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SPECTROCHEMICAL INVESTIGATIONS OF SULPHIDE MINERALS FROM THE ORES OF THE SKELLEFTE DISTRICT

ON THE SIGNIFICANCE OF MINOR CONSTITUENTS FOR CERTAIN PRACTICAL AND THEORETICAL PROBLEMS IN ECONOMIC GEOLOGY

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Contents.

Introduction.

By S. Gavelin.

Spectrochemical analyses of the minor constituents of ores as well as of their gangue minerals and wall rocks have during recent years proved to be a valuable aid in treating problems connected with economic geology. By these investigations both practical and theoretical results have been obtained. From a metallurgical point of view it is obviously of great importance to know the amount and distribution even of small concentrations of certain chemical elements that may be of importance for the refining processes and which may influence the character of the substances to be extracted from the ore. From a theoretical point of view a knowledge of the distribution of the minor constituents may in certain cases be expected to be valuable in elucidating the history of the formation of an ore deposit. However, an ore body is generally a complex mixture of several minerals with mutually different crystal structures, and the various minerals consequently have a different tendency to include various minor constituents in their crystal lattices. In order to obtain commensurable values it is therefore necessary to regard each ore mineral separately.

Several studies dealing with the minor constituents in sulphide minerals have already been published, sphalerite (6a, 8, 12, 18, 20, 23), pyrite (1, 2, 3, 4, 13, 19), pyrrhotite (2, 4, 13, 19), and chalcopyrite (13, 19) being the minerals most thoroughly analysed. Attempts have been made to find a systematic relation between the amount and kind of minor constituents, on the one hand, and the temperature of formation of various mineral assemblages or the province in which the ore deposits occur, on the other. In several cases a kind of systematic relation has indeed been discerned. However, there are probably also other factors that may play an important part, for instance the state and composition of the ore-forming fluids, and therefore it is often very difficult in each special case definitely to establish what may be the cause of a certain association of elements. Further, in many cases the material presented makes it quite difficult to decide to what extent the different factors cooperate or counteract each other with regard to the final result. In the present investigation I have mainly treated material from ore deposits where I am well familiar with the general geological appearance of the various mineral associations. In many cases the ore deposits examined are quite small, but this seems rather an advantage in view of the aim of the research.

The most detailed and comprehensive reports on the ores to be treated here have been submitted by Alvar Högbom (14), S. Gavelin and E. Grip (11). The ores of the Malånäs District, from which a great deal of the material now examined is sampled, have been described in detail by the present author (9). The great majority of the deposits can be characterized as pyrite-pyrrhotite ores with a varying amount of copper and zinc. From these ores differ the ores of the Adak District (with the exception of Rudtjebäcken) and the Laver ore, in which pyrite plays a very subordinate part.

Many of the ore deposits are characterized by a very obvious separation into, on the one hand, pyritic copper ores and, on the other, pyritic zinc-lead-silver ores, a differentiation already earlier discussed by the author (9, 10). As a special type and one very characteristic for the Skellefte District may further be mentioned a dense arsenopyrite ore. This latter is best known from Boliden (16) but has also been found in some of the deposits treated in the present paper. From copper and zinc ores, respectively, there are to be found all stages of transition to pyrite and pyrrhotite ores, relatively free from copper and zinc.

In Table 1 is presented a short survey of the most characteristic chemical, mineralogical, and structural features of each ore deposit. Three ore-bearing regions in the Skellefte District are represented by several analyses from each ore deposit: Ores Nos. 1—5 represent the Malånäs Area (within the central part of the Skellefte District), Nos. 6—8 represent the Kristineberg—Rävliden Area (in the south-western part of the Skellefte District), and Nos. 9—11 the ores of the Adak Area (in the north-western part of the Skellefte District). Further we have the Laver Ore, No. 12, which is situated to the north of the Skellefte District proper.

In addition to the material from these 12 ore deposits a number of samples from other ore bodies or sulphide disseminations have been investigated. In these cases, however, only solitary specimens from each locality could be obtained. The principal object was to find out if any special type of mineralization could be unmistakeably characterized by the aid of the minor constituents and to increase the number of analyses for statistical surveys. On account of the dispersion of the analytic values for the deposits treated by several analyses, solitary values from one locality do not of course necessarily represent the most characteristic values of the locality in question.

The object of the present investigation is practical as well as theoretic. The practical aim, the desirability when refining the ores to possess as much knowledge as possible about all the constituents of the various ore types, has already been mentioned. Furthermore, a knowledge of the minor constituents in the ores may be of great value in prospecting. It might be possible, for instance, upon establishing the existence of fairly high contents of, say, Sn or Mo, to delimit areas in which prospecting for these metals would be particularly promising. As regards the Skellefte District it is, however, possible to discern a problem of more direct importance. The majority of the ores in the poorly exposed areas of the Skellefte District were originally indicated by finds of loose ore boulders. By systematic searching a great many such boulders have been recorded. In some cases, when the boulders have been transported great distances, there may be some uncertainty as to the source. It is, for instance, quite possible that an ore boulder, originally regarded as originating from a known ore deposit, may in fact come from an ore body not yet discovered. In this case it would, of course, be of great value if the distribution of the minor constituents could be used as a guide to determine whether or not a certain ore boulder originates from a deposit already known.

From a theoretical point of view many questions have to be considered. Factors which may influence, and some of which as already shown by the results so far published in fact do influence the distribution of the minor constituents in the sulphide minerals, are: The original genesis of the ore, the temperature of crystallization, the geologic milieu of the ore bodies, the chemical composition of the ores, and the degree of »secondary» metamorphism.

The most abundant sulphide minerals in the ores of the Skellefte District are pyrite, pyrrhotite, chalcopyrite, sphalerite, galena, and arsenopyrite. The sphalerites have already been examined by O. Gabrielson with regard to minor constituents. Most of the ore deposits rich in sphalerite treated in the present paper were examined by Gabrielson. In the present study pyrite, pyrrhotite, chalcopyrite and arsenopyrite have been analysed. Among these minerals pyrite, pyrrhotite, and chalcopyrite from other districts have been treated before, especially with regard to the contents of Co and Ni. Quantitative analyses have been made of Co, Ni, Mn, Cu, Pb, and Ag (see below pp. 6—7), while a number of other metals have been substantially determined qualitatively. The metals thus searched for are Zn, As, Au, Bi, Sb, Mo, Sn, Ti, V, W, Cr, and in some cases the rare elements Cd, Ge, Ga, Ta, Tl. However, as will be shown later only Co, Ni, Mn, and to a certain extent Bi and Sn can be used in a broader sense as significant elements — pilot elements — for the purposes of the present research.

The spectrochemical work was done in the Geochemical Laboratory of the Geological Survey of Sweden by Dr. O. Gabrielson.

The analytical methods were elaborated by Gabrielson under the guidance of Dr S. Landergren, head of the Geochemical Laboratory. I am also greatly indebted to Dr Landergren for many inspiring discussions on geochemical problems during this work. Below Gabrielson gives an account of these methods, their accuracy, and the lower limits of determinability. The separation of the sulphide minerals, where required, has also in most cases been performed by Gabrielson.

Analytical Methods.

By O. Gabrielson.

The purest material possible was selected under the binocular. The samples thus obtained were subjected to magnetic separation by means of a strong electro-magnet, whereby the pyrrhotite could be separated from the other minerals. In certain cases some magnetite was present in the pyrrhotite fraction.

All the samples were subjected to optic spectrochemical analysis at the Geochemical Laboratory of the Geological Survey of Sweden. The analyses were performed with the aid of a quartz spectrograph of the type Zeiss Q 24, the source of light being a permanent electric arc (220 V, 8 Amp.). The method, mainly as recommended by R. Mannkopff and Cl. Peters (15), was described in detail in the author's earlier paper (8).

The quantitative determinations of Co, Ni and Mn were effected according to the visual method of estimation elaborated by L. W. Strock (21). Fe was used as an internal standard and proved to be quite acceptable, as the Fe-contents are on the whole constant in the separate sulphide minerals analysed. Standard series of Co, Ni and Mn were set up in the following concentrations: 3.33 % (for arsenopyrite), 1.0, 0.67, 0.33, 0.1, 0.067, 0.033, 0.01, 0.0067, 0.0033, and 0.001 %. In order to obtain as uniform experimental conditions as possible four different standard series had to be set up: with pyrite, pyrrhotite, chalcopyrite, and arsenopyrite, respectively, as base substances.

The spectral lines used in the visual estimation are listed in the following table.

Element	Spectral lines used	Internal standard lines	Lower limit of determinability
Co	3453.51 Å	Fe 3445.15 Å	0.001 %
Ni	3050.82 Å	Fe 3055.26 Å	0.001 %
Mn	2798.27 Å	Fe 2797.78 Å	0.001 %

The standard deviation in the visual estimation of Co, Ni and Mn has been calculated to be: Co ± 14 %, Ni ± 18 %, Mn ± 18 %.

A qualitative analysis of certain elements has also been carried out, a visual estimation (with three groups) being made of the elements on the basis of the relative intensity of the lines.

The elements determined qualitatively are listed in the following table, which also shows the lines used in the analyses and the lower limits of determinability for the respective elements.

Element	Spectral lines used	Lower limit of determinability
Au	2676.0 Å	0.003 %
Zn	3282.3 »	0.01 »
Cd	3261.1 »	0.01 »
Ga	2943.6 »	0.001 »
In	3039.4 »	0.001 »
Tl	2767.9 »	
Ge	2651.2 »	0.001 »
Sn	3175.0 »	0.005 »
Pb	2833.1 »	0.001 »
Ti	3349.4 »	0.003 »
As	2349.8 »	0.03 »
Sb	2598.1 »	0.03 »
Bi	2898.0 »	0.01 »
V	3184.0 »	0.001 »
Ta	2714.7 »	
Te	2385.8 »	
Cr	4254.3 »	0.003 »
Mo	3170.3 »	0.003 »
W	2944.4 »	0.01 »

Survey of the Results.

By S. GAVELIN.

The Influence of ›Impurities‹ on the Analytical Results.

The majority of the samples examined originate from ores that I studied also under the microscope. In many cases the sulphide minerals are so intimately intergrown that completely pure material for the spectrochemical analyses cannot be obtained. The amounts of Cu, Zn, Pb, Sb, and As as disclosed by the analyses may in all cases where these metals have been proved originate from admixtures of chalcopyrite, sphalerite, galena, Pb-Sb-minerals, and arsenopyrite. The determinations of these elements are in the present case only of interest in order to establish the »purity» of the material examined and to decide to what extent an »impurity» present may influence the values of the element to be determined. Cd, Ga, In, Ge, for instance, are often enriched in certain sphalerites. However, in no case has it been possible to identify these elements, and as none of the other elements treated below are enriched in sphalerite, a slight admixture of this mineral cannot influence the results. Mo, Cr, W, Ta, Tl have not been proved anywhere for certain, and therefore need not be further discussed in this connection. Earlier examinations of the ores in question have shown Ag to be considerably enriched in ores with high contents of Pb and Sb (9, 10) and consequently Ag-values are of interest only when Pb and Sb are absent. The errors of the spectrographic Ag-determinations are, however, comparatively large, and therefore the Ag-values (within the range of dispersion as found by this investigation) are of but little interest.

V has only been proved in three cases, all three in pyrites. Au could never be proved with certainty by the spectrochemical methods used. Ti is often present, especially in pyrrhotites. However, the microscopic examinations show that ilmenite is a very common constituent of the sulphide ores and that the mineral often occurs in a fine-grained form, sometimes intergrown with the sulphides. Thus, the titanium contents found may quite well be caused by inclusions of ilmenite and are therefore of doubtful value as indicators of the Ti-content of the sulphide minerals examined. Sn and Bi occur more or less occasionally and will be treated separately. The greatest interest, however, attaches to the occurrence of Co, Ni, and Mn, partly because they were found in all the sulphide minerals examined, and partly because these elements have been treated comprehensively in earlier studies.

The investigations carried out by Hegemann show that in the ore deposits treated by him the Co- and Ni-contents of the gangue minerals are always fairly insignificant compared with those of the sulphide minerals. The attempts to obtain material almost free from gangue minerals generally did not offer any serious difficulties in the present case. Tests in order to confirm the Si- and Al-contents have clearly shown that no correlation exists between extreme values of Co or Ni, on the one hand, and Al and Si, on the other, and consequently no distraction of the analyses may be feared by fortuitous contaminations from gangue minerals.

Gabrielson's investigations of the amounts of Co and Ni in sphalerite from zinc ores in the Skellefte District show that these metal contents in most cases lie below the limit of determinability, and where they can be determined they are so low that no errors of any significance can arise even though minor intermixtures of sphalerite may exist.

The Cu- and As-contents found in pyrite and pyrrhotite give a measure of the possible intermixture of chalcopyrite and arsenopyrite. With a knowledge of the approximate contents of Co, Ni, and Mn in these last-mentioned minerals it is possible to calculate the influence of such intermixtures on the analyses of pyrite and pyrrhotite. In an analogous way we can by examining pyrrhotite and pyrite from the same specimen establish to what extent a contamination of pyrrhotite in pyrite (or *vice versa*) may influence the results.

Survey of the Co-Ni-Mn-Values.

In Table 1 is presented a survey of the Co-, Ni-, and Mn-values of the entire material subjected to spectrochemical analysis. In order to make it easier for the reader to keep the various minerals apart in the following discussions, the first figure in the number of the analyses is specific for each mineral:

Pyrites have been given numbers 1—134, arsenopyrites begin with No. 301 (301—339), pyrrhotite begins with No. 401 (401—500), and chalcopyrite with No. 601 (601—632). When an element has not been proved the sign — has been used. The sign < 0.001 (lower limit of determinability) denotes that the element has been proved but that the concentration is below the limit for which quantitative values can be stated.

Table 1.

1. *The Bjurträsk Ores.*

General characteristics of the ores: The principle ore is a complex pyrite-pyrrhotite ore with varying amounts of zinc. Cupriferous portions also occur, but only occasionally. One small, separate chalcopyrite-pyrrhotite ore body, »the Southern Ore». The gangue and wallrock minerals indicate comparatively high temperature: Spinel, garnet, cordierite, cummingtonite, hornblende.

Samples analysed; characteristics of the various specimens.

