39	100.0 %
Sp. gr.	2.859		III, 5, 4, 4, Auvergnose		
			Or:Ab:		
			An = 18.2:36.2:45.6		

of the greenstone dykes appear to emanate from the greenstone itself. It is considered as a reaction between the greenstone rest-solution on the one hand and the surrounding liparites and the already crystallized greenstone on the other, some components being dissolved and others precipitated. Narrow greenstone dykes have often altogether a character of reaction products.

At the end of the crystallization epoch there emanated from the greenstone the hydrothermal rest solution with abundant silica, potassium, alumina, iron, and magnesia and probably a separate phase rich in sulphides. Some parts of the greenstone dykes crystallized under the influence of these pneumatolytic-hydrothermal solutions and the parts earlier crystallized were recrystallized under this influence as mentioned above.

Also parts of the surrounding liparitic rocks have been permeated by the late solutions with a more or less strong alteration as a consequence, which often makes it difficult to draw the demarcation line between the liparite and the greenstone. Biotite and muscovite have been formed together with some garnet and epidote. Tourmaline is a sparse but typomorphic mineral. At first an increase in the anorthite molecule of the rock occurred, but later all the feldspar broke down and more epidote was formed, while almost all the sodium was carried away, and some silica at the same time. Then followed a more or less strong deposition of sulphides in the brecciated zones. In fissures more concentrated sulphide ores were deposited.

Table 17. Biotitized greenstones. Vol. percentage.

	a	b	c	d	e	f	g
Hornblende	6	7	5	21			
Plagioclase	14	15	0.1	3.7	23	28	tr.
Quartz	3	7	13	5	7	5.6	17
Biotite	49	60	76	28	58	61	71
Chlorite	4	1	1.3	20	0.2	1	0.7
Epidote (+ orthite)	17	10	4.5	22	11	4.3	10
Titanite	0.2	tr.	0.2	0.3	0.1	tr.	
Copper & iron sulphides	1	tr.		tr.	0.5	tr.	1
Sphalerite	4.7	tr.		tr.	0.1	tr.	0.2
Apatite	tr.	tr.	tr.		0.1	0.1	0.1
Garnet	0.1						
Calcite		tr.			tr.		
Sericite	1						

Narrow quartz-veins in some places cut obliquely through the greenstone dykes, and secretions of quartz have sometimes been found in the greenstone. In this rock, and particularly in the quartz, scheelite occasionally occurs, indicating it to be a late crystallization product of the greenstone magma.

Table 17 shows some typical altered greenstones. Compared with the fresh type these rocks have a lower content of plagioclase and hornblende. On the other hand, biotite is more abundant and the content of epidote relatively high. All microcline has broken down as well as some plagioclase, resulting in the formation of epidote and a carrying away of the sodium. Some specimens from the border of the greenstone dykes and from narrow dykes have no hornblende left at all. The chlorite formed at the expense of biotite and hornblende is a ripidolite. As in the fresh greenstones the biotite is more brownish than in the skarns. The epidote is fairly pistazitic and often orthitic. The hornblende is the sheaf-like bluish green type with varying intensity of colour.

As to composition and appearance these rocks are fairly similar to the metasomatically altered liparites though they are poorer in silica and richer in lime (epidote), which is due to the different composition of the primary rocks. Both rock types have, however, got a strong addition of K_2O , Al_2O_3 , FeO , and MgO , resulting in the formation of biotite as an important constituent. Because of the already primarily high content of magnesia and iron in the greenstones, the biotite completely predominates over sericite-muscovite.

The textural development of some biotitized greenstones is shown by the microphotos, figs. 6 and 7. The first shows an altered greenstone consisting of chiefly biotite, plagioclase, and epidote, while the other is from the border showing biotite enclosing relics of a liparite groundmass. The dark spots in the biotite are small halos formed by diminutive orthites.

