

SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C.

Avhandlingar och uppsatser.

N:o 443.

ÅRSBOK 35 (1941) N:o 6.

RELATIONS BETWEEN
ORE DEPOSITION AND STRUC-
TURE IN THE SKELLEFTE
DISTRICT

BY

SVEN GAVELIN

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

Our knowledge of the ores in the sulphide-bearing areas of the Skellefte District in Northern Sweden and of their relations to the structural features of these areas has been quite considerably enlarged during the past few years, partly thanks to more detailed geological mapping and partly due to the fact that an ever-increasing number of the deposits have been subjected to more thorough investigations or in some cases even to mining. A general survey of the geology and ores of the Skellefte District was published by Alvar Högbom (4), and the reader desiring to locate the various localities and areas to be treated below is referred to the geological map accompanying that survey.

The present paper is intended to illustrate by a few examples certain of the types of ore-controlling structures that are at present surveyable in the field. Of course it must be understood that this survey does not claim to supply an exhaustive picture of the ore-tectonic problems of the whole field, this in view of the fact that a large number of deposits are as yet but little known. The exposition is based partly on the results yielded by more recent investigations which have been at least only incompletely published to date, partly on the material presented in the descriptions of the Malånäs District by S. Gavelin (2) and of the Boliden ore by O. Ödman (5).

The areas to be discussed below are built up of a lower volcanic series with a varying chemical composition — acid, intermediate, and basic lavas and pyroclastic sediments — and an upper sedimentary part, the so-called phyllite series. The strata have been strongly folded and in connexion with the orogenesis two granites make their appearance, one early orogenic, and the other late or to a certain extent also post-orogenic. In a recently published paper the tectonic features of the middle and eastern parts of the Skellefte District have been thoroughly ventilated by E. Grip (3). He distinguishes two orogenic stages. During the earlier stage a general uplift of the strata was produced and the major structures determining the regional distribution of the various rocks were created. These structures are visible for instance as long synclinal belts of phyllites running practically through the whole field. During this stage the earlier granites have been intruded. These granites, together with other harder parts, make up resistance areas against

which more mobile rocks are folded during a later stage. The later stage of the orogenesis often brings about a more intense detailed folding, the rock beds frequently being laid into sharp S-folds, dragfolds, this due to lateral movements within the beds. Grip also points out that although the axes of the earlier folding must have had a fairly flat pitch, the axes of these latter dragfolds often stand comparatively steep and to a certain extent depend upon the resistance offered by the outlines of the above-mentioned resistance blocks. In the final phase of this later orogenic stage, the later, palingene granite of the area, the Revsund granite, was formed. In the following a few examples will be given, demonstrating how the shape and position of the ore bodies are controlled by the structures in the various cases.

1. Ore bodies controlled by the structure of the earlier stage of folding.

The Kristineberg—Rävliden Area.

The main tectonic features of this area are very simple. The phyllite series form a vault over the volcanics, describing a large anticlinal curve and following fold axes pitching flat towards W (see fig. 1). The large

