

SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C.

Avhandlingar och uppsatser.

N:o 454.

ÅRSBOK 37 (1943) N:o 3.

ON THE DISTRIBUTION
OF METALS AT RÄVLIDEN,
NORTHERN SWEDEN,
AND IN SOME OTHER
COPPER-ZINC
ORES

BY

S V E N G A V E L I N

—◆—
Pris 1.00 kr.

STOCKHOLM 1943

KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER

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Introduction.

For our knowledge of an ore deposit it is of course of very great practical and theoretical importance that we are able to survey as far as possible how the various constituents of the ore are distributed in the mineralized area. A classification into certain main types may certainly give a rough idea of the characteristics of the ore and its most striking associations of chemical elements, but generally there are also encountered combinations of elements and of minerals whose origin may appear doubtful. The complicated process of ore formation is regulated by so many different factors that it is frequently very difficult even in very thorough investigations to establish and specify the systematic relationship between elements and minerals. To what extent chemical analyses may be able to elucidate these problems is largely dependent upon the number of analyses available and their distribution throughout the ore-body. In most cases the analyses presented in descriptions of ore deposits either refer to special and characteristic ore types or represent certain large portions of the ore. In neither case do they yield any information regarding the detailed metal distribution within the ore-body or in the ore field.

The author has, however, had access to a material that is admirably suited to demonstrating the variations in the contents of certain metals in a sulphide deposit, *viz.* the Rävliiden mine in the Skellefte District. In addition our knowledge of this deposit has been augmented by both field and microscopic investigations.

Distribution of Elements at the Rävliiden Mine.

Survey of the mineralogical and chemical characteristics of the ore.

The Rävliiden ore deposit is situated in Lycksele parish in the westernmost part of the ore-bearing formation of the Skellefte District and belongs to the ore district comprising also Kristineberg, Rävliiden, and the Vindelgransele ores (cf. 10). The deposit is composed of numerous separate ore lenses. The predominant ore minerals are pyrite, pyrrhotite, chalcopyrite, sphalerite, galena, and Cu-Sb- and Pb-Sb-minerals. The wall-rock consists of sericite schist — sometimes chloritic — graphite-bearing phyllites and tremolitic lime-silicate rocks. The mutual proportions of the different ore minerals display considerable variations in different parts of the deposit; gradual transitions occur between fairly compact pyrite ores or, less frequently, pyrrhotite ores with comparatively low contents of Cu, Zn, and Pb and types extremely rich in Cu or Zn. In other cases the sulphides may occur as irregular breccias, veinlets or disseminations in the wall-rock. Especially in the graphitic phyllites there is frequently found a very pronounced banded structure with alternating pyrite and phyllite bands.

Distribution of the analyses within the deposit.

The ores have been examined by drifts and horizontal drill holes at two levels, the upper one at 38 and the lower one at 120 metres. The analyses from the upper level especially are well suited for statistical working up. In the cross-cuts the analysed samples have been taken in one metre sections in either wall, and in the ore-bearing parts of the main drifts they have been taken in cross sections in the roof at intervals of two metres. In the drill holes apparently uniform sections have been analysed separately. A total of 466 analyses from the 38 m level are available and they are, what is more, fairly uniformly distributed throughout the ore.

The elements that have been determined in the samples and the distribution of which thus can be demonstrated by a chemical-statistical working up are S, Cu, Zn, Pb, As, Ag, Au, and to a certain extent Sb. A fairly comprehensive material (170 analyses) is available also from the 120 m level, but as all the metals have not always been determined in this case, and, furthermore, as partly other principles have been employed in the sampling, larger uniform sections having been analysed in one sample, it has not always been possible to use these analyses for the calculations. The diagrams below mainly include analyses with $> 10\%$ S, the pronouncedly impregnated rocks thus being excluded.

Distribution of metals.

Of the metals determined in the ore Cu and Zn definitely predominate quantitatively and the distribution of these two metals will consequently first be considered. Already in the general mapping of the ore there was noted a



Fig. 1. Relations between Cu and Zn percentages in the Rävliiden ores. Crosses denote a number of copper-ore analyses in which Zn has not been determined, but where the Zn percentages are undoubtedly $< 1\%$.

definite tendency to a separation between copper and zinc in different parts of the ore. Fig. 1 demonstrates how this separation appears in the light of the analyses. The massing of analyses along the Zn and Cu axes is the most striking feature in the diagram. The fact that some analyses are seen to represent more complex ore portions is not very surprising; the very method of analysing

equally large sections without any consideration being paid to ore boundaries must of course cause parts containing zinc ore and parts containing copper ore occasionally to be included in the same analysis. In the diagram the differentiation will thus appear somewhat less pronounced than if for instance considerably smaller sections had been analysed. As the separation between Cu and Zn proves to be the most fundamental trait in the metal distribution, it is suitable first to examine the relation of other metal percentages to that differentiation.

Quantitatively, lead is the metal next in order after copper and zinc. In order to demonstrate in one diagram the relation of lead to the copper-zinc differentiation, the lead percentages of the separate analyses in Fig. 1 have been noted, and to obtain a survey of the results the diagram has been divided into squares, each with a side corresponding to 1 % Zn. The mean percentage of Pb has been calculated for all the analyses within each such square, curves representing the same lead percentages then being drawn with intervals of 0.5 % Pb. The result is demonstrated in Fig. 2. The black points denote the centres of the squares. As might be expected in view of our general experience of ores of the present type, the major part of the lead content is found to be associated with the zinc ores, while the copper ores on the whole prove to be extremely poor in lead; in the purer copper ores the content of Pb is generally < 0.1 %. It is also seen that there is a definite tendency on the part of the Pb percentages to increase as the zinc percentages increase. That the Zn-Pb ratio nevertheless displays fairly considerable variations in the various parts of the ore is apparent *inter alia* from the fact that the increase in the Pb values along the Zn axis is discontinuous and irregular. In spite of the fluctuations in the Pb values in the present diagram having been smoothed by the calculation of certain averages, maxima and minima are frequently seen to supersede each other along the Zn axis.

Fig. 3 is intended to demonstrate the variations in the Pb : Zn quotient in different parts of the ores and also its relations to the copper-zinc differentiation. As the Zn percentage in sphalerite, the chief carrier of the Zn content, is approximately twice the Cu percentage in the chief copper mineral, chalcopyrite, the Cu percentage has been multiplied by 2 and this factor then put into relation to the Zn percentage. By this method an approximate value is obtained of the relation between the minerals chalcopyrite and sphalerite. Both with reference to the Pb : Zn ratio and with reference to the chalcopyrite : sphalerite ratio the results have been expressed in per cent of the sum Pb + Zn and chalcopyrite + sphalerite respectively. The zinc-free copper ore is thus represented by the quotient $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}} = 100\%$, the copper-free zinc ore by $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}} = 0\%$.

The diagram demonstrates more clearly than Fig. 2 that there are considerable variations in the Pb : Zn quotient if the ore is considered as a whole. This is also true of the purest zinc-ore parts, although a definite massing of analyses

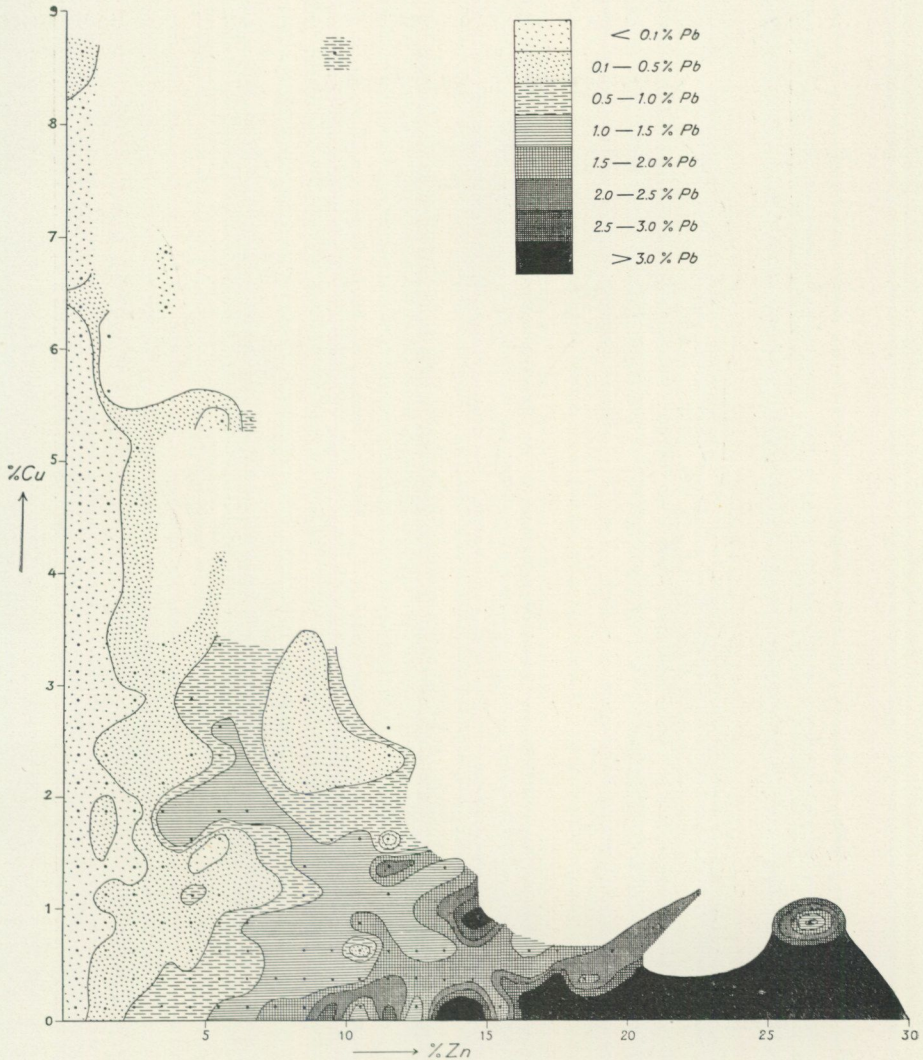


Fig. 2. The distribution of the Pb percentages in relation to Cu and Zn percentages. (For construction of the diagram see p. 6.)

can be established between 8 and 20 per cent $\frac{\text{Pb}}{\text{Pb} + \text{Zn}}$. In the parts of the diagram that represent copper ore there is not such a large number of analyses in which both Zn and Pb have been determined, and the analyses in this part seem to be more uniformly distributed. A tendency to a massing of points is however seen also in this case, *viz.* between 0 and 5% $\frac{\text{Pb}}{\text{Pb} + \text{Zn}}$. In relation to Zn, Pb is thus enriched in the zinc-ore parts as compared with the copper-ore parts.