Some greenstone dykes dissect the sulphide ores sharply and they are consequently younger than the chief metasomatic process. It is probable that the

less altered greenstones belong to this late intrusion epoch, but it is likely that a slight mineralization also accompanied these intrusions. The granite porphyry dykes generally cut the ores sharply. As a rule they are not impregnated by sulphide minerals but in some cases a weak dissemination has been observed, and this slight impregnation (with chiefly chalcopyrite) is scattered in such a manner that it is probable that the sulphides were formed later than the granite porphyry.¹ It is thus possible that this late mineralization may have arrived from the later greenstone dykes as these also cut the granite porphyry.

Conclusion. ¶The mineralogical and chemical alteration of the rocks.

The development of the secondary minerals will be described in the first place and the chemical aspect of the rock alteration afterwards.

In the liparite and the banded tuff primary quartz occurs chiefly as very fine grains in the groundmass of the rock. In the metasomatically altered rocks the quartz becomes the coarser the larger the skarn minerals grow in size. Due to the decomposition of the acid feldspars and to a development of more basic minerals, such as micas and intermediary plagioclase, an amount of quartz is set free, although the total content of silica has diminished. The most altered rocks consequently have a high percentage of quartz, though the percentage of silica in the rock is less than in the original rock. The altered greenstones have a conspicuous content of quartz, notwithstanding the fact that the norm of the rock may show a considerable content of olivine. The dense altered liparites may have a content of more than 50 % quartz although the SiO₂ percentage of the rock is much lower than of an ordinary liparite. This is chiefly due to the development of basic micas.

The content of acid feldspars, *i. e.* the albite in the plagioclase and the potassic feldspar (chiefly microcline), diminished in the formation of the skarn. The potassic feldspar is easily broken up and the potassium will be bound in the mica while quartz is set free. The albite decreases successively as the alteration increases and sodium is dissolved more and more, its content being very limited in the strongly altered rocks. The anorthite component, on the other hand, is more resistant and even increases in quantity in the first stage of alteration, but it is unstable in the completely altered rocks. Here it has been decomposed and epidote has been formed. In general the plagioclase is scarcer in the dense altered rocks than in the biotite skarn breccias, as the alteration is more complete in the former rocks. In the agglomerates in the banded tuff complex the plagioclase of the primary rock is not quite so sodic as in the liparite. The recrystallized plagioclase in the alteration product of these rocks is consequently often richer in anorthite, generally averaging An₄₀.

A secondary formation of sericite is common in almost all the altered rocks. It is ordinarily very fine-grained and has grown as a network through the rock. It was principally formed in the decomposition of the acid feldspar. In the

¹ And not mobilized by it as suggested by Ödman (*loc. cit.*, p. 28).

coarse rocks it may also appear as leaves or bundles and it is often intergrown with biotite. Judging from the slightly brownish colour of the muscovite and from the analyses of the rocks it ought to be rich in iron. In the dense altered rocks the sericite is very abundant, but in the biotite skarn breccias, where the content of magnesia and iron is higher, it is generally much less common than the biotite.

The biotite of the altered liparites is generally a megascopically greenish mineral rich in divalent iron and alumina. In the rocks with an originally fairly high content of magnesia the biotite will not be quite so rich in iron, and as it has also some content of trivalent iron, it is more brownish in colour. The biotite often contains small spools of prehnite and tiny orthite grains with dark halos. In the skarn-rich rocks the biotite often contains some green spinel, according to the rock analyses an iron-bearing pleonast, which indicates that all of the excess alumina and magnesia cannot be contained in the biotite molecule.

The red garnet of the altered rocks is an almandite with a relatively high content of spessartite and grossularite.

The biotite as well as the garnet is hydrothermally altered into a strongly green delessite-prochlorite with a weak birefringence. In the alteration products of the more basic rocks it is closer to penninite.

The metasomatically altered rocks always contain some epidote, as a rule a megascopically yellowish green, pistazitic type, often with a core of orthite but generally the epidote and the orthite form separate grains. The epidote is usually very fine-grained and the epidote amount of the rock is often about 1%. In some altered agglomerates the content of epidote is conspicuous and in certain cases genuine epidote skarn appears. In the altered basic rocks, such as dacites and greenstones, the percentage of epidote will be much higher than in the altered liparitic rocks.

