SVERIGES GEOLOGISKA UNDERSÖKNING

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# GEOLOGY AND ORES OF THE KRISTINEBERG DEPOSIT, VESTERBOTTEN, SWEDEN

BY

TORSTEN DU RIETZ

WITH 4 PLATES

*Pris 6.50 kr.*

STOCKHOLM 1953

KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER

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## Preface.

A description of the geology of the Kristineberg ore body was presented by the author as a company report in 1944. The geology of the region around Kristineberg was described in a separate report. It is now published with some additional facts ascertained while working the mine. In 1944 the 250 m level was the lowest one investigated (but not completed); at the present time a good part of the 490 m level is known.

The geologic reconnaissance during the first mining period from 1937 to 1940 was carried out by O. Ödman, assisted by G. Lindgren. The present author continued the investigation from 1940 to 1944 with the assistance of Helmer Andersson. Subsequent investigation has been carried out chiefly by E. Grip and Å. Wirstam with the assistance of H. Andersson.

For the co-operation rendered by my fellow-geologists, the assistants, and the mining engineers of the Boliden Mining Company I wish to express my sincere thanks.

Finally, it is a pleasure for me to express my gratitude to Mr. S. Schwartz, President of the Boliden Company, and to Mr. B. Norén, Managing Director at Boliden, for their kind permission to publish this report, as well as to Prof. N. H. Magnusson, Chief Director of the Geological Survey of Sweden, who allowed this paper to be published in the series of the Geological Survey.

Boliden in June 1949.

*Torsten Du Rietz*

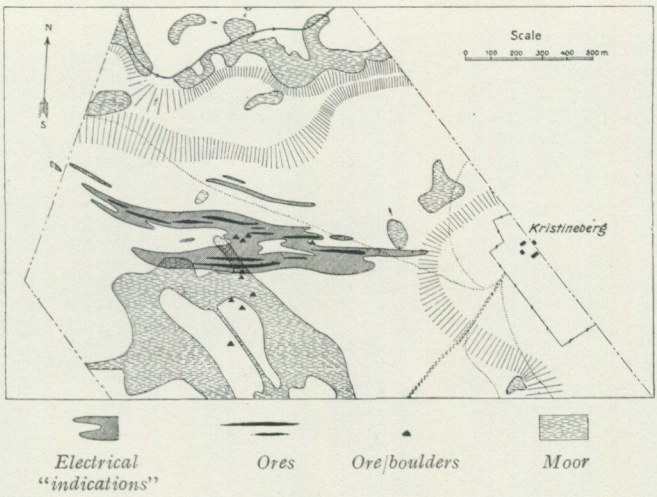



Fig. 1. Map of original electrical measurement by H. Lundberg in 1918—19.

## Introduction.

The Kristineberg region is situated on the boundary between the parishes of Lycksele and Malå at longitude 0,30° E Stockholm and latitude 65° 4', within the western part of the Skellefte formation of volcanic rocks and phyllites.

The Kristineberg ore body was discovered as early as 1918 during an electrical prospecting survey carried out by Hans Lundberg. (cf. Fig. 1). It was the first sulphide ore discovered in Sweden by this means. Some time afterwards the region was geologically investigated by the Geological Survey of Sweden, to a great part by J. Eklund.

After new electrical measurements, and diamond drillings prompted by the indications received, the Boliden Mining Company started an underground investigation of the ore bodies in 1934. The real mining of the ore started in 1941.[1]

The geological mapping of the region around the ore deposit was chiefly carried out by the present author in 1942 and 1943. A map of the rock outcrops was prepared in the scale 1: 20 000. Within the western part of the region the boundary between the more or less altered volcanic rocks and the overlying phyllitic slates was drawn according to the maps of the Geological Survey provided by S. Gavelin. For the drawing of the boundary lines between the Jörn granite and the altered porphyries, the contours of the vertical isodynamic lines of a magnetic survey carried out by J. Eklund have been quite useful.

[1] Fig. 2 shows a photo of the open pits of the ore bodies.



Fig. 2. Open pits of the Kristineberg ore body, seen from the shaft tower in the NW. 1947. The A ore in the foreground, the B ores in the background. The community in the upper right corner. — By the Swedish General's staff approved for publishing.

The fact is that the Jörn granite contains finely disseminated magnetite grains whereas the volcanic rocks do not.

The main levels investigated within the ore bodies are 90 m, 130 m, 170 m, and 250 m. As the author concluded his detailed investigation in 1944 and has since only made short visits to the mine, the surface of the ores as well as some parts of lower levels down to the 490 m level, which have been opened up by the mining operations but were not closely investigated by the author, will not be particularly described apart from some special features.

The author's geologic mapping within the ore deposit was carried out in the scale 1: 200, but it has later on been done in the scale 1: 400. The official maps are in the scale 1: 800.

Of the levels mentioned above, the 170 m level is the one most completely investigated. The central part of the mine area is also well known on the 90 and 250 m levels. The 90, 170, and 250 m levels are printed in the scale 1: 1 600.

The surface map of the region around Kristineberg (Plate 1) is given in the scale 1: 43 000.

## The Kristineberg Region.

The mapped area of outcrops extends from Hornberget in the N to Säter in the S, from the areas east of Kronås in the E to the cross road Kristineberg—Rävliden to Rävlidmyran in the W. In the middle and eastern part of the region the bed-rock outcrops quite frequently. The following areas are well exposed: the road from Rävliden beyond Kristineberg up to Viterliden (E of Kristineberg), a north-southerly area over the hills of Viterliden, the hills of Hornberget, the area N of Säter and further toward the NE, an area SE of Kronås, and another one on the south-eastern side of Hornträsket. Most of the exposed areas are marked out on the map, Pl. 1. The areas where outcrops are lacking are represented by depressions and swamps.

The central complex of probably predominantly volcanic rocks originally consisted of chiefly sodic quartz porphyry or albite porphyry[1] (sodic rhyolite with phenocrysts of albite). Most of this complex is now altered to quartzitic schists. As may be deduced from the map, the volcanic complex has been interfolded with the overlying slates (in the W) and the Jörn granite complex (in the E). Isoclinal folding with westerly pitching axes dominates. — In the S, these rock complexes are cut by (intruded by) the younger Archaean Revsund granite.

Remnants of the original porphyries occur within the northern part of the region, *e. g.* at the south-western side of Hornträsket, in the northern and eastern parts of Hornberget, and on the north-western side of the Kristineberg—Rävliden road. Generally, quartz-sericite schists predominate, and the porphyries are more or less sericitized or chloritized. The slightly altered rocks may contain some biotite, but in the strongly altered ones this mineral is quite chloritized. The strongly altered rocks have a higher percentage of pyrite than the weakly transformed ones.

The alteration of the volcanic complex in the southern part of the region is of a slightly different type. Besides sericite much biotite, cordierite, or andalusite appear, and chlorite diminishes or disappears. Sericite-biotite-cordierite-quartz schist predominates. Northwards, the cordierite disappears before the biotite, which occurs sporadically in the area around Kristineberg.

The neighbouring part of the Jörn granite has also been altered. The westerly protruding anticline at Kristineberg is thus chloritized and sericitized, and the larger anticline to the S, NE of Säter, contains much secondary biotite and cordierite.

There are a few small areas with dacitic and hornblende-bearing dacitic rocks in the northern part of the region. These rocks are generally chloritized, though less sericitized than the surrounding rocks, evidently due to their originally more basic composition.

[1] As the designation quartz-keratophyre originally signified an alkali-intermediate acid volcanic rock and as the name has been used for potassium-dominant as well as sodium-dominant rocks (cf. A. Johannsen, Petrography, Vol. II, p. 67, 1932) this name is avoided by the author.

The primary volcanics have comprised both lavas and tuffs. The least altered remnants of the volcanics are acid flows with well-developed albite phenocrysts.

The map, Pl. 1, shows that the Jörn granite occurring below the volcanic complex appears in the E, and that the roof of the complex (the slate) appears in the W. This indicates a westerly pitching fold axis. The observations in the field have given westerly or west-south-westerly axes dipping between 20° and 45° to the W. At Kristineberg the intermediate value is 38° and at Rävliden about 20°. The latter value is probably the most regular one for the volcanic complex as a whole, but in the vicinity of the Jörn granite it pitches more steeply. At a distance of 4 km between Kristineberg and Rävliden the maximal thickness of the volcanic complex should thus be less than 2 km, but is probably much less due to the folding of the complex.

The dip of the schistosity of the rocks at Hornberget is almost vertical to the N. At the Kristineberg mine it is about 60° S, while in the southern part of the region, the dip is often steep to the N.

The altered rocks are generally strongly schistose and to the north often wrinkled. Because of the uniform composition of the volcanics and the strong alteration of the complex, it is not possible to distinguish any stratigraphic subdivision of the original volcanics.

Within the Kristineberg area, several greenstone dikes have been observed cutting the volcanics and the Jörn granite. Both at Kristineberg and Viterliden quartz-tourmaline veins appear, which also cut the same rocks. The quartz-tourmaline veins are often divided into several seams which contain alternately quartz and masses of fine needles of tourmaline. Tourmaline may also appear in quartz segregations in the surrounding rocks and infrequently also in the altered rocks. Since the tourmaline is not hydrothermally altered as in the case of the surrounding rocks, it is probably later than the alteration of the volcanics and the Jörn granite and it may thus belong to the epoch of the Revsund granite intrusion just preceding the deposition of the sulphide ores.

The Kristineberg ore deposit is situated in the altered volcanics on the southern slope of a westerly wedge of an anticline of Jörn granite. This protruding wedge of granite was plastically folded into the volcanic complex and partly broken up. It was thus in a tectonically exposed position where the rocks have later been strained and made prone to fissuring.

To the W, the deposits of Rävlidmyran, Rävliden, and Mörkliden, which are at the roof of the volcanic complex, are in an analogous position (cf. S. Gavelin 1942, p. 4). The low position of the Kristineberg deposit in the volcanic complex is thus rather unusual in the Skellefte District. The Kristineberg ore body is a copper- and zinc-bearing pyritic ore, the Rävliden ore mainly a zinc-copper ore, and the Rävlidmyran a zinc-lead ore with a recently discovered copper-bearing ore, the Sture ore, close by.

Contrary to the Jörn granite, the Revsund granite in the S shows cutting contacts with the volcanic complex. Otherwise this granite seems to be of a migmatitic nature (cf. S. Gavelin 1947).

Excluding the phyllites, which do not occur in the Kristineberg region proper, the following sequence of the primary rocks is recognized:

Revsund granite (youngest),
Quartz-tourmaline veins,
Greenstone- or lamprophyric dikes,
Jörn granite (aplite, granite porphyry, and granites),
Volcanic rocks (porphyries).

## Porphyries.

The least altered volcanic rocks consist mostly of soda-dominant, acid porphyries with albite phenocrysts. Porphyries with phenocrysts of quartz have been observed, but they are very subordinate.

Well-developed albite porphyries occur within the southern part of the outcrops at the south-eastern side of Lake Hornträsket. The lamellate albite phenocrysts are about 1 cm in length.[1] The groundmass is somewhat sericitic and chloritic. An analysis of a rock sample from this locality is given in Table 1.