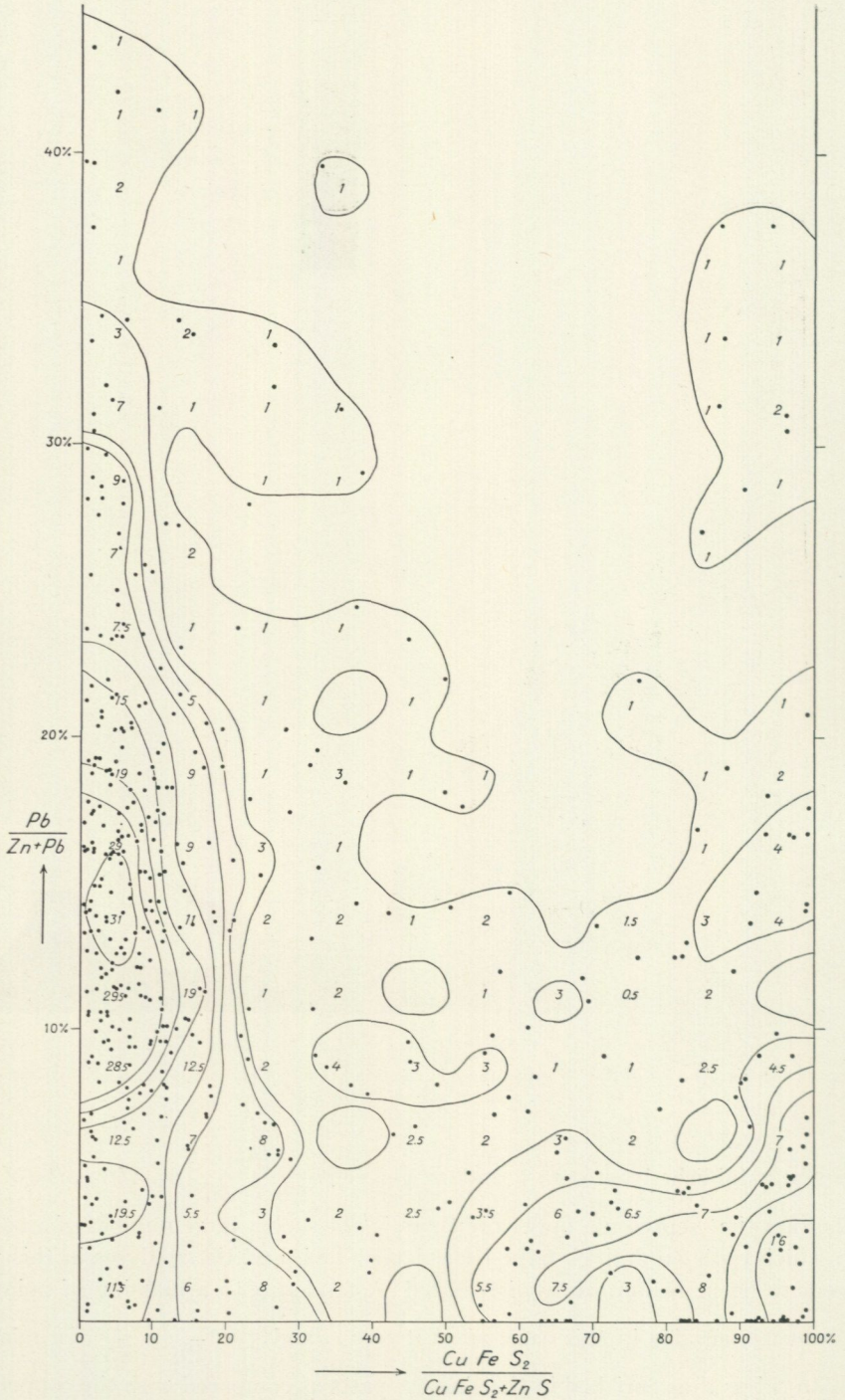


Fig. 3. Diagram showing the mutual relations between Cu, Zn and Pb. The figures show the number of analyses in a square the side of which is 10 % of $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}}$. Curves drawn for 1, 3, 5, 7, 10, 15, 20, 25, 30.

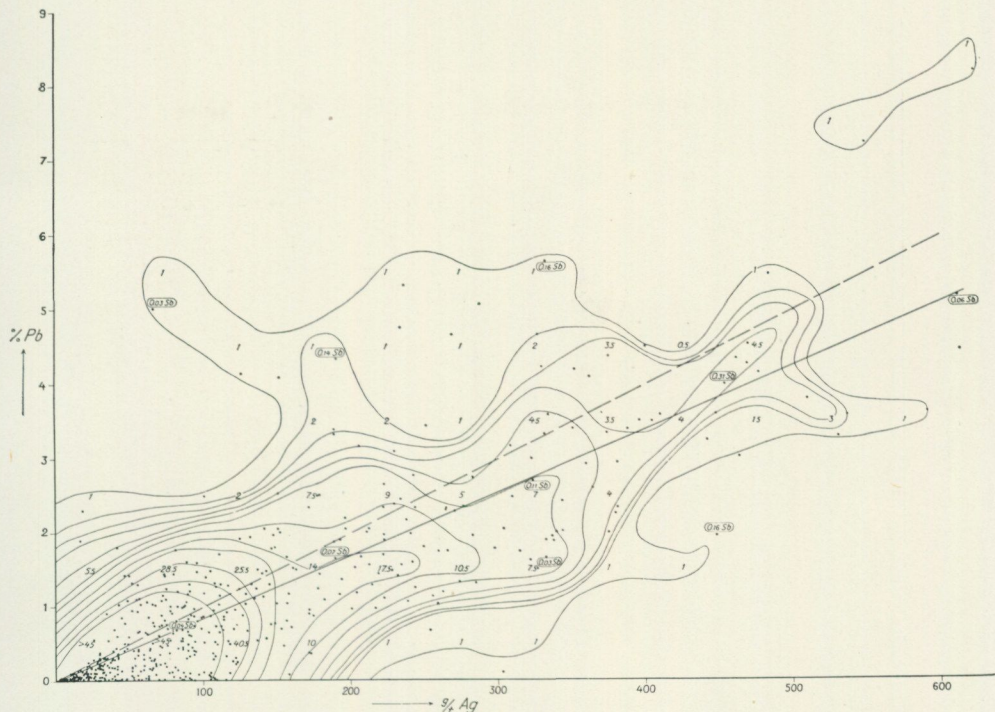


Fig. 4. Relations between Ag and Pb percentages in the Rävliiden ore. The figures show the number of analyses in a square the side of which is 1 % Pb. Curves drawn for 1, 2, 3, 4, 5, 7, 10, 15, 20, 30, 40, 45. The broken line represents an Ag : Pb quotient of 100 g/t Ag to 1 % Pb; the unbroken line represents 120 g/t to 1 % Pb.

Silver is found to be closely associated with lead and is thus enriched in the zinc-ore parts as compared with the copper ores. Fig. 4 shows the relations between Ag and Pb. The tendency on the part of the Ag percentage to increase along with increasing contents of Pb is evident, even though the analyses display a fairly considerable dispersion from a simple linear relationship. In order to make this tendency more surveyable, curves have been drawn for the same frequency of analyses in the diagram. The analyses are then found to be concentrated around a line corresponding approximately to 120 g/t Ag to 1 % Pb.

The dispersion of the analyses from such a line either implies a certain »capriciousness» on the part of the silver distribution or that silver is more closely associated with some other element which also on the whole accompanies lead. The metal that then might first be considered is antimony. Both under the microscope and with the naked eye antimony minerals have frequently been observed together with the galena in the zinc ores. Chemical determinations of antimony have, however, been made to but a limited extent, there being but 23 determinations for the whole ore. They were chosen in such a manner, however, that they throw at least some light on the relationship between Sb and Ag. On examining how Sb is distributed in relation to the copper-zinc differentiation, it is found that the element is mainly enriched in the zinc-

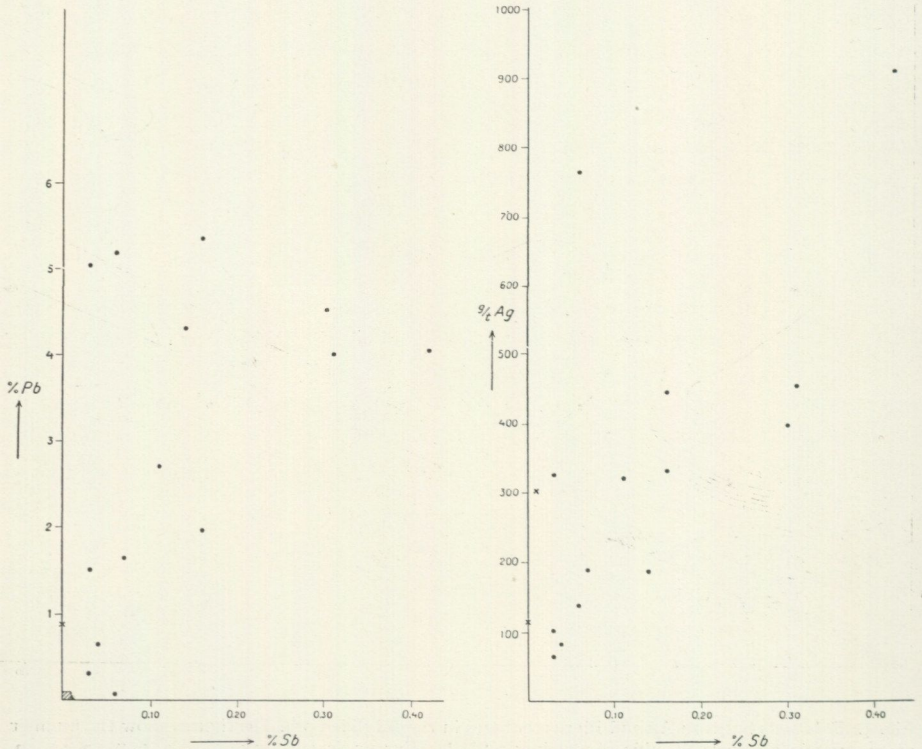


Fig. 5. Relations between Pb and Sb and between Ag and Sb. Dots represent analyses of zinc-ore types, crosses analyses of copper-ore types. The small lined square in the left-hand diagram encloses five copper-ore analyses.

ore parts. This is apparent *inter alia* from the analyses available: in 5 out of 7 analyses of copper-ore sections the Sb percentage was = 0.00 %, and in the remaining 2 analyses = 0.01 %. In the zinc ores the values lie between 0.01 and 0.42 %.

The left-hand diagram in Fig. 5 shows the relations between Sb and Pb. We may possibly discern a general tendency on the part of the Sb percentages to increase parallel to increasing Pb percentages, but we cannot establish any definite ratio between the two elements. The microscopic observations also support such a relationship between the Sb and Pb contents: antimony minerals are occasionally observed in fairly large, occasionally in quite small quantities in galena, but they never seem to be entirely lacking in samples containing fair quantities of galena.