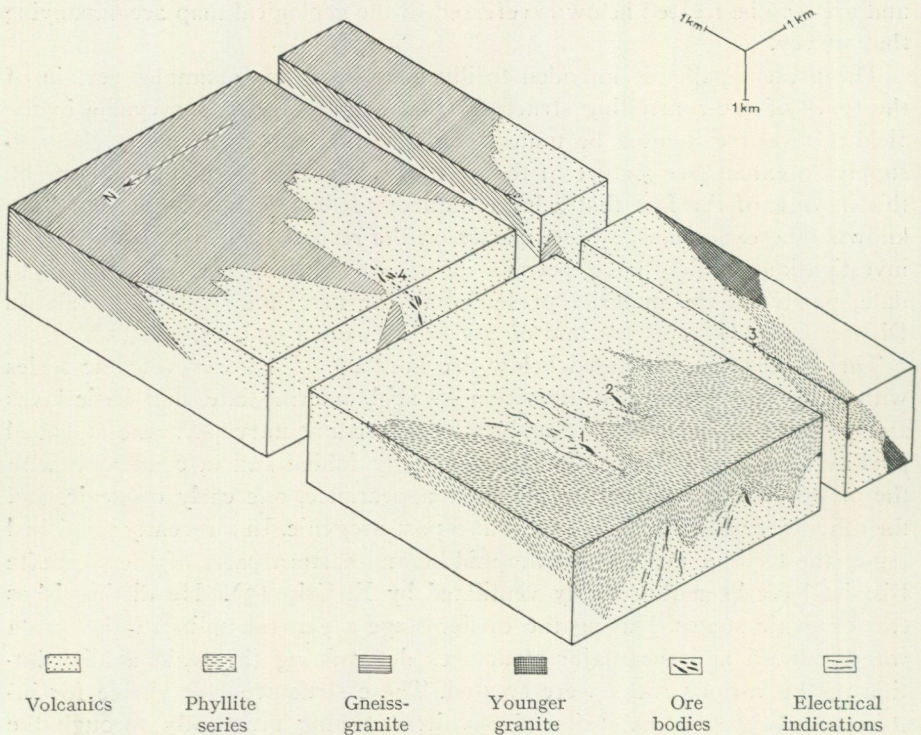


Fig. 1. Isometric block-diagram of the Kristineberg-Rävliden area. 1 = Rävlidmyran; 2 = Rävliden; 3 = Mörkliden; 4 = Kristineberg.

curve is divided into a number of small undulations among which it is possible to distinguish three anticlines. The phyllites are strongly sheared and — in the shape of slabs or points — dynamically pressed into the more competent volcanics. The two northernmost anticlines are very strongly "broken" in this manner whereas the southernmost one displays a more even curve. Linear structure is often distinctly visible in the rocks, especially in the curves.

Towards the east, i. e. downwards in the rock sequence, gneiss-granite belonging to the oldest granite group of the Skellefte District makes its appearance and this rock too has very lobate contact lines towards the volcanics, contact lines which are orientated along the main structural features of the area (cf. fig. 1). The whole appearance of the structure above described indicates that it developed during the earlier stage of folding and that the fold axes must be regarded as the axes of the main folding.

The mineralization in the area displays a simple but very obvious relation to the regional structure. In the northern and middle anticline appear the solid zinc and zinc-copper ores of Rävliidmyran and Rävliiden. They are situated immediately below the boundary between the volcanics and the phyllite series but partly in strips of phyllite, mechanically pressed or folded into the volcanites. In the southernmost anticline there are also found traces of ore deposition, Mörkliiden, but the mineralization there has only led to disseminations of sphalerite and galena, which have so far not been found to be sufficiently rich to be attributed any economic importance.

The fourth and largest mineralization area in this district, the solid pyrite, copper, and zinc ores of Kristineberg, is situated quite near the gneiss-granite contact and in a belt of altered rocks that can be followed into the mineralized belt of Rävliiden. The Rävliiden and Kristineberg ores are thus both localized to a zone of weakness in the central part of the middle anticline.

Another characteristic feature is that the shape of the individual ore bodies is quite obviously dependent on the general tectonic style of the area, for here the individual ore bodies form particularly elongate lenses, the longitudinal axes of which coincide with the fold axes.

2. Ore bodies controlled by the structure of the later stage of folding.

Boliden and the Eastern Malänäs Field.

The geology of the Boliden ore has recently been treated in detail by O. Ödman (5). The tectonic features predominant in the surroundings of Boliden are essentially of a character different to that of the structure of the Kristineberg-Rävliiden area, but as regards the relationship between ore deposition and structure it is nevertheless possible to establish certain important points of similarity between the two ore-fields. Similar to what was true of case 1, the Boliden ore is situated in an anticlinal curve of the

boundary between phyllites and volcanics, and here, too, the ore is situated in the latter fairly close to the boundary towards the sediments (fig. 2). The anticlinal fold that in this latter case regulates the mineralization has, however, developed under tectonic conditions quite different to those in the Kristineberg—Rävliden area and has been classified by Ödman as a drag-

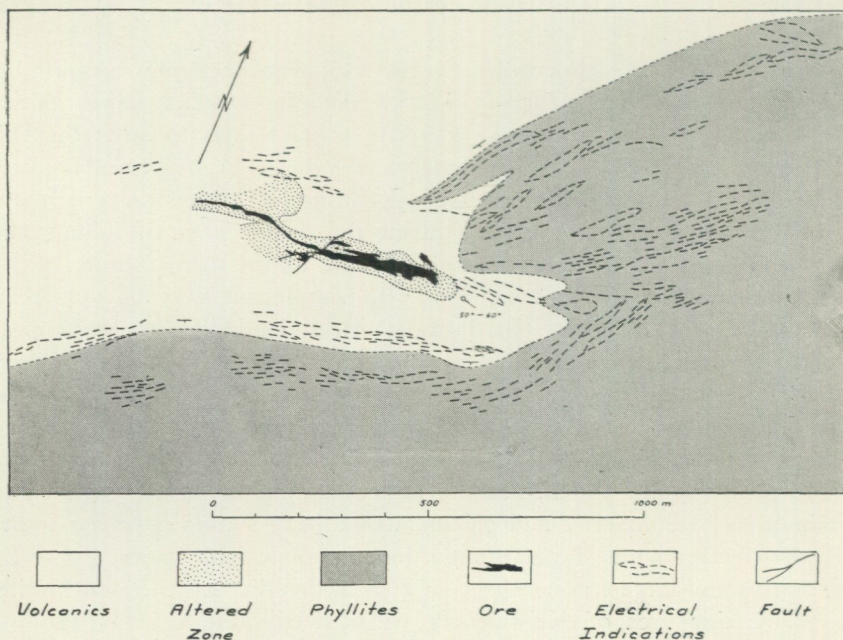


Fig. 2. Relations of Boliden ore to structure (From Ödman (5, fig. 3)).