No.		*)	No.	% Co	% Ni	% Mn
				Pyrite		
1	Trench IV: Dissemination of pyrite and pyrrhotite in chlorite-rock containing andalusite and magnetite.	i	1	0.03	—	0.5
2	= 402 Trench V: Porphyritic pyrite crystals in pyrrhotite. Some sphalerite and chalcopyrite.	p	2	0.07	—	0.02
3	Trench III: Even-grained, quartzuose pyrite ore with some pyrrhotite.	p	3	0.03	—	0.02
4	Trench II: Coarse-grained pyrite ore with sphalerite.	z	4	0.03	—	0.03
				Arsenopyrite		
301	Southern ore: Crystals of arsenopyrite in chlorite-quartzite.	i	301	0.33	<0.001	0.03
				Pyrrhotite		
401	Trench IX: Compact pyrrhotite ore.	p	401	—	<0.001	0.03
		p	402	0.003	0.01	0.1
403	Trench III: Pyrrhotite with bands of sphalerite.	z	403	—	<0.001	0.2
404	Trench II: Coarse-grained zinc-rich pyrite-pyrrhotite ore.	z	404	—	—	0.03
405	= 602 Southern ore: Chalcopyrite-pyrrhotite ore.	c	405	0.03	<0.001	0.01
				Chalcopyrite		
601	Trench V: Porphyritic pyrite in pyrrhotite with some chalcopyrite.	c	601	—	<0.001	0.01
		c	602	—	—	<0.001

2. *Bjurliden.*

General characteristics of the ore: A complex zinc ore with pyrite and pyrrhotite in varying amounts. Sphalerite and pyrite often in alternating bands. Galena very irregularly distributed. The gangue and wallrock minerals indicate comparatively high temperature: Spinel, garnet, staurolite, andalusite, hornblende.

Samples analysed; characteristics of the various specimens.

No.		*)	No.	% Co	% Ni	% Mn
				Pyrite		
5	»Outcropping ore, 11»: Fine-grained, banded, pyritic zinc ore.	z	5	—	—	0.1
6	»Outcropping ore»: Large pyrite cubes and fine-grained pyrite in sericite-quartzite with spinel.	p	6	—	—	<0.001
7	»Shaft A»: Fine-grained pyrite bands in quartzite.	p	7	0.007	—	0.005
8	= 412 Trench II: Porphyritic pyrite in pyrrhotite. High-grade sphalerite-galena bands.	z	8	0.07	—	0.05
9	Trench II: Pyrite ore with high-grade sphalerite bands.	z	9	0.07	<0.001	0.01
10	Trench II: Fine-grained pyrite ore with sphalerite bands.	z	10	0.05	<0.001	0.02

*) i = sulphide impregnation; p = »pyrite ore»; z = »zinc ore»; c = »copper ore»; d = dense arsenopyrite ore.

†1—473283. *S. G. U., Ser. C, N:o 491. Gavelin och Gabrielson.*

No.		*)	No.	% Co	% Ni	% Mn
11	Trench IV b: Fine-grained pyrite ore with occasional sphalerite bands.	z	11	—	0.001	0.3
12	Trench IV b: High-grade pyritic zinc ore.	z	12	—	0.001	0.2
13	= 410 Trench VI a: High-grade pyritic zinc ore.	z	13	—	<0.001	0.1
14	Trench VI a: Fine-grained banded zinc ore with pyrite, pyrrhotite and galena.	z	14	—	<0.001	0.1
15	= 411 Trench IV b: Even-grained pyritic high-grade zinc ore.	z	15	0.07	<0.001	0.01
16	»Outcropping ore»: Fine-grained pyrite ore with veinlets of galena.	z	16	—	0.003	1.0
				Arsenopyrite		
302	»Outcropping ore, 9»: Dense arsenopyrite ore. Fragments in high-grade zinc ore.	d	302	—	—	0.1
303	Trench IV, N: Complex sulphide ore with crystals of arsenopyrite.	z	303	—	—	0.001
304	»Outcropping ore, 3»: Veinlets of galena with crystals of arsenopyrite and pyrite.	z	304	—	—	<0.001
305	Trench II: Arsenopyrite crystals in quartzite with staurolite and garnet.	i	305	0.001	<0.001	<0.001
306	»Outcropping ore»: Arsenopyrite crystals in coarse chlorite-quartzite.	i	306	0.03	0.01	<0.001
				Pyrrhotite		
406	Trench VIII: Compact pyrrhotite ore with scattered pyrite crystals and some sphalerite.	p	406	—	<0.001	0.07
407	Trench VI a: Pyrite-pyrrhotite ore.	p	407	—	<0.001	0.07
408	Trench IV, N: Pyrrhotite ore with high zinc and lead contents.	z	408	—	<0.001	0.03
409	Trench VI b: Coarse pyrrhotite with sphalerite and galena.	z	409	—	<0.001	0.07
		z	410	—	<0.001	0.07
		z	411	0.02	<0.001	0.05
		z	412	0.02	0.001	0.2

3. *The Bjurfors Ores.*

Three separate ore deposits occur in this field. The Eastern Ore is a copper ore, chalcopyrite being subordinate, however, as compared with pyrite and pyrrhotite. The Middle Ore is a pyritic zinc ore and the Western Ore is composed of pyrite and pyrrhotite. Chalcopyrite and sphalerite are very rare minerals. The gangue and wallrock minerals indicate lower temperature than at Bjurträsk and Bjurliden but higher than at Eastern Högkulla (see below).

The Eastern Bjurfors Ore.

Samples analysed; characteristics of the various specimens.

No.		*)	No.	% Co	% Ni	% Mn
				Pyrite		
17	= 413 = 603 »Outcropping ore, 8»: High-grade pyritic copper ore.	c	17	0.2	—	0.01
18	= 414 »Outcropping ore, 10»: Pyrite crystals in pyrrhotite, some chalcopyrite.	c	18	0.1	—	0.02
19	= 415 »Outcropping ore»: Fine-grained pyrite ore.	p	19	0.08	0.003	0.02
20	= 416 »Outcropping ore»: High-grade complex copper ore.	c	20	0.1	0.003	0.08
21	»Outcropping ore, 9»: Fine-grained pyrite ore.	p	21	0.07	0.001	0.03
22	30 meter level: Veinlets of pyrite and sphalerite in chlorite-quartzite.	z	22	0.01	<0.001	0.01
23	Eastern part of the outcropping ore: Dissemination of pyrite in skarn.	i	23	—	—	—
				Pyrrhotite		
		c	413	0.025	<0.001	0.01
		c	414	0.07	<0.001	0.03
		p	415	0.03	<0.001	0.01
		c	416	0.07	—	0.03
417	»Outcropping ore»: High-grade complex copper ore.	c	417	0.02	<0.001	0.03
418	= 604 »Outcropping ore, 14»: Quartzuose cupriferous complex ore.	c	418	—	<0.001	0.3
				Chalcopyrite		
		c	603	0.1	—	0.001
		c	604	—	—	<0.001

*) See p. 9.

The Middle (M) and Western (W) Ores.

Samples analysed; characteristics of the various specimens.

No.	*)	No.	% Co	% Ni	% Mn
			Pyrite		
24 = 419M Drill hole 2, 43.6 m: High-grade pyritic zinc ore.	z	24	0.07	—	0.01
25M Drill hole 2, 31.4 m: Fine-grained zinc-bearing pyrite ore.	z	25	0.003	0.007	0.3
26M Drill hole 1, 43.5 m: Fine-grained zinc-bearing pyrite ore.	z	26	0.02	0.007	0.3
27M Drill hole 1, 37.0 m: Fine-grained pyrite ore.	p	27	—	0.003	0.1
28M Drill hole 3, 56.7 m: High-grade pyritic zinc ore.	z	28	0.07	0.01	0.07
29M Drill hole 2, 27.5 m: Pyrite dissemination in chlorite-quartzite.	i	29	0.03	<0.001	0.003
30W Drill hole 1, 36.6 m: Fine-grained pyrite ore with some pyrrhotite.	p	30	—	<0.001	0.03
			Pyrrhotite		
	z	419	0.03	0.002	0.03

4. *The Eastern Högkulla Ore.*

General characteristics of the ore: Compact complex zinc ore, mainly uniform distribution of the different sulphides in various portions of the ore. Chiefly a pyritic banded zinc ore with some galena. The gangue and wallrock minerals indicate lower temperatures as compared with the Bjurliden and the Bjurfors Ores.

Samples analysed; characteristics of the various specimens.

No.	*)	No.	% Co	% Ni	% Mn
			Pyrite		
31 Outcropping ore, 26: Pyrite crystals in chlorite-rock with garnet.	i	31	—	—	0.1
32 = 420 Outcropping ore: Sphalerite-banded pyrite ore.	z	32	—	—	0.3
33 = 421 Outcropping ore, 19: Sphalerite-banded pyrite ore.	z	33	—	0.002	0.02
34 = 422 Outcropping ore, 2: Pyrite-banded zinc ore.	z	34	—	0.007	0.02
35 37 meter level: Complex zinc ore with abundant pyrrhotite.	z	35	0.003	0.002	0.3
36 37 meter level: Coarse pyrite in a sphalerite-pyrrhotite mass.	z	36	0.003	0.001	0.03
37 = 423 Drill hole 7, 33.3 m: Fine-grained pyrite-banded zinc ore.	z	37	—	0.001	0.03
38 Drill hole 7, 37.1 m: Complex zinc ore.	z	38	—	0.002	0.1
39 Drill hole 7, 39.3 m: Complex, banded zinc ore.	z	39	—	0.002	0.1
40 = 424 Drill hole 8, 61.3 m: Complex, banded zinc ore.	z	40	—	0.002	0.3
41 = 425 Drill hole 9, 48.0 m: Complex, banded zinc ore.	z	41	—	0.005	0.1
42 = 426 Outcropping ore, 10: Coarse pyrite in a pyrrhotite-sphalerite mass.	z	42	0.03	—	0.1
			Arsenopyrite		
307 37 meter level: Dense arsenopyrite ore, inclusion in zinc ore.	d	307	0.3	—	0.1
308 Outcropping ore: Arsenopyrite crystals in complex zinc ore.	i	308	—	—	0.001
			Pyrrhotite		
	z	420	—	<0.001	0.2
	z	421	—	<0.001	0.03
	z	422	—	0.001	0.01
	z	423	—	0.001	0.03
	z	424	—	<0.001	0.2
	z	425	—	<0.001	0.2
	z	426	—	0.001	0.03
427 Outcropping ore, 9: Zinc ore with pyrrhotite bands.	z	427	—	0.001	0.03
428 Outcropping ore, 12: Zinc ore with pyrrhotite bands.	z	428	—	0.001	0.07
429 Outcropping ore: Coarse pyrrhotite, associated with quartz, epidote and garnet.	i	429	—	<0.001	0.3

*) See p. 9,

5. *Skäggträskberget.*

General characteristics of the ore: A number of minor ore lenses of varying composition. Solid, dense arsenopyrite ore, high-grade zinc ore, copper ores (disseminations of chalcopyrite in quartzites), pure pyrite ore alternating. No minerals in the wall rock or the gangue parageneses indicating high temperatures (sericite-quartzite, chlorite-quartzite, hornblende skarn).

No. Samples analysed; characteristics of the various specimens.	*)	No.	% Co	% Ni	% Mn
			Pyrite		
43 Trench 8: Pyrite cubes in biotite-schist.	i	43	—	—	0.01
44 Trench 3: Fine-grained pyrite in sericite-quartzite.	i	44	—	—	0.003
45 Trench 7: Fine-grained pyrite ore with hornblende.	p	45	—	—	0.03
46 = 309 Trench 6: Dense arsenopyrite ore with veinlets of sphalerite and scattered crystals of pyrite.	z	46	0.1	<0.001	0.02
47 Trench 7: Compact zinc ore with some pyrite.	z	47	0.007	—	0.1
48 Drill hole 1, 48.6 m: Pyritic copper ore.	c	48	0.05	0.003	0.03
			Arsenopyrite		
	d	309	0.01	—	0.02
310 Trench 1: Arsenopyrite crystals in quartzite, close to a quartz vein.	i	310	0.07	<0.001	0.01
311 Trench 9: Arsenopyrite crystals in quartzite, close to a quartz vein.	i	311	0.07	<0.001	<0.001
			Pyrrhotite		
430 Trench 7: High-grade zinc-ore with pyrrhotite.	z	430	—	<0.001	0.03
			Chalcopyrite		
605 Trench 8: Veinlets of chalcopyrite in white quartzite.	c	605	—	—	<0.001

6. *Kristineberg.*

General characteristics of the ores: The major portions of the ore bodies are pyrite ores with a varying amount of chalcopyrite, a minor part is pyritic zinc ore. Pyrrhotite is practically absent. The wall rocks are composed of sericite-quartzite, chlorite-quartzite or chlorite-rock.

Samples analysed; characteristics of the specimens.	*)	No.	% Co	% Ni	% Mn
			Pyrite		
49 = 606 Outcropping ore: High-grade copper ore with quartz lenses.	c	49	0.085	<0.003	0.005
50 Outcropping ore: Quartzuose pyrite ore with low copper content.	p	50	0.1	<0.001	—
51 = 607 Outcropping ore: Cupriferous pyrite veinlets in quartzite.	c	51	0.07	<0.001	0.01
52 = 608 Outcropping ore: Dissemination of chalcopyrite and pyrite in chlorite-rock.	c	52	0.1	<0.001	0.01
53 170 meter level, stope 3: Cupriferous pyrite ore.	c	53	0.003	—	0.01
54 Outcropping ore: Pyrite ore with quartz-chalcopyrite veinlets.	c	54	—	—	0.002
55 Outcropping ore: Compact copper-free pyrite ore.	p	55	0.03	—	0.005
56 Outcropping ore: Sphalerite-pyrite veinlets in quartzite.	z	56	0.03	<0.001	0.001
57 170 meter level: Pyrite ore with sphalerite.	z	57	—	<0.001	0.1
58 170 meter level, stope 8: Pyrite ore with sphalerite.	z	58	—	0.003	0.02
			Chalcopyrite		
	c	606	—	—	0.001
	c	607	—	—	0.001
	c	608	—	—	0.001

7. *Rävliden.*

General characteristics of the ores: A number of compact ore bodies. A marked differentiation between copper and zinc, pyritic zinc ores and pyritic copper ores generally appearing separately. Pyrite or pyrrhotite ore portions with small amounts of copper and zinc also occurring. The wall rocks are: Sericite-quartzites, more or less chloritic, amphibole skarn and graphite-phyllite.

Samples analysed; characteristics of the specimens.	*)	No.	% Co	% Ni	% Mn
			Pyrite		
59 = 431 = 609 38 meter level, eastern part: Copper ore with coarse pyrite.	c	59	0.01	—	0.05

*) See p. 9.