**Table 1. Sodic quartz porphyry. South-east of Hornträsket.**

Analysis by N. Sahlbom.

| | | Mol. prop. | Norm. | | Mineral composition | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 70.20 | 11 688 | Q | 36.7 | Quartz | 38 |
| $TiO_2$ | 0.70 | 88 | Or | 5.5 | Albite ($An_5$) | 40 |
| $Al_2O_3$ | 13.52 | 1 326 | Ab | 34.2 | Biotite | 2 |
| $Cr_2O_3$ | tr. | | An | 1.9 | Chlorite (Ripidolite) | 13 |
| $Fe_2O_3$ | 1.95 | 122 | C | 5.2 | Sericite-muscovite | 5 |
| | | | Sal | 83.5 % | | |
| FeO | 3.79 | 528 | | | Titanomagnetite | 1 |
| MnO | 0.10 | 14 | | | Apatite | 0.6 |
| MgO | 2.44 | 605 | Hy | 10.5 | Rutile | 0.4 |
| CaO | 0.78 | 139 | Mt | 2.8 | Titanite | tr. |
| $Na_2O$ | 4.04[2] | 652 | Il | 1.3 | Epidote | tr. |
| $K_2O$ | 0.92[2] | 98 | Ap | 0.7 | Pyrite | tr. |
| $P_2O_5$ | 0.30 | 21 | | | Chalcopyrite | tr. |
| F | tr. | | Fem | 15.3 | | |
| Cl | tr. | | | | Tourmaline | tr. |
| $B_2O_3$ | tr. | | | | | 100.0 |
| S | tr. | | $H_2O$ | 1.5 | | |
| Cu | tr. | | | 100 % | | |
| $H_2O+$ | 1.52 | 844 | | | | |
| $H_2O-$ | 0.10 | | II, 3, 1, 4 | | | |
| | 100.36 | | Varingase | | | |
| Sp. gr. | 2.65[3] | | | | | |

The high content of biotite, sericite, and chlorite in the albite porphyry (Table 1) is due to metasomatic alteration with an addition chiefly of magnesium with some iron and potassium. Excluding the alteration products the probable

[1] The trachytoidal texture of the rock points to an extrusive origin.
[2] S. Henriksson
[3] O. Alvfeldt

original composition of the rock was that of an extreme soda porphyry. The alteration of the original rock began with biotitization. The sericitization started a little later, somewhat before and also contemporaneously with the chloritization. A much altered porphyry has a stronger sericitization, with sericite and chlorite generally intergrown. Rutile, often blackened by iron oxides, is a typical product of the hydrothermal alteration. Solitary grains of tourmaline may also occur and sometimes calcite, too. Sulphides are common in the strongly altered rocks. The albite phenocrysts suffer less from the alteration process than the groundmass, but they may be corroded and may even disappear.

In order to display the variable mineralogical composition of the porphyries Table 2 has been compiled from volumetric analyses of rock specimens:

**Table 2. Quartz porphyries. Mineral composition per cent of volume.**

| Locality | Road to Säter | Road to Rävliden | Hornberget to the W. | SE of Hornträsket | | | Kristineberg mine 170 m level | | | SE of Hornträsket | Hornberget to the NE | N of Viterliden | Hornberget to the NE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Albite | 35 | 38 | 39 | 47 | 33 | 29 | 34.5 | 23 | 26 | 23 | 11.5 | 4 | 3 |
| Microcline | 8 | | | | | | | | | | | | |
| Quartz | 20 | 37 | 34 | 28 | 41 | 35 | 36 | 39 | 33 | 34 | 41.5 | 52 | 46 |
| Biotite | 23 | 12 | 8 | 1.1 | 5 | 1.7 | 18.5 | 7.2 | 2 | 1.0 | 0.2 | 5 | 3.5 |
| Chlorite | | 0.1 | 5 | 16 | 10 | 14 | 0.3 | 3.2 | 8.5 | 26.3 | 17.8 | 6.5 | 23 |
| Sericite | 12 | 10.8 | 13.5 | 7 | 9 | 19.7 | 10.5 | 27 | 30 | 15 | 28.5 | 32 | 24 |
| Apatite | | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | tr. | 0.2 | | 0.1 | 0.1 | 0.1 | 0.2 |
| Rutile | 0.4 | 0.1 | 0.3 | 0.2 | tr. | 0.2 | | 0.4 | 0.3 | 0.6 | 0.4 | 0.2 | 0.2 |
| Titanite | | | | tr. | tr. | | | | | | | 0.1 | |
| Epidote | 1.6 | tr. | tr. | 0.1 | 0.2 | | tr. | | | | tr. | | |
| Tourmaline | | | | | tr. | | | | | | tr. | 0.1 | 0.1 |
| Ore grains | | 1.9 | | 0.4 | 1.5 | 0.3 | 0.2 | | tr. | | | | |
| Prehnite | | | | | | | | | | | | tr. | |
| Sillimanite | | | | | | | | | 0.2 | | | | |
| Zircon | | | tr. | | | | | | | | tr. | tr. | |
| Calcite | | | | | 0.1 | | | | | | | | |

The phenocrysts are generally about 1 mm in size, and the grain size of the groundmass averages 0.05 mm, when the groundmass is well preserved, but about 0.1 mm when it has been subjected to metasomatism. Phenocrysts of quartz of about the same size as the albite and generally more or less fractured are seen now and then. The biotite is commonly a turbid brown variety. It is often altered into a strongly greenish pleochroitic, ripidolitic to prochloritic, chlorite. The biotite may also be replaced by an intergrowth of sericite and chlorite.

The strongly altered rocks are schistose and generally have sericite and chlorite congregated in *schlieren*.

A biotitized porphyry to the W of Kristineberg has also been analyzed, Table 3.

Much secondary biotite and sericite have been formed in this rock by metasomatic alteration on addition of chiefly magnesium and potassium. The rock probably primarily had some potassic feldspar.

**Table 3. Fine-grained quartz porphyry rich in biotite. W of Kristineberg.**
Chemical analysis by the Boliden Laboratory, Boliden.

| | | Mol. prop. | Norm | | Mineral composition | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 74.3 | 12 371 | Q | 39.3 | Quartz | 41 |
| $TiO_2$ | 0.34 | 43 | Or | 9.5 | Acid oligoclase | 42 |
| $Al_2O_3$ | 12.9 | 1 266 | Ab | 31.3 | Biotite | 11 |
| $Fe_2O_3$ | 0.39 | 24 | An | 7.9 | Chlorite | 0.4 |
| FeO | 2.42 | 337 | C | 2.2 | Sericite | 4 |
| MnO | 0.09 | 13 | Sal | 90.2 % | Pyrite | 0.7 |
| MgO | 1.74 | 432 | | | Titanite | 0.4 |
| CaO | 1.70 | 303 | Hy | 7.3 | Rutile | 0.1 |
| $Na_2O$ | 3.7 | 597 | Mt | 0.6 | | |
| $K_2O$ | 1.6 | 170 | Il | 0.7 | Epidote + orthite | 0.2 |
| $H_2O+$ | 0.57 | 316 | Ap | 0.1 | | |
| $H_2O-$ | 0.10 | | Py | 0.7 | Apatite | 0.2 |
| S | 0.37 | 115 | Fem | 9.4 % | | 100.0 % |
| $P_2O_5$ | 0.06 | 4 | | | | |
| | 100.28 | | $H_2O$ | 0.6 | | |
| — O | 0.18 | | | 100.2 % | | |
| | 100.10 | | I, 3, 2, 4 | | | |
| | | | Alsbachose | | | |

## Dacitic rocks.

On the south-western slope of Hornberget quartz-sericite schists predominate but there are some small areas with dark, grayish green rocks which are much chloritized and are generally surrounded by quartz-chlorite schist aureoles. These rocks are hornblende-, hornblende-biotite-, and biotite-bearing dacites.

The biotite-bearing dacites show transitions to albite porphyries. Some of them have contained andesine feldspar and some have been oligoclase-bearing. They are generally more or less altered to chlorite quartzites.

One slightly altered hornblende-bearing dacite has been analyzed.

The hornblende is strongly pleochroic: $\gamma$ bluish green, $\beta$ grass-green, $\alpha$ yellowish green. The axial angle $2V\alpha$ is 68°, and the indices $N\alpha$ 1.659, $N\beta$ 1.674. This hornblende is rich in alumina. The present composition of the plagioclase is about $An_{28}$. It is saussuritic and was originally an andesine or a labradorite.

## Jörn granite.

The volcanics of the Kristineberg region are bounded by the Jörn granite toward the E. This rock either took part in the folding of the volcanics or was intruded during the folding. The contact line with the porphyry thus shows an angular boundary line which almost corresponds to the curving against the phyllite complex to the W of the volcanic complex. The schistosity of the granite is also conformable with that of the extrusive rocks.[1] The Jörn granite complex

[1] Probably developed during the Revsund granite epoch.

**Table 4. Hornblende dacite. Hornberget.**
Analysis by the Boliden Laboratory, Boliden.

| | | Mol. prop. | Norm. | | Mineral composition | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 52.50 | 8 741 | Q | 5.2 | Quartz | 12 |
| $TiO_2$ | 0.66 | 83 | Or | 2.6 | Oligoclase-andesine | 31 |
| $Al_2O_3$ | 16.40 | 1 609 | Ab | 25.4 | Greenish hornblende | 43 |
| $Fe_2O_3$ | 3.00 | 125 | An | 30.0 | Epidote | 8 |
| FeO | 7.38 | 1 027 | Sal | 63.2 % | Apatite | 0.4 |
| MnO | 0.10 | 14 | | | Titanite | 0.5 |
| MgO | 5.33 | 1 322 | Di | 11.0 | Sericite | 0.5 |
| CaO | 8.95 | 1 596 | Hy | 17.6 | Chlorite | 0.7 |
| $Na_2O$ | 3.00 | 484 | Mt | 2.9 | Calcite | 0.3 |
| $K_2O$ | 0.44 | 47 | Il | 1.3 | Ilmenite + magnetite | 0.5 |
| $P_2O_5$ | 0.15 | 11 | Ap | 0.4 | Pyrite + pyrrhotite | 1.2 |
| $H_2O+$ | 1.34 | 744 | Py | 1.2 | Sphalerite | 0.9 |
| $H_2O-$ | 0.10 | | ZnS | 0.9 | Chalcopyrite | tr. |
| ZnO | 0.71 | 87 | Fem | 35.2 % | | 100.0 % |
| Cu | 0.01 | 2 | $H_2O$ | 1.3 | | |
| S | 0.94 | 293 | | 99.7 % | | |
| $CO_2$ | 0.14 | 32 | | | | |
| F | 0.11 | 58 | II, 5, 4, 5, Hessose | | | |
| BaO | tr. | | | | | |
| | 100.27 | | | | | |
| -O (F, S) | 0.52 | | | | | |
| | 99.75 | | | | | |
| Sp. gr. | 2.95 | | | | | |

has two protruding anticlines toward the W, the one at Kristineberg, and the other $1^1/_2$ km N of Säter.

The Jörn granite is generally developed as a granite porphyry towards the contact, but may be aplitic. The rock in the neighbourhood of Kristineberg is often a granite porphyry with well-developed granophyric texture. The interior of the granite is generally darker in colour and often has a composition corresponding to a tonalite.