The green hornblende is observed as a skarn mineral in some altered agglomerates. The green hornblende of the greenstones is of the same type, *i. e.* with pleochroism from bluish green to greenish yellow, but it has a somewhat varying intensity of colour, being generally a little paler due to a lower content of iron and alumina than the hornblende of the altered agglomerate. The hornblende of the greenstone is always a recrystallized mineral intersecting the primary minerals, and it is probable that the chemical composition was influenced by the pneumatolytic-hydrothermal solutions.

The bluish tourmaline is a scarce but almost always present product of the skarn mineralization. It may be considered a typomorphic mineral indicating the pneumatolytic character of the solutions effecting the recrystallization of the rocks.

The strongly altered rocks usually have some magnetite, which appears as porphyroblastic grains, often with conspicuous cleavage planes giving the magnetite a lamellar appearance. A chemical analysis of this magnetite showed that it had only a fraction of one per cent of MnO and TiO₂.

The dense metasomatically altered rocks always carry accessory sulphide

grains, generally one or a few tenths of one per cent of pyrrhotite and sphalerite and a little less of chalcopyrite. In the skarn-brecciated rocks the sulphide content is usually more conspicuous and most of these rocks form skarn-sulphide breccias with fairly much chalcopyrite and pyrrhotite but an insignificant amount of sphalerite. There are locally other sulphides of less abundance, such as arsenopyrite, marcasite, cubanite, pyrite, molybdenite, galena, valleriite, etc. The mineral composition of the Laver sulphide ores has been more closely described by Ödman. Ilvaite has also been observed by him in the ore veins.

As to the distribution of the altered rocks, the biotite and skarn breccias generally accompany the breccia ores. The richest breccia ores as a rule have the strongest biotite and skarn brecciation.

The ore vein bodies are often also accompanied by an enrichment of skarn minerals, but the variations in the development of secondary minerals are here still greater than in the breccia ores. Some ore veins thus contain but a very small amount of skarn minerals and enclosed portions of the wall rock are more or less silicified liparitic rocks.

The main ore vein body of the deposit, the CDE body at the boundary of the liparite and the banded complex, is often accompanied by brecciating ore on the liparite side, this ore generally being associated with a strong biotite brecciation. On the banded tuff side of the ore vein the wall rock is often altered to a dark, dense rock which may have visible streaks of biotite, but sometimes the rock is very little altered. Where the wall rock is an agglomerate breccia the formation of secondary minerals is generally conspicuous. Besides the usual skarn minerals a formation of epidote or hornblende skarn is often met with. In addition to chalcopyrite and pyrrhotite (pyrrhotite is more abundant here than in the breccia ores), arsenopyrite may be locally abundant, often as a dotting of rounded grains.

The dense altered rocks are most strongly developed at or between dissecting ore veins, faults, and brecciating zones. The dark dense rocks are thus most common in fissured and shattered areas.

Within the large breccia ores, the A1 and A2 bodies, the biotite and skarn brecciation accompanying the ore brecciation decreases on the lower levels, at the same time as the areas of these ores have diminished. The general alteration of the rocks also seems to be stronger on the 50 m level than on the lower levels (130 and 170 m levels). Where new ore bodies are met with, the alteration of the bed-rock is again rather strong. It is thus probable that the formation of micas and other skarn minerals, *i. e.* the metasomatism, is most strongly developed around the upper parts of the ore bodies.

To give a better idea of the chemical distinction of the analysed rocks a compilation of the Niggli values will be given, Table 18.

The analysed liparite is a little too rich in silica and potassium to correspond to an average of the fresh liparites.