No.		*)	No.	% Co	% Ni	% Mn
60	120 meter level, eastern part: Coarse-grained complex copper ore.	c	60	0.03	0.003	0.02
61	= 432 Outcropping ore, eastern part: Fine-grained pyritic copper ore.	c	61	—	<0.001	0.01
62	Drill hole $3_{(120)}$, 20.6 m: Coarse-grained pyritic copper ore.	c	62	0.02	0.003	0.01
63	Drill hole $3_{(120)}$, 22.0 m: Fine-grained pyritic copper ore.	c	63	0.01	0.003	0.07
64	Drill hole $18_{(38)}$, 31.0 m: Cupriferous pyrite ore.	c	64	0.02	0.003	0.02
65	Drill hole $1_{(120)}$, 46.0 m: Pyrite crystals in chlorite-rock.	i	65	0.03	<0.001	0.01
66	38 meter level, middle part: Pyrite bands in graphite-phyllite.	p	66	0.01	0.03	0.03
67	38 meter level, western part: Fine-grained pyrite ore with hornblende. Low zinc contents.	p	67	—	<0.001	0.03
68	38 meter level, western part: Compact zinc ore with small pyrite cubes.	z	68	0.085	0.015	0.1
69	= 434 Drill hole $2_{(38)}$, 2.7 m: Pyritic zinc ore.	z	69	—	0.01	0.1
70	= 435 Drill hole $2_{(38)}$, 6.5 m: Zinc-bearing pyrite ore.	z	70	—	0.003	0.03
71	= 436 Drill hole $14_{(38)}$, 12.9 m: High-grade zinc ore.	z	71	—	0.01	0.2
72	Drill hole $14_{(38)}$, 10.3 m: Pyritic zinc ore.	z	72	—	0.003	0.08
				Arsenopyrite		
312	= 437 80 meter level: Dense arsenopyrite ore; inclusions in zinc ore.	d	312	0.07	0.003	0.3
313	38 meter level: Dissemination of arsenopyrite in quartzite.	i	313	0.03	0.07	<0.001
				Pyrrhotite		
		c	431	—	<0.001	0.02
		c	432	—	—	0.03
433	= 610 80 meter level: Compact high-grade copper ore with pyrrhotite bands.	c	433	—	0.001	0.003
		z	434	—	0.02	0.04
		z	435	—	0.01	0.07
		z	436	—	0.01	0.2
		dz	437	0.01	0.003	0.2
438	120 meter level: High-grade zinc ore with pyrrhotite.	z	438	—	0.003	—
				Chalcopyrite		
		c	609	—	—	0.03
		c	610	—	—	0.1

8. *Rävlidmyran.*

General characteristics of the ores: In part compact, very rich zinc ores, often with considerable Pb- and Ag-contents, in part compact pyritic zinc ores, in part copper ores with coarse pyrite. The altered rocks are characterized by sericite — chlorite — calcite.

Samples analysed; characteristics of the various specimens.

No.		*)	No.	% Co	% Ni	% Mn
				Pyrite		
73	= 439 = 611 60 meter level: Chalcopyrite-pyrrhotite-pyrite veinlets in quartzite.	c	73	—	0.001	<0.001
74	60 meter level: Pyrite crystals in chlorite-rock.	i	74	0.01	0.001	0.001
75	Drill hole 23, 42.8 m: Abundant pyrite in calcareous tremolite skarn.	p	75	0.03	—	0.001
76	Drill hole 23, 42.6 m: Compact pyrite ore with some sphalerite.	z	76	—	—	0.03
77	= 440 The shaft: High-grade zinc ore with pyrite.	z	77	—	0.001	0.03
				Pyrrhotite		
		c	439	—	—	0.003
		z	440	—	0.01	0.01
				Chalcopyrite		
		c	611	—	—	<0.001

*) See p. 9.

9. *The Adak Mine.*

General characteristics of the ores: Disseminations, breccias and minor compact lumps of chalcopyrite and pyrrhotite. Occasionally pyrrhotite-pyrite masses, poor in chalcopyrite. Pyrite generally very rare in the copper-ore portions. Arsenopyrite occurring as scattered crystals. The wall rock consists of cordierite-cummingtonite-bearing quartzites. Adjacent to the ore bodies often skarn.

Samples analysed; characteristics of the specimens.

No.

78 = 441 = 612 Drill hole 1, 18.9 m: Cupriferous pyrrhotite-pyrite ore.
79 Outcropping ore, 5: Pyritic copper ore.
80 = 442 Stope 10, 135 m level: Chalcopyrite-pyrrhotite ore with large pyrite crystals.
81 = 454 40 meter level, eastern part of the ore: Pyrite-pyrrhotite bands in quartzite.
82 = 455 Drill hole 1, 21.0 m: Pyrite ore with sphalerite.
83 40 meter level: Druses of pyrite and calcite.

314 = 449 80 meter level: Veinlets in quartzite of pyrrhotite with large crystals of arsenopyrite.
315 = 450 = 613 165 meter level: Compact high-grade copper ore with large arsenopyrite crystals.
316 165 meter level: Compact high-grade copper ore with large arsenopyrite crystals.
317 = 451 165 meter level: Pyrrhotite, chalcopyrite, arsenopyrite forming veinlets in skarn.
318 80 meter level: Chalcopyrite with arsenopyrite, forming veinlets in quartzite.

443 Outcropping ore: Fine-grained chalcopyrite-pyrrhotite ore.
444 Outcropping ore, 7: Chalcopyrite-pyrrhotite breccia in quartzite.
445 = 614 Outcropping ore: High-grade copper ore with calcite.
446 = 615 Outcropping ore: High-grade copper ore with garnet.
447 = 616 Outcropping ore, 2: High-grade coarse-grained copper ore.
448 = 617 Shaft in outcropping ore: Fine-grained copper ore in skarn.

452 Outcropping ore, north-eastern part: Copper ore with abundant sphalerite and pyrite.
453 Outcropping ore, eastern part: Compact coarse-grained pyrrhotite.

*)	No.	%Co	%Ni	%Mn
		Pyrite		
c	78	0.2	—	0.03
c	79	0.2	<0.001	0.03
c	80	0.1	0.01	0.01
p	81	0.03	<0.001	0.005
z	82	0.2	—	0.03
i	83	<0.003	—	—
		Arsenopyrite		
p	314	>1	0.03	<0.001
c	315	3	0.01	0.001
c	316	3	0.003	<0.001
c	317	3	0.03	0.1
c	318	>3	0.03	0.01
		Pyrrhotite		
c	441	—	<0.001	0.03
c	442	0.03	0.003	0.04
c	443	0.03	<0.001	0.03
c	444	0.2	<0.001	0.03
c	445	0.07	<0.001	0.003
c	446	0.07	0.01	0.01
c	447	0.03	<0.001	0.01
c	448	0.07	<0.001	0.07
c	449	0.03	0.001	0.003
c	450	0.1	<0.001	0.03
c	451	0.07	0.001	0.01
c	452	0.07	<0.001	0.07
p	453	—	<0.001	0.01
p	454	—	<0.001	0.03
z	455	0.07	<0.001	0.05
		Chalcopyrite		
c	612	0.07	—	0.015
c	613	0.01	—	0.001
c	614	0.005	—	0.001
c	615	—	—	0.003
c	616	—	—	0.001
c	617	—	—	1.0

9 a. *The Karlsson Ores.*

General characteristics of the ores: Identical with the Adak ores. Two ore bodies, the eastern and the western ore.

*) See p. 9.

No.	*)	No.	%Co	%Ni	%Mn
Samples analysed; characteristics of the various specimens.					
			Arsenopyrite		
319 = 457 = 618 The eastern ore, outcropping ore: High-grade copper ore with arsenopyrite crystals.	c	319	2.5	0.01	0.001
320 The eastern ore, 20 meter level: Vein of chalcopyrite with arsenopyrite crystals in quarzite.	c	320	2	0.04	0.02
321 The western ore, shaft: Chalcopyrite veins with abundant arsenopyrite.	c	321	0.6	0.001	0.03
			Pyrrhotite		
456 = 619 The eastern ore, outcropping ore: High-grade copper ore.	c	456	0.03	—	0.003
	c	457	0.02	—	0.01
			Chalcopyrite		
	c	618	—	0.001	0.001
	c	619	—	—	0.001

10. *The Lindsköld Mine.*

General characteristics of the ores: Sulphide minerals, wallrock and gangue minerals in the main as at the Adak Mine. The sulphides often more fine-grained than at the Adak Mine. Fine-grained, compact arsenopyrite ores occur.

	*)	No.	%Co	%Ni	%Mn
Samples analysed; characteristics of the specimens.					
			Pyrite		
84 Drill hole 14, 22.3 m: Pyrite veins in quartzite.	i	84	0.07	0.007	0.01
85 Drill hole 46, 87.9 m: Pyrite veins in quartzite.	i	85	0.03	<0.001	0.001
86 Drill hole 55, 89.6 m: Pyrite veins in quartzite.	i	86	0.1	0.02	0.005
87 Drill hole 59, 74.7 m: Pyrite veins in epidote skarn.	i	87	—	0.02	0.05
88 — 458 Drill hole 61, 87.8 m: Pyrrhotite with some pyrite, veins in quartzite.	i	88	0.02	0.007	0.01
89 = 459 100 meter level: Pyrite-pyrrhotite veins in quartzite.	i	89	0.02	0.008	0.03
			Arsenopyrite		
322 100 meter level: Dense compact arsenopyrite ore with fine-grained chalcopyrite.	d	322	0.2	0.03	0.3
323 = 467 100 meter level: Chalcopyrite brecciating dense arsenopyrite ore.	d	323	0.1	0.03	0.001
324 100 meter level: Dense arsenopyrite ore with very little chalcopyrite.	d	324	0.3	0.07	0.005
325 = 620 100 meter level: Chalcopyrite with arsenopyrite crystals in a fissure in quartzite.	c	325	0.3	0.3	<0.001
326 = 621 Prospecting shaft: Dissemination of abundant arsenopyrite and some chalcopyrite in quartzite.	c	326	0.3	0.1	0.001
327 = 468 Prospecting shaft: Chalcopyrite with arsenopyrite crystals in a fissure in quartzite.	c	327	0.4	0.25	0.001
328 Drill hole 45, 91.2 m: Dissemination of arsenopyrite in quartzite.	i	328	0.5	0.1	0.001
329 100 meter level: Arsenopyrite crystals in high-grade, dense copper ore.	c	329	0.7	0.07	0.005
330 = 469 = 623 100 meter level: Steeply dipping vein of coarse-grained chalcopyrite with arsenopyrite crystals.	c	330	1.2	0.2	0.01
			Pyrrhotite		
	i	458	—	0.01	0.01
	i	459	0.01	0.003	0.06
460 Drill hole 15, 27.2 m: Pyrrhotite veins in quartzite.	i	460	—	0.01	0.03
461 Drill hole 63, 120.2 m: Dissemination of pyrrhotite in biotite-schist.	i	461	0.03	0.03	0.003
462 Drill hole 59, 72.0 m: Dissemination of pyrrhotite in epidote skarn.	i	462	—	0.03	0.07
463 Drill hole 55, 92.8 m: Dissemination of pyrrhotite in quartzite.	i	463	0.007	0.01	0.03

*) See p. 9.

No.

464 50 meter level: Pyrrhotite veinlets with quartz and molybdenite.
465 = 622 Prospecting shaft: Chalcopyrite-pyrrhotite veinlets in quartzite.
466 50 meter level: Pyrrhotite-chalcopyrite breccia in quartzite.

*)	No.	%Co	%Ni	%Mn
p	464	0.01	0.01	<0.001
c	465	—	0.01	0.03
c	466	—	0.07	0.03
dc	467	0.03	0.01	0.003
c	468	0.25	0.07	0.08
c	469	—	0.003	<0.001
		Chalcopyrite		
c	620	0.03	0.03	0.001
c	621	0.005	0.001	0.03
c	622	—	0.001	0.001
c	623	—	<0.001	0.001

11. *Rudtjebäcken.*

General characteristics of the ore: Compact coarse-grained pyrite ore with varying amounts of pyrrhotite, chalcopyrite and sphalerite. High-grade zinc and copper ores only occasionally. Probably comparatively high temperatures. Pegmatites in close association with the ores.

Samples analysed; characteristics of the specimens.

90 = 470 = 624 Drill hole 7, 167.6 m: Coarse-grained pyrite ore with chalcopyrite.
91 = 471 Drill hole 11, 191.6 m: Coarse-grained pyrite ore with abundant chalcopyrite.
92 = 472 Drill hole 10, 187.0 m: Coarse-grained pyrite ore with some sphalerite.
93 Drill hole 7, 165.9 m: Coarse-grained pyrite ore with sphalerite.
94 = 473 Drill hole 10, 184.8 m: Pyritic high-grade zinc ore.
95 Drill hole 7, 172.8 m: Coarse-grained pyrite, veinlets in pegmatite.
96 = 474 Drill hole 3, 46.5 m: Pyrrhotite-pyrite veinlets in quartzite.

331 The shaft: Chalcopyrite-pyrrhotite-arsenopyrite veinlets in quartzite.

*)	No.	%Co	%Ni	%Mn
		Pyrite		
c	90	0.01	<0.001	0.002
c	91	0.02	0.005	0.1
z	92	0.03	<0.001	<0.001
z	93	0.01	0.007	0.08
z	94	—	0.007	0.05
i	95	—	—	<0.001
p	96	0.1	0.003	0.01
		Arsenopyrite		
c	331	0.03	0.03	0.002
		Pyrrhotite		
c	470	—	<0.001	0.2
c	471	—	0.003	0.03
z	472	0.007	0.001	0.003
z	473	—	0.005	0.01
z	474	—	0.005	0.07
		Chalcopyrite		
c	624	0.003	0.001	0.03

12. *Laver.*

General characteristics of the ores: Chalcopyrite and pyrrhotite by far the predominating sulphides, pyrite and arsenopyrite rare. Sphalerite may sometimes be a common mineral. The sulphides generally form disseminations or breccias in more or less altered liparites. The alteration often leads to the formation of skarn. Veins of more accumulated sulphides also occur.

Samples analysed; characteristics of the specimens.

97 = 476 B-ore, 50—90 m: Pyrrhotite ore with some pyrite and chalcopyrite.

*)	No.	%Co	%Ni	%Mn
		Pyrite		
p	97	0.4	0.01	0.015

*) See p. 9.