The two westerly projecting portions of the granite have been partly altered similarly to the neighbouring volcanic rocks. The granite porphyry at Kristineberg has thus been greatly chloritized as well as partly sericitized and the composition of the rock at the contact with the original albite porphyry corresponds to a sericite-bearing quartz-chlorite schist. The alteration product of the granite is always richer in chlorite than that of the volcanics which is due to a difference in primary composition. The granite was thus originally biotite-bearing, the biotite always altering to chlorite. The more basic composition of the rock also favours the development of secondary chlorite. The granite to the N of Säter contains much secondary biotite and cordierite, and it is richer in these minerals than the alteration product of the volcanics close by, which contains more sericite instead. The more basic rock generally shows a greater affinity for magnesium.

Table 5 gives a statistical analysis of ordinary rock specimens. The number of porphyries and aplites are in excess of their areal extension owing to their

**Table 5. Jörn granites. Mineral composition per cent of volume.**

| | Granite porphyries | | | | | | Aplites | | | | | Granites | | | Tonalites | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| Quartz | 42.7 | 40 | 39 | 34 | 31 | 28.2 | 40 | 38 | 36 | 30 | 30 | 41 | 39 | 27 | 36 | 25 | 30 | 30 |
| Andesine | | | | | | | | | | | | | | | 38 | 32 | | 40 |
| Oligoclase | 44 | 52 | 48 | 56 | 61 | 58 | | | 55 | | | | 49.5 | 63 | | | 38 | |
| Albite-oligoclase | | | | | | | 53 | 59 | | 59 | 64 | 54 | | | | | | |
| Potassic feldspar | | | | | | | | 0.8 | | | | | | | | | | |
| Hornblende | | | | | | | | | | | | | | | 16 | 30 | 17 | 11 |
| Biotite | 5.4 | 2.3 | 1.3 | 8 | 2.9 | 11 | 5.3 | 1.4 | 6.6 | 9 | 1.9 | 0.3 | 4.5 | 6 | 1.3 | 11.5 | 12 | 14 |
| Chlorite | 1 | 2.3 | 2.4 | 1.5 | 1 | 2 | 0.8 | 0.8 | 1 | 1 | 2 | 3.7 | 4 | 1 | 5.7 | | 0.4 | tr. |
| Muscovite-sericite | 0.6 | 0.3 | 8 | 0.1 | tr. | 0.1 | | | tr. | 0.5 | 1.9 | | 1.7 | 1.4 | | | | |
| Epidote + orthite | 3 | 0.1 | 0.2 | tr. | 0.2 | 0.1 | tr. | 0.2 | 0.1 | 0.1 | | 0.1 | tr. | 0.3 | 1.6 | 0.2 | 1.8 | 3.1 |
| Titanite | | 0.3 | tr. | tr. | 0.1 | 0.2 | 0.1 | 0.2 | 0.5 | tr. | tr. | | tr. | 0.3 | tr. | 0.2 | 0.2 | 0.5 |
| Apatite | 0.6 | 0.4 | 0.1 | 0.1 | 0.2 | 0.4 | 0.1 | 0.1 | 0.2 | 0.2 | tr. | 0.1 | 0.2 | 0.2 | 0.2 | 0.4 | 0.2 | 0.1 |
| Magnetite + ilmenite | 0.7 | 2.0 | tr. | 0.2 | | | | tr. | 0.5 | tr. | | 0.7 | 0.8 | 0.7 | 0.2 | 0.7 | 0.4 | 1 |
| Pyrite | 0.2 | | 0.8 | | 3.3 | | 0.5 | tr. | 0.1 | | | | | | 1 | | tr. | 0.3 |
| Rutile | 0.1 | 0.1 | 0.2 | 0.1 | 0.3 | | tr. | tr. | tr. | 0.2 | 0.2 | 0.1 | 0.3 | 0.1 | | | | |
| Tourmaline | 1.5 | tr. | tr. | | | | | | | | tr. | | | tr. | | tr. | | |
| Prehnite | | 0.2 | | | tr. | | 0.2 | | | | | | | | | | | |
| Calcite | 0.2 | | | | | tr. | | | | | | | | | | | | |
| Zircon | | | | | tr. | tr. | | | | tr. | tr. | | | tr. | | | | |

relative frequency in the Kristineberg area. The table shows that the sodic feldspar (molecule) of the intrusive rocks predominates over the potassic, as in the case of the volcanics. The composition of the intrusive rocks which are always biotite granites, is, however, more basic. The biotite is less chloritized than in the extrusive rocks. The basic granites, the tonalites, are hornblende-bearing. The fact that the acid granites contain some sericite, rutile, tourmaline, prehnite, calcite, and sulphides is due to their relative vicinity to the alteration zone. Oligoclase or basic oligoclase is the predominant feldspar of the ordinary Jörn granite, while the tonalitic varieties generally contain andesine and some acid porphyries, especially the aplites contain albite-oligoclase or acid oligoclase.

An ordinary, small-grained granite, and a basic granite have been chemically analyzed, Tables 6 and 7. An analysis of a granite porphyry from the Kristeneberg mine will be described later on.

**Table 6. Jörn granite. The road at Viterliden. Kristineberg.**

Analyst Th. Berggren.

| | | Mol. prop. | Norm. | | Mineral composition | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 73.08 | 12 168 | Q | 35.1 | Oligoclase | 56 % |
| $TiO_2$ | 0.74 | 93 | Or | 4.0 | Quartz | 35.6 |
| $ZrO_2$ | tr. | | Ab | 40.8 | Biotite | 3.5 |
| $Al_2O_3$ | 13.96 | 1 369 | An | 13.4 | Chlorite (ripidolite) | 1.3 |
| $Fe_2O_3$ | 1.27 | 80 | C | 0.4 | Sericite | 0.7 |
| FeO | 1.67 | 233 | Sal | 93.7 | Titanomagnetite | 2 |
| MnO | 0.03 | 4 | | | Titanite | 0.5 |
| MgO | 0.83 | 206 | Hy | 2.9 | Rutile | 0.1 |
| CaO | 2.76 | 492 | Mt | 1.9 | Epidote (+ orthite) | 0.3 |
| BaO | 0.01 | 1 | Il | 1.4 | Apatite | tr. |
| SrO | 0.04[1] | 4 | Py | 0.1 | Pyrite | tr. |
| $Na_2O$ | 4.82 | 778 | Fl | 0.1 | Tourmaline | tr. |
| $K_2O$ | 0.67 | 71 | | | Zircon | tr. |
| $H_2O+$ | 0.37 | 205 | Fem | 6.4 | | 100.0 % |
| $H_2O-$ | 0.04 | | $H_2O$ | 0.4 | | |
| F | 0.03 | 16 | | 100.5 % | Sp. gr. 2.63 | |
| S | 0.02 | 6 | | | | |
| $P_2O_5$ | 0.01 | 1 | I, 3, 2, 5 | | | |
| Co | 0.001 | | Yukanose | | | |
| | 100.38 | | | | | |

[1] S. Henriksson.

The texture of the rock is granitic with somewhat porphyritic oligoclase ($An_{23}$), grain-size about 3 mm. The biotite is greenish brown and pleochroic: $\gamma$ brownish green, $\beta$ grass green, $\alpha$ pale greenish yellow. A partial analysis of a light-coloured granite porphyry shows: $Na_2O$ 5.5 % and $K_2O$ 0.44. This rock is more soda-dominant and contains an oligoclase-albite, with only traces of potash feldspar and $1^1/_2$ % biotite.

The plagioclase in the tonalitic granite (Table 7) is a sodic andesine. The hornblende exhibits strong absorption pleochroism: $\gamma$ greenish blue, $\beta$ (1.676)

**Table 7. Dark, schistose, hornblende-biotite granite (tonalite).**
Viterliden. Analyst Th. Berggren.

| | | Mol. prop. | Norm. | | Mineral composition | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 63.14 | 10 516 | Q | 17.7 | Andesine | 41 % |
| $TiO_2$ | 1.01 | 126 | Or | 8.8 | Quartz | 28 |
| $ZrO_2$ | tr. | | Ab | 29.2 | Greenish hornblende | 12 |
| $Al_2O_3$ | 13.91 | 1 365 | An | 18.0 | Biotite | 15 |
| $Fe_2O_3$ | 0.42 | 26 | Sal | 73.7 | Epidote | 2 |
| FeO | 7.30 | 1 016 | | | Ilmenite | 1.2 |
| MnO | 0.12 | 17 | Di | 5.6 | Titanite | 0.6 |
| MgO | 3.50 | 868 | Hy | 17.3 | Pyrite | 0.1 |
| CaO | 5.05 | 901 | Mt | 0.6 | Apatite | 0.1 |
| BaO | 0.01 | 1 | Il | 1.9 | Chlorite | tr. |
| SrO | 0.04[1] | 4 | Cr | 0.1 | Zircon | tr. |
| $Na_2O$ | 3.45 | 557 | Ap | 0.1 | | 100.0 % |
| $K_2O$ | 1.50 | 159 | Fl | 0.2 | | |
| $H_2O+$ | 0.49 | 272 | Py | 0.1 | Sp. gr. 2.68 | |
| $H_2O-$ | 0.01 | | Fem | 25.9 | | |
| F | 0.04 | 21 | | | | |
| Cl | 0.01 | 3 | $H_2O$ | 0.5 | | |
| S | 0.04 | 13 | | 100.1 % | | |
| $P_2O_5$ | 0.04 | 3 | | | | |
| Cr | 0.03 | 6 | II, 4, 3, 4 | | | |
| Co | 0.001 | | Tonalose | | | |
| | 100.14 | | | | | |

[1] S. Henriksson.

grass-green, $a$ greenish yellow. Axial angle $2V_a$ is 63°. The biotite is turbid brown.

There are also other tonalitic granites which are somewhat more basic with a higher content of hornblende and labradoritic feldspar. They are all quartz-bearing.

## Revsund granite.

Revsund granite appears within the southernmost part of the region, around Säter and toward the south. The northernmost outcrops run in a WNW—ESE direction just north of Säter.

The Revsund granite is a light gray to reddish, coarsely porphyritic biotite granite with large, rectangular or somewhat rounded microcline eyes which may amount to $6 \times 3$ cm. The porphyritic plagioclase is not quite so large. It is an oligoclase or albite-oligoclase. The chief components of the groundmass are quartz, biotite and feldspars. The assortment of the minerals is often uneven and the rock may consequently appear schistose because of a certain orientation of the minerals. The northernmost outcrop was also a porphyritic granite but it was not so coarse-grained.

Table 8 shows the composition of a coarse-grained granite according to a chemical analysis of a very large sample.

Both feldspars are somewhat perthitic. The high content of potash is due to the very large microcline eyes. Fluorite has also been seen in other outcrops of the granite.