fold. The fold axes pitch fairly steeply and according to Grip (3) the development of the fold must be referred to the latter stage of the tectonic evolution (which rather has the character of lateral movements within the rock series themselves). Using Derry's (1) terminology, Ödman calls the fold an independent dragfold. On account of the general distribution of the rocks, Grip assumes that the pitch of the fold axes shaped by the main regional folding of the older orogenic stage was very flat. The persistence of the individual ore bodies along the longitudinal direction appears in this case to be less decided than in case 1.

In the Eastern Malänäs Field a tectonic style is predominant, the main features of which strongly remind of those of the Boliden area. In this case, too, the beds display fairly pronounced S-folds. The frequently comparatively flat pitch of the fold axes and the relatively uniform directions in large areas make it quite probable that these folds coincide at least fairly closely with the main regional folds and that they might thus be termed dependent dragfolds, according to Derry's terminology. However, this question is of no decisive importance in the present discussion, seeing that

the regional relations between the Malånäs area and the Boliden field indicate that the dragfolds of the two areas were formed during the same stage of the orogenesis.

In the Eastern Malånäs Field, according to the data so far known, the ore-lenses are on the whole orientated along the fold axes of the S-folds above

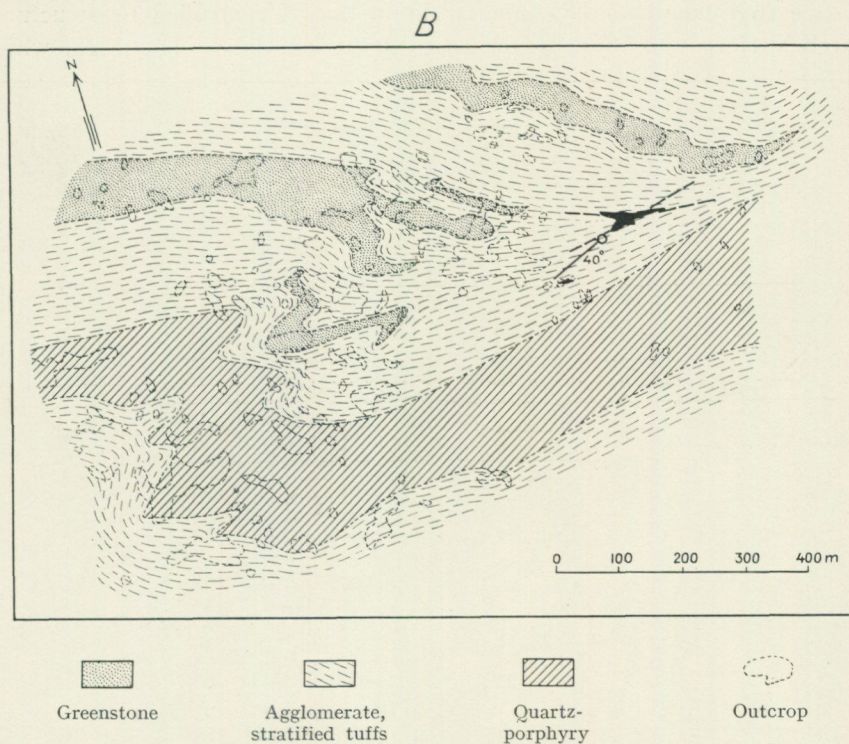


Fig. 3. Position of the Bjurträsk ores (ore bodies black) in the crumpled beds of volcanic rocks. The broken heavy lines show the two main directions of ore-controlling structure.

described, and these directions are conspicuous also in the field in the shape of minor folds or linear structure in rocks. The most striking instance in this area of the relationship between ore deposition and structure is found in the neighbourhood around the small Bjurträsk ores (fig. 3). Contrary to what was true of the ores already discussed, these ores display no connexion with shear zones close to the contact between competent volcanics and incompetent pelitic sediments. Studying the sketch-map (fig. 3), however, we encounter no great difficulty in making out the structure that is responsible for the ore deposition in question. The different grade of crumpling of various beds must to a large extent be suited to loosening the bedrock and creating openings in which the ore solutions may deposit their materials. The ore is situated at a point of intersection between two main directions of strike of the beds within the area (see fig. 3). As regards

the persistence of the individual ore bodies in their longitudinal directions, very little is at yet known from this area.