No.		*)	No.	% Co	% Ni	% Mn
				Arsenopyrite		
332	CDE-ore, 210 m: Arsenopyrite with some chalcopyrite, veinlet in liparite.	i	332	0.15	0.07	0.003
333	CDE-ore, 130—170 m: Arsenopyrite veinlets in liparite.	i	333	0.35	0.1	0.001
				Pyrrhotite		
475	= 627 A-ore, 170 m: High-grade copper ore with some pyrrhotite.	c	475	0.02	0.02	0.02
		p	476	0.02	0.006	0.1
477	= 628 CDE-ore, 250 m: High-grade copper ore with some pyrrhotite in banded tuff.	c	477	0.03	0.03	0.1
478	= 629 CDE-ore, 250 m: Chalcopyrite-pyrrhotite breccia in liparite.	c	478	0.03	0.02	0.02
479	CDE-ore, 210 m: Dense compact pyrrhotite ore.	p	479	0.02	0.003	0.05
480	CDE-ore, stope 6: Dense compact pyrrhotite ore with some chalcopyrite.	c	480	0.01	0.003	0.1
481	CDE-ore, 210 m: Dense compact pyrrhotite ore with chalcopyrite veinlets.	c	481	0.03	0.01	0.1
482	= 630 I-ore, 130—170 m: Chalcopyrite-pyrrhotite veinlets in chlorite-garnet skarn.	c	482	0.03	0.06	0.01
				Chalcopyrite		
625	A-ore, 250 m: Compact chalcopyrite ore.	c	625	0.002	0.01	0.008
626	A-ore, 250 m: Chalcopyrite veinlets in liparite.	c	626	0.004	0.006	0.06
		c	627	0.004	0.005	0.02
		c	628	0.004	0.01	0.002
		c	629	0.006	0.005	0.002
		c	630	0.007	0.01	0.001
631	A_3-ore, 170 m: Chalcopyrite in ore-bearing fault.	c	631	0.003	0.004	1—2

Sulphides from sporadic samples of other ore deposits, disseminations, etc. (For each mineral the analyses are arranged according to the positions of the localities; from E to W and from S to N).

Pyrites.

No.		% Co	% Ni	% Mn
98	Kusfors, Norsjö parish: Sericite-quartzite with pyrite bands	0.01	<0.001	0.001
99	» » » Basic dike with pyrite	0.03	0.001	0.05
100	Heden, » » Dissemination of pyrite in coarse quartzite	0.001	0.001	—
101[1]	Snåttermyran, Norsjö parish: Compact fine-grained pyrite ore in sericite-quartzite	—	—	0.005
102[1]	Rutselheden, » » Pyrite dissemination i graphite-phyllite	0.03	0.1	0.1
103[1]	Norrliden, » » Fine-grained pyrite. Breccia in sericite-quartzite	—	<0.001	0.07
104[1]	Österbäcken, » » Fine-grained pyritic zinc ore in graphite-phyllite	0.1	0.007	0.07
105[1]	Rörmyrberget, 2 km N of the Bjurfors ores, Norsjö parish: Pyrite dissemination in sericite-quartzite	—	0.007	0.01
106	Borup, Norsjö parish: Pyrite dissemination in graphite-phyllite	0.01	0.03	0.03
107	S of Mensträsk, Norsjö parish: Pyrite dissemination in sericite-quartzite	0.003	<0.001	0.001
108	Lillholmträsk, » » Coarse pyrite and some pyrrhotite in graphite-phyllite	0.3	0.007	0.005
109	The Rakkejaur ore, Malå parish: Dense compact pyrite ore in graphite-phyllite	0.02	0.03	0.03
110	» » » » » Dense pyritic zinc ore in sericite-quartzite	—	0.001	0.07
111	Brattmyrhögen, » » Coarse-grained compact pyrite ore	0.01	0.03	0.02
112	» » » Coarse-grained compact pyrite ore with pyrrhotite	0.003	0.02	0.003
113	Nådagubbliden, » » Pyrite dissemination in sericite-quartzite	0.01	0.001	—
114	» » » Pyrite dissemination in sericite-quartzite	—	—	0.05

* See p. 9. — [1] See p. 19.

No.		% Co	% Ni	% Mn
115[2]	S of Kristineberg, Lycksele parish: Pyrite dissemination in cordierite-quartzite	0.03	0.02	0.03
116[2]	W of » » » Pyrite dissemination in sericite-quartzite	0.1	0.03	<0.001
117[3]	N of Hornträsket, » » Compact pyritic zinc ore	—	—	0.03
118[3]	NW of » » » Pyrite dissemination in cordierite-quartzite	—	—	0.03
119[3]	NW of » » » Pyrite dissemination in chlorite-quartzite	0.03	0.001	0.01
120[3]	NW of » Långträskåsen, Lycksele parish: Pyrite dissemination in chlorite-quartzite	0.25	<0.001	0.03
121[3]	Granselliden, E of Vindelgransele, Lycksele parish: Pyrite ore in sericite-quartzite	0.01	0.007	0.1
122[3]	» E of Vindelgransele, Lycksele parish: Pyrite dissemination in sericite-quartzite	0.01	0.03	0.03
123[3]	The Vindelgransele ore, Lycksele parish: Zinc ore rich in pyrite	—	0.002	0.04
124[3]	» » » » » Compact pyrite ore	0.07	0.07	0.03
125[3]	» » » » » Dissemination of pyrite in quartzite	—	—	0.1
126[4]	Lappliden, E of Adak, Malå parish: Pyrite in quartz-tourmaline vein	0.03	<0.001	—
127[4]	Trench W of the Adak mine, Malå parish: Pyrite dissemination in cordierite-quartzite	0.3	—	0.07
128[4]	Gråberget, 20 km NW of Adak, Malå parish: Quartz-bearing pyritic copper ore in Vargfors conglomerate	0.03	0.03	0.01
129[4]	Gråberget, 20 km NW of Adak, Malå parish: Pyrite dissemination in porphyry dike in Vargfors conglomerate	0.03	0.001	0.003
130	Grundfors, Lycksele parish: Pyrite bands in graphite-phyllite	0.07	0.02	0.05
131	Högbränna, NE of Glommersträsk, Arvidsjaur parish: Pyrite dissemination in »hälleflinta»	0.07	—	0.01
132	Svartliden, WNW of Glommersträsk, Arvidsjaur parish: Pyrite dissemination in chloritic tuff	0.07	0.001	0.03
133	Svartliden, WNW of Glommersträsk, Arvidsjaur parish: Pyrite dissemination in quartzporphyry	—	—	<0.001
134	NW of Storavan, Arjeplog parish: Fine-grained pyrite dissemination in sericite-quartzite	—	0.001	0.005

Arsenopyrites.

334	Stöverfors, Skellefte parish: Quartz vein with arsenopyrite	0.02	<0.001	0.005
335	Torsbäckliden, Skellefte parish: Quartz vein with arsenopyrite	0.3	0.2—	0.01
336	Ol Ersberget, Norsjö parish: Quartz vein with arsenopyrite and pyrrhotite	0.7	0.003	<0.001
337	Rakkejaur, Malå parish: Dense compact arsenopyrite ore	0.1	—	<0.001
338	Middagsberget, SW of Vindelgransele, Lycksele parish: Quartz vein with arsenopyrite	—	—	0.03
339	Fäboliden, NW of Vindelgransele, Lycksele parish: Quartz vein with arsenopyrite	—	0.1	<0.001

Pyrrhotites.

483	Högås, WNW of Vännäs, Umeå parish: Pyrrhotite accumulations in gneiss (pentlandite observed under the microscope)	0.03	0.1	—
484	E of Lövånger, Lövånger parish: Pyrrhotite accumulations in gneiss	0.02	0.07	0.07
485	Dalkarlsliden, NW of Skellefteå: Coarse pyrrhotite in gneiss with skarn	0.01	0.03	0.3
486	» » » » Fine-grained pyrrhotite in gneiss	0.01	0.03	0.003
487	Tallberg, Norsjö parish: Pyrrhotite in phyllite-stringers (inclusions in gabbro)	0.1	0.2	0.07
488	Rutselheden, Norsjö parish (cf. No. 102): Pyrrhotite veinlets in graphite-phyllite	—	0.2	0.03
489	Österbäcken = No. 104	0.03	0.01	0.2
490	Rörmyrberget (cf. No. 105): Pyrrhotite-bearing quartz vein in sericite-quartzite	0.002	0.08	<0.001
491	E of Skäggträskberget, Norsjö parish: Pyrrhotite veinlets in graphite-phyllite	0.003	0.07	0.007

2–4 See p. 19.

No.		% Co	% Ni	% Mn
492	Gävliden, Norsjö parish: Pyrrhotite bands in quartzitic graphite-phyllite	0.01	0.03	0.
493	Ol Ersberget = No. 334	—	0.003	<0.001
494	Lillholmträsk = No. 108	—	0.07	0.001
495	Brattmyrhögen = No. 112	—	0.07	0.1
496	Brattmyrhögen, southern ore: Compact pyrrhotite ore in coarse quartzite	0.007	0.02	0.1
497	Njasacken, S of Siäppträsket, Malå parish: Pyrrhotite dissemination in graphite-phyllite	0.02	0.03	0.07
498	Vindelgransele (cf. Nos. 123—125): Compact pyrrhotite ore with some sphalerite	0.01	<0.001	0.2
499	Gunnarn, Stensele parish: Compact dense pyrrhotite ore	0.01	0.1	0.03
500	18 km W of Gunnarn, Stensele parish: Pyrrhotite-chalcopyrite veinlets in graphite-phyllite	0.02	0.1	0.01
Chalcopyrite				
632	18 km W of Gunnarn = No. 500	—	0.01	0.03

[1] Nos. 101—105 from the Malånäs District.
[2] Nos. 115—116 from the Kristineberg District.
[3] Nos. 117—125 from the Vindelgransele District.
[4] Nos. 126—129 from the Adak District.

Considering primarily the *pyrites* we find that the Co-values vary between < 0.001 % and 0.40 %. The Ni-contents are considerably lower in the same samples, and with one exception (0.1 % Ni) they do not exceed 0.03 %. In Table 2 the analytical values have been grouped in four percentage-classes. The 97 analyses from ores Nos. 1—12 are listed in the upper row and approximately the same distribution appears in the lower row, where the entire material analysed is presented.

Table 2. Survey of the Co-Ni-values in pyrites.

% Co				% Ni				
<0.001	0.001—0.009	0.01—0.09	0.1—0.3	<0.001	0.001—0.009	0.01—0.09	> 0.09 %	
39	6	41.5	13.5	54	39	7	—	% of 97 analyses of ores 1—12
36.5	7.5	42.5	13.5	48.5	38	12.5	1	% of all 134 analyses

The numerical values as well as the quotients between Co and Ni show considerable variations also within one and the same deposit. All this, however, agrees with our knowledge of the Co-Ni-contents of pyrites from other sulphide deposits of a similar type (4, 13, 19). In conformity with earlier experiences Co generally dominates over Ni quite considerably, but in some cases a certain Ni-dominance over Co has been proved. This holds true especially of pyrites in zinc ores (cf. p. 33).

The Co-values of the *pyrrhotites* amount to 0.2 % and the Ni-contents to 0.085 %. In a large number of samples, however, no Co has been found. A

Table 3. Survey of the Co-Ni-values in pyrrhotites.

% Co				% Ni				
<0.001	0.001—0.009	0.01—0.09	0.1—0.2	<0.001	0.001—0.009	0.01—0.09	0.1—0.3	
51.5	3.5	41.5	3.5	46.5	28	25.5	—	% of 82 analyses or ores 1—12
45	6	45	4	39	24	32	5	% of all the 100 analyses

certain Ni-dominance over Co exists in several cases, but Co dominates just as often. A grouping of the pyrrhotite analyses according to percentage-classes, in the same way as was done in the case of pyrite, is presented in Table 3.[1]

In this case one type of sulphide mineralization, *i. e.* sulphides in phyllites and gneisses, differs quite strikingly from ores Nos. 1—12 as regards the Co- and Ni-values. In Table 3 this difference appears on comparing the upper and the lower row. In the case of the Ni-values this dissimilarity is particularly obvious.

In many cases neither Co nor Ni has been proved in *chalcopyrite*. The highest Co-value obtained in chalcopyrites, 0.1 %, originates from the Eastern Bjurfors Ore. As the pyrite from the same specimen contains only 0.2 % Co and the pyrrhotite only 0.025 % Co, the high value cannot be explained by contamination by these minerals. From the Adak Mine there is recorded one value of 0.07 % Co. In pyrrhotite from the same specimen Co is lacking and As has not been proved, and consequently there is neither in this case any reason to suspect considerable errors in the Co-values, caused by intermixture of pyrrhotite or arsenopyrite. As regards Ni, only one value > 0.01 % has been found, but in that case contamination by arsenopyrite may have influenced the results. Very distinct As-lines were observed in this analysis, and as arsenopyrite from the same specimen contains 0.3 % of both Co and Ni, a comparatively slight admixture of this mineral must raise the Co-Ni-values. Table 4 shows the distribution of all 32 analyses for chalcopyrite in percentage-classes.

Table 4. Survey of the Co-Ni-values in chalcopyrites.

% Co				% Ni				
<0.001 %	0.001—0.009	0.04—0.09	> 0.09	<0.001	0.001—0.009	0.01—0.03		
53.5	31	12.5	3	59.5	25	15.5		% of 32 analyses

[1] These values, of course, do not claim to express the quantitative distribution of Co and Ni in the entire pyrrhotite portion of the ores treated, as the material available is much too incomplete and the samples too irregularly distributed. Thus, for instance, 31 of the analyses originate from the Adak Area.

Table 5. Survey of the Co-Ni-values in arsenopyrites.

% Co					% Ni				
<0.001	0.001— —0.009	0.01— —0.09	0.1— —0.9	1—3	<0.001	0.001— —0.009	0.01— —0.09	0.1— —0.9	
15.5	—	23	41	20.5	36	7.5	36	20.5	% of 39 analyses

The Co- and Ni-percentages of *arsenopyrite* have generally not been treated in the previous spectrochemical researches of the Co- and Ni-contents of sulphide minerals (Rost (20) has one analysis from Pfaffenreuth), this probably being due to the fact that arsenopyrite is lacking or plays a relatively insignificant rôle in the deposits examined. In the Skellefte District, on the other hand, arsenopyrite is a common constituent in many ore deposits, and it has also appeared to be of great importance for the distribution of Co and Ni in the ore bodies.