**Table 8. Revsund granite, Säter 4 1/2 km SW of Kristineberg.**

Analyst Th. Berggren.

| | | Mol. prop. | Norm. % | | Mineral composition | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 72.91 | 12 140 | Q | 30.9 | Microcline | 40 % |
| $TiO_2$ | 0.86 | 108 | Or | 36.0 | Oligoclase-albite | 14 |
| $ZrO_2$ | tr. | | Ab | 20.7 | Quartz | 35.5 |
| $Al_2O_3$ | 11.98 | 1 175 | An | 3.7 | Biotite, dark greenish brown | 7 |
| $Fe_2O_3$ | 0.10 | 6 | Sal | 91.3 | | |
| FeO | 3.97 | 553 | | | Hornblende, greenish | 0.2 |
| MnO | 0.05 | 7 | Di | 0.3 | Apatite | 0.3 |
| MgO | 0.04 | 10 | Hy | 5.7 | | |
| CaO | 1.17 | 209 | | | Fluorite | 0.3 |
| BaO | 0.01 | 1 | Mt | 0.1 | Ilmenite | 0.6 |
| SrO | 0.01 | 1 | Il | 1.7 | | |
| $Na_2O$ | 2.45 | 395 | | | Orthite | 0.2 |
| $K_2O$ | 6.09 | 647 | Ap | 0.3 | Epidote | 0.2 |
| $P_2O_5$ | 0.13 | 9 | Fl | 0.3 | | |
| Cl | 0.01 | 3 | | | Zoisite (pigment) | 0.3 |
| F | 0.12 | 63 | Fem | 8.4 | Sericite | 0.4 |
| $CO_2$ | tr. | | | | | |
| S | tr. | | $H_2O$ | 0.4 | Chlorite (delessite) | 0.2 |
| $H_2O+$ | 0.38 | 211 | | 100.1 | Prehnite | 0.1 |
| $H_2O-$ | 0.10 | | | | | |
| | 100.27 | | I, 4, 2, 2 | | Zircon | tr. |
| -O (F) | 0.05 | | | | | 100.0 % |
| | 100.22 | | Dellenose | | | |
| Sp. gr. | 2.60 | | | | | |

According to several thin sections of the granite, rocks with large porphyritic grains are richer in potash than less coarse-grained varieties. By segregation of the large crystals of microcline this part of the rock has been relatively enriched in potash.

The area north of the northernmost granite outcrops is devoid of outcrops. The contact with the volcanics cannot thus be studied here.

To the E of this region the Revsund granite turns northward. According to S. Gavelin[1] the Revsund granite in this section strongly migmatitizes the older rock complexes.

## Altered rocks.

The rock complexes north of the Revsund granite in this region have been strongly metamorphosed so that only a few remnants of the primary rocks remain. A metamorphic zoning has been developed with the high-temperature facies nearest the Revsund granite and more low-temperature ones toward the north. At the same time a certain zoning in the exchange of material has taken place. North of this region the metamorphism successively diminishes.

The alteration is greatest along the border on the Jörn granite.

[1] Personal communication

From the S towards the N the following metamorphic zones are distinguished:

1. Quartz-sericite schists with andalusite.
2. Cordierite-biotite-sericite-quartz schists.
3. A transitional zone with biotite-sericite-quartz schist.
4. Chlorite-sericite-quartz schists.

The chief variations in the mineral composition of the different zones are seen in the compilation in Table 9. The quartz-sericite schists, which have the largest areal distribution, are not proportionally represented in the table since they are closely described in the description of the mine.

### Andalusite-sericite-quartz schists.

These rocks occur in a narrow and irregular zone in the exposures nearest the granite. They are white or pinkish white in colour due to the content of andalusite and some acid plagioclase and to the lack of chlorite and biotite. The mineral composition in this zone is rather variable. Sometimes the rock is a quartz-sericite schist with chiefly quartz and sericite, and sometimes the andalusite dominates. White feldspar, a sodic plagioclase or albite, occurs here and there as remnants, but it is sometimes porphyroblastically recrystallized.

Compared with the original albite-porphyries the andalusite-sericite-quartz schist is an alteration product in which some aluminium and potassium have been added, while sodium more or less has been carried away. The lack of biotite and cordierite in this zone shows that no Mg has been added. The rocks may have solitary pyrite crystals but no distinct addition of sulphur has occurred.

In one outcrop a microcline-bearing andalusite-quartz schist occurs. It is possible that the original porphyry in this locality was somewhat potassic.

### Cordierite-quartz schists.

Cordierite-biotite-sericite-quartz schists constitute a much broader zone north of the andalusite-sericite-quartz schists. The metamorphic grade is almost the same, but now magnesium metasomatism appears as shown by the presence of cordierite and biotite. Rather similarly altered rocks, such as those at Kristineberg, have earlier been described by S. Gavelin (1939) from the Malånäs region.

In the northern part of this zone, around the rivulet Kronåsbäcken, south of Kristineberg, the cordierite seems to be unstable. A dense, grayish cordierite-quartz schist here appears as ball-like remnants in sericite-biotite-quartz schist. A photo of a typical specimen of this rock is reproduced in Fig. 3.

The cordierite-quartz schists are light-coloured to dark-gray rocks. In rock samples the cordierite has a brownish gray, glossy colour, so that rocks rich in cordierite are rather dark. In thin sections, the cordierite has a faintly yellowish pleochroism. The cordierite is porphyroblastic and poikiloblastic and generally occurs in streaks conformable with the schistosity of the rock. It is sometimes pseudomorphic after albite.

**Table 9. Altered volcanic rocks. Mineral composition in per cent of volume.**

| | Andalusite-sericite-quartz schist | | | | | Cordierite-biotite-sericite-quartz schist | | | | | | | | | Chlorite-sericite-quartz schist | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Quartz | 35 | 17 | 28 | 48 | 45.5 | 41 | 42 | 44 | 47 | 67 | 57 | 22 | 53 | 55 | 31 | 47 | 48 | 53 | 69 | 61 |
| Sericite | 32 | 63 | 51 | 34 | 51 | 16 | 8 | 10 | 32 | 25 | 25 | 28 | 36 | 17 | 22 | 14 | 22 | 22.5 | 13 | 19 |
| Biotite | | | | tr. | | 15 | 2 | 11 | 6 | 1 | 4 | 9 | 4 | 20 | | | | | | 2 |
| Chlorite | | | | | | | 0.3 | 2 | | | 6 | | | 0.3 | 41 | 36 | 30 | 23 | 16.4 | 6 |
| Cordierite | | | | | | 25.4 | 22.6 | 15 | 11 | 5.5 | 5 | 4.4 | 4 | 1.5 | | 0.5 | | | | |
| Andalusite | 26 | 19 | 14 | 11.4 | 2 | 0.1 | | 0.1 | tr. | | 0.2 | | | | | | | | | |
| Sodic plagioclase | 5 | 0.5 | 5.5 | 6 | 1.2 | | 24 | 16 | | | 1 | 35 | | | 2.4 | | | tr. | | 11 |
| Pyrite | | | | | | 2.4 | 0.8 | 1 | 3.2 | 1 | 1 | 1 | 0.6 | 0.8 | 0.2 | 0.7 | | 0.5 | 1 | 0.3 |
| Pyrrhotite | | | | | | | | | | | | | | | | 1 | | | | |
| Ilmenite-magnetite | | | | | | | | 0.4 | 0.3 | 0.1 | 0.3 | | 0.1 | 0.7 | | 0.2 | | | | |
| Oxidized sulphide | | | | | | | | | | | | | | | | | | | | |
| Rutile | 2 | 0.5 | 1.5 | 0.6 | 0.3 | 0.1 | 0.2 | 0.2 | 0.3 | 0.4 | 0.5 | 0.5 | 0.2 | 0.4 | 1.7 | tr. | tr. | 0.8 | 0.1 | 0.7 |
| Titanite | | | | | | | tr. | | | | | | | 0.1 | | | | | | |
| Apatite | | | tr. | | tr. | tr. | 0.1 | 0.1 | 0.2 | tr. | tr. | tr. | 0.3 | 0.1 | 1.7 | 0.4 | tr. | 0.2 | | tr. |
| Tourmaline | | | | | | | tr. | tr. | | | | | 0.3 | | | | | | | |
| Zircon | tr. | tr. | tr. | tr. | tr. | | tr. | tr. | | | tr. | | | tr. | | | tr. | | tr. | tr. |
| Epidote-orthite | | | | | | | | | | | | 0.1 | | 0.1 | | | | tr. | | |
| Garnet | | | | | | | | | | | | | | | | 0.2 | | | | |
| Cordierite altered to pinite | | | | | | | | 0.2 | | | | | | 4 | | | | | | |
| Serpetine-like alteration | | | | | | | | 0.1 | | | | | 1.5 | | | | | | | |

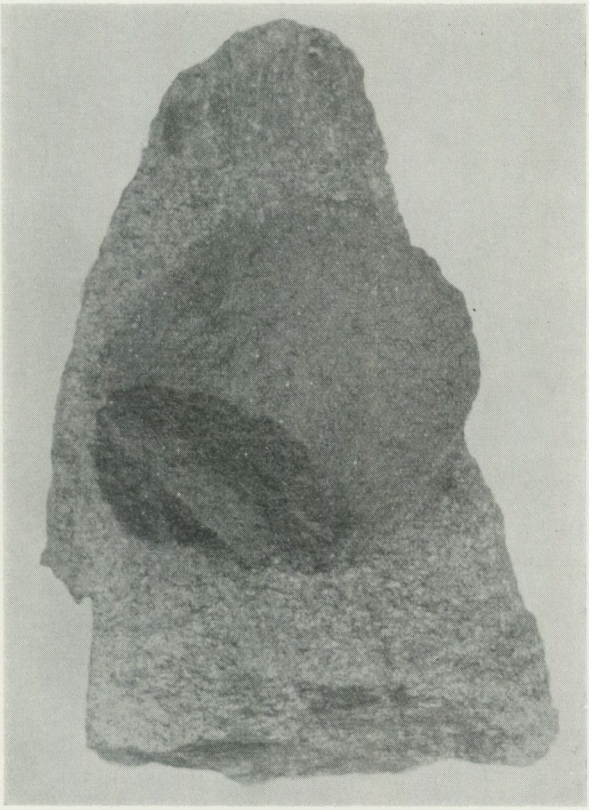


Fig. 3. Nodule of dense, grayish cordierite-quartz schist in sericite-biotite-quartz schist. S of Kronåsbäcken. × $^3/_4$.

Pyrite grains, generally less than 1 mm in size, are disseminated throughout the rocks. The sulphide grains often have a coating of alteration products of iron oxides, hydroxide, or iron sulphate. The cordierite is often also surrounded by an iron hydroxide precipitation. Some cordierite is altered to so-called pinite which consists of quartz grains strongly intergrown with a powder of biotite, sericite, and probably also sillimanite. This is the first alteration phase of the substitution of cordierite by biotite and sericite. Locally another more amorph-like alteration of cordierite occurs, in which the alteration product corresponds to serpentine, which, since it is unstable, is prone to alter.

The biotite of the rocks is a light-coloured, yellowish brown (under the microscope) variety, evidently low in iron. Locally it may be much darker, brownish green to reddish green. The biotite alters into a chlorite, variety between chlinochlore and prochlorite.

A cordierite-sericite-quartz schist south of Kronåsbäcken has been chemically analyzed (Table 10).