The banded tuff has a quartz-keratophyric composition corresponding to a

Table 18. Niggli values of analysed rocks.

	si	ti	al	fm	c	alk	k	mg	c/fm
1. Liparite	645	0.3	45.8	8.9	6.5	38.8	0.48	0.00	0.73
2. Banded tuff	407	1.1	41.3	17.7	7.7	33.4	0.21	0.00	0.43
3. Greenstone	121	1.5	22.3	44.7	24.5	8.5	0.32	0.6	0.55
4. Copper ore breccia	156	0.3	20.2	61.2	8	10.6	0.37	0.17	0.13
5. Micaceous skarn & ore breccia	187	0.3	23.5	66.5	2.6	7.3	0.72	0.19	0.04
6. Mica- and skarn-rich ore	123	0.24	26.4	55	7.3	11.3	0.5	0.28	0.07
7. Biotite skarn breccia in skarn- rich ore	74.3	0.3	31.3	56	2.7	10	0.94	0.26	0.05
8. Biotite skarn breccia	262	0.1	30.3	50.6	9.2	9.9	0.48	0.36	0.18
9. Micaceous liparite	474	0.1	44.6	35	2.6	17.8	0.8	0.18	0.08
10. » »	356	0.01	146.6	38	1.4	14	0.94	0.25	0.14
11. » quartz keratophyre	252	0.01	144	25	12.5	18.5	0.28	0.23	0.5
12. Biotitized dacite	124	0.1	33.4	32	20.8	13.8	0.45	0.47	0.65
13. Metasomatically altered banded tuff	287	0.1	44.7	38.7	2.2	14.7	0.85	0.22	0.06
14. Metasomatically altered agglom- merate	146	1.4	28	39.3	21.7	11	0.26	0.43	0.55

trondhjemitic magma type. Among the coarse tuffs and agglomerates the lime content is usually somewhat higher. There are also banded tuffs, which are close to the liparite in composition although not so rich in potassium as the one analysed. Both the analysed liparite and tuff show how very low is the primary content of magnesia in the fresh rocks.

The analysed greenstone is close to Niggli's gabbro-dioritic magma type. It probably obtained a higher k value in the biotitization.

The breccia ore, No. 4 (analysis Table 6), has a very high fm value due to the large addition of chalcopyrite and pyrrhotite. As the rock has many relics of liparite, the alk content is not especially low and the potassium-sodium proportion is fairly normal. The anorthite proportion of the feldspar has increased though it is not obvious in the Niggli values. The si value of the rock is low. About 22 % of quartz is free, but as the rock contains predominatingly basic minerals, the si value must be low. Some silica of the original rock must have been carried away.

The skarn- and copper ore breccia, No. 5 (analysis Table 5), has not only sulphides but also much magnetite, and the fm value is consequently high. The rock is strongly altered and the sodium content is therefore low, and the lime is also low as the greater part of the feldspar has disappeared. As the rock is rich in mica, the k value is high, but the mg is not high, this due to the abundant content of iron. The rock has about as much free quartz as a granite, but owing to the abundance of ore and orthosilicate minerals, the si value will be low, but not so extremely low as in the skarn-rich ore and skarn, Nos. 6 and 7, which otherwise have a relatively low c and a high k value. The degree

of alteration is here higher, so that al and mg have increased, notwithstanding the high iron content. All the breccia ores naturally have a high iron content, owing to the addition of much chalcopyrite and pyrrhotite. The magnetite content, which may be conspicuous, was deposited at the same time as the skarn minerals. In spite of the great addition of iron the altered rocks are poor in titanium and the ti value is about the same as in the primary rocks. The ti value of the dense altered rocks poor in ore minerals is, however, still lower.

The skarn breccia poor in ore minerals, No. 8, as compared with the rocks above, has a lower fm value and at the same time higher mg and si values. The increased c value is due to the high content of anorthite and garnet.

The dense altered rocks are richer in silica than the biotite brecciated rocks, as they have more free quartz and much sericite instead of some biotite. The much altered rocks are rich in potassium and low in lime, except those that primarily were prominent sodium-lime-bearing rocks. The al content is high and the fm low in the dense rocks due to much mica and a low percentage of ore minerals.

The metasomatically altered banded tuff, No. 13, has a composition analogous to the altered liparites, this on account of strong formation of mica and the almost complete decomposition of the feldspar content. The rock thus has a low c value but a high k value.

The metasomatically altered agglomerate, No. 14 (Table 15), has a composition that is fairly similar to that of the greenstone, No. 3. The mineralogical as well as the chemical composition indicates a conspicuous addition of material from the rest solution of the greenstone, so that the resulting composition is similar to that of the greenstone.