It is a well-known fact that Co can be contained in arsenopyrite up to several per cent of weight and isomorphously substitute iron. Doelter (6) also mentions arsenopyrites with high Ni-contents (containing 4—5 % Ni), but according to the latest edition of Dana's System of Mineralogy (5) these statements have not been verified. The uncertainty frequently attaching to the »purity» of the minerals in earlier analyses often makes it difficult to decide to what extent Ni may be present in the crystal lattice of arsenopyrite. Judging from the chemical analyses it appears that Co has a greater tendency to occur in arsenopyrite than Ni, but this may also be due to the fact that arsenopyrite is frequently formed in metallogenetic provinces characterized by Co-supremacy.

Out of the 39 analyses of arsenopyrite 18 derive from the ores of the Adak area, 13 from other ores in group Nos. 1—12, 1 from Rakkejaur, and 7 from quartz-arsenopyrite veins. Even though arsenopyrite is more abundant in the copper ores of the Adak District than in the other deposits, the table cannot, due to the great frequency of analyses from the Adak area, give a correct conception of the distribution of Co and Ni in arsenopyrites for the entire areas treated in the present investigation. The table is only intended to give a survey of the arsenopyrites analysed.

For the Adak and the Karlsson ores the analyses, with one exception, show values between 1 and 3 % Co, while the Ni-values vary between 0.003 and 0.03 %. For the Lindsköld Mine the Co-percentages are (with one exception) between 0.1 and 1 %, while the Ni-contents are higher than in the Adak-Karlsson ores: no less than 5 analyses, *i. e.* more than half the analyses from the Lindsköld Mine, show between 0.1 and 0.3 % Ni. For the other deposits the Co-values vary between 0.003 and 0.33 % and the Ni-values between 0.01 and 0.07 %. Co generally dominates more or less over Ni, the opposite being established in but one case.

The *Mn-percentages* vary considerably in all the four minerals analysed. The

Table 6 Survey of the Mn-values in pyrites and pyrrhotites.

% Mn		<0.001	0.001—0.009	0.01—0.09	0.1—0.9	>0.9 %
Pyrite	% of 97 analyses from ores 1—12	8	12.5	55	23.5	1
	% of all 134 analyses .	9.5	16.5	53.5	19.5	1
Pyrrhotite	% of 82 analyses from ores 1—12	3.5	8.5	71	17	—
	% of all 100 analyses .	6	10	64	20	—

Mn-values of pyrites and pyrrhotites are fairly regularly grouped around the interval 0.01—0.09 %, as will be seen from Table 6.

The Mn-distribution appears somewhat more uniform in pyrrhotite than in pyrite, especially in ores Nos. 1—12, which is demonstrated by the fact that 71 % of all the analyses of pyrrhotite are contained within the interval 0.01—0.09 % Mn, while the corresponding value for pyrite is 55 %. According to Gabrielson's results (8) the Mn-contents of sphalerite from the same zinc deposits as treated here are higher than is generally the case in pyrite and pyrrhotite, and consequently certain errors in the results may be caused by a contamination by sphalerite in the material analysed. The particularly high values in some cases can, however, not be explained in this way, and on the whole errors due to the admixture of sphalerite richer in Mn will not be of any great importance. In arsenopyrite and chalcopyrite the Mn-contents are generally lower than in pyrite and pyrrhotite, but occasional high contents have been noted also in these minerals. Table 7 shows the Mn-values grouped in various percentage-classes.

Table 7. Survey of the Mn-values in arsenopyrites and chalcopyrites.

		<0.001	0.001—0.009	0.01—0.09	0.1—0.9	>0.9 %
Arseno-pyrite	Number of analyses ..	12	13	7	5	—
	% of analyses	32.5	35	19	13.5	—
Chalco-pyrite	Number of analyses ..	6	15	8	1	2
	% of analyses	19	47	25	3	6

The Distribution of Co, Ni and Mn in the Various Sulphide Minerals.

The general surveys of the Co-Ni-Mn-values when grouped in percentage-classes (Table 2—7) give a rough idea of the dissimilarities between the various sulphides with regard to their contents of Co, Ni and Mn. If the minerals are arranged according to a decreasing ability to concentrate Co, the following sequence will appear: Arsenopyrite — pyrite — pyrrhotite — chalcopyrite. For Ni the same order between the minerals holds true, with the difference, however, that pyrrhotite and pyrite change places. Mn generally seems to be more enriched in pyrite and pyrrhotite as compared with arsenopyrite and chalcopyrite. No striking dissimilarities between pyrite and pyrrhotite as regards the Mn-values can be demonstrated, if the entire material is considered.

Of special interest is the distribution of Co and Ni in the minerals pyrrhotite and pyrite. This problem has recently been discussed by Rost (19), Hegemann (13), and Carstens (4). It has been shown that if pyrite and pyrrhotite occur together, Co is enriched in pyrite and Ni in pyrrhotite. The difference appears particularly pronounced upon comparing the Co-Ni-quotients of the two minerals. Among the examples given by the authors cited above several cases are found in which a conspicuous separation between Co and Ni has been accomplished by the recrystallization of a pyrite ore with a partial transformation of pyrite into pyrrhotite. In addition, Rost pointed out that pure pyrrhotite masses containing no other mineral particularly apt to include Co, may hold considerable amounts of Co.

If we consider the results obtained in the present investigation, a tendency is in fact frequently found towards a separation of Co and Ni, due to the enrichment of Co in pyrite and Ni in pyrrhotite. This appears most strikingly in the Co-Ni-ratios of the averages for the various ores (see p. 36). And yet this separation is considerably less pronounced here than in the majority of the examples presented by Rost, Hegemann, and Carstens. Instead it is often found that the Co-Ni-quotients of different sulphide minerals disclose a similar tendency in all minerals from the same deposit and that this feature is far more conspicuous than the tendency towards a concentration of Co and Ni, respectively, in separate minerals. If, for instance, we compare the Co-Ni-values of the pyrrhotites with those of the pyrites in ores Nos. 2—4 and 7—10, a close relationship between these two minerals, when they occur in the same ore body, is indicated: A distinct Co-supremacy in both pyrites and pyrrhotites from the Bjurfors ores (No. 3 in Table 1), a slight Ni-supremacy in the two minerals from Eastern Högkulla (No. 4 in Table 1), etc. Nor has it been possible to prove any general enrichment of Co in pyrrhotite from ore portions entirely free from pyrite.

In view of the results of Rost, Hegemann, and Carstens the distribution of Co and Ni in these ore portions can be taken to imply that the ores have not been subjected to any appreciable »secondary» recrystallization. It seems more probable that the distribution of Co and Ni in most cases is due to certain properties of the ore-forming liquids themselves.

On account of the comparatively great variations of the Co-Ni-values also in one ore body, the best conception of the enrichment of these metals in separate minerals is obtained by comparing closely adjacent minerals from complex sulphide ores. Table 8 is a survey of Co-, Ni-, and Mn-values of different minerals from one and the same specimen.

Table 8. Survey of Co-Ni-Mn-values of different minerals from the same specimen.

(The analyses referring to the same specimen are in the same horizontal row.)

Locality	Pyrite				Pyrrhotite				Arsenopyrite				Chalcopyrite			
	No.	% Co	% Ni	% Mn	No.	% Co	% Ni	% Mn	No.	% Co	% Ni	% Mn	No.	% Co	% Ni	% Mn
The Bjurträsk Ores	2	0.07	—	0.02	402	0.003	0.01	0.03								
» » »					405	0.03	<0.001	0.01					602	—	—	<0.001
Bjurliden	13	—	<0.001	0.1	410	—	<0.001	0.07								
»	15	0.07	<0.001	0.01	411	0.02	0.001	0.05								
»	8	0.07	—	0.05	412	0.02	<0.001	0.2								
Eastern Bjurfors Ore	17	0.2	—	0.01	413	0.025	<0.001	0.01					603	0.1	—	0.001
» » »	18	0.1	—	0.02	414	0.07	<0.001	0.03								
» » »	19	0.08	0.003	0.02	415	0.03	<0.001	0.01								
» » »					418	—	<0.001	0.3					604	—	—	<0.001
Middle » »	24	0.07	—	0.01	419	0.03	0.002	0.02								
Eastern Högkulla	32	—	—	0.3	420	—	<0.001	0.2								
» »	33	—	0.002	0.02	421	—	<0.001	0.03								
» »	34	—	0.007	0.02	422	—	0.001	0.01								
» »	37	—	0.001	0.03	423	—	0.001	0.03								
» »	40	—	0.002	0.3	424	—	<0.001	0.2								
» »	41	—	0.005	0.1	425	—	0.001	0.03								
» »	42	0.03	—	0.1	426	—	0.001	0.03								
Skäggträskberget	46	0.1	>0.001	0.02					309	0.01	—	0.02				
Kristineberg	49	0.085	<0.003	0.005									606	—	—	0.001
»	51	0.07	<0.001	0.01									607	—	—	0.001
»	52	0.1	<0.001	0.01									608	0.01	—	0.001
Rävliden	59	0.01	—	0.05	431	—	<0.001	0.02					609	—	—	0.03
»	61	—	<0.001	0.01	432	—	—	0.03								
»	69	—	0.01	0.1	434	—	0.02	0.04								
»	70	—	0.03	0.03	435	—	0.01	0.07								
»	71	—	0.01	0.2	436	—	0.01	0.2								
»					437	0.01	0.003	0.2	312	0.07	0.003	0.3				
»					433	—	0.001	0.003					610	—	—	0.1
Rävlidmyran	73	—	0.001	<0.001	439	—	—	0.003					611	—	—	<0.001

Rävlidmyran	77	—	0.001	0.03	440	—	0.01	0.01					612	0.07	—	0.015
The Adak Ores	78	0.2	—	0.03	441	—	<0.001	0.03								
» » »	80	0.1	0.01	0.01	442	0.03	0.003	0.04								
» » »	81	0.03	<0.001	0.005	454	—	<0.001	0.05								
» » »	82	0.2	—	0.03	455	0.07	<0.001	0.05								
» » »					449	0.03	0.001	0.003	314	>1	0.001	<0.001				
» » »					450	0.1	<0.001	0.01	315	3	0.01	0.001	613	0.01	—	0.001
» » »					451	0.07	0.001	0.01	317	3	0.03	0.1				
» » »					445	0.07	<0.001	0.003					614	0.005	—	0.001
» » »					446	0.07	<0.001	0.01					615	—	—	0.03
» » »					447	0.03	<0.001	0.01					616	—	—	0.001
» » »					448	0.07	<0.001	0.07					617	—	—	1
The Karlsson Ores					457	0.02	—	0.01	319	2.5	0.01	0.001	618	—	0.001	0.001
» » »					456	0.03	—	0.003					619	—	—	0.001
The Lindsköld Ore ...	88	0.02	0.007	0.01	458	—	0.01	0.01								
» » » ...	89	0.02	0.008	0.03	459	0.01	0.003	0.06								
» » » ...					467	0.03	0.01	0.003	323	0.1	0.03	0.001				
» » » ...									325	0.3	0.3	<0.001	620	0.03	0.03	0.001
» » » ...									326	0.3	0.1	0.001	621	0.005	0.001	0.03
» » » ...					468	0.25	0.07	0.08	327	0.4	0.25	0.001				
» » » ...					469	—	0.003	<0.001	330	1.2	0.2	0.01	623	—	<0.001	<0.001
» » » ...					465	—	0.01	0.03					622	—	0.001	0.001
Rudtjebäcken	90	0.01	<0.001	0.002	470	—	<0.001	0.2					624	0.003	0.001	0.03
»	91	0.02	0.005	0.1	471	—	0.005	0.03								
»	92	0.03	<0.001	<0.001	472	0.007	0.001	0.003								
»	94	—	0.007	0.05	473	—	0.005	0.01								
»	96	0.1	0.003	0.1	474	—	0.005	0.07								
Laver	97	0.4	0.01	0.015	476	0.02	0.006	0.1								
»					475	0.02	0.02	0.02					627	0.004	0.005	0.02
»					477	0.03	0.03	0.1					628	0.004	0.01	0.002
»					478	0.03	0.02	0.02					629	0.006	0.005	0.002
»					482	0.03	0.06	0.01					630	0.007	0.01	<0.001
Österbäcken	104	0.1	0.007	0.07	489	0.03	0.1	0.2								
Lillholmträsk	108	0.3	0.007	0.005	494	—	0.07	0.001								
Ol Ersberget					493	—	0.003	<0.001	336	0.7	0.003	<0.001				
W of Gunnarn					500	0.02	0.1	0.01					632	—	0.01	0.03

As will be seen, it is only in a few cases possible to observe a distinct separation of Co and Ni by enrichment of either element in pyrite and pyrrhotite, respectively (analyses Nos. 2—402, 42—426, 96—474, 108—494, 88—458). In most cases we find high Co-values in pyrrhotites to correspond to particularly high Co-values also in pyrites (see especially the analyses from the Eastern Bjurfors Ore and the Adak Mine). Analyses Nos. 411 and 412 are of great interest, as out of seven pyrrhotite analyses from Bjurliden they are the only ones showing any considerable amount of Co. The pyrites from the same specimens also show Co-contents particularly high for that deposit (cf. the survey of the values from Bjurliden in Table 1).

Several analyses of arsenopyrite and pyrrhotite from the same specimen are presented. In most cases the results disclose a conspicuous concentration of Co, sometimes also of Ni in arsenopyrite as compared with pyrrhotite. However, also in these cases the same general tendency is found to be prevailing in the two minerals: At Rävliden (No. 437) and the Lindsköld Mine (Nos. 467 and 468) the pyrrhotites from the specimens containing arsenopyrite (*i. e.* the mineral containing the highest amounts of Co and Ni in the respective deposits) differ from the other pyrrhotites with respect to the Co-Ni-contents. Particularly high Co-values are found in the arsenopyrites from the Adak ores, which ores, however, are characterized by particularly high Co-contents also in the pyrrhotites. Only analyses Nos. 334—493 (from a sulphide-bearing quartz vein) show a very obvious separation between Co and Ni in adjacent arsenopyrite and pyrrhotite.

The chalcopyrites generally contain considerably less Co and Ni than the other sulphide minerals treated here. In the cases when determinable quantities of either Co or Ni occur, we find, however, also here a relationship with other adjacent minerals. The Co-values as sometimes found in the Eastern Bjurfors Ore, the Kristineberg, the Adak, and the Lindsköld ores correspond to comparatively high values in pyrite, pyrrhotite, and arsenopyrite from the same specimens. Significant in this respect are the Ni-contents of chalcopyrites from the Lindsköld ore, where Ni compared with Co plays a greater rôle than in the other three of the four above-mentioned deposits. A distinct Ni-supremacy over Co is also evident in the two analyses Nos. 500 and 632 (the specimen from a sulphide vein in graphite-phyllite).