The right-hand diagram in Fig. 5 demonstrates the relationship between Sb and Ag. Here the relationship is of the same character. The variations in the Sb : Ag ratio are so large, that it is difficult to imagine the dispersion of the analyses in the Pb-Ag diagram (Fig. 4) from the mean line (120 g/t Ag to 1 % Pb) to be caused by variations in the Pb : Sb ratio. And that this is not the case is also quite apparent if we consider the Sb values of some of those analyses

in Fig. 4 whose Pb : Ag ratios differ most strikingly from the mean line. The framed values of antimony percentages show that at least in the majority of these cases the differences in the mean quotient of Pb : Ag do not correspond to extremely high or extremely low Sb percentages. On the other hand the correlation between microscopic and analytic results often clearly indicates that the Sb minerals must be regarded as the most important silver-bearers. It would consequently appear very likely that the variations in the Sb : Ag ratio may greatly depend upon variations in the absolute silver content of the antimony minerals themselves.

Although the predominant part of the silver content of the ores is associated with Pb-Sb minerals, a smaller part is also distributed among the other sulphides. To demonstrate the distribution of this »remaining» silver content and its relation to the minerals sphalerite and chalcopyrite, the Ag contents of analyses with less than 0.3 % Pb have been put in relation to the percentages of Zn and Cu in the same samples (Fig. 6). The analyses for which the quotient

$\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}} = 70-100 \%$ (denoted by dots in the diagram) have been regarded as copper ore, those for which the quotient $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}} = 0-30 \%$

(denoted by open circles in the diagram) as zinc ore. If we first consider the distribution of Ag in the zinc ores, no regular connection between zinc and silver seems to be traceable. The diagram shows that solitary comparatively high silver percentages certainly may correspond to comparatively low zinc percentages also in the zinc ores, but on the whole there is no systematic increase in the silver percentages parallel to increases in the zinc percentages. This lack of relationship between Ag and Zn is even more evident in a zinc ore located 1.5 km N of Rävliiden, which is partly very similar in composition. In this deposit exceedingly high Zn percentages (30—40 % Zn) are often encountered, but in sections with low Pb contents no very great increase is found in the silver percentage as compared with the sections with lower zinc percentages.

In the distribution of the analyses that represent sections of a copper-ore type, on the other hand, we find that Fig. 6 demonstrates a fairly clear tendency towards a linear increase in the silver percentages parallel with increasing copper percentages, this being especially evident in the parts of the diagram that represent more high-grade copper ores. On constructing a mean line for the quotient Cu : Ag, we find that 1 % Cu is accompanied by approximately 14 g/t Ag. The fairly considerable dispersion of the analyses shows, however, that sporadic higher silver percentages may occur even when the copper percentage is low. That these deviations must be regarded as local exceptions and cannot be due to any local enrichment in for instance antimony minerals is apparent from the low Sb values in some of those analyses which deviate most strikingly (see fig. 6).

The difference in the relations of silver to Cu and Zn respectively is most conspicuous, however, if we consider the variations in the Ag percentages in a

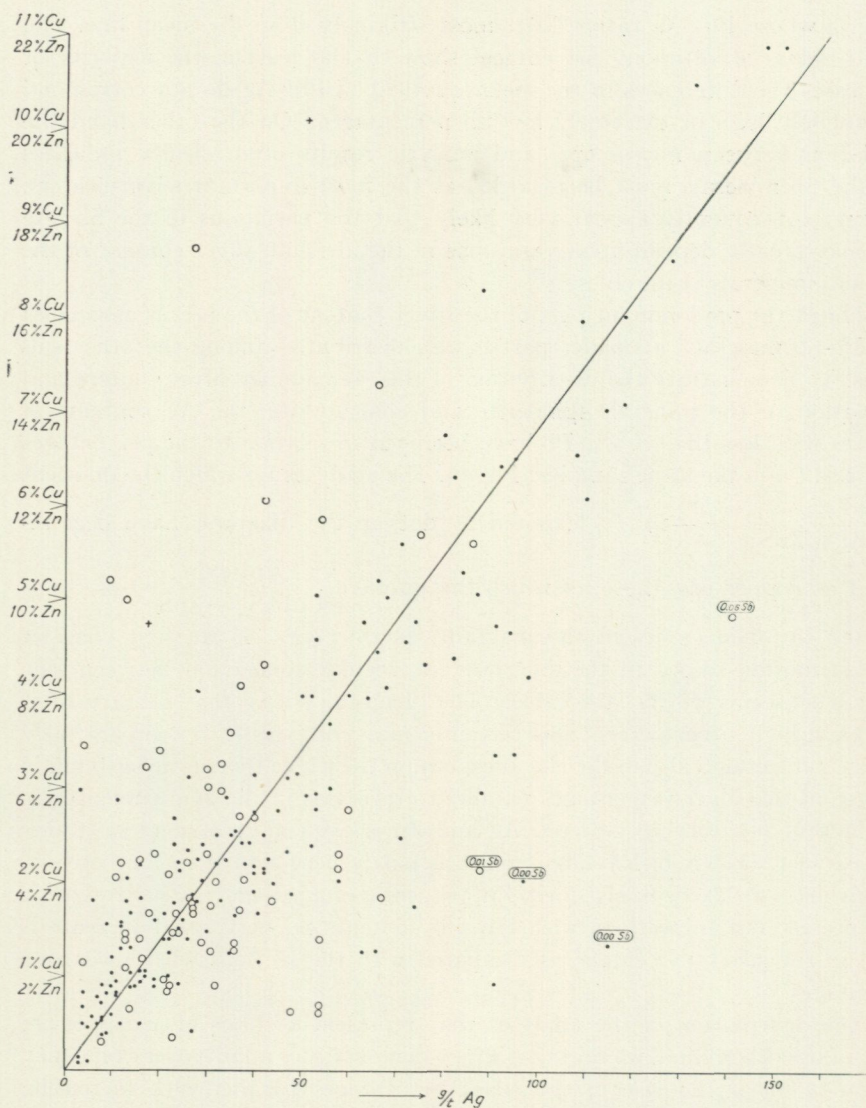


Fig. 6. Relations between Ag and Cu and between Ag and Zn in analyses with $< 0.3\%$ Pb. Dots represent copper ores, open circles zinc ores.

number of adjoining analysed sections in cross-cuts. Fig. 7 demonstrates five series of sections through parts of the ore in which, firstly, the lead percentages are low throughout, which implies that one need not count with any considerable quantities of silver being associated with the lead minerals, and, secondly, Zn and Cu display comparatively great variations from one section to the other. The values of sections adjoining each other are connected by broken and continuous lines. The great resemblance between the courses of the Cu curves

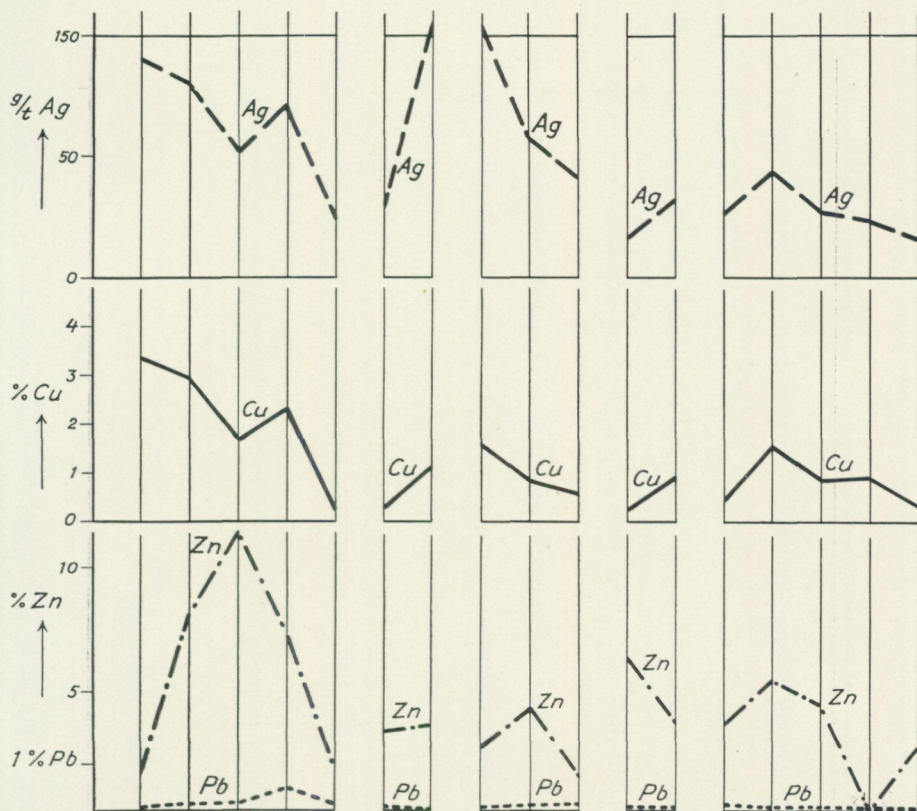


Fig. 7. Variations in percentages of Ag, Cu, Zn and Pb in adjoining analysed sections in five cross-cuts through ore parts with low Pb percentages.

and the Ag curves is very striking, while nothing indicates that Zn and Ag are co-variant.

It may thus be established that the far greater part of the silver content of the ores accompanies the Pb-Sb minerals, and that the remainder appears to prefer associating with chalcopyrite rather than with sphalerite. There are, however, also purely fortuitous local enrichments in silver, which cannot be established to have any systematic relationship to other elements or minerals. Such sporadic higher silver contents may, what more, occur also in the purer iron-sulphide parts of the ore, in spite of these parts generally being extremely poor in silver, and they are thus good examples of the »capriciousness» sometimes found in the distribution of silver.

Arsenic is fairly commonly distributed throughout the ores and then always forms the mineral arsenopyrite. This mineral occurs here in well developed idiomorphic crystals, both in the copper ores and in the zinc ores. In addition arsenopyrite occurs as idiomorphic crystals disseminated in areas entirely separated from the actual ore-bodies.

Fig. 8, which demonstrates the relations of As to the copper-zinc differenti-



Fig. 8. Diagram showing the relations of the As percentages to the copper-zinc differentiation.