In order to determine more closely the addition or subtraction of material in the metamorphism of the rocks, the altered rocks will be compared with the primary ones and the difference in composition calculated, the assumption being that the volume has been constant. In the first place an average of the much altered ordinary liparites of Tables 10 and 12 will be compared with the fresh liparite.

During the alteration of the original liparite iron and alumina were first added and then magnesia and water and to a lesser extent some sulphides. The contents of potassium and titanium were not greatly altered. The subtracted substances were first of all silica and sodium and then also some lime.

	Average of the rocks in Tables 10 and 12	Fresh liparite	Difference
SiO ₂	71.55	81.43	- 9.88
TiO ₂	0.15	0.06	+ 0.09
Al ₂ O ₃	13.64	9.80	+ 3.84
Fe ₂ O ₃	1.76	0.37	+ 1.39
FeO	5.23	1.15	+ 4.08

	Average of the rocks in Tables 10 and 12	Fresh liparite	Differences
MgO	0.95	0.00	+ 0.95
CaO	0.31	0.76	- 0.45
Na ₂ O	0.38	2.64	- 2.26
K ₂ O	3.78	3.66	+ 0.12
H ₂ O	1.39	0.11	+ 1.28
Zn	0.10		+ 0.10
Cu	0.24		+ 0.24
S	0.52	0.02	+ 0.50
	100.00	100.00	± 12.59

A comparison between the altered banded tuff and the unaltered rock discloses the following quantities:

	Altered tuff in Table 14	Fresh banded tuff	Difference
SiO ₂	65.28	74.34	- 9.06
TiO ₂	0.38	0.26	+ 0.12
Al ₂ O ₃	17.14	12.80	+ 4.34
Fe ₂ O ₃	1.13	0.53	+ 0.60
FeO	7.90	3.56	+ 4.34
MgO	1.27	0.01	+ 1.26
CaO	0.46	1.31	- 0.85
Na ₂ O	0.53	4.98	- 4.45
K ₂ O	4.44	2.02	+ 2.42
H ₂ O	1.29	0.10	+ 1.19
Zn	0.06		+ 0.06
S	0.12	0.09	+ 0.03
	100.00	100.00	± 14.36

The conditions in this alteration are thus very similar to those discussed above, the same substances being added and subtracted and to almost the same amounts, with the exception of the potassium, which shows a much greater increase here. During the alteration the percolating solutions have thus chiefly given off iron, alumina, magnesia, water, and potassium, while silica, sodium, and some lime have been carried away.

The biotite-skarn brecciated liparite, analysis Table 7, will also be compared with the fresh liparite:

	Biotite-skarn breccia	Liparite	Difference
SiO ₂	65.91	81.41	- 15.50
TiO ₂	0.36	0.06	+ 0.30
Al ₂ O ₃	12.98	9.79	+ 3.19
Fe ₂ O ₃	0.63	0.37	+ 0.26
FeO	9.05	1.15	+ 7.90
MnO	0.42	0.03	+ 0.39

	Biotite-skarn breccia	Liparite	Difference
MgO	3.07	0.00	+ 3.07
CaO	2.17	0.76	+ 1.41
Na ₂ O	1.32	2.64	— 1.32
K ₂ O	1.85	3.66	— 1.81
H ₂ O	1.61	0.11	+ 1.50
Cu	0.01	—	+ 0.01
Zn	0.18	—	+ 0.18
S	0.13	0.02	+ 0.11
P ₂ O ₅	0.19	0.00	+ 0.19
Mo	0.03	—	+ 0.03
B ₂ O ₃	0.03	—	+ 0.03
F	0.06	—	+ 0.06
	100.00	100.00	18.63

This comparison shows a gain chiefly of iron, alumina, magnesia, lime, and water and a loss of silica, potassium, and sodium. As compared with the alteration to the dense altered rocks, the table above indicates an addition of lime and a subtraction of potassium, which does not agree with the conditions described before. The alteration of the biotite-skarn breccias is not a stabilized reaction, and particularly in the case of lime and potassium conditions are different in different cases. As described earlier, lime has often increased in the first phase of alteration but may have been carried away later on. Certain rocks will thus show a gain in lime and others a loss as compared with the liparite. As to the potassium, it has sometimes increased and sometimes decreased, but on the whole it is probable that it did not change very much. Otherwise the breccias also show a greater addition of magnesia than in the case of the dense rocks as well as a greater loss of silica.