As has already been mentioned, the Mn-values of the four sulphide minerals here analysed show extremely great and irregular variations also within one ore deposit. A comparison of the Mn-contents of different minerals from the same specimen discloses no systematic relationship. In some cases, however, a certain co-variance is indicated between the Mn-contents of pyrite, on the one hand, and those of pyrrhotite, on the other, viz. in the samples from Eastern Högkulla and to some extent also from the Eastern Bjurfors Ore. In other cases, as for instance in the series from Rudtjebäcken, the variations also in these two minerals are quite independent of each other.

The Variations of the Co-Ni-Mn-Values in the Separate Ore Deposits and their Significance.

The surveys of the various ore deposits (Table 1) have proved that even in the same ore deposit the Co-, Ni-, and Mn-values of each sulphide mineral show considerable variations. These variations often appear to be quite haphazard. In deposits where, for instance, several separate ore bodies occur it has never been possible to distinguish the individual ore lenses on the basis of the Co-Ni-Mn-values. At Bjurliden, for instance, where two separate, very similar ore lenses occur and where simultaneously Co-bearing as well as Co-free pyrites have been found, both kinds are represented in the two ore lenses.

Further, it may be questioned whether there exists any systematic relationship between the Co-Ni-Mn-values and different types of wall rock. The majority of the ore bodies here examined are surrounded by sericite-quartzites and chlorite-quartzites or chlorite-rocks. However, sulphide mineralization has also been encountered in cordierite-quartzites, in graphite-phyllites and sedimentogeneous gneisses, and finally in basic or acid dikes. In searching for a relationship between the Co-Ni-Mn-values and different wall rocks it is most advantageous to consider the disseminations, where the relations are most clearly indicated. Table 9 shows the Co-Ni-Mn-values in a number of pyrites, the analyses being grouped according to various types of country rock.

This material does not demonstrate any definite difference between the pyrites from sericite-quartzites, chlorite-quartzites, cordierite-quartzites, graphite-phyllites, or dikes. In the cordierite-quartzites are found both high and low Co-values, extreme Co-supremacy over Ni as well as more similar Co- and Ni-values. The same general tendency also appears in the sericite-quartzites. The three analyses of pyrites from chlorite-quartzites fall entirely within the limits of the values referring to cordierite-quartzites and so do the two analyses of pyrites from intrusive dikes. Out of the four analyses of pyrite from graphite-phyllites the two first contrast with the normal character of pyrites from other rock types with respect to the Co-Ni-quotients in that they show a pronounced Ni-dominance. As regards No. 108 it must be kept in mind that this analysis does not represent the Co-Ni-quotient of the entire sulphide veinlet. This sample belongs to the ones mentioned before, in which a pronounced separation between Co and Ni in pyrite and pyrrhotite occurs. The pyrrhotite from the same specimen does, in fact, not contain any Co at all but shows a Ni-content of 0.07 %.

The analytic values of pyrites from graphite-phyllites thus seem to indicate that these are characterized by lower Co-Ni-quotients than pyrites from the other types of sulphide mineralization here investigated. This tendency appears still more pronounced in the pyrrhotites. In the survey of the Co-Ni-values of the pyrrhotites, Table 3, it was pointed out that the analyses of pyrrhotites from phyllites and gneisses showed a distribution of the values in percentage-classes quite different to that of the rest of the material. Table 10 shows the

Table 9.

Survey of the Co-Ni-Mn-values of disseminated pyrites from various rocks.

Sericite-quartzite				Chlorite-quartzite				Cordierite-quartzite and coarse biotite-quartzite				Intrusive dikes				Graphite-phyllite			
No.	% Co	% Ni	% Mn	No.	% Co	% Ni	% Mn	No.	% Co	% Ni	% Mn	No.	% Co	% Ni	% Mn	No.	% Co	% Ni	% Mn
98	0.01	<0.001	0.001	119	0.03	0.001	0.01	100	0.001	0.001	—	99	0.03	0.001	0.05	102	0.03	0.1	0.1
105	—	0.007	0.07	120	0.25	<0.001	0.03	115	0.03	0.02	0.03	129	0.03	0.001	0.003	106	0.01	0.03	0.03
107	0.003	<0.001	0.001	132	0.07	0.001	0.03	126	0.03	<0.001	—					108	0.3	0.007	0.005
113	0.01	0.001	—					127	0.3	—	0.07					130	0.07	0.02	0.05
114	—	—	0.05					118	—	—	0.03								
116	0.1	0.03	<0.001																
122	0.01	0.03	0.03																
134	—	0.001	0.005																

Table 10. Survey of the distribution of Co and Ni in pyrrhotites.

	% Co				% Ni			
	< 0.001	0.003—0.009	0.01—0.09	0.1—0.2	< 0.001	0.001—0.009	0.01—0.09	0.1—0.3
% of 88 analyses of pyrrhotite in other rocks than phyllites and gneisses	43	5	37	3.5	44.5	27	28.5	—
% of 12 analyses of pyrrhotite in phyllites and gneisses . .	17	8.5	66	8.5	—	—	58	42

difference in distribution of Co and Ni in pyrrhotites from phyllites and gneisses, on the one hand, and from all other types of mineralization here analysed, on the other.

The table discloses the Co-values as well as the Ni-values to be higher in pyrrhotite from phyllites and gneisses than in pyrrhotite from other rocks, though this difference is much more obvious for Ni than for Co. In other words, in sulphides from phyllites and gneisses the Co-Ni-quotient is considerably changed towards Ni-dominance as compared with sulphides from other types of mineralization.

The above-mentioned difference between the iron sulphides in phyllites or gneisses and those of a normal hydrothermal type might at first sight be taken as an argument for different genesis of the mineralization in the two cases. Rost (19), Hegemann (13), and Carstens (4) have shown that pyrites from sedimentary sulphide deposits not subjected to »secondary» metamorphism are characterized by a striking Ni-supremacy over Co, whereas the reverse generally holds true for hydrothermal pyrites. It might now easily be concluded that the sulphides in the Skellefte District, which appear in unmistakeably sedimentary rocks, are also of a sedimentary origin. They might possibly have been secondarily mobilized but then to a considerably less degree than the other types of sulphide mineralization. However, when considering the geological conditions in some of the ore deposits treated here, we shall find some results urging to great caution when using the distribution of Co and Ni in sulphides for this reasoning. At the Rävliden Mine ore bodies occur partly in chlorite- and sericite-quartzites, partly in skarn, and partly in graphite-phyllite. The ore bodies can be characterized as pyritic copper and zinc ores, the different types preferably occurring in separate lenses. The zinc ores as well as the copper ores may grade into pure pyrite with very small amounts of Zn or Cu. Compact ore bodies occurring in graphite-phyllite often grade into pyrite-banded graphite-phyllite in the direction of the strike, this being a very characteristic type for the Rävliden Mine. The genetic association between the various ore types is, however, quite indisputable, and the pyrite in the pyrite-banded phyllites is quite as distinctly epigenetic as the other sulphides (besides, the banding locally often changes into breccias, in which the phyllite appears as well-defined inclusions in a pyrite mass). In the survey of the Rävliden pyrites (Table 1) it now appears that the analysis of pyrite from the pyrite bands in phyllite (No. 66) to some extent differs from the other Rävliden pyrites by showing just such Co-Ni-values as may be expected in pyrites in phyllites and gneisses elsewhere. As this difference cannot at Rävliden be explained as due to a difference between sedimentary and hydrothermal origin, the minor constituents cannot here be taken as an argument for a primarily sedimentary origin of certain sulphides. Similar conditions are indicated at Rakkejaur, where clearly epigenetic pyrite from graphite-phyllite displays Ni-dominance (0.02 % Co, 0.03 % Ni). On account of there being only two samples analysed from Rakkejaur it is not possible to decide whether or not these values are characteristic of the deposit as a whole.

In view of our incomplete knowledge of the physical and chemical conditions at the formation of the ores it is of course impossible to say anything with certainty about the cause of this phenomenon. Possibly the graphite in the phyllites may have some kind of selective effect on the ore-forming liquids and cause a separation between Co and Ni, but as such a hypothesis lacks experimental foundation, this is a mere guess.

Influence of the Crystallization Temperature on the Co-Ni-Mn-Contents of the Sulphides.

Our knowledge of the exact temperatures at the formation of the ore bodies is very incomplete. By comparing various ore deposits we can in most cases only establish the relative values. A rough idea of the crystallization temperatures of epigenetic ore deposits can be gained from the mineral facies as represented by gangue minerals and the mineral composition of the wall rocks. In order to obtain from the figures in Table 1 an idea of the relationship between temperature and the distribution of the minor constituents, chemically and mineralogically similar ores from the same geological milieu ought to be compared, as we do not know as yet to what extent the chemical composition and the milieu may influence the results. Only two ore deposits of Nos. 1—12 really satisfy these conditions and differ with regard to wall rocks and gangue minerals, *i. e.* Bjurliden and Eastern Högkulla. Both are pyritic zinc ores, displaying almost identical mineralogical and structural features as regards the sulphides. On the other hand, the silicate parageneses very clearly indicate that the Bjurliden ore was formed at a higher temperature than the Eastern Högkulla ore. In Table 11 is given a survey of the amounts of Co, Ni, and Mn in pyrites as well as in pyrrhotites from the two deposits.

The difference between the two deposits is obviously that sporadically higher Co-values are more common at Bjurliden than at Eastern Högkulla and that a certain, though low Ni-content is more common in the latter deposit. As regards the Mn-values there is no real difference between the two deposits. Seemingly the results only indicate that the Co-Ni-quotients are slightly lower in low-temperature pyrites than in high-temperature pyrites. However, this

Table 11.

Survey of the Co-Ni-Mn-values in pyrites and pyrrhotites from Bjurliden (higher temperatures) and Eastern Högkulla (lower temperatures).

Pyrite	Bjurliden	%Co	—	—	—	—	—	—	—	0.007	0.05	0.07	0.07	0.07
		%Ni	—	—	<0.001	<0.001	0.001	0.001	0.003	—	<0.001	—	<0.001	<0.001
		%Mn	<0.001	0.1	0.1	0.1	0.2	0.3	1.0	0.005	0.02	0.05	0.01	0.01
	Eastern Högkulla	%Co	—	—	—	—	—	—	—	—	—	0.003	0.003	0.3
		%Ni	—	—	0.001	0.002	0.002	0.002	0.002	0.005	0.007	0.001	0.002	—
		%Mn	0.1	0.3	0.03	0.02	0.1	0.1	0.3	0.1	0.02	0.03	0.3	0.1
Pyrrhotite	Bjurliden	%Co	—	—	—	—	—	0.02	0.02					
		%Ni	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001					
		%Mn	0.03	0.07	0.07	0.07	0.07	0.02	0.05					
	Eastern Högkulla	%Co	—	—	—	—	—	—	—	—	—	—		
		%Ni	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	0.001	0.001		
		%Mn	0.03	0.2	0.2	0.2	0.3	0.01	0.03	0.03	0.03	0.07		

tendency must be considered fairly indistinct. In the rest of the material from Table 1 it is difficult to descry a similar tendency. The pyrites from Brattmyrhögen (Nos. 111 and 112), for instance, are characterized by a distinct Ni-supremacy over Co, in spite of this ore deposit being a decided high-temperature formation as compared with the majority of the other ores treated here. Nor does a study of the pyrites from disseminations disclose anything to support the assumption of there being a systematic relation between the Co-Ni-quotients and the crystallization temperatures of the sulphides. For instance, a comparison between pyrite from the sericite-quartzite of the Kristineberg—Rävliden District (0.1 % Co, 0.03 % Ni) and pyrite from a mineral assemblage indicating a higher temperature, *i. e.* in cordierite-quartzite from the same district (0.03 % Co, 0.02 % Ni), yields a result quite contrary to the results from Bjurliden and Eastern Högkulla. Thus it seems evident that temperature (in the types of mineralization treated in this work) is at least of subordinate importance as compared with other factors.

Influence of the Chemical Composition on the Co-Ni-Mn-Contents of the Sulphides.

As has already been mentioned, the ores treated here can to a large extent be characterized as copper or zinc ores. Both types are as a rule pyritic and besides usually contain varying amounts of pyrrhotite. Arsenopyrite often occurs as scattered crystals in the complex sulphide ores but also forms solid, dense masses. However, the most conspicuous feature being the differentiation into separate zinc ore and copper ore portions, these ore types will first be considered.

Of ores Nos. 1—12 in Table 1 Bjurliden and Eastern Högkulla contain only zinc ore. In the Bjurträsk and Rävlidmyran mines the by far predominating portions are zinc ores; only quite small parts can be classified as copper ore. The Adak, Lindsköld, and Laver ores are typical copper ores. In the Adak ores, however, also zinc-bearing portions with very low contents of copper occur, though they constitute a very insignificant part of the entire ore bodies. A conspicuous differentiation into separate zinc and copper portions is present in the mines at Bjurfors, Rävliden, Kristineberg, and to some extent also at Skäggträskberget. At Rudtjebäcken, finally, both copper and zinc ore portions exist, but the Cu- as well as the Zn-contents are in most cases fairly low and the separation is here less pronounced than in the other deposits mentioned above.

Primarily we shall consider those cases in which zinc and copper ore portions occur in close connection with each other and where thus factors due to geologic milieu or temperature cannot be supposed to influence the results. Table 12 shows the averages of Co, Ni, and Mn in pyrites and pyrrhotites from these deposits.

Considering the pyrites, we notice a distinct tendency towards a change in the Co-Ni-quotient from copper ore to zinc ore. The Co-values for pyrites from

Table 12. Survey of the means of Co, Ni, and Mn of pyrites from ore deposits with adjacent copper-ore and zinc-ore portions.