This rock is from the northern part of the cordierite zone and as a consequence the cordierite is much sericitized. The rock contains some chlorite in common

**Table 10. Cordierite-sericite-quartz schist, south of Kristineberg.**
Analyst Th. Berggren

| | | Mol. prop. | Mineral composition | |
|---|---|---|---|---|
| $SiO_2$ | 74.30 | 12 371 | Quartz | 55 % |
| $TiO_2$ | 0.55 | 69 | Sericite | 28 |
| $Al_2O_3$ | 12.79 | 1 255 | Biotite (pale yellowish brown) | 5.4 |
| $Fe_2O_3$ | 0.64 | 40 | | |
| FeO | 0.68 | 95 | Chlorite (chlinochlore) | 6 |
| $FeS_2$ | 1.59 | 133 | Cordierite | 5.5 |
| MnO | 0.015 | 2 | Andalusite | 0.1 |
| MgO | 2.97 | 737 | Albite remnant | 0.3 |
| CaO | 0.11 | 20 | Pyrite | 1.6 |
| BaO | 0.06 | 4 | Iron sulphate (+ oxide) | 0.4 |
| $Na_2O$ | 0.46 | 74 | | |
| $K_2O$ | 3.29 | 349 | Rutile | 0.5 |
| $H_2O+$ | 1.80 | 999 | Apatite | 0.2 |
| $H_2O-$ | 0.36 | | | 100.0 % |
| $P_2O_5$ | 0.09 | 6 | | |
| $SO_3$ | 0.15 | 19 | Sp. gr. 2.68 | |
| F | 0.07 | 37 | | |
| Cu | tr. | | | |
| | 99.93 | | | |

with the rocks north of the cordierite zone. The axial angle of the cordierite is close to 90° and the refraction index is relatively low, which indicates that the mineral is rather poor in iron. The pyrite has a rim of iron sulphate and a little iron oxide-hydroxide.

The analysis displays the usual magnesia-metasomatic alteration of the original porphyry. The content of magnesium and potassium has increased, while sodium and partly also calcium have decreased.

The Jörn granite anticline, which projects into the cordierite zone, is also altered, the end section of it being especially strongly transformed. An ordinary rock sample within the granite outcrops shows the following mineral composition: oligoclase-albite 45 %, quartz 34, biotite 11, cordierite 6.5, pyrite 2.2, sericite 1, rutile 0.2, and apatite 0.1 %.

The altered Jörn granite usually contains much unaltered plagioclase, and the grain size of the altered granite is larger than that of the altered volcanics. It is also greyer in colour because of a smaller content of sericite and greater amount of biotite. The plagioclase of the granite is generally grayish while the albite of the extrusive rock is white.

To the N, the cordierite-quartz schist grades into sericite-biotite-quartz schist, but there are very few outcrops within this zone. In the central Kristineberg area the biotite is no longer stable.

### Sericite-chlorite-quartz schists.

In the northern half of the Kristineberg region the altered rocks consist of alternating sericite-quartz schists and sericite-chlorite-quartz schists, the sericite-quartz schists being dominant (cf. the more detailed description of the mine). Sericite-quartz schists are common alteration products of volcanic rocks

around sulphide ores in the Skellefte District. Cf. A. Högbom (1937), who gives a short description of most of the mines in the Skellefte District. A detailed description of the sericite-quartz schists at Boliden is given by O. Ödman (1941). Cf. also S. Gavelin (1941) and E. Grip (1941).

At Hornberget there are some small areas of chlorite-quartz schists within the otherwise dominating sericite-quartz schist. As described earlier, these chlorite-quartz schists are alteration products of more basic volcanics. We have two different possibilities of origin for the chlorite-quartz schists, *viz.* alteration phases of basic volcanics (or Jörn granite), or magnesia-metasomatic alteration products of acid volcanics, either (and chiefly) as hydrothermal alterations of earlier formed biotite-quartz schists or as chlorite-quartz schist formed directly. The last eventuality occurred partly at the formation of the sulphide ores. This point is discussed at greater length further on (cf. the description of the mine and the final discussion).

The sericite quartz schists are quartzitic rocks consisting of quartz with some sericite and pyrite. When the chlorite content is low the rocks are generally white, but a small content of chlorite can serve to colour the rock.

The sericite-quartz schists are mostly schistose, either wrinkled or with a flat lamination, and sometimes also with well-developed linear structure.

In this part of the region, the magnesium metasomatism is on the whole weaker than within the cordierite zone, and it diminishes successively towards the north.

## The Kristineberg mine.[1]

The best investigated level of the Krististineberg mine, that on 170 m, is reproduced in Pl. 2. It is somewhat generalized. Neither the thin greenstone dike at the footwall contact of the $A_1$ ore nor the quartz-tourmaline veins are thus indicated. The 90 m and 250 m levels, which are reproduced on a smaller scale, are generalized to give merely the cross sections through the mine.

The following rock complexes are distinguished within the mine area: In the N, Jörn granite (a granite porphyry), towards the south a chlorite-quartz schist alteration product of the granite with more or less sericite, greenstone or lamprophyre dikes cutting granite and quartzites, quartz-tourmaline veins cutting the same rocks, alteration products of the albite porphyry developed as sericite-quartz schists with intercalating chlorite-quartz schists and intermediate variants, and an extreme chlorite rock at the hanging wall of the A ore with transitions towards soapstone.

The chief ore types distinguished are: more or less compact pyrite ore, chalcopyrite-bearing pyritic ore or copper-pyrite ore (wet ore), zinc ore (ZnS-bearing pyritic ore with some chalcopyrite and galena), and dry ore or quartzitic ore (chalcopyrite-bearing ore with more or less pyrite and intermixing rock). There are also impregnation ores or transitional phases towards wall rock.

[1] Open pits of the mine, see Fig. 2.

## Granite porphyry.

Within the mine, the granite porphyry occurs at the shaft on 170 m level and lower levels. Because of the southerly dip, the corresponding part of the upper levels contains only alteration products of the granite.

The granite in the mine area is developed as a fine-grained granite porphyry, which is rather uniform in composition. There are, however, many inclusions of another rock, which has been more or less contaminated with the granite and on strongly chloritized during the hydrothermal alteration of albite-porphyry as well as granite.

The granite porphyry is cut by many fractures or shears, which may be connected with quartz-tourmaline veins. These may have a filling of calcite, or they may be joints. There are also a few shear zones with a steep dip (50—80°) towards the south.

In order to show the variation in composition of the granite porphyry and the beginning alteration of the rock, the following (11) table has been compiled:

**Table 11. Granite porphyries. Mineral composition in per cent of volume.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Oligoclase | 61 | 62 | 45 | 68 | 48 | 52 | 51 | 62 |
| Quartz | 31 | 29 | 42 | 30 | 39 | 40 | 23 | 29 |
| Biotite | 3 | 4 | 5 | | 1.3 | 2.2 | 1.5 | |
| Chlorite | 1 | 1 | 1 | 1.5 | 2.4 | 2.5 | 3.4 | 6.5 |
| Sericite | tr. | 0.1 | 0.6 | | 8 | 0.1 | 20 | 0.1 |
| Magnetite | | 1.3 | 0.7 | | tr. | 2.2 | 0.2 | 0.8 |
| Apatite | 0.3 | 0.5 | 0.6 | 0.1 | 0.1 | 0.4 | 0.2 | 0.3 |
| Rutile | 0.4 | 1 | 0.2 | 0.2 | 0.2 | tr. | 0.3 | 0.7 |
| Titanite | 0.1 | | tr. | tr. | tr. | 0.4 | tr. | |
| Epidote + orthite | 0.2 | 0.7 | 3 | | 0.2 | 0.1 | 0.2 | 0.3 |
| Tourmaline | | 0.1 | 1.5 | tr. | tr. | tr. | | |
| Pyrite | 3 | 0.3 | 0.2 | | 0.8 | tr. | 0.2 | 0.2 |
| Prehnite | tr. | | | tr. | | 0.1 | | 0.1 |
| Zircon | tr. | | | | | | | |
| Calcite | | | 0.2 | 0.2 | | | | |

The silicification of these rocks is not noticeable, but they may be cut by solitary quartz veins. The quartz phenocrysts are often deformed, and strongly altered rocks have secondary quartz. The chlorite of the rocks is usually ripidolite or prochlorit; occasionally it may be clinochloritic.

One rock sample has been chemically analyzed (Table 12).

The plagioclase in all the rocks investigated is an oligoclase, averaging about $An_{25}$ as in the analyzed rock. The composition of the plagioclase in the granophyre close to the mine was, however, found to be $An_{15}$. The biotite in the analyzed rock is brown to brownish green The chloritization of the biotite shows the degree of hydrothermal alteration of the rock. Pyrite, tourmaline, and rutile are also products of alteration. The impregnation of magnetite in the granite has made it possible to »map» the contacts magnetically.

**Table 12. Granite phorphyry. 250 m level.**
Analyst N. Sahlbom.

| | | Mol. prop. | Norm. | | Mineral composition | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 72.98 | 12 151 | Q | 38.7 | Oligoclase | 51 |
| $TiO_2$ | 0.60 | 75 | Or | 2.1 | Quartz | 39 |
| $Al_2O_3$ | 12.57 | 1 233 | Ab | 35.6 | Biotite | 2 |
| $Fe_2O_3$ | 2.15 | 135 | An | 14.5 | Chlorite (ripidolite) | 2.5 |
| FeO | 1.90 | 265 | | | Sericite | 0.1 |
| MnO | 0.01 | 1 | Sal | 90.9 | Magnetite | 3.7 |
| MgO | 1.28 | 318 | | | Pyrite | tr. |
| CaO | 3.16 | 564 | Hy | 3.9 | Apatite | 0.4 |
| $Na_2O$[1] | 4.20 | 678 | Mt | 3.1 | Titanite | 1 |
| $K_2O$[1] | 0.35 | 37 | Il | 1.1 | Rutile | 0.1 |
| $H_2O+$ | 0.35 | 194 | Ap | 0.4 | Prehnite | 0.1 |
| $H_2O-$ | 0.05 | | Fem | 8.5 | Epidote | 0.1 |
| $P_2O_5$ | 0.18 | 13 | | | | |
| Cl | 0.07 | 20 | $H_2O$ | 0.4 | Bluish green tourmaline | tr. |
| F | 0.00 | | | | | 100.0 % |
| S | 0.00 | | | 99.8 % | | |
| BaO | 0.00 | | I, 3, 3, 5 | | | |
| | 99.85 | | Vulcanose | | Sp. Gr.[2] 2.70 | |

[1] S. Henriksson, [2] O. Alvfeldt

The inclusions in the granite porphyry have a varying appearance and form, and they may be oriented in various directions, but most of them are arranged more or less horisontally as flat parallel inclusions, as seen in the photo, Fig. 4. Small inclusions are relatively diffuse and are more or less resorbed by the granite.



Fig. 4. Dark inclusions in granite porphyry. Main drift, 250 m level. × 1/9.

Some inclusions are coarsely recrystallized with chloritized biotite plates intergrown in various directions surrounded by a light-coloured granitic matrix. Large inclusions have often borders composed of this structure, and some may also have an outer aplitic border.