In the case of the ore breccias, the addition of iron, copper, and sulphur is very prominent and thus somewhat changes the proportion of the other substances as compared with the biotite-skarn breccia referred to above.

A general summary of the alterations of the rocks, as regards the addition or subtraction of substances, thus clearly shows that iron, alumina, magnesia, and some water have been added in all cases. Silica and sodium always show a loss. The composition of the dense altered rocks indicates that potassium has also been added. In the formation of the skarn- and ore breccias the addition of iron and magnesia has been prominent. Lime, too, has often been added. The addition of titanium is very slight but it is more evident in the case of the skarn- and ore breccias. The subtracted substances are chiefly silica and sodium. In some cases lime has been subtracted and in a few cases also potassium. The silica subtracted from the primary rock seems mainly to be that which was originally bound with sodium in the albite molecule. In some cases more silica has been carried away and in other cases less.

The first metasomatic soaking of the original rocks probably occurred subsequently to and in close connection with the intrusion of the greenstone dykes,

but the main ore deposition and mineral brecciation which succeeded the first metasomatism, probably emanated directly from the mother liquid of the dyke rocks in the shattering of the wall rocks during the cooling stage of the former.

It is not possible to ascertain whether the ore-forming solution came as one mixed liquid containing both the elements of the skarn and of the ore minerals, or in two fractions, one liquid fraction from which the skarn minerals crystallized and one fraction, liquid or gaseous, from which the ore minerals crystallized. The former explanation may be more likely in view of the close association of the skarn and ore mineralizations.

The Laver deposit must be considered a high-temperature, (pneumatolytic-) hydrothermal formation. Because of this, the addition of K—Al—Mg is more pronounced in the Laver deposit than in most of the other copper deposits of the Skellefte district, which are generally considered to have been deposited farther away from the magmatic source, so that the solutions had already rid themselves of the excess of the elements mentioned above.

The metasomatic process is chiefly considered to have been a replacement with a fairly constant volume, though the marked shattering of the region of the main ore bodies (with later readjustments by faults) may indicate a greater addition than subtraction of material. The smaller content of some of the original elements in the ore as compared with the content in the completely metasomatically altered, dense rocks is thus best interpreted by supposing that more material was added than was subtracted. In the altered rocks, however, it is more likely that the gains and losses equalized one another.

The author desires to express his gratitude to the Managing Directors of the Boliden Mining Company for their kind permission to publish this paper.



Fig. 1. Biotite skarn and ore breccia. Cross-cut 202, 130 m level. About 1/10 nat. size.