The Western Malänäs Field (Ö. Högkulla, Skäggräskberget).

In the vicinity of Skäggräskberget in the western part of the Malänäs area we find examples of a mineralization that is controlled by structures entirely different to those in the cases discussed above. This area, which

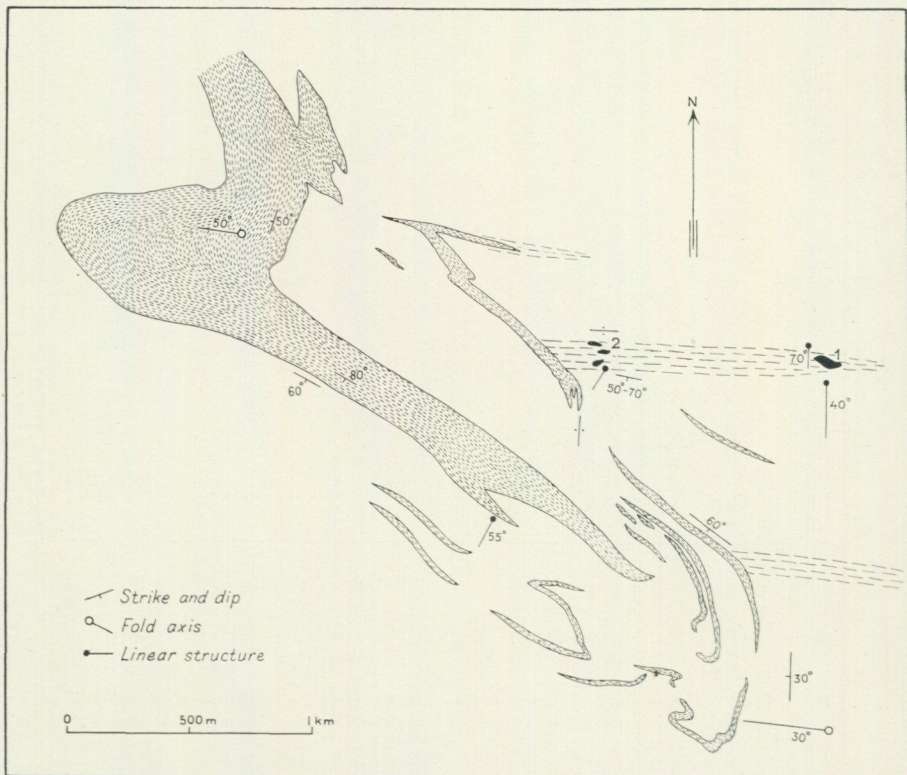


Fig. 4. Sketch map of the Skäggräskberget area. Folded beds of graphite-phyllite (small dense lines) in acid lavas and tuffites. Long broken lines denote altered schistose zones. Ore bodies black. 1 = Ö. Högkulla; 2 = Skäggräskberget.

is built up of a mixed complex of sediments and volcanics, is dominated from a tectonic point of view by a large and conspicuous synclinal curve of the whole series (see fig. 4). By combining the values of strike and dip of the beds in different parts of the area it is possible to establish that the syncline was controlled by a fold axis dipping about 30° towards W, and one is thus first of all inclined to regard this fold axis as the linear structure of the main folding. On the other hand a study of the map discloses quite distinctly that the strong curve received its present shape at least partly in connexion with the formation of the S-folds in the Eastern Malänäs Field. In my treatment of the tectonic features of the Malänäs

area (2), the material available did not allow of a regional analysis of the various stages of the main orogenic evolution, but considering Grip's results from the eastern parts of the Skellefte District, the most probable interpretation of the conditions at Skäggräskberget would seem to be that the development of the syncline was started already during the regional folding, the first stage of the orogenic evolution, but was intensified in the second stage. It would then appear as if the folding of the later stage developed with practically the same fold axes directions as the earlier stage.

As has already been stated in the description of the Malåsnäs area, the linear structures and the axes of the minor folds directly visible in the outcrops do not run parallel to the main fold axes of the area, but generally pitch fairly steeply (50° — 70°) towards S or SW (see fig. 4). The origin of these structures is, however, of a character somewhat different to that encountered in the areas characterized by the normal independent dragfolds, and the structures were obviously formed under the influence of minor movements in the beds along shear zones more or less at right angles to the main fold axis. Such movements bring about a kind of independent dragfolds, the individual folds, however, never attaining the same size as in the foregoing cases.