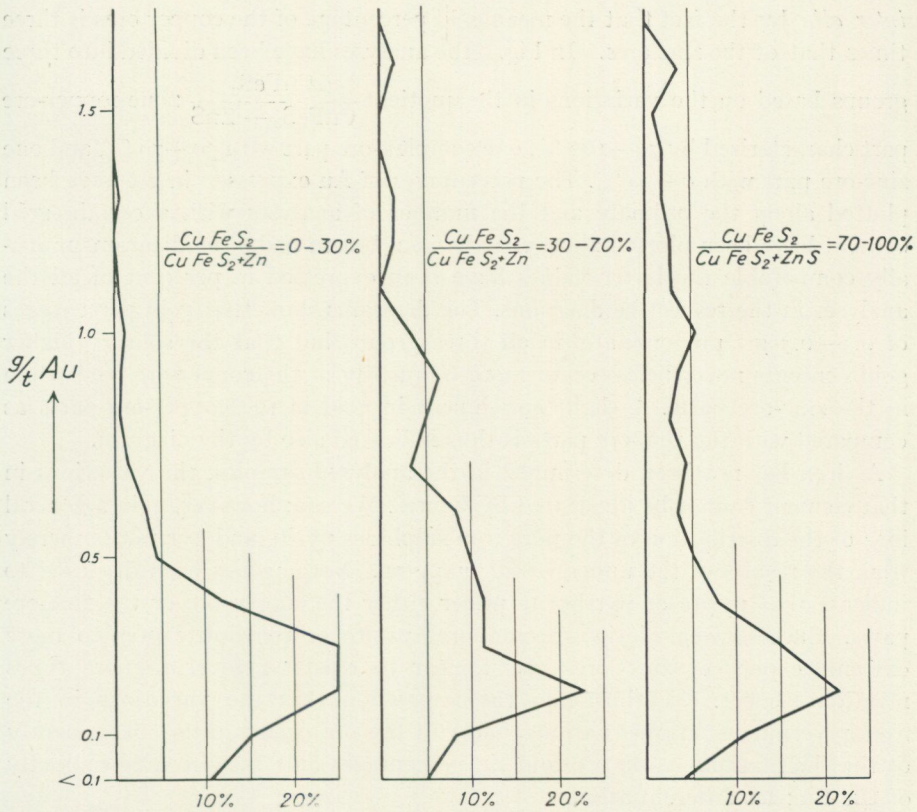


Fig. 9. Diagram showing the relations of the gold percentages in different intervals of the $\frac{CuFeS_2}{CuFeS_2 + ZnS}$. The figures below the abscissae denote the percentage of the number of analyses used in each diagram.

ation, shows no very marked or systematic enrichment of the element either in the copper-ore or in the zinc-ore parts. A slight tendency towards an enrichment in As in the zinc ores is however reflected in the fact that the solitary higher values for As occur in zinc ores exclusively.

The gold content of the ores at Rävliiden is very low throughout and the variations are consequently too insignificant to allow of any general conclusions regarding the laws of distribution for that element. At certain other localities in the Skellefte District (Boliden, Holmtjärngruvan, Rackejaur) a tendency towards an enrichment in gold has been established in solid bodies of dense arsenopyrite ore. At Rävliiden, however, no kind of relationship has been recorded between gold and arsenic. This fact agrees fairly well with our experience from the Skellefte District, which indicates that in most cases arsenopyrite occurring in the shape of isolated and idiomorphic crystals is not gold-bearing to any great extent.

As regards the relation of gold to the Cu-Zn differentiation, this metal is found to be slightly enriched in the copper-ore parts, which is demonstrated

inter alia by the fact that the mean gold percentage of the copper ores is three times that of the zinc ores. In Fig. 9 the analyses have been divided into three groups based on the variations in the quotient $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}}$: one copper-ore part characterized by 70—100 %, one complex-ore part with 30—70 %, and one zinc-ore part with 0—30 %. The percentages of Au expressed in g/t have been plotted along the ordinate and the number of analyses with a certain gold content have been plotted along the abscissa, but to make the diagrams mutually comparable the latter values have been expressed in per cent of all the analyses in the respective diagrams. The diagrams show that gold percentages of 0.2—0.3 g/t predominate in all three groups but that the solitary higher gold contents nevertheless occur more frequently in the copper-ore parts than in the zinc-ore parts. A slight enrichment in gold in the copper-ore parts as compared with the zinc-ore parts is thus indicated also by the diagram.

As iron has not been determined in the analysed samples, the variations in that element cannot be illustrated by figures. We can, however, gain a general idea of the distribution of the pure iron sulphides pyrite and pyrrhotite merely from the results of the underground mapping. Nothing has been disclosed to indicate that pyrite or pyrrhotite prefer either the copper-ore or the zinc-ore parts. Successive gradations from purer pyrite or pyrrhotite ores to more extreme copper or zinc ores also appear to exist wherever the ore types mentioned meet. We thus gain the impression that the variations in the iron percentages in the various parts of the ore occur quite independently of the fluctuations in the Cu and Zn percentages and likewise independently of the Cu : Zn differentiation.

Distribution of the various ore types within the deposit.

The material from the 38 m level is very well suited for the construction of a picture illustrating the distribution of the various types of ore. Fig. 10, which is intended to illustrate the variations in the quotient $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}}$ at this level, has been constructed as follows: The values of the quotient in question have been plotted on the mine plan. Areas representing certain values of the quotient have then been constructed, with due reference to the results of the geological mapping. The values of the quotient have been subdivided as follows: 0—10 % = pure zinc ore; 10—30 % = Cu-bearing zinc ore; 30—70 % = complex ore; 70—90 % = zinc-bearing copper ore; 90—100 % = pure copper ore. The sketch-map discloses that the purer ore types predominate quantitatively. Complex ore types are rarer, in spite of that group representing a considerably larger interval of the chalcopyrite : sphalerite quotient than the other types. The transitional types between copper ore and zinc ore occur partly between the purer ore types, partly and to a comparatively large extent in the southernmost of the western ore-bodies. This last-mentioned more complex ore differs also in another respect from the other ore lenses, for the sulphides there are

associated with lime silicates, a fact that will later be found possibly to be of a certain importance for the theoretic interpretation of the causes of the metal distribution.

If the relations between other elements that have proved to a certain extent to accompany each other are examined, *e. g.* Pb : Zn and Ag : Pb, and if an attempt is made to illustrate the variations in these quotients according to the same principles as in Fig. 10, far more confused pictures result. No additional contributions to the results obtained in the general statistic study of the analyses can be gained.

Differences in the metal distribution in solid and disseminated portions of the ore.

Even a preliminary survey of the analyses that more or less represent transitions between the extreme copper and zinc ores indicates that such more complex types very often show lower S percentages than the more decidedly differentiated ore parts. This would imply that the more solid ores are differentiated to a greater extent than the disseminated types. Roughly the absolute S percentage may be considered to be an expression of the sulphide content of the sample analysed, the theoretical S percentage of the dominating minerals pyrrhotite, chalcopyrite, and sphalerite being fairly equal. The fourth of the main ore minerals, pyrite, deviates slightly more from the others in this respect, but not so much that the total S percentage cannot be used in a statistic comparison to give at least a rough idea of the »solidity» of the ore.

We will first consider the variations in the quotient $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}}$ within different intervals of the S percentage in the analyses. To that end the analyses from the 38 m level have been divided into four groups: with 10—15 % S, with 15—20 % S, with 20—25 % S, and with > 25 % S. Furthermore a number of analyses have been included that were not embodied in the earlier diagrams, *viz.* a group with 1—10 % S. For each analysis in the various groups the quotient $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}}$ and the sum $\text{CuFeS}_2 + \text{ZnS}$ have been calculated and plotted in a diagram. In this way the individual diagrams are given the same general appearance as for instance the diagram in Fig. 3, and we obtain an expression on the one hand for the degree of differentiation into Cu ore and Zn ore and on the other for the gradations from purer copper or zinc ores to pure iron sulphides.

The purpose here being only to illustrate the frequency of the analyses within different parts of the diagrams, the method of construction is the same as that used for the diagram in Fig. 3. The number of analyses in equally large surfaces of the diagram has been recorded, whereupon curves have been drawn for suitable intervals of the figures thus obtained. A different number of analyses being the foundation of each of the diagrams, the frequency of the analyses within a certain area has been expressed in per cent. of the total number used

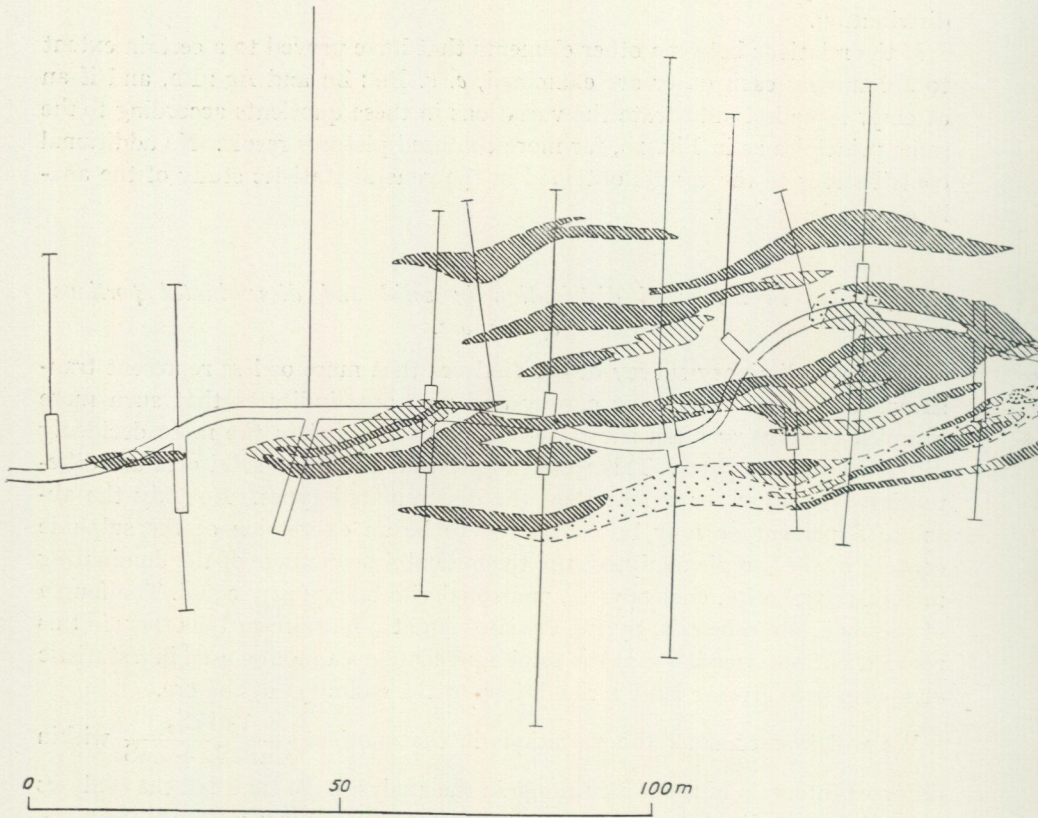
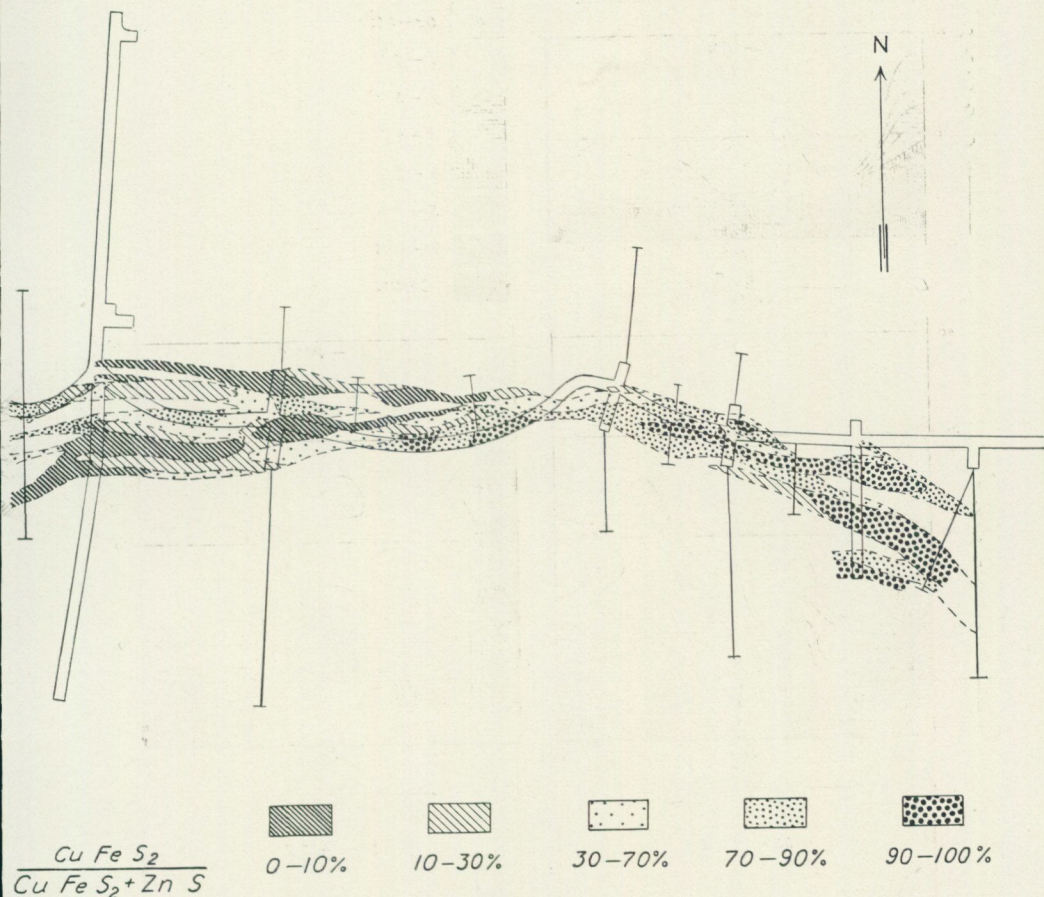