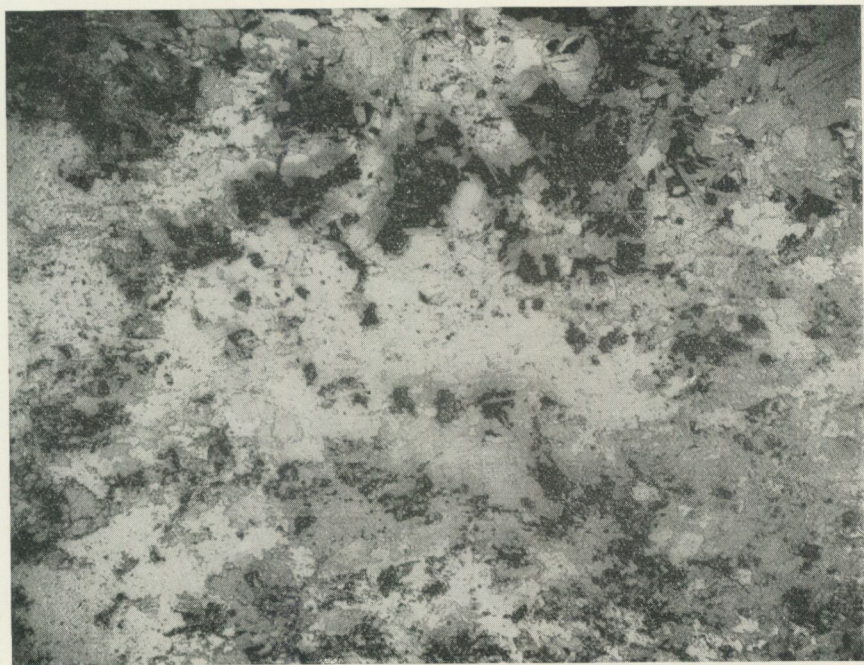


Fig. 2. Biotite and sulphides brecciating liparite. The A-ore, about 74 m level. 10 X, ordinary light.

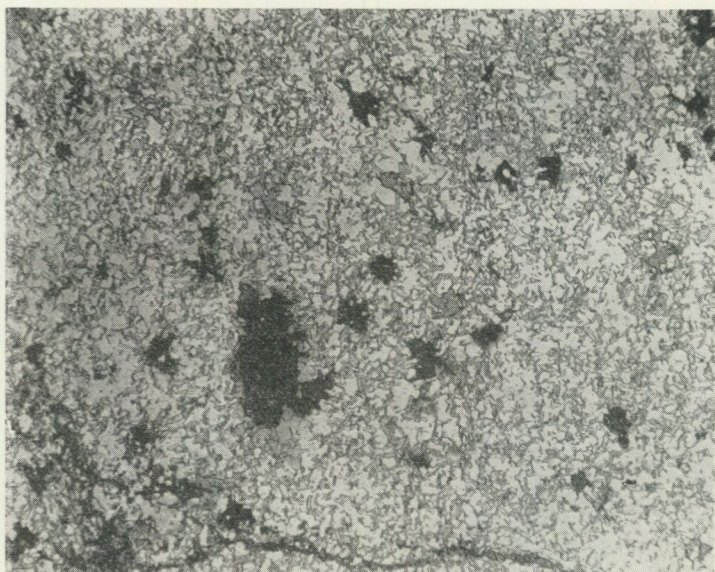


Fig. 3. Dense micaceous liparite with chiefly biotite, sericite, and quartz. 90 m level. 40 X, ordinary light.

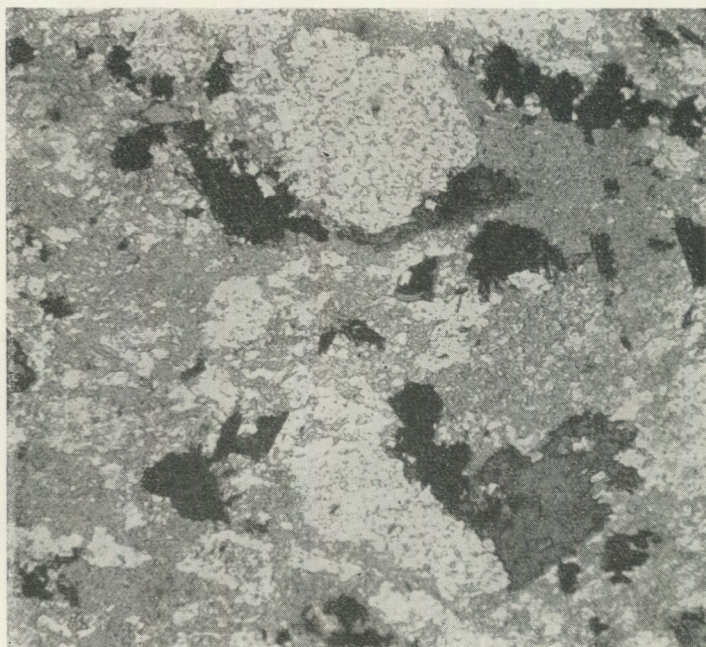


Fig. 4. Micaceous liparite with fine-grained sericite and porphyritic biotite (dark gray to black). White is chiefly quartz. Cross-cut 20, 50 m level. 45 X, ordinary light.