The sulphide mineralization is now entirely controlled by these structures. In addition schistose belts striking parallel to the main fold-axis have been found to play a certain part. In the cases subjected to a close examination the ores generally present a decidedly elongate shape, the ore-axes pitching tolerably steeply towards S and SW. The two deposits of more concentrated sulphide ore, Ö. Högkulla and Skäggräskberget, also seem to be localized to the same east-westerly zone of schistosity. In this area the ore deposition is thus controlled by fractures and shear zones developed in a tectonic stage still more advanced than in the above cases.

3. Ore bodies controlled by regional folding combined with local fracturing.

The Kuorbevara Area.

The part of this area in which the ores now known are situated forms a fairly regular cupola. Its central parts, consisting of acid, comparatively massive volcanic rocks, dip in all directions under a series of banded intermediate tuffites and effusive greenstones (fig. 5). The acid volcanics in the inner parts of the cupola are strongly altered and now mainly consist of quartziferous, fairly massive rocks bearing biotite, cordierite, Mg-amphiboles, garnet, plagioclase, chlorite. The actual ore bodies seem to be confined to areas close to the boundary between the banded tuffites and the massive altered rocks. The group of ores best known to date, is the Adak ores. They are situated in the westernmost part of the cupola in the very

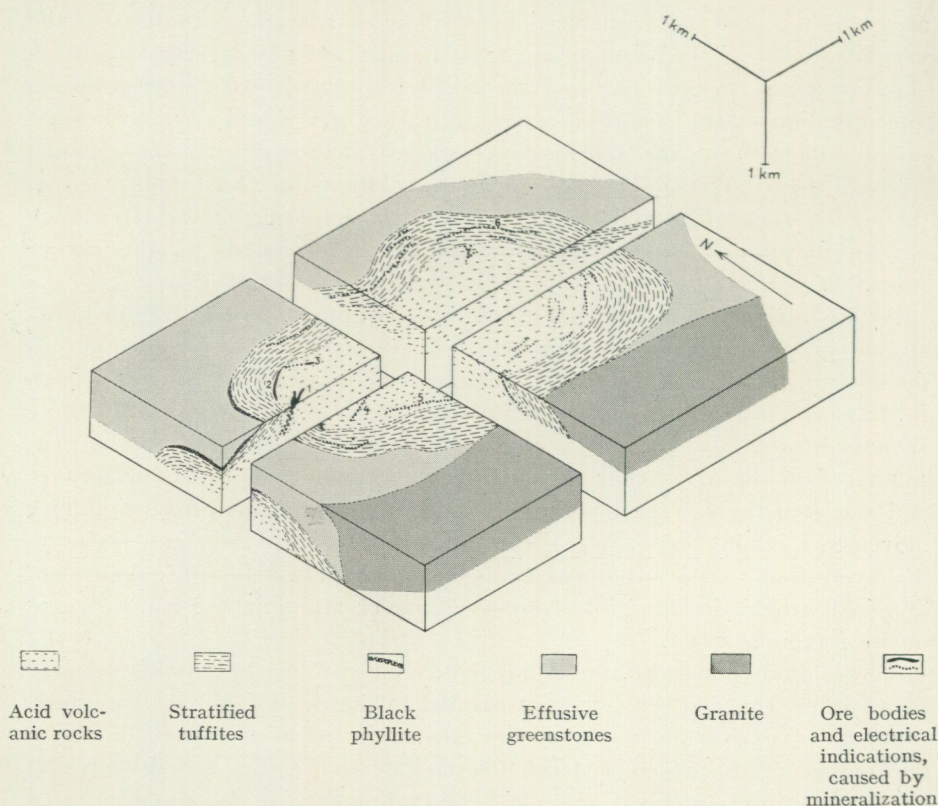


Fig. 5. Isometric block-diagram of the Kuorbavare cupola. 1 = The Adak ores; 2 = The Lindsköld ore; 3 = The »Karlsson» ores; 6 = Rudtjebäcken.

top of the anticline and stratigraphically somewhat below the banded rocks. The outlines of the individual ore bodies are extremely irregular. As lamellar and linear structures are lacking or at least in most cases but very indistinctly developed in the bedrock, it is in itself not very remarkable that the ore bodies generally do not display any very pronounced or simple lamellar or linear form. However, also in the cases when foliation is fairly distinct, the tendency of the sulphides to accumulate parallel to the foliation planes appears to be far less prominent than is true of e. g. the more common solid pyrite ores in chlorite or sericite schists (Boliden, Kristineberg, Rävliiden, etc.). The structures that in detail are responsible for the shape of the ore bodies are to be found in the systems of fractures formed in the more competent beds in connexion with the development of the cupola. These to a great extent give the ore bodies the character of breccias consisting of veins of chalcopyrite and pyrrhotite in more or less massive quartz-ous altered rocks. The sizes of the enclosed fragments may vary quite considerably, the diameter being anything from a millimetre to a few metres. The sulphide veins in the breccias may likewise vary in size, from as much

as a metre wide to merely thin coatings on fissures. In certain cases the ore boundaries are fairly distinct whereas in others the sulphides gradually decrease, the broader veins of chalcopyrite grading into fine veinlets which successively die out, and only analyses can determine the boundaries of the part that may be termed "pay ore".