Table 13 contains volumetric analyses of some of the various inclusions:

**Table 13. Inclusions in granite porphyry. Per cent of volume.**

| | a | b | c | d | e | f | g | h | i | j |
|---|---|---|---|---|---|---|---|---|---|---|
| Oligoclase | 11 | 48 | 48 | 38 | 42 | 43 | 42 | 39.5 | 32 | 27 |
| Quartz | 11 | 4 | 16 | 10 | 15 | 15 | 18 | 12 | 17 | 13.4 |
| Biotite | | | 12 | 4.4 | 8 | 12 | 4 | 18 | 10 | 21 |
| Chlorite | 11 | 14 | 12 | 38 | 26 | 24 | 32 | 23.5 | 34 | 33 |
| Greenish hornblende | 37.4 | 20 | | | | | | | | |
| Epidote | 28 | 3.8 | 7 | 3.9 | 6.8 | 1 | 0.7 | 2.8 | 5.5 | 1.5 |
| Titanite | 1 | 0.7 | 1 | 0.8 | | | | | | |
| Rutile | 0.2 | | 0.2 | 1 | tr. | 0.7 | 0.3 | 0.3 | 0.6 | 0.5 |
| Apatite | 0.2 | 0.2 | 0.2 | 1 | 0.2 | 0.8 | 0.2 | 0.2 | 0.6 | 0.6 |
| Pyrite | 0.2 | 9 | 3.5 | 3.7 | 1.2 | 3.5 | 2.8 | 3.7 | 1.3 | 3 |
| Calcite | | | 0.1 | | | | | | tr. | |
| Sericite | | 0.3 | | | | | | | | |
| Orthite | | | | | | tr. | tr. | | tr. | |

The first two rocks (a and b) are evidently inclusions of basic rocks which have not been greatly altered by the granite. They have a more basic plagioclase than the others. The other inclusions are of the schistose and flat type of uncertain origin. Since they differ from the greenstone-like inclusions (a and b), which have not been greatly altered by the granite, it is probable that they have an origin genetically different from that of the granite. They may thus be inclusions of shale as indicated by their plate-like appearance. They have been very much altered by the granite.

Compared with the granite, the inclusions are more chloritized and more enriched in pyrite. This is due to their originally more basic composition which favoured the formation of chlorite and more easily bound the sulphur content in the solutions. The more basic original composition is also displayed by the higher content of epidote and titanite or rutile. c—j are contaminated with or partly resorbed by the granite.

On the 490 m level the granite porphyry contains much granite aplite. The aplite consists almost only of feldspar and quartz, and as it is poor in biotite, it has not been very hydrothermally altered while the surrounding granite porphyry has been partly »quartzitified», all of its biotite being altered to chlorite. The chlorite is more or less scattered in the rock. The aplite thus appears almost white within the dark, chloritized porphyry and it often shows a brecciating appearance within the granite porphyry. It thus generally crystallized within already consolidated granite, but in some places it also shows gradations towards the porphyry. Where the hydrothermal alteration is strong it also cuts the aplite, appearing rather distinctly against the light-coloured aplite. The volumetric composition is roughly the following: albite-oligoclase



Fig. 5. Granite aplite brecciating granite porphyry. Aplite is white; porphyry dark because of much secondary chlorite. 490 m level. × 1/12.

59 %, quartz 37.5, chlorite 1.5, biotite 0.5, ore grains (pyrite and magnetite) 0.5, epidote and orthite 0.5, titanite 0.2, apatite 0.2, sericite 0.1 and traces of rutile and zircon. It sometimes contains some pale greenish hornblende and secondary calcite. The composition is thus similar to that of the aplites observed at the surface (cf. Table 5) although a little more hydrothermally altered.

To the S the granite porphyry becomes more and more altered, though very unevenly, because the schistose or fractured parts were soaked much more easily by hydrothermal solutions.

The granite is mainly altered into a chlorite-quartz schist which locally contains sericite. It becomes richer in sericite when the original boundary with the albite porphyry is approached.



Fig. 6. Altered greenstone with interpenetrating hornblende crystals. Some quartz, plagioclase, epidote, and titanite in the interstices. Central shaft, 250 m level. × 50.

## Greenstone dikes.

Greenstone or lamprophyre dikes occur in several places in the mine area. The largest one is up to 2 $^1/_2$ m wide and runs in a south-eastern direction through the granite toward the $A_1$ ore. A thin but continuous dike passes along the foot-wall of the $A_1$ ore with about the same dip as the ore. It appears in part as inclusions in the ore. Two thin dikes run between the A ore and the $B_1$ ore. At the central shaft in and beneath the 170 m level there is a somewhat uneven dike with a northerly strike and a steep dip towards the W.

The dikes in or close to the ore are strongly altered to a variety of chlorite-epidote-quartz schist, while those which are farther away from the ore within the granite still have hornblende and plagioclase preserved. The least altered rocks are hornblende greenstones with microscopically relatively large, pale bluish green amphiboles which penetrate the greenstone at rondom ($\gamma$ about 1.660) as well as a somewhat saussuritized plagioclase (cf. photo, Fig. 6). The texture of the hornblende and the abundant appearance of epidote and titanite shows that the rock is a recrystallized one. The later alteration at the period of the ore formation has resulted in the appearance of chlorite, epidote, quartz, pyrite, and rutile at the expense of chiefly hornblende and plagioclase (cf. photo, Fig. 7).



Fig. 7. Hydrothermally altered greenstone. Remnants of amphibole in chlorite matrix (with epidote and titanite). Close to central shaft, 250 m level. × 50.

**Table 14. Greenstones. (Mineral composition in per cent of volume.)**

| Numbers | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Level | 170 m | 250 m | 170 m | 0 m | 250 m | 170 m | 170 m | 145 m | 170 m |
| Hornblende | 68 | 49 | | 44 | 10 | | tr. | | |
| Plagioclase | 20 | 14 | 22 | tr. | 11 | 4 | | | |
| Potassic feldspar | | | 0.1 | | 1 | | | | |
| Quartz | 1.8 | 4.5 | 28 | 4 | 15 | 23 | 15 | 32 | 24 |
| Biotite | | | | 4 | tr. | | 8 | | |
| Chlorite | 2.8 | 9 | 13 | 27 | 41 | 44 | 40 | 24 | 29 |
| Epidote | 6 | 21 | 7.5 | 18 | 18 | 26 | 31 | 40 | 43 |
| Titanite | 0.9 | 1 | 0.1 | 2 | 1.8 | 1.8 | 3 | 0.8 | 2.3 |
| Rutile | 0.3 | 0.8 | 0.5 | 0.2 | 0.4 | 1 | 0.8 | 1 | 0.2 |
| Pyrite | | | 4.3 | 0.3 | 0.1 | 0.1 | 1.3 | tr. | 0.5 |
| Other ore grains | | | | | 0.3 | tr. | | 0.1 | tr. |
| Apatite | 0.2 | 0.4 | 0.5 | 0.3 | 0.4 | 0.1 | 0.4 | 0.1 | 1 |
| Orthite | | | | 0.2 | | | | | |
| Sericite | | | 24 | | | | | | |
| Calcite | | 0.1 | | | 1 | | 0.2 | | |
| Gibbsite | | | | | | | 0.3 | | |

Numbers 1, 2, and 5 are from greenstone dikes in the granite, 3, 4, 6, and 7 are from the dike at the footwall of the ore, and numbers 8 and 9 are from inclusions in the ore. Table 14 shows variations in the composition of the rocks from the relatively well preserved hornblende-plagioclase rocks in the granite to the chlorite-epidote schist in the ore. The latter is reminiscent of chlorite-quartz

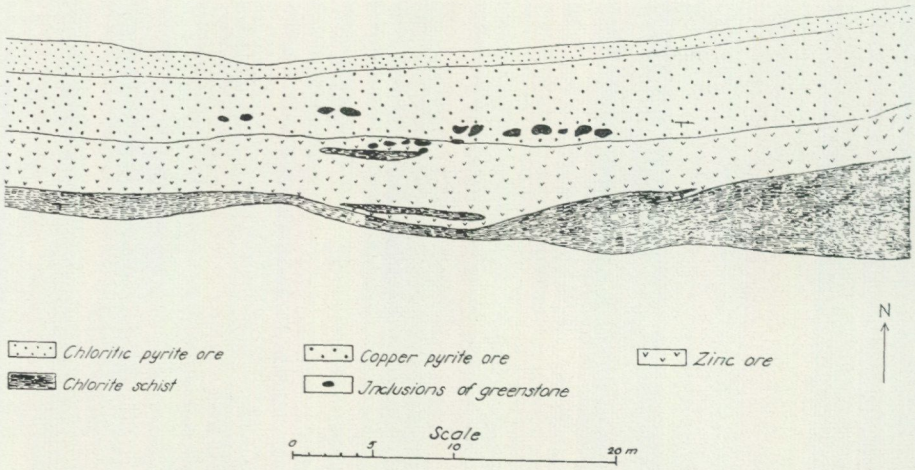



Fig. 8. Inclusions of greenstone within the $A_1$ ore. Stope 8.

schist alteration products of the porphyries, but it is denser, darker, and heavier than those. At the zinc ore the greenstone dike is so altered that it is recognisable only with difficulty.

Fig. 8 shows the appearance of the greenstone inclusions in the $A_1$ ore. The inclusions are often displaced and may be hard to find, especially in the zinc ore. They may be quite disintegrated.

**Table 15. Greenstone. Close to the central shaft. 250 m level.**
Analyst N. Sahlbom.

| | | Mol. prop. | Norm. | | Mineral composition | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 48.36 | 8 052 | Q | 3.0 | Actinolitic hornblende | 15 % |
| $TiO_2$ | 1.50 | 188 | Or | 3.6 | Remnants of feldspar | 15 |
| $Al_2O_3$ | 13.44 | 1 318 | Ab | 7.6 | Quartz | 14 |
| $Fe_2O_3$ | 3.13 | 196 | An | 30.8 | Chlorite (ripidolite) | 31 |
| FeO | 7.35 | 1 023 | Sal | 45.0 | Antigoritic chlorite | 3 |
| MnO | 0.22 | 31 | | | Epidote | 17 |
| MgO | 12.96 | 3 214 | Di | 4.4 | Titanite | 2.4 |
| CaO | 7.80 | 1 391 | Hy | 38.9 | Rutile | 0.5 |
| BaO | 0.12 | 8 | Mt | 4.5 | Apatite | 0.8 |
| $Na_2O$[1] | 0.90 | 145 | Il | 2.9 | Ilmenite | 0.5 |
| $K_2O$ | 0.60 | 64 | Ap | 0.8 | Pyrite | 0.1 |
| $H_2O+$ | 3.52 | 2 120 | Py | 0.1 | Calcite | 0.7 |
| $H_2O-$ | 0.06 | | Fem | 51.6 | Biotite | tr. |
| $P_2O_5$ | 0.36 | 25 | $H_2O$ | 3.5 | | 100.0 % |
| S | 0.05 | 16 | | 100.1 % | Sp gr. 2.93[2] | |
| F | 0.00 | | | | | |
| Cl | 0.00 | | | | | |
| $CO_2$ | 0.31 | 71 | | | | |
| | 100.68 | | | | | |

There are slight traces of Cu, Zn, Co, Ni, Sn, V, As (K. G. Lindkvist).

[1] S. Henriksson.
[2] O. Alvfeldt.

The occurrence of greenstone dikes, particularly within the ore zone before the ores were formed, indicates that a tectonic zone of weakness was present there before the ore-bearing solutions arrived. The narrow greenstone dike that runs along the footwall of the $A_1$ ore has thus been intruded in about the same fissure as the ore.

A partly altered greenstone dike has been analyzed. Table 15.