Fig. 10. Sketch-map of the 38 m level at Rävleden

for the construction of the respective diagrams. In this way the diagrams for analyses with different S-intervals can be mutually compared.

Fig. 11 shows five diagrams constructed according to this method. The darkest areas thus indicate the areas where the analyses are most frequent, *i. e.* where an enrichment of points occurred in the original diagram. On comparing the five diagrams a certain change of the general type can be established from case to case. In diagram *a*, comprising the sections of analysis with the lowest sulphide percentages, we find a certain tendency towards the development of maxima in the parts corresponding to sulphide mixtures of pure zinc and pure copper ore respectively, but also in the parts of the diagram representing complex ore types the frequency is fairly large. The same general tendency is also apparent in *b* and *c*, although the transitional types here are quantitatively less important than in *a*. In *d* and *e*, finally, the differentiation into copper-ore parts and zinc-ore parts is much more complete, and in these cases the analyses in the parts of the diagram corresponding to sulphide



showing the distribution of the various ore types.

mixtures of a complex-ore character are very rare or entirely absent. Fig. 11 thus represents the numerical expression of the difference in the copper-zinc differentiation between more solid and more disseminated parts of the ores.

The variations in the Cu:Zn quotients and the S percentages from one analysed section to another within the deposit is best illustrated by a number of cross-sections through the ore-bearing zone at the 38 m level. In Fig. 12 seven such cross-sections through the ores are illustrated, where the individual analyses represent adjoining one-metre samples. The curves drawn in heavy lines denote the variations in the quotient $\frac{CuFeS_2}{CuFeS_2 + ZnS}$ in the different sections; the finer curves denote the S percentages. Maxima of the latter thus represent the more solid ore beds; minima represent disseminated sections or sections highly intermixed with barren rock. In order to make the diagrams more surveyable a subdivision into different percentage classes has been

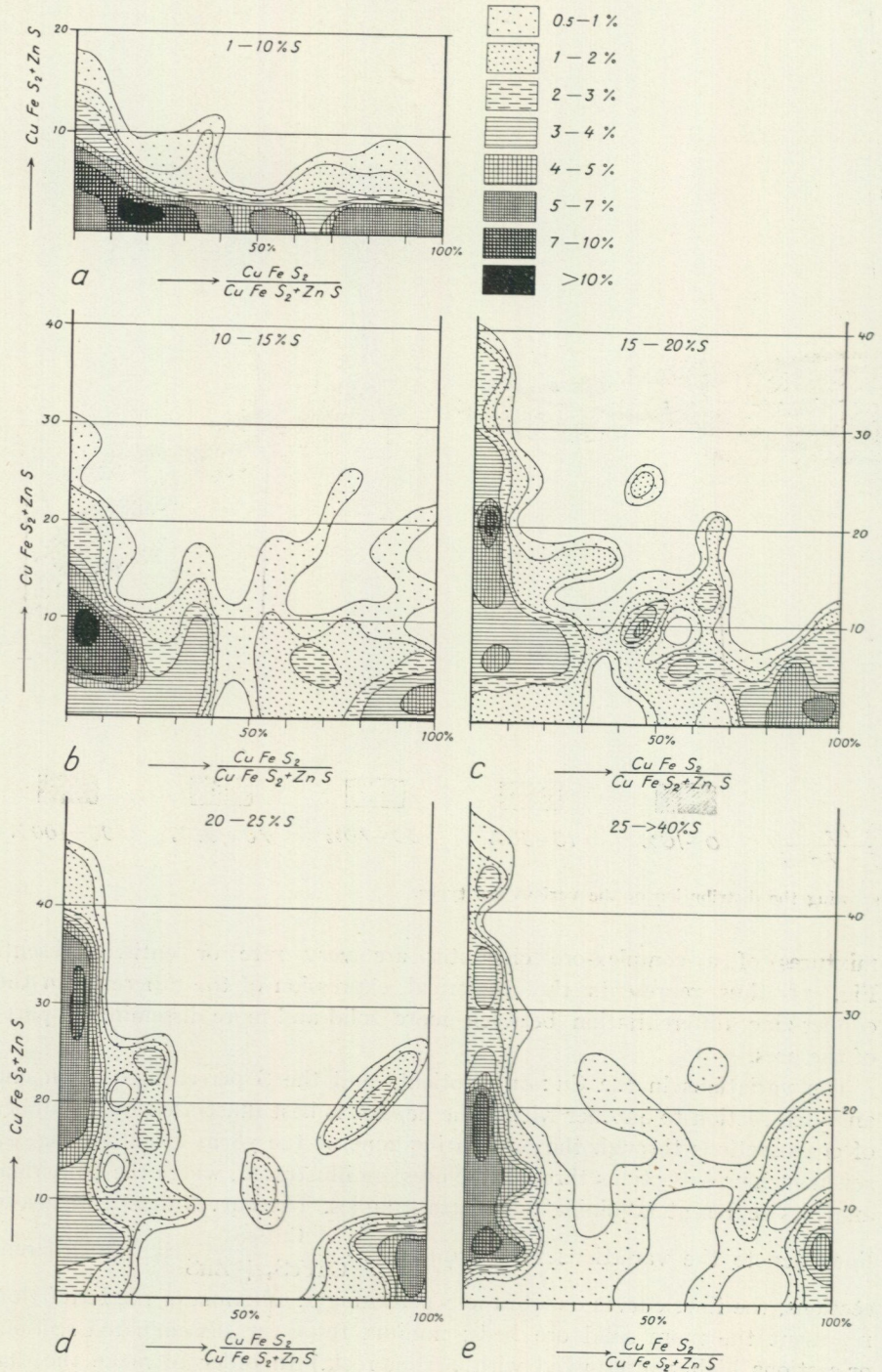


Fig. 11. Diagram showing differences in the quantitative distribution of $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}}$ for different S-percentages. (For construction of the diagram see p. 17.)

effected according to the same principles as before: $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}} = 0-30\%$ (zinc ore); 30—70 % (complex ore); 70—100 % (copper ore). Diagrams *a* and *b*, and to a certain extent also *c*, thus represent cross-sections through ore parts where the more solid ore-bodies are of a zinc-ore character. These diagrams show that the course of the S curves is generally quite the reverse of the course of the Cu : Zn quotient curves; in other words the Cu : Zn quotients increase in the sulphide-poorer surroundings of the more solid ore lenses. We notice that in the minima of the S-curves a sulphide mixture of complex-ore character often occurs, or, as in *b* and *c*, even of a copper-ore character. In the two latter cases, however, the absolute zinc percentages are very low. The fact that the right-hand part of diagram *c*, in spite of fairly high S values, nevertheless is of a complex-ore character, may also partly be due to this part corresponding to the more solid copper-ore parts in diagram *d*, and it is thus possible that the analyses in this part also comprise stringers of a copper-ore character.

In diagram *d* the more solid copper ore is represented at the right, while the left part of the diagram corresponds to the zinc-ore lens in the left part of *c*. The more solid copper ore is found to be surrounded by a mineralization of a complex- or zinc-ore character, while the S minimum that occurs close to the zinc-ore bed at the left is likewise of a complex-ore character.

Diagram 12 *e* demonstrates a case where no systematic relationship whatever can be traced between the Cu : Zn quotient and variations in the S percentages. The solid ore lens here consists of pyrite with chalcopyrite and sphalerite in subordinate quantities, and also in the light of the analyses it appears as a decidedly complex ore. Diagrams *f* and *g* represent sections through the purer copper-ore parts of the deposit. Here the curves for the Cu : Zn quotient and the S percentages present a similar course, which implies that the most solid ores are also the purest copper ores, while the Zn percentages in relation to the Cu percentages increase in the more disseminated ore portions. In Fig. 12 *f* a comparatively regular zoning around the solid ore lens is indicated, the Cu : Zn quotients decreasing parallel to the S percentages.

The results derived from the diagrams in Fig. 12 thus imply the same as is indicated by the diagrams in Fig. 11: The more solid ore lenses are more completely differentiated both as regards copper ores and zinc ores, while mineralized areas with lower S percentages surrounding such ore lenses are either to a greater extent of a complex-ore character or tend towards a Cu : Zn ratio opposed to that typical of the compact lens. These results also indicate that the differentiation into copper ore and zinc ore illustrated in previous diagrams would have appeared still more pronounced if only analyses of the most solid ore lenses had been included in the diagrams.