Although the mineralization generally speaking in a broader sense is controlled by the regional structural features, i. e. the cupola-shape of the rock mass, it is only locally possible to establish any regular system of fractures in the individual directions of the ore veins that may have been decisive in distributing the sulphides in detail. Fig. 6 demonstrates the positions of the individual ore bodies in the part of the mine so far studied. The vertical sections are laid at approximately right angles to the mean direction of the longitudinal axes of the ore bodies, which are generally almost horizontal or have a very flat pitch. The irregular shape of the ore bodies in the various cross sections is conspicuous as is the already mentioned tendency of the sulphides not to spread parallel to the faces of bedding and foliation (the heavy broken lines in fig. 6). The ores assume the character of more or less horizontal "pipes" with very irregular cross sections and the projecting lobes are dependent upon what structural element was of decisive importance in each special case. It will be seen from the diagram that planes dipping slightly towards NW occur in several places and play an important part in determining the outlines of the individual ore bodies. However, a larger structure seems to be responsible for the general distribution of the sulphides, a structure that is not directly demonstrated by individual observations in the field. The upper part of fig. 7 shows the longitudinal axes of the various ore bodies projected on the horizontal plane. As regards the directions, it will be seen that it is possible to discern a certain tendency towards agreement and that the approximate mean of the various directions of the axes deviates about 30° from the main axis of the cupola. In the bottom right-hand picture the distribution of the ore bodies is projected on a vertical plane through the mean direction of the axes (A—A). It will be seen that the stronger mineralization forms a belt that generally speaking dips about 55° (towards SW). If a corresponding projection is made on a plane at right angles to A—A (the bottom picture, to the left), it is found that the ore bodies in this section spread fairly regularly vertically downwards. This ore distribution demonstrated in fig. 7 gives a general idea of the distribution and course of the system of fractures that served as channels through which the ore solutions entered in the present case. The only unmistakable sign of relationship to the major structural features of the area that can be established at present is the accumulation of sulphides at the top of the anticlinal curve of the cupola.

Other occurrences of less importance but of a similar type occur in the vicinity (500—700 m NE and E of the Adak ores), but they are as yet not sufficiently known to contribute to the general picture of the mineralization of the area. 300—400 m N of the ores of the Adak group, however,