Chemically this rock is of a hypersthene-noritic type, and primarily it may have been either a hypersthene-dolerite or a spessartite dike rock.[1]

## Quartz-tourmaline veins.

Quartz-tourmaline veins frequently occur within the mine area. They are found almost everywhere, but their greatest frequency is at the footwall of the A ore. Within the granite porphyry they also occur but there they are not plentiful. Around or south of the B ores the veins are rare. On account of the small scale of the maps reproduced in this paper it has not been possible to plot the quartz-tourmaline veins.

The quartz-tourmaline veins may appear in almost every direction. Most of them strike in a north-western or a north-eastern direction. The strike direction of quite a number of them has been measured and the compass readings plotted in a diagram, cf. Fig. 9.

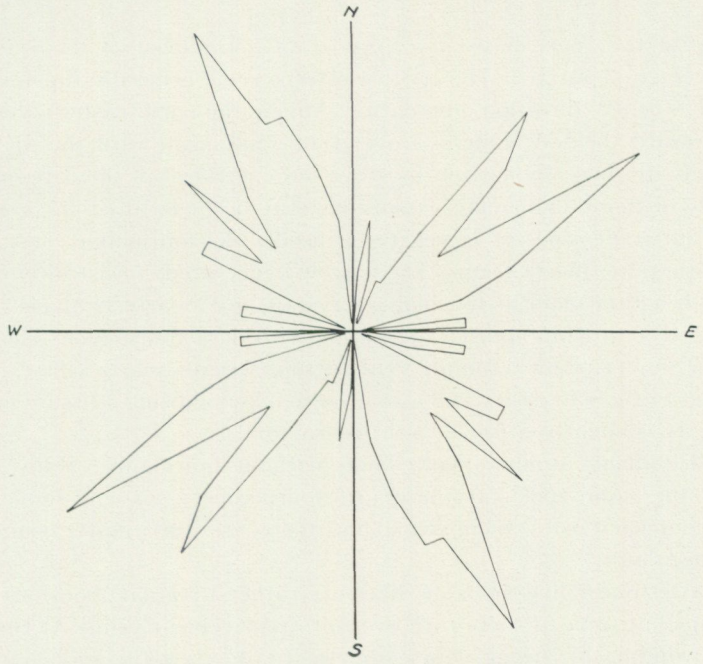



Fig. 9. Diagram showing relative frequency of the various directions of strike of the quartz-tourmaline veins.

[1] The rock analysis resembles two analyses of »trap» from the Wrede dike in Falun (G. F. F. 1926, p. 69, analyses 18 and 21 according to Hj. Sjögren).

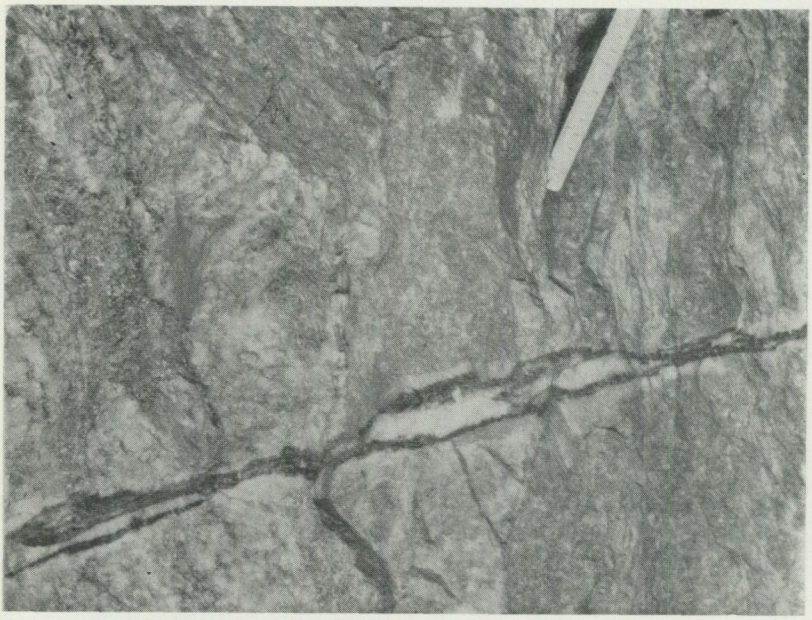


Fig. 10. Simple quartz-tourmaline vein cutting sericite-quartz schist at right angles to schistosity. Crosscut 112, 90 m level.

The dip of the veins may vary considerably, but most of them are steep, on the average about 70°. The north-westerly veins generally dip toward the SW or NE, the SW direction dominating. Among the north-easterly veins those dipping toward the NW dominate over those dipping toward the SE.

The veins are generally narrow, mostly a few cm wide, but they are sometimes 1 dm wide or more, and bulky expansions may occur locally. The veins often consist of different zones of aggregates of needle-like tourmaline crystals alternating with pure quartz seams. The narrow veins often consist of one zone of quartz with a thin seam of tourmaline crystals, but relatively thick veins are often banded with white quartz alternating with dark tourmaline. The photos, Figures 10 and 11, show a simple vein cutting sericite-quartz schist almost at right angles to the schistosity and a composite dike following a fissure in granite porphyry. It is slightly offset at a cross fracture.

There are many similar quartz veins without tourmaline. Many of them belong to the same epoch as the quartz-tourmaline veins, and some of these may be connected with such veins, but there are also quartz veins which were formed later.

The quartz-tourmaline veins or dikes are rather irregular. Some are regular fissure veins but some of these turn over into replacement veins. At times they exhibit a winding or zigzag course or else finish abruptly and continue *en échelon*. They may pass over from a general north-western to a north-eastern direction, or from a vein following the schistosity of the surrounding rock to one directly cutting it.



Fig. 11. Composite quartz-tourmaline vein cutting granite porphyry.
Main drift, 250 m level.

The quartz-tourmaline veins are younger than the Jörn granite and the alterae tion of the volcanics, since unaltered veins cut the altered rocks, and they ar- also later than the greenstone dikes for these are almost as much altered hydrothermally as the country rock surrounding them. The quartz-tourmaline veins are cut by the pyritic ore and inclusions of them are found in the ore. The micro-photo, Fig. 12, shows sulphide veins brecciating a tourmaline aggregate of a quartz-tourmaline vein.

The frequency of the veins at the footwall side of the A ore shows that a brittle zone of weakness existed in this part of the sericite-quartz schist even before the ore deposition. On examination of the frequency diagram of the strike directions of the quartz-tourmaline veins it is apparent that most of the dikes strike approximately N 30° W and N 60° E, which corresponds to the conjugate shearing planes at about 45° inclined direction to the maximal stress, which was about at right angles to the schistosity of the rock complexes as a whole, which runs approximately parallel to the $B_1$ and $A_3$ ores and not parallel to the rather local direction of the other ores. The shearing directions (NW and NE) corresponding to the local strike of the rocks around the $A_1$ ore are also represented in the frequency diagram.

In bulk composition, the quartz content of the veins dominates over the tourmaline, though with considerable variation between the two minerals. Other minerals are scanty and may partly be looked upon as inclusions, *e. g.* sericite and chlorite, or as later additions, *e. g.* pyrite. Feldspar, fluorite, or scheelite have been observed quite locally.



Fig. 12. Tourmaline rock brecciated by sulphides (mainly chalcopyrite). Close to the $B_1$ cre. 90 m. 50 ×.

The tourmaline is so fine-needled that the single prisms are often hard to discern in a sample. It is dark grayish green in hand specimens, but the colour may vary from almost black to almost colourless. In thin section the pleochroism is $\omega$ bluish green, grayish green, or olive green, and $\varepsilon$ colourless to pale green, yellowish green or pale rose. A tourmaline from a vein in granite porphyry has refraction indices $\omega$ 1.651 and $\varepsilon$ 1.631 (T. Krokström) with pleochroism from dark olive green to very pale rose. Another tourmaline has the refractive index $\omega$ 1.656 with pleochroism from bluish gray-green to pale yellowish green. This one shows a content of $Na_2O = 2.21$, $Fe = 4.60$ %, and $Li_2O$ none (A. G. Hybbinette).

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Scheelite has been met with in several places close to the $A_1$ ore, especially on the footwall side, where the quartz-tourmaline veins are frequent. It has thus often been observed close to the quartz-tourmaline veins, near the boundary or in fractures proceeding from them. It has also been seen as lumps in the pyrite ore close to quartz-tourmaline inclusions.

The scheelite appears as solitary grains varying in size from small microscopic grains to large lumps which sometimes are as much as a few cm in diameter. The most common size is about 1 mm. Crystal form is not generally visible.

Economic aggregations of scheelite have not yet been found. The scheelite

crystals occur too sparsely, and no analysed sample contains as much as 0.1 % $W_2O_3$.

The general association of scheelite in the same area as the quartz-tourmaline veins points to their mutual origin. Scheelite is also generally regarded as a pneumatolytic mineral just as tourmaline is.

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In a paper about tungsten and molybdenum in sulphide ores in the Skellefte District E. Grip (Geol. Fören. Förhandl. Bd 73, 1951, p. 463) has given an analysis of a scheelite crystal from the A-ore of the 130 m level of Kristineberg:

| | Weight % |
|---|---|
| $SiO_2$ | 0.00 |
| $Al_2O_3$ | 0.02 |
| FeO | 0.16 |
| CaO | 19.17 |
| MgO | 0.17 |
| $WO_3$ | 80.82 |
| $MoO_3$ | 0.00 |
| | 100.34 |
| $H_2O < 105°$ | 0.02 |

$TiO_2$, MnO, $Na_2O$, $K_2O$, $H_2O > 105°$ Cu, Bi, Co and $CO_2$ have shown 0.00 %
Analysis by Th. Berggren.

| | |
|---|---|
| La | 0.00006 |
| Ce | 0.00094 |
| Pr | 0.00006 |
| Nd | 0.00048 |
| Sm | 0.00031 |
| Eu | 0.00005 |
| Gd | 0.00058 |
| Tb | 0.00008 |
| Dy | 0.00084 |
| Ho | 0.00008 |
| Tm | ? |
| Yb | 0.00009 |
| Cp | ? |

X-ray analysis by O. Alvfeldt.

The sparse occurrence of scheelite in other sulphide ores of the Skellefte District such as at Boliden, Långdal, Kedträsk, Rävliden, Lainejaur, Lindsköld Mine, and Laver in Norrbotten has also been pointed out by Grip.

Gypsum appears on the 490 m level as lumps or veins in altered granite porphyry not far from cutting quartz-tourmaline veins. It may thus belong to the same epoch, but probably it crystallized somewhat later.

## Sericite-quartz schists.

Sericite-quartz schist is the most extensive rock occurring in the mine area. It is probably chiefly an alteration product of original quartz porphyry (albite porphyry, cf. earlier description of the field area).

The predominant minerals of the sericite-quartz schist are quartz and sericite. A little pyrite is always present and often chlorite in varying quantities. Rutile and apatite are accessories. Remnants of albite, cyanite, biotite, and sometimes epidote, and accidental zircon occur at times. Tourmaline, andalusite, talc, light-coloured sphalerite and chalcopyrite occur locally. Sillimanite, fuchsite, garnet, magnetite, titanite, and limonite have been observed sporadically.