Locality	Pyrite				Pyrrhotite			
	Number of analyses	% Co	% Ni	% Mn	Number of analyses	% Co	% Ni	% Mn
The Eastern Bjurfors ore (Cu-ore)	5	0.12	0.0015	0.033	6	0.036	<0.001	0.072
(Zn-ore)	1	0.01	<0.001	0.01				
The Middle Bjurfors ore (Zn-ore)	5	0.035	0.0045	0.135	1	0.03	0.002	0.03
Kristineberg (Cu-ore)	7	0.056	<0.001	0.007				
» Zn-ore	3	0.01	0.001	0.04				
Rävliden (Cu-ore)	6	0.015	0.002	0.03	4	—	<0.001	0.021
» (Zn-ore)[1]	4	—	0.0065	0.1	4	—	0.011	—
	5	(0.021)	(0.008)	(0.102)	5	(0.002)	(0.009)	(0.108)

[1] For the zinc ores of Rävliden two series of values have been given, as one extremely high Co-value strongly influences the mean. The upper row shows the means if this analysis is excluded.

the copper ores are generally higher than those of the zinc ores, while the contrary is the case as regards the Ni-values. At Rävliden the comparatively high Co-mean of all analyses from zinc ores is caused by one single extremely high value. In the other pyrites from the zinc ores we find, however, that Co has not been proved, while Ni was found throughout. In the pyrites of the copper ores from the Rävliden mine Co is absent only in one case, in which, however, the Ni-value is also very low (< 0.001 %).

The analyses of pyrites from the zinc ores at Eastern Högkulla and Bjurliden, which belong to the ore deposits of the Malånäs District, may be compared with the analyses from the Eastern Bjurfors (copper) ore. This comparison confirms the results from Table 12. For Eastern Högkulla the means are 0.003 % Co and 0.002 % Ni (or, if one single, extremely high value is subtracted, 0.0005 % Co and 0.0025 % Ni) and for Bjurliden 0.022 % Co and 0.0005 % Ni.

The same tendency can be discerned on comparing the Co-Ni-values of the pyrrhotites from copper and zinc ores, although in this case the analyses are too few to disclose the difference with the same degree of accuracy. However, it is sometimes possible to trace the tendency also in those deposits where only a few samples have been analysed. Considering the analyses not included in Table 12 we find, for instance, that the only comparatively high Co-value of pyrrhotites from the Bjurträsk Mine originates from the small separate copper ore, while the other analyses from the same deposit refer to the zinc-bearing ore portions (cf. Table 1). From Rävlidmyran there exist two pyrrhotite analyses, one from zinc ore and one from copper ore. In both of them Co is absent but in the zinc ore a Ni-content of 0.01 % has been found, while Ni could not be proved in the copper ore.

At Rudtjebäcken no difference whatever has been established between zinc-ore and copper-ore portions in the samples analysed. As already pointed out, the separation between zinc and copper is, however, here much less pronounced than in the above cases. The same is also true of the Adak Mine.

However, even if it has been possible to discern a kind of systematic relation between the Co-Ni-quotients for pyrites and pyrrhotites, on the one hand, and the copper-zinc-differentiation, on the other, the dissimilarities between copper and zinc ores are not so general as to permit, in each individual case, a pyrite of a copper ore to be distinguished from a pyrite of a zinc ore by means of the Co-Ni-values only. In the Bjurfors ores as well as in the Kristineberg and the Rävliden ores similar values may be found in both copper- and zinc-ore portions. Solitary values from the various ores thus overlap and only on comparing a large number of analyses is it possible to establish an unmistakable dissimilarity.

The values in Table 12 indicate that pyrites from zinc ores are enriched in manganese compared with pyrites from copper ores. The variations in the Mn-contents are, however, so great and so irregular, as compared with those of Co and Ni (cf. the values for the separate deposits, Table 1), that this tendency must be considered very vague. In pyrrhotites it is not noticeable at all.

Pure pyrite and pyrrhotite portions with low contents of Cu and Zn often occur in close connection with copper or zinc ores and may, when they do not form large separate masses, be included in these. No pronounced difference could be detected in the Co-Ni-Mn-distribution between such ore portions and the more high-grade copper and zinc ores. When separate pyrite lenses occur in connection with copper or zinc ores, or when pyrite forms disseminations around solid sulphide bodies, it sometimes contains less Co and Ni than pyrites from the high-grade ores, but the reverse has also been found. The former case is exemplified by analyses from the Bjurfors Field (The Western Bjurfors Ore, No. 30, and disseminated pyrite from the Eastern Ore, No. 23), from Eastern Högkulla, No. 31, from the small ore lenses at Skäggträskberget, Nos. 43—45. An enrichment of Co and Ni in the copper- and zinc-free ore portions has been recorded from Rävlidmyran, Nos. 74 and 75, and to some extent from Rudtjebäcken, No. 96.

In the classification of the ores dense arsenopyrite was mentioned as a special type. This is best known from Boliden, where it locally contains so much Co that certain parts have been mined as cobalt ore. In ores Nos. 1—12 dense arsenopyrite ore has been encountered as quite small but well-defined fragments in zinc ore at Bjurliden, Eastern Högkulla and Rävliden. At Skäggträskberget there occur arsenopyrite lenses, one or two meter wide, and in the

Lindsköld Mine even larger masses have been found. As has already been pointed out, arsenopyrite always has a tendency to become enriched with Co and, to a certain degree, also with Ni, as compared with the other sulphide minerals. A comparison between the contents of Co and Ni in the dense arsenopyrite masses and those in the scattered crystals of arsenopyrite from complex ores or from wall rocks discloses no systematic difference. At Eastern Högkulla Co is very concentrated in the dense arsenopyrite ore (No. 307) compared both with pyrite and pyrrhotite in the zinc ore and with arsenopyrite crystals in the complex ores (No. 308). From a previous investigation we know that the dense arsenopyrite ore contrasts with the principal ore also by a very remarkable content of gold. At Bjurliden neither Co nor Ni could be detected in the dense arsenopyrite (No. 302), nor in crystals in complex zinc ore (No. 303) or in veins containing sulphominerals with arsenopyrite (No. 304). On the other hand, crystals of arsenopyrite in quartzites surrounding the main ore bodies show a certain Co- and Ni-content (Nos. 305 and 306). Also at Skäggträskberget the Co-Ni-values are lower in dense arsenopyrite ore (No. 309) than in the isolated crystals occurring in quartzite close to quartz veins (Nos. 310 and 311). The analyses from Rävlidmyran and the Lindsköld Mine only disclose that the Co- and Ni-values are higher in arsenopyrite than in the other sulphide minerals. From Rakkejaur one sample of dense arsenopyrite ore has been analysed (No. 337), which analysis as compared with those of pyrite from the same deposit displays a considerable enrichment of Co.

Influence of the Geological Milieu on the Co-Ni-Mn-Contents of the Sulphides.

The ores treated in the present research are distributed over a fairly large area, and it might thus be conceived that various regions should be characterized by different amounts and kinds of minor constituents. In Table 13 the Co-Ni-Mn-values of pyrites, pyrrhotites and arsenopyrites from ores 1—11 (in means for the respective ore deposits) have been grouped according to the three principal ore districts, the copper-ore portions and zinc-ore portions then having to be considered separately.

No very characteristic differences between the various districts are disclosed by this table. In the Rävliden—Kristineberg region a faint tendency can possibly be discerned towards generally lower Co-values as compared with the Malånäs District. Considering the analyses from other localities than ores No. 1—11 but belonging to the three main ore districts (Table 1, latter part, pp. 17, 18), we do not observe any very characteristic or general difference between the various districts. However, the Vindelgransele region, which borders on the Kristineberg—Rävliden District, is characterized by comparatively high Ni-values as compared with the Co-values. In this connection the arsenopyrite from Fäboliden (No. 337, in the Vindelgransele region) is of interest, showing the remarkable figures: Co — %, Ni 0.1 %.

Table 13. The Co-Ni-Mn-values of pyrites, pyrrhotites and arsenopyrites from zinc- and copper-ore portions in deposits Nos. 1—11.

The figures represent the arithmetical mean for each ore.
The deposits are grouped according to the three main ore regions.

		Pyrite			Pyrrhotite			Arsenopyrite		
		% Co	% Ni	% Mn	% Co	% Ni	% Mn	% Co	% Ni	% Mn
Zinc ores.										
The Malånäs Region	The Bjurträsk ores	0.04	—	[1]0.14 0.025	0.001	0.0025	0.09			
	Bjurliden	0.022	0.0005	0.165	0.006	<0.001	0.08	0.008	0.002	[1]0.02 <0.001
	The Middle Bjurfors ore	0.032	0.0045	0.13	0.03	0.002	0.03			
	Eastern Högkulla.	0.003	0.002	0.125	—	<0.001	0.11	[1]0.3 —	[1]— —	[1]0.1 0.001
	Skäggträskberget .	0.007	—	0.1	—	<0.001	0.03	0.05	<0.001	0.01
The Kristineberg—Rävliden Region	Kristineberg	[1]0.01 0.021	[1]0.001 0.008	0.006						
	Rävliden	—	0.0065	0.1	0.002	0.015	0.100	0.07 0.03	[2]0.003 0.07	[2]0.3 <0.001
	Rävlidmyran.....	—	0.0005	0.03	—	0.01	0.01			
The Adak Region	Rudtjebäcken....	0.013	0.005	0.04	—	0.003	0.003	0.006		
Copper ores.										
The Malånäs Region	The Bjurträsk ores				0.03	<0.001	0.01	0.33	<0.001	<0.001
	Eastern Bjurfors ore...........	0.12	0.0015	0.033	0.036	<0.001	0.072			
	Skäggträskberget .	0.05	0.003	0.03						
The Kristineberg—Rävliden Region	Kristineberg	0.056	<0.001	0.007						
	Rävliden	0.015	0.002	0.03	—	<0.001	0.021			
	Rävlidmyran.....	—	0.001		—	—	0.003			
The Adak Region	The Adak ores...	0.146	<0.001	0.021	0.056	0.001	0.029	2—3	0.021	0.021
	The Karlsson ores				0.025	—	0.006	2—3	0.025	0.01
	The Lindsköld ore	0.06	0.01	0.018	[3]0.028 0.006	[3]0.022 0.019	[3]0.029 0.026			
	Rudtjebäcken	0.015	0.003	[2]0.1 0.002	—	0.003	[2]0.2 0.003			

[1] The upper figure is the mean of all analyses, the lower figure is the mean if one extreme value is excluded.

[2] Only two mutually distinctly different values, both of them presented.

[3] The upper figures are the means of all analyses, the lower figures are the means when two extreme analyses are excluded, in which contamination by arsenopyrite may have influenced the results.

Variations in the Co-Ni-Mn-Contents of Ores from the Adak Area.

It has been shown above that the temperature of crystallization and geological milieu have very little bearing on the distribution of Co, Ni, and Mn in the ores treated here. The chemical composition of the ores, on the other hand, is of some importance, as a certain difference in the Co-Ni-distribution can be discerned between pyrites and pyrrhotites from zinc ores and those from copper ores. This difference, too, is comparatively small, however, as compared with the variations in each type of ore. In the light of these results the analyses from some of the ores in the Adak District are very remarkable indeed. On comparing the means of Co and Ni in the ores from the Adak, Lindsköld, and Karlsson Mines (see Table 13), we immediately observe a marked difference between the Adak and Karlsson Mines, on the one hand, and the Lindsköld Mine on the other. In the pyrites from the first two deposits the Co-values are considerably higher, and the Ni-values remarkably lower than at the Lindsköld Mine.

On studying the pyrrhotites, we note exactly the same thing, and this becomes still more accentuated when regarding the mean for pyrrhotites from which the two values, Nos. 467 and 468, were excluded (these latter originate from pyrrhotite intimately mixed with arsenopyrite rich in Co and Ni, and are therefore not representative of the common type of pyrrhotite). The pyrrhotites of the Karlsson Mine are closely related to those of the Adak Mine.

The difference is most conspicuous, however, in the arsenopyrites. The Co-Ni-quotients from the Adak and Karlsson Mines display great agreement, but contrast distinctly with the values of the arsenopyrites from the Lindsköld Mine. Even as regards the chalcopyrites the same tendency can be discerned in those cases where Co and Ni have been proved. The difference between the above-mentioned deposits in the Adak area is so consistent that the ranges of variation of the various deposits do not overlap, at least not as regards arsenopyrite and pyrrhotite and substantially also with respect to pyrite (cf. the surveys of the Adak, Karlsson and Lindsköld Mines in Table 1). In other words, by determining Co and Ni in any of the minerals pyrite, pyrrhotite, or arsenopyrite, it is in most cases possible to decide whether the mineral originates from the Adak-Karlsson ores or from the Lindsköld ore. Solitary analyses of pyrrhotite and pyrite from the Adak and the Lindsköld ores are too similar to permit an identification on the basis of the Co-Ni-values only, but the tables distinctly show that those values are exceptional ones and that no uncertainty exists as to the majority of the analyses. In any case, the difference between the Adak-Karlsson ores and the Lindsköld ores with regard to the Co-Ni-distribution is the most conspicuous one in the entire material treated here. This is all the more remarkable as these three ores very closely agree with regard to geologic milieu, »secondary» metamorphism, temperature of crystallization, and chemical and mineralogical composition: The distance between the outcropping portions of the Adak and the Lindsköld ores is about 350 metres and between the Lindsköld and the Karlsson ores 600 metres; the ores are surrounded by very similar types of altered rocks; the mineral composition of the wall rocks and the gangue minerals indicates a similar crystallization temperature; the chemical and mineralogical composition as regards the major constituents of the ores proper are practically identical in all three deposits. From this we must conclude that the Co-Ni-distribution in the Adak-Karlsson-Lindsköld ores was caused by factors that are independent of geologic milieu, temperature, and chemical composition but which affect the distribution to a higher degree than do the three above-mentioned factors in the other deposits treated in this research.

The only difference discernible between the Adak and the Lindsköld ores (irrespective of the dissimilarities in the Co-Ni-distribution) is mirrored in the structure. In the Adak and Karlsson ores the sulphides to a great extent form breccias, chalcopyrite and pyrrhotite appearing as veins in massive quartzites. Steeply dipping sulphide veins are abundant. This mode of occurrence of the sulphides gives the individual ore bodies an extremely irregular shape and small »pockets» of a practically compact mass of chalcopyrite are often formed. In these »pockets» and in the thicker veins the sulphides are always coarse-grained.

The Lindsköld ore is in the main controlled by quite different structures. Here the sulphides occur on the whole along the border between massive quartzites and an overlying, distinctly stratified rock series. The layers dip slightly (15°—25°) and the mineralization follows this structure. Thus the ores acquire the shape of a somewhat undulating plate, extending parallel with the stratification. To a great extent the sulphides are here more fine-grained than in the Adak ores. However, breccias and disseminations very similar in detail are to be found in the two deposits. Somewhat below the main ore in the Lindsköld Mine occasional steeply dipping and more coarse-grained chalcopyrite veins occur in the massive quartzites, their appearance and grain-size approaching those of the mineralization type in the Adak Mine. When the difference between the Co-Ni-contents of the Adak and the Lindsköld ores was discovered, additional analyses were made of arsenopyrite, pyrrhotite, and chalcopyrite from such a steep sulphide vein in the Lindsköld Mine. The results were of great interest, as the Co-Ni-values of this arsenopyrite (No. 329) to a certain extent differ from the other values from the Lindsköld Mine and approach the values of the arsenopyrites from the Adak Mine.