An examination of the relations between other elements displaying a close relationship, *e. g.* Pb : Zn or Ag : Pb, with reference to their variation in ore types with different S percentages, shows that no gradation corresponding to the one above can be established. These quotients show the same degree of variation either they refer to sections poor or rich in sulphides.

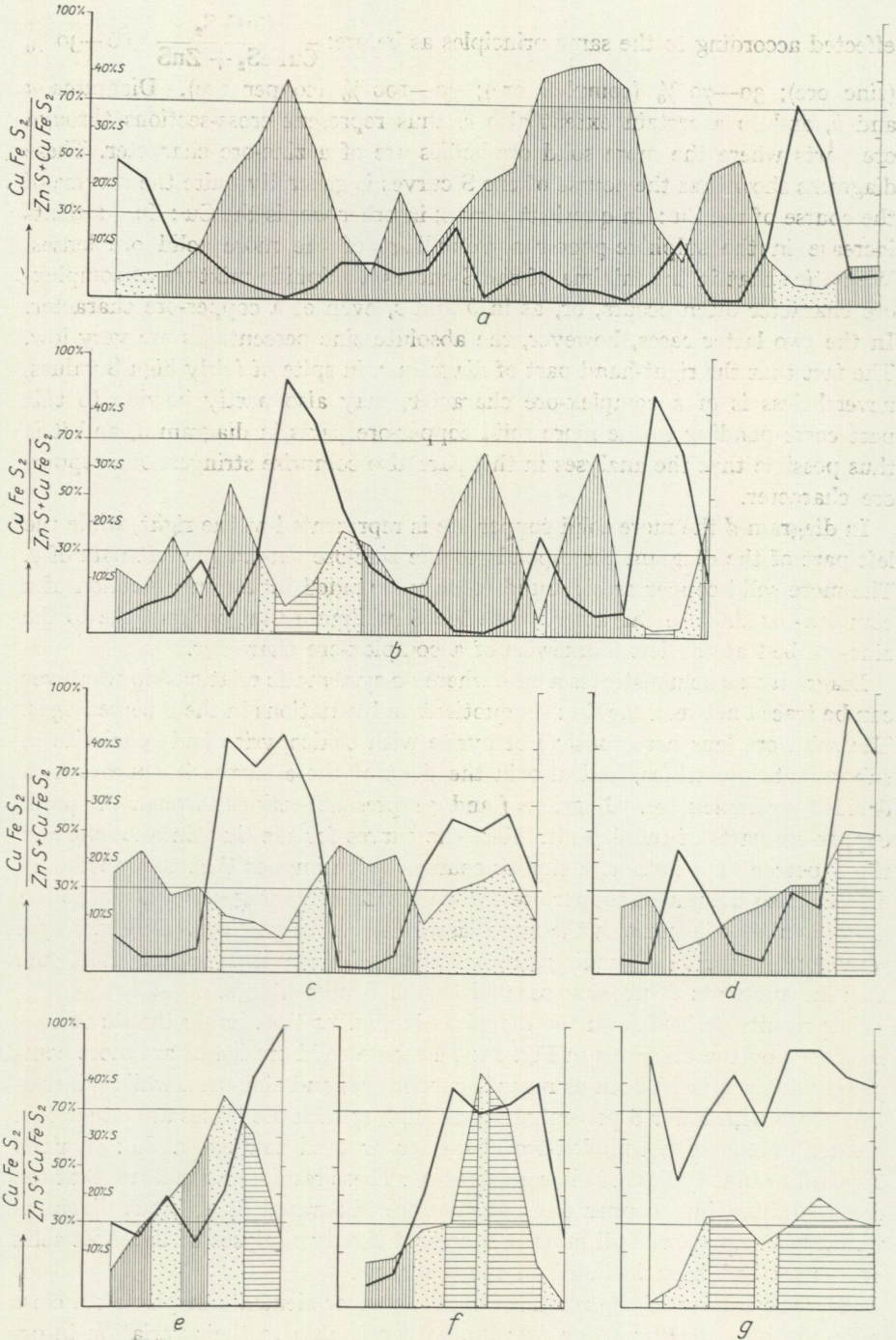


Fig. 12. Diagram showing the variations in the Percentages and the $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}}$ quotients in seven cross-sections through the deposit. Vertical shading represents zinc ore with $\frac{\text{CuFeS}_2}{\text{CuFeS}_2 + \text{ZnS}} = 0 - 30\%$, dotted shading complex ore with the quotient = $30 - 70\%$, horizontal shading copper ore with the quotient = $70 - 100\%$.

Sequence of crystallization.

When seeking for the causes of the systematic associations of elements that have been evidenced in the diagrams, we must first investigate to what extent they may have originated through the selective crystallization of one mineral after the other from an ore solution. As far as the sequence of crystallization is concerned, the microscopic structures usually give quite univocal results: certain minerals are found to brecciate or replace others along fissures or cleavage planes. We must remember, however, that what can really be concluded from a microscopic investigation is that the »later» minerals have occurred in solution later than the »older» minerals, and the crystallization of an »earlier» mineral need thus not necessarily have been completed before the crystallization of the mineral next in order begins.

As is usually the case in sulphide ores of the present type, pyrite and arsenopyrite are the first minerals to crystallize. On the basis of the material available it has not been possible to establish the age-relations between these two minerals, but as this question has no bearing upon the problems here under discussion, it is of no importance. Pyrrhotite is the mineral next in order after pyrite and arsenopyrite. As regards the age-relations between pyrrhotite and sphalerite it is often difficult to obtain positive results, but at least in two cases from Rävliiden the author found the pyrrhotite to be enclosed, brecciated and partly replaced by sphalerite. Chalcopyrite in turn replaces all the above-mentioned minerals but is itself replaced by galena. In the galena, and partly replaced or brecciated by it, we find antimony minerals, of which tetrahedrite and jamesonite or falkmanite are most abundant. The sequence of crystallization as interpreted under the microscope can thus be expressed as follows: Pyrite and arsenopyrite → pyrrhotite → sphalerite → chalcopyrite → Cu-Pb-Sb-minerals → galena, *i. e.* a sequence of crystallization generally disclosed by microscopic examinations of ores of the present type. It is also of interest to note that the same order of crystallization is found in the extreme zinc ores as in the extreme copper ores.

Survey of migration and concentration of the metals during the ore-forming process.

If the individual minerals were formed by a successive crystallization from an originally homogeneous ore solution, we immediately realize that certain features in the distribution of the metals as established previously cannot be explained solely as the result of such a process. It is thus impossible to explain a separation into zinc and lead on the one hand and copper on the other by some sort of fractional crystallization, for in the sequence of crystallization chalcopyrite stands between sphalerite and galena, and these three minerals are also quantitatively predominant carriers of the Zn, Pb, and Cu contents of the ores. If the sequence of crystallization had been of very great importance in regulating the distribution of the elements in question, we should expect the Pb : Zn quotient to increase in the copper ores as compared with the zinc

ores, while, as was shown for Rävliiden, a change in the very opposite direction was found. It must consequently be concluded that the separation into copper ores and zinc ores must have taken place independently of the crystallization of the individual ore minerals and must be due to some sort of fractional process preceding it.

Fig. 13 is a schematic survey of the distribution of the various metals mentioned above, their migration and concentration during the ore-forming process. In or from the original ore solution, or from the primary magmatic source of

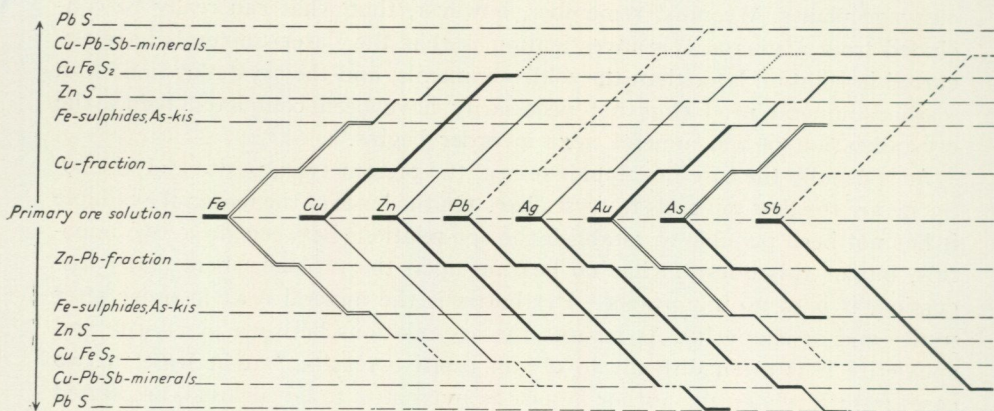


Fig. 13. Schematic survey of the migration and fixation of the chief metals during the ore-forming process at Rävliiden.

the ore substances, there is first a differentiation into one copper-rich and one zinc-rich fraction, which, however, does not imply that copper and zinc are completely separated from each other. From each of these fractions the different sulphide minerals then crystallize, beginning with pyrite and arsenopyrite and ending with galena. It is of course possible that the original separation process was intensified during the later stages of the mineralization. The total quantity of each of the metals concerned is denoted in the diagram by the heavy horizontal line below the symbols of the respective elements. By varying the thickness of the oblique lines the author has wished to denote to what degree the element in question enters into either fraction and is fixed in the respective minerals (the latter is denoted by horizontal lines of varying thickness on the same level as the respective mineral symbols).

Fe thus enters the copper and the zinc fractions to about the same extent. The main part is fixed in pure iron sulphides, and a smaller portion in chalcopyrite and sphalerite. As the total quantity of chalcopyrite in the zinc ores is very small, only a very insignificant portion of the total quantity of iron will be fixed in the chalcopyrite belonging to the lower half of the diagram.

Cu is enriched in the copper fraction, where it is mainly fixed in chalcopyrite; a very insignificant quantity may be bound in tetrahedrite. The small

part of the copper that enters the zinc fraction is also mainly fixed in chalcopyrite; a small part in tetrahedrite, which, however, is of much greater importance here as a copper mineral than was the case in the copper fraction.