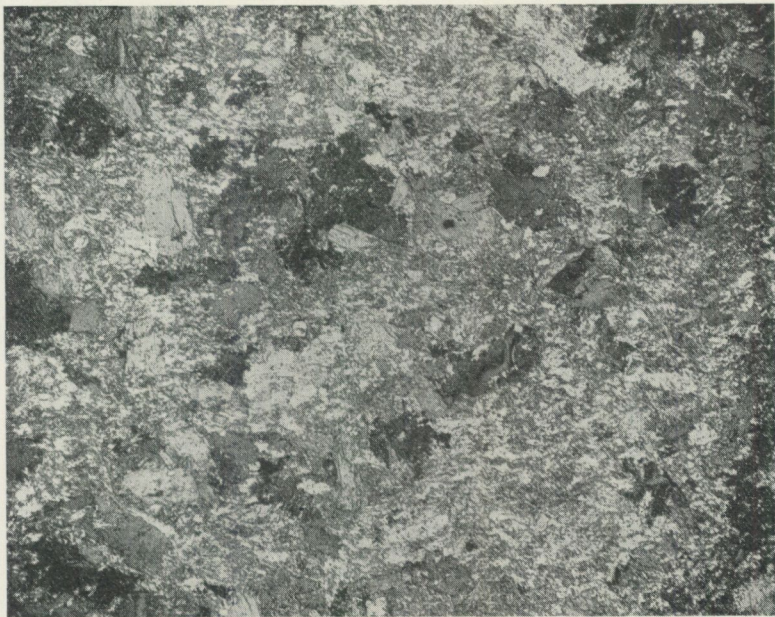


Fig. 5. Strongly altered banded tuff. Coarse-grained biotite, fine-grained sericite, a few ore minerals and garnet, very little quartz. 90 m level, 10 X, ordinary light.

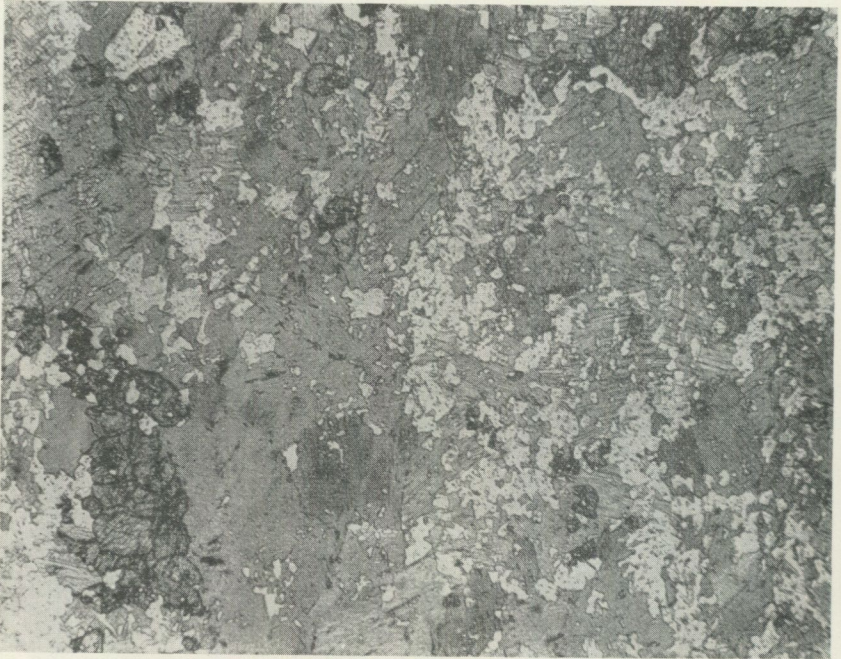


Fig. 6. Biotitized greenstone dyke. The rock consists chiefly of biotite, quartz, and epidote. 90 m level. 51 X, ordinary light.



Fig. 7. Border of greenstone dyke. It is mainly remnants of liparite between biotite grains. Dark spots are halos round orthite grains. Cross-cut 20, 50 m level. 51 X, ordinary light.

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