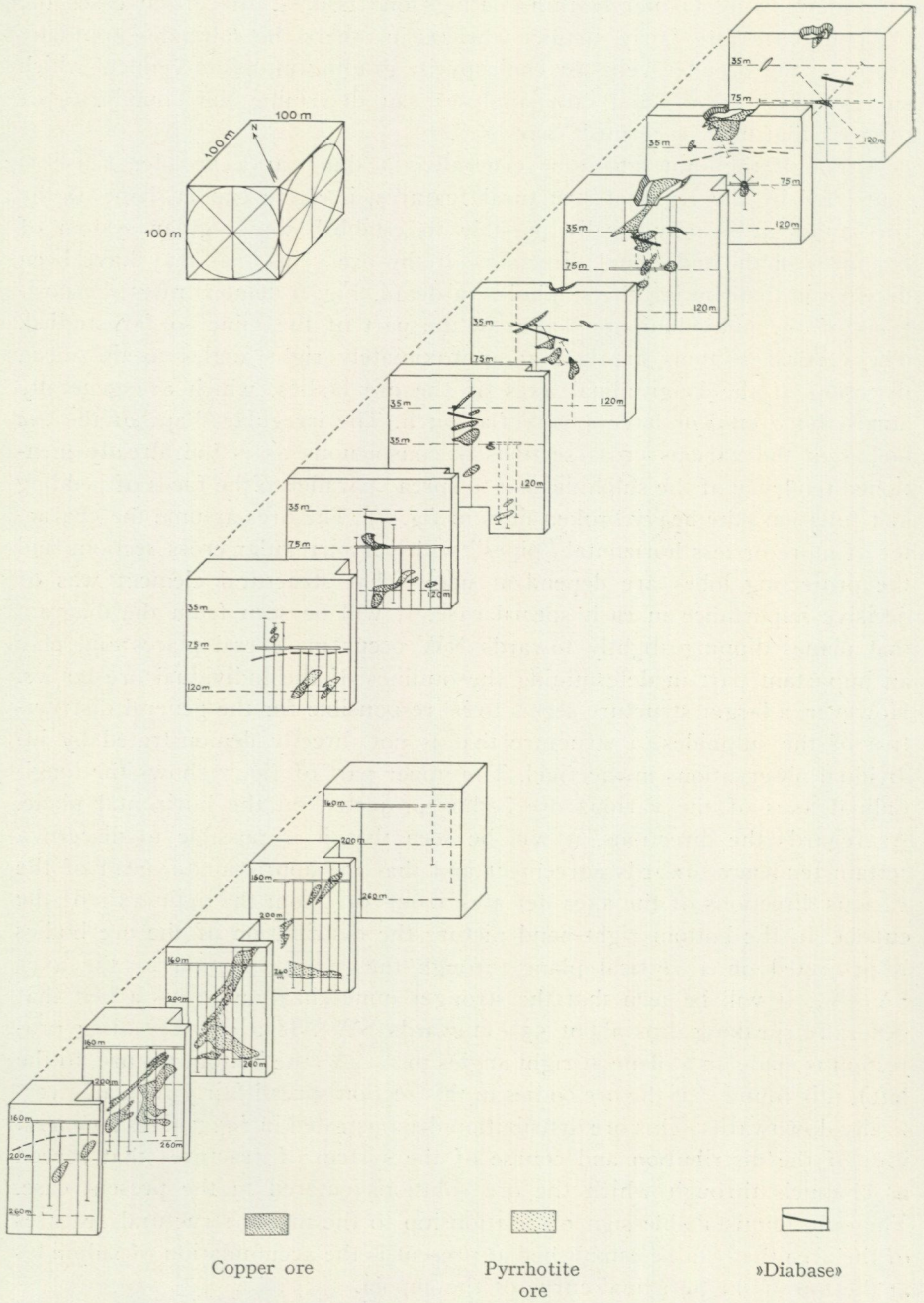


Fig. 6. Isometric block-diagram of the Adak ores. (The blocks moved apart). Drifts, shaft and drill-holes are plotted. The heavy broken lines denote the bedding in the rocks.

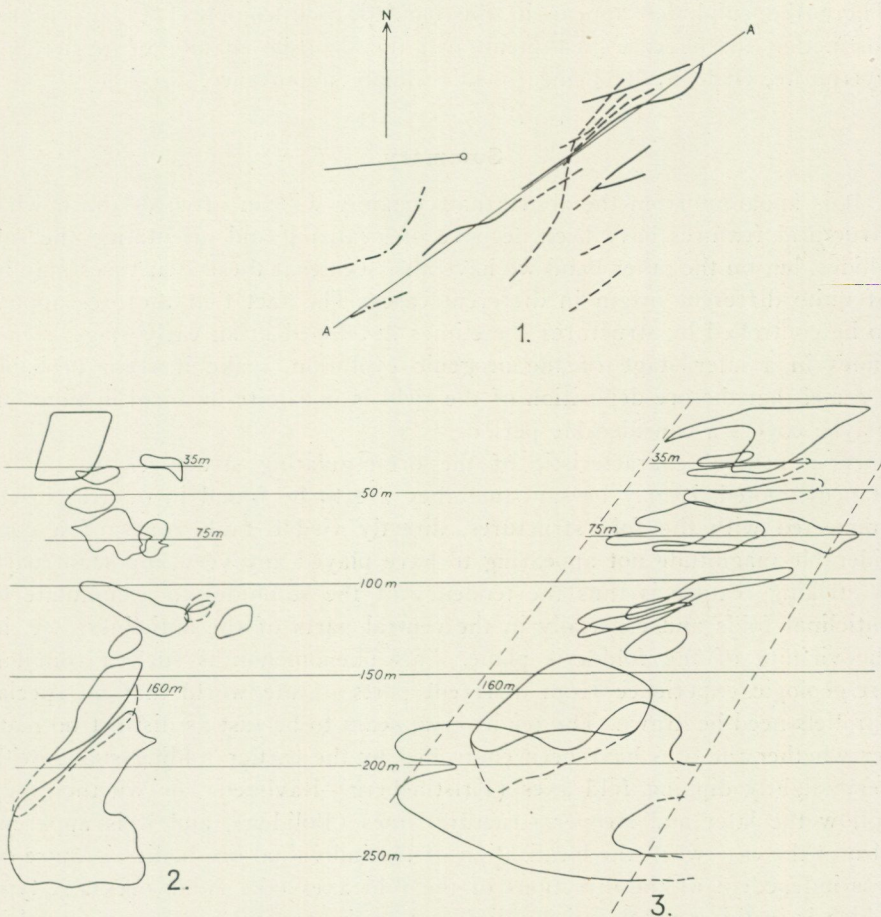


Fig. 7. 1. The main axes of the ore bodies in fig. 6 projected on the horizontal plane. Continuous lines = axes of ore bodies exposed in drifts. Broken lines = axes of ore bodies cut by drill holes. A—A = mean direction of the axes.