- Zn* is of course mainly concentrated in the zinc fraction. A small part is found in the copper fraction, and in both cases the element is practically entirely fixed in sphalerite.
- Pb* mainly accompanies zinc to the zinc fraction, out of which it crystallizes mainly as galena and to a smaller degree as Pb-Sb-minerals. The part of the total quantity of lead that enters the copper fraction is proportionally smaller than was the case with zinc.
- Ag* mainly enters the zinc fraction. Some silver probably enters sphalerite and chalcopyrite, but the by far greater part is fixed in the Sb-minerals and possibly also in the galena itself. A small portion of the silver content that accompanies the Cu fraction enters sphalerite, but the main part is bound in the chalcopyrite. Possibly some silver may also be bound in the very rare quantities of antimony minerals in the copper ores. In most cases the iron sulphides can probably be disregarded as carriers of silver.
- Au* shows a slight enrichment in the Cu fraction as compared with the Zn fraction. It seems to a certain extent to accompany chalcopyrite, but otherwise the extremely small quantity of gold would appear to be fairly equally divided between iron sulphides and sphalerite.
- As* is probably somewhat enriched in the zinc fraction as compared with the copper fraction. It crystallizes exclusively as arsenopyrite.
- Sb* goes almost exclusively into the zinc fraction and is fixed there together with galena as tetrahedrite or lead-antimony sulphides.

Comparisons with Other Deposits of a Similar Type.

When discussing the causes that may possibly contribute to a separation of the ore materials into several fractions as has been assumed for the Rävli- den ore, it is of course of very great importance to know whether the associations of elements and minerals that have been established to exist should be considered peculiar to the deposit in question, or if they are of more general significance. If we first consider other ore deposits in the Skellefte District, we frequently find striking analogies with regard to the distribution of the elements. In a previous paper the author discussed fairly thoroughly the distribution of the constituents of the ore deposits in the Malånäs District (6) and arrived at the conclusion that the most striking feature also there was the tendency towards a differentiation into copper ores and lead-zinc-silver ores. As the sequence of crystallization in the Malånäs ores was practically identical to that found at Rävli- den, the author concluded, on the same grounds as in the present case, that the copper-zinc differentiation must be due to a fractional process prior to the crystallization. The general course of the differentia-

tion of the elements, as illustrated in the schematic survey of the ores of the Malånäs group (6, p. 179), is in the main identical to that outlined for Rävliiden in fig. 13. The only exception is that in the Malånäs District it was possible in several cases also to distinguish an As fraction rich in gold, which, however, in turn showed a closer relationship to the zinc ores than to the copper ores.

In the ore deposits at Kristineberg and Rackejaur (cf. 10, pp. 89 and 91), which contain both copper and zinc in considerable quantities, it is also possible to establish a definite tendency towards a differentiation into zinc ores poor in copper and copper ores poor in zinc. At Boliden, the most famous ore deposit of the Skellefte District, which has been exhaustively described by Ödman (22), the differentiation into copper and zinc ores seems to be of less importance. This may partly be due to the fact, however, that on the whole zinc is here quantitatively less important. The As fraction, whose occurrence is merely indicated in the ores of the Malånäs District, plays a more prominent rôle at Boliden than in the other deposits, and it is really only the ore types belonging to the stage of the ore formation that Ödman calls the pyrite stage that might be compared with the types previously mentioned here. According to a personal communication from Ödman, however, small quantities of pyrite ore, rich in zinc and at the same time poor in copper, sporadically occur also at Boliden, while the parts of the ore that are especially rich in copper usually contain very little zinc.

Although the sulphide ores in the ore districts of Central Sweden generally contain Cu, Zn and Pb in considerable quantities, it is usually difficult to form as clear a conception of the mutual distribution of these metals as is possible with reference to the ores of the Skellefte District. We certainly recognize the tendency towards a differentiation into copper ores and Zn-Pb ores if the ore district is taken as a whole, and it is also conspicuous in several cases within the individual deposits, but quantitative data are still lacking. Geijer (7, p. 152) reports from Falun, for instance, that the quantity of sphalerite in the pyritic copper ores varies considerably, so that large parts of the solid ore bodies are practically free from zinc, while locally sphalerite may even predominate.

For the Kaveltorp sulphide ores in the Ljusnarsberg ore district Magnusson (16, pp. 84—87) has tried to make a thorough survey of the distribution of the ore, gangue and wall-rock minerals and of the relative abundance of the various associations. As the chemical composition of the wall-rock proves to be partly responsible for the distribution of the sulphide minerals and seeing that it is not possible to explain the most characteristic mineral associations by the sequence of crystallization determined by microscopic examinations, he draws the conclusion that also in this case some sort of fractioning must have preceded the crystallization. The most conspicuous differentiation at Kaveltorp is expressed in the association of iron and copper in pyrrhotite-chalcopyrite ores, while lead and zinc occur together as galena and sphalerite. Complex ore portions do occur, too, but no definite judgment can be passed upon the proportions between them and the more completely differentiated ore parts as

compared with the corresponding conditions in the deposits of the Skellefte District. A remarkable dissimilarity in the distribution of the chemical elements at Kaveltorp and Rävliiden is the change of the Pb : Zn quotients from zinc ore to copper ore. Magnusson mentions that at Kaveltorp galena enters the chalcopyrite-pyrrhotite ores to a greater extent than sphalerite, *i. e.* the Pb : Zn quotient is usually higher in the copper ores than in the zinc ores. As already mentioned, a tendency in the very opposite direction could be established at Rävliiden. It is of course impossible to say anything definite about the factors that may have caused such a dissimilarity as long as the character of the sulphide-bearing solutions is not known. A fact which in this respect may have been of importance is that the absolute lead content when calculated on the pure sulphide phase is much larger at Kaveltorp than at Rävliiden.

If we wish to go further afield and search the literature on sulphide ore deposits for analogies to the arrangement of elements and minerals that has proved characteristic for Rävliiden, it is evident that certain analogies can be discerned in many cases, but we generally fail to form a conception of the exact degree and character of the resemblances and differences. On the basis of descriptions of a large number of classical and famous deposits of a type similar to those discussed above, the author has tried to form a conception of the degree and extent of the differentiation into Cu and Zn-Pb ore parts. Statements are often encountered, for instance, to the effect that copper ores occasionally carry a small quantity of sphalerite, but on the other hand the occurrence of quite zinc-free high-grade copper ores is mentioned, as well as local enrichments of zinc in zinc-ore parts poor in copper. If we turn to deposits of predominantly copper-ore type, zinc mineralization poor in copper is even mentioned as a special phase later than the copper ore proper (*e. g.* Butte and Shasta County, 14, pp. 617 and 621). As no quantitative data are available, it is in such cases necessary to possess a thorough personal knowledge of the deposits before we can say anything about the degree of differentiation into certain mineral assemblages.

In this connection it may be of interest to make a comparison with a deposit where the distribution of metals is illustrated by analyses, even though certain other important differences make it difficult to draw any very general conclusions regarding the similarities or dissimilarities in the processes that lead to the distribution of elements as established in that case. In a description of the Tsumeb ores Schneiderhöhn (19) has illustrated the most characteristic features of the metal distribution in the deposit by means of diagrams of the analyses. At Tsumeb as at Rävliiden the chief constituents are copper, zinc, and lead, but the absolute percentages as well as the mutual proportions of the different metals differ considerably in the two cases. At Tsumeb the metal contents are thus very high, and of the three elements mentioned lead predominates; copper comes next and then zinc, thus quite the reverse as compared with Rävliiden. Furthermore, iron plays a very subordinate part compared with the pyritic deposits previously discussed.

The diagram in Schneiderhöhn's report demonstrating the variations of

Cu, Zn, and Pb in a cross-section through the ore body clearly shows that Cu and Zn or Cu and Pb display a reciprocal relationship. On the other hand there is nothing to indicate that zinc and lead have a tendency to accompany each other to any great extent. When comparing conditions at Tsumeb with those at Rävliiden, for instance, it must be remembered, however, that besides the differences in the absolute and relative proportions of the chief metals there also exists a great mineralogical dissimilarity. Quantitatively chalcopyrite plays a comparatively unimportant part at Tsumeb: the predominant primary copper mineral is enargite, but there also occur a number of other copper minerals, among which chalcocite seems to be of a certain importance. We must also count with a considerable supergene enrichment of copper, when large quantities of secondary chalcocite were formed. These circumstances prompt a certain feeling of doubt whether this separation of Cu from Zn and Pb may be compared to the differentiation in the pyritic ore deposits previously discussed. What can be seen, however, is that the analyses from Tsumeb indicate the same general tendency to a separation between copper on the one hand zinc or lead on the other as was found in the deposits of pyritic ores.

The Tsumeb ores also contain silver in fairly large quantities and it is very interesting to compare the distribution of this metal at Tsumeb with conditions for instance at Rävliiden. As a matter of fact the analyses from Tsumeb (20, pp. 13—16) show very clearly that silver accompanies copper with great regularity but varies quite independently of lead and thus on the whole presents different relationships to those at Rävliiden. The most important primary copper mineral at Tsumeb, however, is enargite, a mineral that to a certain extent may be said to be of the tetrahedrite type, and the quantity of silver accompanying copper at Tsumeb does not very greatly differ from the quantity of silver that proved to accompany copper at Rävliiden. (Tsumeb: about 24 g/t to 1 % Cu; Rävliiden: about 14 g/t Ag to 1 % Cu.) Another circumstance deserving attention in this respect is that although the parageneses from Tsumeb are very rich in As, Sb is practically entirely lacking. As we have seen that a comparatively large content of Sb is a characteristic feature of the silver-carrying zinc ores of the Skellefte District, in which Sb-minerals are largely the silver carriers, also this dissimilarity may be of a certain importance.

Hence we have seen that it is often difficult when examining individual deposits to decide to what extent the scheme of the metal distribution presented here for Rävliiden is of a more regional character. If we examine the distribution of the elements in question on a larger scale, however, we shall find certain remarkably consistent features. The zonal arrangement, which is often indicated for instance in the distribution of the metals of an ore district around a magmatic centre, thus leads to an arrangement of elements that on the whole corresponds to the one outlined for Rävliiden. As regards the zonal arrangement Cu thus belongs to an inner zone as compared with Zn, Pb and Ag, and of the three last-mentioned elements Zn comes closest to Cu, while Pb and Ag are enriched in the outer zones. This has been recognized by a large number of geologists dealing with problems pertaining to ore deposits, and although the associations

are frequently more or less influenced by secondary factors of various kinds (irregularities in the tectonic features, etc.), it has nevertheless been possible to draw up some general outlines for this zonal arrangement in several ore districts. An exhaustive summary of the literature dealing with this problem being given by Lindgren (14, p. 112), it hardly seems necessary to repeat it here.

Discussion on the Causes of the Ore Differentiation.

In spite of the difficulties of making exact comparisons we have seen that the assemblages of elements or minerals claimed to be characteristic of the Skellefte District are at least indicated in many ores of the same kind, and that certain important characteristics, for instance the tendency towards a differentiation into copper ores and zinc-lead ores, are of a fairly general character. Hence it is close at hand to conclude that the factors causing the more systematic associations of elements are not to be found in exceptional traits that vary from case to case (for instance the intervals of pressure and temperature during the ore formation, irregularities in the composition of the wall-rock), but that they must instead lie in certain special qualities in the very nature of the ore solutions themselves.