On the Distribution of Sn.

Tin is present as a mineral-forming element in several of the sulphide ore deposits of the Skellefte District and then in the form of stannite. In the mineral parageneses examined in the present research stannite has only been observed at Eastern Högkulla (9), but most probably it also occurs in the very similar Bjurliden ore.

By the spectrochemical analyses Sn was proved in many cases but not so generally that it could always be used as a pilot element for the purposes outlined in the introduction to this paper. Consequently no attempt has been made to make the Sn-determinations really quantitative; semi-quantitative estimations were made on the basis of the comparative strength of particular lines. Owing to the comparatively sporadical appearance of Sn, the best survey of the distribution of this element is gained by merely calculating how frequently Sn has been demonstrated in the samples examined:

Pyrite: Sn demonstrated in 26 per cent of the samples analysed
Pyrrhotite: » » » 13.5 » » » » » »
Arsenopyrite: » » » 6.5 » » » » » »
Chalcopyrite: » » » 52 » » » » » »

In sphalerite from the same ores as have been investigated in this paper Gabrielson (8) proved Sn in 9 out of 32 samples, *i. e.* in 28 % of the samples examined. However, as will be shown below, the Sn-distribution is highly dependent on the geologic milieu, and therefore these figures are dependent on the frequency of analyses from each of the various ore districts. Especially as regards sphalerite this factor will influence the results. Table 14 illustrates the frequency of Sn in the sulphide minerals from ores Nos. 1—12.

The table demonstrates the following facts: Both zinc- and copper-ore portions may contain Sn when the element is really present in the paragenesis. A very striking difference between the two ore types is, however, demonstrated by the fact that in the copper ores Sn occurs almost exclusively in chalcopyrite but is lacking in pyrites and generally also in pyrrhotites, while the pyrites of the zinc ores to a great extent contain Sn (note especially the difference between the Adak-Karlsson-Lindsköld ores and the Eastern Bjurfors ore, on the one hand, and Bjurliden, Eastern Högkulla, and the Middle Bjurfors ore, on the other). As, in all cases, pyrite is the first mineral to crystallize, this must

Table 14. Survey of the frequency of Sn-bearing samples from ores Nos. 1—12.

		Pyrite		Pyrrhotite		Arsenopyrite		Chalcopyrite	
		Number of analyses	% Sn-bearing samples	Number of analyses	% Sn-bearing samples	Number of analyses	% Sn-bearing samples	Number of analyses	% Sn-bearing samples
The Malå-näs Region	The Bjurträsk ores	4	50	5	20	1	0	2	50
	Bjurliden	12	50	7	43	5	20	0	—
	Eastern Bjurfors ore	7	0	6	17	0	—	2	50
	Middle and Western Bjurfors ores	7	28	1	0	0	—	0	—
	Eastern Högkulla	12	75	10	30	2	0	0	—
	Skäggträskberget	6	33	1	0	3	0	1	100
The Kristineberg—Rävliden Region	Kristineberg	10	0	0	—	0	—	3	0
	Rävliden	14	0	8	0	2	0	2	0
	Rävlidmyran	5	0	2	0	0	—	1	0
The Adak Region	The Adak ores	6	0	15	0	5	0	6	67
	The Karlsson ores	0	—	2	0	2	50	2	100
	The Lindsköld ore	6	0	12	0	9	0	4	75
	Rudtjebäcken	7	43	5	20	0	—	1	100
	Laver	2	50	8	62	2	0	7	43

signify either that when large quantities of copper are present in the ore solution, Sn remains in solution during the crystallization of the iron sulphides, or that Sn enters some Sn-mineral (*e. g.* stannite), which may be presumed to have a greater tendency to react with chalcopyrite than with, for instance, pyrite. As, however, when observed under the microscope, stannite has always proved to be older than adjacent chalcopyrite, the latter alternative appears to be less probable.

Furthermore, in Table 14 a very marked difference between the various ore districts appears: The Kristineberg—Rävliden District turns out to represent a region strikingly poor in Sn, while especially the Malånäs District but also the Adak District and the Laver ores are Sn-bearing. The same difference is apparent in Gabrielson's values for the sphalerites. The Sn-contents of sphalerites from ores in the Malånäs District were found to be tenths and hundredths of one per cent, while the only analysis from the Kristineberg—Rävliden District in which Sn was proved disclosed but 0.003 % (8). Thus, the Sn-values of all the sulphide minerals examined display a distinct general difference between the Kristineberg—Rävliden District, on the one hand, and the Malånäs District, the Adak District, and the Laver ores, on the other.

On the Distribution of Bi.

Native bismuth has been observed under the microscope on several occasions and then always in association with galena. As most of the galena in the ores here examined is linked up with the zinc ores, the mineral-forming part of bismuth should also be expected in the zinc ores. In the Adak area, however, galena with native bismuth has been observed in zinc-carrying ore portions with very small amounts of copper as well as in sulphide veinlets with abundant chalcopyrite. In the spectrochemical investigation Bi has been proved only in a few cases. A control of the Pb-contents of the Bi-bearing samples discloses that the Bi-values cannot be due to contaminations of Bi-bearing galena.

In 134 analyses of pyrite, Bi was found in 7 cases; 4 from the Kristineberg copper ores, 1 from the Eastern Bjurfors ore, 1 from the Adak Mine, and 1 from the copper ore at Skäggträskberget.

In 105 analyses of pyrrhotite Bi was proved in 2 samples; 1 from the Bjurträsk copper ore and 1 from the Lindsköld Mine.

In 37 analyses of arsenopyrite Bi was proved with certainty in one case only (from the Adak Mine) and in one sample, with some doubt (from the Lindsköld Mine).

In 33 chalcopyrite analyses Bi was proved in 4 samples, 3 from Kristineberg and 1 from the copper ore of the Bjurträsk Mine.

Kristineberg turns out to be the deposit showing the incomparatively greatest frequency of Bi-bearing samples (half of all Bi-bearing samples are from this deposit). The strongest Bi-lines were also found in analyses of samples from Kristineberg (two of chalcopyrite and one of pyrite).

A very interesting fact is that all the Bi-values are found in minerals from typical copper ores. By the microscopical investigations and by chemical analyses the Bi-contents of the ores have been found to be higher in the Zn-Pb-ores than in the Cu-ores. In view of this it is quite remarkable that pyrites and pyrrhotites from zinc ores could not be proved to contain Bi, whereas these minerals are sometimes Bi-bearing when found in copper ores. As the Bi-bearing galena is the last mineral in the sequence of crystallization, Bi ought to have been contained in the ore solution at the crystallization of the iron sulphides from zinc ores (cf. the behaviour of Sn in zinc and copper ores). It appears, in this case, as if Pb contributed to preserving the Bi in solution at the crystallization of the iron sulphides.

Summary and Discussion of the Results.

By S. Gavelin.

Pyrite, pyrrhotite, arsenopyrite, and chalcopyrite from a series of ore deposits and sulphide disseminations in the Skellefte District have been examined by spectrochemical analysis. Of the elements examined Co, Ni and Mn have proved to be of the greatest general interest, as it has been possible to prove these elements in the majority of the samples analysed. As regards Cu, Zn, Pb, As, Sb and Ag, it is generally impossible to say with certainty to what extent a value obtained represents the content of the mineral examined, and to what extent it originates from contamination by other minerals strongly enriched in these elements. Of the other elements, only Sn and Bi have proved to be of interest (this in spite of their very sporadic occurrence).

The Co-, Ni- and Mn-values all display great variations in the material examined. Mn is generally enriched in pyrite and pyrrhotite as compared with arsenopyrite and chalcopyrite, but even if we consider each mineral separately the variations of the Mn-values are so irregular and show so little correlation with the chemical composition of the ores, the crystallization temperature, etc., that the Mn-contents can practically never be used for the purposes outlined in the introduction to this paper. In this respect Co and Ni are of greater interest and gain in importance by the fact that in earlier spectrochemical examinations from other ore districts these constituents have been thoroughly treated.

As regards the distribution of Co and Ni in the various sulphide minerals, we find the greatest enrichment in arsenopyrite. Pyrite, which comes next to arsenopyrite in this respect, is especially characterized by a concentration of Co, whereas Ni in some cases prefers to enter pyrrhotite. Chalcopyrite is the one of the above minerals that has the lowest Co-Ni-contents. These results agree well with those presented by Rost, Hegemann and Carstens. Contrary to the results presented by the above authors a separation of Co and Ni by the concentration of Co in pyrite and Ni in pyrrhotite is, however, not very pronounced in the ores here examined. It is much more common to find a striking co-variance between the values of the various minerals from the same specimen or from the same deposit, there being a certain tendency towards Co-dominance or Ni-dominance in all the sulphide minerals from a certain limited portion of an ore.

The variations in the Co- and Ni-values of the same mineral are often quite independent of each other even if the samples compared originate from adjacent localities. This involves that also the Co : Ni-quotients in many cases show considerable variations. The type of altered rock surrounding the ore bodies has no bearing on the distribution of Co and Ni within the material here investigated. Comparisons between sulphide parageneses that are chemically and mineralogically similar but which may be assumed to have been formed at different temperatures, do not disclose such differences in the Co-Ni-values as to indicate a systematic relation between the Co-Ni-distribution and the temperatures of formation.

The most important deposits examined occur in groups representing three separate ore regions. Possibly there can be discerned a tendency towards higher Co-values in the Malånäs and the Adak Districts than in the Kristineberg—Rävliden District (and lower Co : Ni-quotients in the latter), but the dissimilarities between the various ore districts in respect of the Co-Ni-values must be considered very vague indeed.

Between copper and zinc ores there exists a fairly distinct difference, as pyrites and pyrrhotites from copper ores show a clear tendency to become enriched with Co as compared with the same minerals in the zinc ores. In the zinc ores, on the other hand, a slight concentration of Ni can often be discerned. The dispersion of the Co-Ni-values within the various ore bodies is certainly so wide that also on comparing zinc- and copper-ore portions from one and the same ore deposit identical values can be found in both copper and zinc ores. It is thus not possible in each case only on the basis of the Co-Ni-values to decide whether a pyrite or a pyrrhotite derives from a copper-ore or a zinc-ore portion, but on considering several analyses the tendency is quite clear.

The most conspicuous difference between the various ore bodies as illustrated by the Co-Ni-values is, however, to be found between the Adak-Karlsson ores, on the one hand, and the Lindsköld ore on the other. As the geological milieu, the temperature of formation (as indicated by gangue and wall-rock minerals), and the chemical and mineralogical composition are practically identical for these three ores, there must exist some other factor than the above governing the distribution of Co and Ni in the sulphides. Evidently this factor can affect the Co-Ni-distribution to a much higher degree than geological milieu, temperature and chemical composition (as regards the major constituents).

On the whole it must be concluded that the results obtained can only to a very limited extent be used for the purposes as outlined in the introduction. The possibility of elucidating the history of formation of a sulphide ore must still be regarded as comparatively small. On the other hand, as our knowledge of the composition and state of the ore-forming fluids increases, it is of course conceivable that also what may now appear to be random variations may contribute valuable information on the origin of the ore. However, it is not advisable at present to use the Co-Ni-contents as proof of the »primary» genesis of sulphide ores to such an extent as, for instance, has been done by Hegemann. We have seen how ores that must be considered indisputably identical with regard to »primary» genesis, sometimes display considerably and consistent dissimilarities as to the Co-Ni-values (the ores of the Adak District). Unfortunately, we do not at present know anything definite about the fundamental cause of the dissimilarities in the Co-Ni-contents from one case to another, and the variations in the Co-Ni-quotients are especially puzzling. Co and Ni have in fact very similar chemical properties. The methods of separating Co from Ni as described in the chemical literature are to such a high degree dependent on very special physical and chemical conditions (for instance certain limited intervals of temperature, particular pH-conditions, etc.) that it is as yet impossible to apply them to natural conditions.

The fact that adjacent minerals (*e. g.* different minerals from the same specimen of an ore) often display a clear relationship in respect of the Co-Ni-contents has a certain theoretical signification. The same thing may be said of the fact that the Co-Ni-distribution in the pyrites and pyrrhotites of copper ores differs from that of the zinc ores. The present author has previously pointed out that the separation into copper and zinc ores must be due to some kind of fractioning in the ore solutions themselves. The most probable interpretation of the above circumstances seems to be that also the Co-Ni-distribution was to a great extent founded in the liquid phase. Thus the pyrite and pyrrhotite in the copper-ore portions crystallized from another kind of ore solution than pyrite and pyrrhotite in a zinc-ore portion. The difference between the Sn-contents of pyrites and pyrrhotites in zinc ores, on the one hand, and in copper ores, on the other, also indicates this. Of course, it might also be conceived that for instance all pyrite crystallized first, and that zinc-bearing and copper-bearing solutions, with mutually different contents of Co and Ni, were introduced later on. By partly resorbing the iron sulphides such solutions could be assumed to add Co and Ni in different amounts to the remaining pyrite or pyrrhotite. As Co and Ni to some extent may be contained in both chalcopyrite and sphalerite, it might then be expected, however, that in the purest zinc and copper ore portions (with the comparatively lowest contents of iron sulphides) these minerals would display the highest Co- and Ni-values. However, no such tendency can be detected, and the latter explanation of the difference between the copper and zinc ores therefore seems less probable.

The possibility of utilizing the distribution of the minor constituents for practical purposes, *e. g.* to prove whether or not an ore boulder originates from a specific ore deposit, seems to be very limited, judging from the present results. The variations within the individual deposits are so great that only in very favourable cases can an ore boulder be unambiguously classified on the basis of the minor constituents. The most favourable conditions in this respect have been encountered in the Adak District. Considering the distribution of Co and Ni we can, for instance, by analysing arsenopyrite from an ore boulder from the Adak area decide whether it originates from the Adak or from the Lindsköld Mine.

Further we have seen that essential amounts of Sn in the sulphide minerals from an ore boulder suggest that the minerals do not emanate from the ores at Kristineberg or Rävliden. But in most cases, if an ore boulder is assumed to derive from a specific ore deposit, we can only state a certain probability for or against this conception, and even then a very thorough knowledge of the minor constituents and of their dispersion in the ore deposits already known is required.

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