- 2. The ore bodies projected on a vertical plane perpendicular to A—A.
- 3. The ore bodies projected on a vertical plane through A—A.

an ore deposit occurs which in certain respects is of an entirely different character to those mentioned above, viz. the so-called "Lindsköld" ore. This ore is situated in the boundary zone between the banded tuffites and the massive acid volcanics. The very pronounced anisotropism of part of the mineralized material results in the sulphides now to a great extent following the bedding structure. The mineralized zone has the character of a slab dipping very slightly towards NW, in which chalcopyrite and pyrrhotite penetrate the bedrock as a fairly irregular network. Owing to the comparatively uneven distribution of the sulphides, the copper content in the ore zone is rather varying. A structurally similar occurrence of sulphide ore is also found on the north-eastern side of the cupola, at Rudtjebäcken.

There the sulphides appear in the banded rock complex but in contradistinction to the case just mentioned they consist mainly of pyrite and pyrrhotite, chalcopyrite being of subordinate importance.

Summary.

It is apparent from the above that certainly we can often establish what structural features have been decisive in localizing and orientating the sulphides, but on the other hand we have also seen that these structures may be of quite different origin in different cases. The fact that the ores appear to be controlled by structures sometimes developed in an early stage, sometimes in a later stage of the orogenic evolution, make it seem probable *a priori* that the ore deposition of the field is not quite uniform in time but maybe covers a considerable period.

As a general characteristic of the ore-regulating structures in the instances quoted, it may be said that they are to be found in or are closely connected with the fold structures, directly visible fault zones of a considerable magnitude not appearing to have played any very important part. A striking feature is thus the tendency of the sulphides to accumulate in anticlinal folds and especially in the central parts of the anticlines, i. e. in the vicinity of the fold-axis plane. This phenomenon is such a common ore-geologic experience from different parts of the world that no special parallels need be drawn. The tendency appears to be just as distinct no matter whether the ores have been controlled by the earlier folding stages with very slightly dipping fold axes (Kristineberg—Rävliden), or whether they follow the later and steeper structural lines (Boliden), and it is apparent also in the case when the localization of the individual ore bodies is more or less independent of the directions of the fold axes (the Adak ores). A type which is in this respect entirely different to the examples now mentioned is encountered, finally, in the ores of Ö. Högkulla—Skäggräskberget, which were shown to be controlled by tectonic lines quite independent of any kind of anticlinal structures.

A certain adaption of the shape of the individual ore bodies to the type of structure in which they are situated can also be traced in the instances quoted. The ore lenses found in areas characterized by pronounced folds of a regional character (Kristineberg—Rävliden) attain a more distinct elongate form than the ores controlled by the later stage of folding (e. g. Boliden). The least pronounced and least regular ore axes and those least uniform as regards direction, are encountered when the fold structure is least distinct and the folding has been comparatively gentle (e. g. the Adak ores).

As regards the stratigraphic positions of the ores, we find that in a number of cases they are situated in the uppermost parts of the volcanic formation, quite close below the boundary towards the phyllites, a phenomenon that has been emphasized by all mining-geologists working in the Skellefte

District. The explanation of this circumstance is probably to be found in the difference in competence between the rocks of the phyllite series and those of the volcanic series, which leads to irregular deformation, fracturing, etc., in the contact areas between these rock series, but also in a certain disinclination on the part of the pronouncedly banded rocks to let through ore solutions. This "damming" quality can sometimes be established in the Adak ores. There is certainly no great amount of phyllites, but from a dynamic point of view the banded and bedded tuffites may undoubtedly to a certain extent be juxtaposed to phyllites. The general distribution of the sulphides as well as direct observations disclose that the sulphides in general cannot to a very great extent permeate this series.

As regards the correspondence between the chemical and mineralogical characteristics of the ores and the predominant structures, finally, the instances discussed above display no traces of any kind of regular relationship. The differentiation that does occur in the field, viz. into purer pyrite or pyrrhotite ores, into ores especially rich in copper, lead-zinc, arsenic, or in silver and gold, seems to take place entirely independent of different structural types, and a similar differentiation can often be established or is at least indicated in all the structurally different ore types now discussed.

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