However, our general knowledge of the composition of the ore-forming medium and of its state of aggregation is in many respects very incomplete. Sulphides and gangue minerals as well as alterations in the wall-rocks caused by the ore-bearing fluids give a certain idea of the mutual proportions between certain compounds, but as regards those constituents of which but insignificant parts are fixed during the ore-forming process (such as water, halogenides) and as regards the concentration of the constituents, we are restricted to the conclusions that can be drawn from certain general conceptions of the late-magmatic evolution in the process of magmatic differentiation.

A summary of our present knowledge of the nature of the ore solutions is given in the »Lindgren Volume» by Fenner (3), Bowen (1), and Ross (18), and also in a comprehensive critical survey by Graton (8) of the results and conceptions presented in the »Lindgren Volume», and finally in some discussions on Graton's paper. In all these works the discussions mainly deal with the stage of the development represented by the departure of the ore substances from the original magmatic source. While Bowen and Fenner argue that the ore substances departed in a gaseous state from the silicate phase, Ross considers it more probable that the ore materials were transported in alkaline solutions, which latter opinion is shared also by Graton. Ingerson and Morey (11), on the other hand, emphasize the importance of a gaseous phase as a carrier of the ore substances. They were able to show that water in a super-critical state on certain conditions is able to dissolve not unimportant quantities of non-volatile constituents.

The problems ventilated in these discussions differ in some respects from those with which the mining geologist working in the field is confronted. For

the latter it is first of all a matter of answering the questions: What do the observed structures and textures, associations of minerals, etc., tell us about the processes that lead to the present appearance of the ores? Although when answering these questions it of course would be of very great importance to have full knowledge of the composition and state of aggregation of the ore-bearing medium also during the earlier stages of the evolution, it is nevertheless the reactions and the course of events in the milieu of the very ore deposit that first of all need an explanation. It does not seem altogether improbable that the physico-chemical qualities of the ore solutions out of which the sulphides finally crystallize to a certain extent differ from the phase that was separated from the original magmatic source. Fenner, for instance, points out that even if the ore substances originally were transported in a gaseous phase, the latter may subsequently have been condensed to a liquid phase. Even if the ore solution was originally acid, it is very plausible that by reaction with the surrounding rocks it may have been neutralized or may even have become alkaline.

In the literature dealing with the special conditions causing the precipitation of the sulphides one notes a palpable agreement on the importance of the solubility of the sulphides in water. Wells (21), Lindgren (14, p. 123), Newhouse (17), and others, emphasize the agreement between the order of crystallization of the sulphide minerals and the Schürman series, but also point out that the solubility is extremely sensitive to changes in the acidity. Kordes (13) discusses the importance of the dissociation vapour pressure of S_2 and considers this a decisive factor for the sequence of crystallization. As the principal textbooks (Lindgren 14, Schneiderhöhn 20) give exhaustive surveys of the discussions on these questions, it is superfluous to go into them here.

In the discussion on the distribution of the chief elements in the ores of the Malånäs District, where the problem was practically the same as at Rävliiden, the author emphasized that although the above-mentioned factors may contribute to explaining the mutual succession of the ore minerals, they nevertheless fail to give a satisfactory explanation of the associations of elements that cannot be explained solely as a result of a fractional crystallization. As there seems to be a consistent agreement in the order of crystallization within ores of the types in question all over the world, this statement even seems to be generally applicable. In the Malånäs paper the author emphasized the striking analogies between the associations of elements established there and the arrangement in certain groups of elements that Freeman (5) obtained as a result of the different behaviour to water of the double sulphides with alkalies, and in which one group is made up of Fe, Cu, and Ni, another of Zn, Pb, Ag, and Fe, and a third of Au, Sb, As, and Fe.

In the above-mentioned discussion in the »Lindgren Volume» and in Gratton's survey the authors seem very little inclined to ascribe any importance to double sulphides with alkalies and colloidal solutions in connection with the ore-forming processes. Schneiderhöhn (20, p. 303) expresses a similar opinion in his recent textbook, stating that »on the basis of recent experiments» he

considers it improbable that double sulphides with alkalis play an important part. This opinion is probably at least partly based on Foreman's (4) and Gruner's (9) results, according to which iron- and copper-sulphides are very little soluble even in the presence of Na_2S . Kania (12) has, however, subsequently succeeded in producing colloidal solutions which may contain quite considerable quantities of FeS_2 , CuFeS_2 , and ZnS together with Na_2S . It is difficult to determine what factors cause these differences in the empirical results. Gruner emphasizes that the solubility of iron sulphides is particularly low in the presence of silica, while Kania found that SiO_2 in a crystalline state does not exercise any peptizing influence on double sulphide solutions saturated with H_2S and CO_2 . It is also of great interest to note Kania's statement that sphalerite is precipitated from a colloidal solution somewhat later than chalcopyrite, and also the circumstance that he has actually succeeded in getting chalcopyrite to crystallize out of the solutions without any signs of colloform structures. This latter result certainly does weaken the value of one of the arguments often raised against the assumption that sulphides have crystallized from solutions of a colloidal nature, *viz.* that colloform structures are usually entirely lacking in the types of ore here in question. Kania's survey of the factors that can influence the stability of the colloidal solutions in one direction or the other also seems to indicate that the pre-requisite conditions for such solutions to exist in nature are perhaps not so negligible as has previously been assumed.

If we could actually prove the existence of a colloidal state under conditions similar to those prevailing in nature, it would be easier to explain certain conditions in connection with the ore-forming processes which otherwise would be difficult to comprehend, for instance the differentiation of the ore materials, which cannot originate from the sequence of crystallization of the individual ore minerals. As a matter of fact both Freeman's and Kania's results show that the separation that might be expected from a colloidal solution follow partly other lines than crystallization from electrolyte solutions.

Many of the arguments that are raised against the theories that colloidal solutions are carriers of sulphides can be refuted, however, if we merely assume that during a certain stage of the evolution and on certain conditions the sulphides of the metals enter colloidal solutions from a gaseous or normal liquid phase, for instance as double sulphides with alkalis. In the latest edition of *Mineral Deposits* and evidently largely in view of Kania's results, Lindgren (14, p. 125) seems inclined to ascribe fairly great importance to the colloidal state. In a later survey, when discussing the importance of various physico-chemical factors in ore formation (15, p. 10), he expresses an opinion that generally speaking tallies with the ideas of the present author. Speaking of the transportation of sulphides in colloidal solutions, he says: »It is not meant to imply that all minerals were deposited as colloidal precipitates . . . But, speaking generally, the writer believes that most sulphides passed through a colloidal state, although it may have been short.» Lindgren thus seems to believe that even if the sulphides need not necessarily have been transported from the

magmatic source in colloidal solutions, certain changes in the original character of the ore-bearing solutions or gases may have transferred them to a colloidal state. In such a case the processes of mineralization become the result of a co-operation between colloidal and true solutions.

The experiences reported by Kania seem to indicate that the introduction of larger quantities of Na_2S into the ore solutions would serve to stimulate the development of colloidal double sulphide solutions with alkalis. The significance of the changes that usually precede the precipitation of the sulphides in nature is, however, that the solutions extract alkalis from the altered wall rock, and these processes may thus possibly be the cause of the formation of a colloidal state. As a matter of fact silicification, chloritization and sericitization first affect the alkali feldspars in the rocks, generally causing the total alkali content to decrease, which in turn must produce an increase in the alkali content of the sulphide-bearing solutions themselves. It may then be possible that the sulphide material is concentrated to a certain extent also prior to its crystallization, which may perhaps explain certain structural and textural peculiarities that cannot readily be regarded as created by highly diluted solutions.

The difference in the differentiation of the metals that could be established at Rävliiden between the more compact ore parts on the one hand and the more disseminated parts on the other could also be explained along the lines discussed above. The most compact and most distinctly differentiated ores, which mainly appear as fillings in open spaces and fissures, may then be considered to originate from the colloidal, comparatively concentrated solutions, whose power of diffusion, however, is very small, while the sulphide ores appearing more or less as disseminations may be considered to emanate from electrolyte solutions with a comparatively great power of diffusion. The fact that the differentiation into copper and zinc parts is not so complete as in the more compact ores may thus possibly be due to certain qualities in the sulphide-bearing solutions themselves.

On the other hand the results as demonstrated in fig. 12 showed that sulphide mixtures of a copper-ore character occur also in the S-poorest sections between more compact zinc-ore beds. The diagrams in fig. 12 may thus also indicate a segregation of sphalerite from compact copper ore and of chalcopyrite from solid zinc ore. It must be remembered, however, that in the sections poorest in S the absolute metal contents are very low and consequently slight accidental changes in the quantity of one of the components may produce considerable changes in the quotient. If the separation of Cu from Zn is continued and slightly intensified also during the later stages of the mineralization, such conditions may be expected.

In this connection another one of the results from Rävliiden is of importance. Fig. 10 seems to indicate that the separation into copper ore and zinc ore within the more important ore bodies is much less predominant in the »lime-silicate ore» than in the other ore lenses. Among the facts increasing the stability of colloidal solutions Kania mentions the introduction of alkali salts, while Ca

salts are said to have the opposite influence. It would thus be reasonable to expect that if electrolyte solutions replace limestone or lime silicates, the premises for the formation of colloidal solutions would be less pronounced than if they replace acid alkali-bearing rocks, and this would also weaken the basis for a separation between Cu on the one hand and Zn and Pb on the other. If such an argument is to hold good, we may expect, however, to find a general tendency in the »lime-silicate ores» towards a less advanced differentiation between Cu and Zn than in other, more solid ore bodies.

An argument often raised against the assumption that the sulphide minerals crystallized from colloidal solutions is that such solutions are far less capable to penetrate the capillary pores and openings of the bedrock than are electrolyte solutions. The value of this argument is greatly diminished, however, if, in accordance with the theories expressed above, a »colloidal stage» is assumed to have existed, which then implies that the ore substances need not have been transported any very long distances in a colloidal state. Duffell (2) has recently investigated the power of penetration of colloidal as well as true solutions in different kinds of rock. His investigations showed that in many cases the bedrock acts as a semi-permeable membrane also as regards electrolyte solutions, certain parts of the solutions penetrating the rocks more easily than others. This being true of electrolyte solutions, there is reason to expect such factors to be of great importance for the separation of different constituents of colloidal solutions and for a potential enrichment in certain parts of the material.

Of course the view-points discussed above are quite hypothetical and far more laboratory work is needed before it is possible to state anything definite on the causes of the differentiation of the ore materials. The author has desired, however, *inter alia* to emphasize that when discussing the nature of the ore-forming fluids we should also pay attention to the systematic relationships between the elements of the ores. Unfortunately we do not definitely know what is the general applicability of the relationships that have been established at several sulphide ore deposits. In proportion as our knowledge of other ore districts is enlarged in this respect, a better platform will also be provided for further laboratory experiments.

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