When sericite is particularly plentiful, the rock becomes a sericite schist. On the other hand, the rock may be almost devoid of sericite. When the content of chlorite becomes abundant the rock is designated a sericite-chlorite-quartz

**Table 16. Quartz schists. Mineral composition in per cent of volume.**

| | Sericite-quartz schists | | | | | | | | | Sericite-chlorite-quartz schists | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Level | 90 | 90 | 170 | 170 | 170 | 90 | 170 | 90 | 130 | 130 | 0 | 90 | 130 | 170 | 170 |
| Quartz | 81.8 | 62 | 85.3 | 72.5 | 22 | 3 | 48 | 76 | 71 | 40 | 31 | 54 | 35 | 79.3 | 0.2 |
| Sericite | 12 | 23 5 | 10 | 17 | 24.3 | 50 | 32 | 11 | 11 | 24 | 22 | 14 | 10 | | |
| Clinochlore or prochlorite | | | 2 | 5 | 12 | 7.8 | 16 | 9 | 12 | 20 | 41 | 24.5 | 30 | 19 | 94.5 |
| Antigoritic chlorite | | | | | | 9 | | | | | | | | | |
| Remnant of feldspar | | | | 1 | | | 3 | | | | 2.5 | 7 | | | 0.1 |
| Cyanite | | tr. | | 0.1 | 24 | 0.1 | 0.3 | | | 12.5 | | | 20 | | |
| Sillimanite | | | | | | | | | | 3 | | | 3.4 | | |
| Pyrite | 6 | 13.5 | 2.5 | 4 | 11 | 29 | 0.1 | 3.8 | 4.9 | tr. | 0.1 | tr. | 1 | 1 | 4 |
| Other ore grains | | tr. | | tr. | tr. | | | | | | 0.3 | | | 0.6 | 0.5 |
| Rutile | 0.1 | 0.6 | 0.1 | 0.2 | 0.7 | 0.7 | 0.5 | 0.1 | 0.1 | 0.5 | 1.5 | 0.1 | 0.6 | 0.1 | 0.7 |
| Apatite | 0.1 | 0.4 | 0.1 | 0.2 | tr. | 0.4 | 0.1 | 0.1 | tr. | tr. | 1.6 | 0.4 | tr. | | tr. |
| Tourmaline | | | | tr. | | | | | | tr. | | | tr. | | |
| Zircon | | tr. | | | | tr. | | | | | | | | | |

schist, which may pass over into a chlorite-quartz schist with little to no sericite. Chlorite-rich varieties thus occur here and there within the sericite-quartz schist. They often occur as aureoles around the ores, and they may also occur in what were originally passages for the ore-bearing solutions. Chlorite-quartz schist or sericite-chlorite-quartz schist also appears as a hydrothermal alteration product of earlier Jörn granite. An isolated area of sericite-chlorite-quartz schist within the south-western part of the 170 m level probably indicates a granite-porphyry intrusion within the otherwise predominating altered volcanic rocks.

Table 16 gives the composition of some typical schists within the mine area according to volumetric mineral analyses of thin sections.

One sample each of sericite-quartz schist (17) and sericite-chlorite-quartz schist (17 A) has been chemically analyzed (Table 17). Both represent normal alteration products from the mine area. Compared with a probable original sodic quartz porphyry both analyses show a diminishing content of sodium while potassium has increased somewhat. Added components are chiefly sulphur, iron, and magnesium. The content of pyrite in the sericite-quartz schists is often higher than in the analyzed rocks, but it varies very much from case to case. In the chlorite-rich rocks the content of magnesium will of course be much higher.

From the analyses, the composition of the sericite has been calculated approximately: $SiO_2$ 45.3, $Al_2O_3$ 37, $Fe_2O_3$ 2, CaO 1, $Na_2O$ 1.8, $K_2O$ 8.9, and $H_2O$ 4 %. The refractive index $\beta$ was determined as 1,597.

Rocks rich in quartz are uniform and solid, while schists rich in sericite are schistose and often wrinkled or buckled, seen from the photo, Fig. 13. On such a corrugated sericite schist linear structure parallel to the pitch axis of the folding is often pronounced. This structure is generally conformable with the pitching of the ore bodies.

Fig. 14 shows a microphoto of a normal sericitic quartz schist with chiefly quartz, sericite, and pyrite.

Certain portions of the sericite-quartz schist are enriched in segregated masses of quartz. This phenomenon is often coupled with ore enrichment. The association will be further dealt with in the description of the $B_1$ ore.

In the rock zone between the $B_1$ and $B_2$ ores there is often much cyanite. The cyanite frequently appears as a coarse, spherulitic crystallization product in rock rich in quartz. A photo of such a structure is given in Figure 15. Single cyanite crystals attain a length of 1 dm. The cyanite occurs, however, more often in chlorite-rich sericite-quartz schist, which indicates that it may be associated with the formation of the ores. The cyanite is frequently sericitized and remnants of it may appear in fibrous masses of sericite, as is shown in Fig. 16. Generally, only the sericite pseudomorphs are visible.

The crystallization of the cyanite is considered to be contemporaneous with the alteration which occured during the first phase of the percolation of the ore-bearing solutions, and the sericitization of the cyanite may be associated with hydrothermal alterations during the latest phase of ore formation, when

**Table 17. Sericite-quartz schists. Chemical analyses.**

| | 17, Boliden Laboratory | | 17 A, N. Sahlbom | |
|---|---|---|---|---|
| | | Mol. prop. | | Mol. prop. |
| $SiO_2$ | 74.8 | 12 454 | 75.32 | 12 541 |
| $TiO_2$ | 0.34 | 43 | 0.30 | 38 |
| $Al_2O_3$ | 6.1 | 598 | 8.02 | 787 |
| $Fe_2O_3$ | 8.1 | 1 128 | 5.54 | 347 |
| FeO | | | 1.42 | 198 |
| MnO | 0.01 | 1 | tr. | |
| MgO | 0.65 | 161 | 3.18 | 789 |
| CaO | 0.79 | 141 | 0.42 | 75 |
| BaO | | | tr. | |
| $Na_2O$ | 0.31 | 50 | 0.26[1] | 42 |
| $K_2O$ | 1.51 | 160 | 1.26[1] | 134 |
| $H_2O+$ | 0.84 | 466 | 1.10 | 611 |
| $H_2O-$ | 0.14 | | 0.10 | |
| $CO_2$ | 0.06 | 14 | | |
| F | | | 0.00 | |
| Cl | | | 0.19 | 54 |
| $P_2O_5$ | 0.09 | 3 | 0.19 | 13 |
| $B_2O_3$ | | | 0.02[2] | 3 |
| S | 6.9 | 3 152 | 4.08 | 1 273 |
| Cu | 0.02 | 3 | tr. | |
| Zn | 0.20 | 31 | | |
| | 100.86 | | 101.20 | |
| $-O_2$ (to S) | 1.7 | | 1.5 | |
| | 99.16 | | 99.70 | |
| Sp. gr. | 2.93 | | 2.75 | |
| Mineral composition (weight %): | | | | |
| Quartz | 67 | | 67 | |
| Sericite | 17.4 | | 14.5 | |
| Chlorite | 1 | | 9 | |
| Pyrite | 13 | | 7.8 | |
| Chalcopyrite | 0.1 | | tr. | |
| Sphalerite | 0.3 | | | |
| Rutile | 0.4 | | 0.3 | |
| Apatite | 0.2 | | 0.5 | |
| Tourmaline | 0.4 | | 0.2 | |
| Cyanite | tr. | | 0.2 | |
| Altered plagioclase | | | 0.5 | |
| Magnetite | tr. | | | |
| Calcite | 0.2 | | | |
| Zircon | tr. | | | |
| | 100.0 % | | 100.0 % | |

[1] S. Henriksson. — [2] K. E. Funke. — [3] O. Alvfeldt.

much of the sphalerite was deposited. Solitary sphalerite crystals have thus been observed in quartz concretions with sericite clusters, reminiscent of cyanite pseudomorphs.

Some sericite pseudomorphs imitate the crystal form of andalusite, from which they have been derived, the host mineral having crystallized during an earlier epoch than the cyanite.

Together with concretionary masses of quartz in sericite-quartz schist, sul-



Fig. 13. Finely wrinkled sericite schist. Close to the $B_1$ ore, 90 m level.

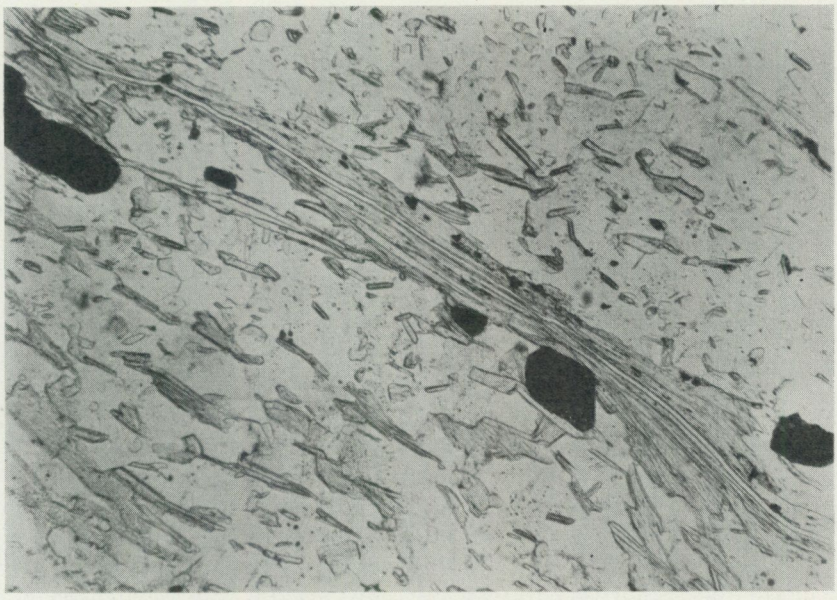


Fig. 14. Sericite-quartz schist. Microphoto. × 60.



Fig. 15. Cyanite spherulites in quartz concretion in sericite-chlorite-quartz schist. Crosscut 235, 170 m level. × 1/9.

phide minerals, fuchsite intergrown with muscovite, tourmaline, sillimanite, and epidote sometimes occur. Talc may occur as a coating on sericite, especially on surfaces of gliding and was consequently formed during a later period.

Towards the A ore, the sericite-quartz schist is always more or less enriched in chlorite. Sericite-quartz schist at first changes successively into chlorite-quartz schist and this into chlorite-schist. Simultaneously the content of pyrite will be increased.

The composition of the chlorite-quartz schist is analogous to that of the sericite-quartz schist with the exception of the relative abundance of chlorite to sericite. A chlorite-rich rock indicates a still stronger metasomatic and hydrothermal alteration. Addition of minerals, particularly magnesium-rich ones, has occurred and quartz has been more or less removed. The chlorite-rich rocks will be described in greater detail under the description of the ores.

## Chlorite-rock and soapstone.

A rock extremely rich in chlorite generally occurs along the hanging wall of the A ore. It has its greatest extension along the zinc ore of the $A_1$ ore. Where the chlorite-rock is not very tectonically disarranged it is dense and tough and rather monomineralic. The texture and composition of it is reminiscent of some reaction-zone rocks which the author has described earlier from the

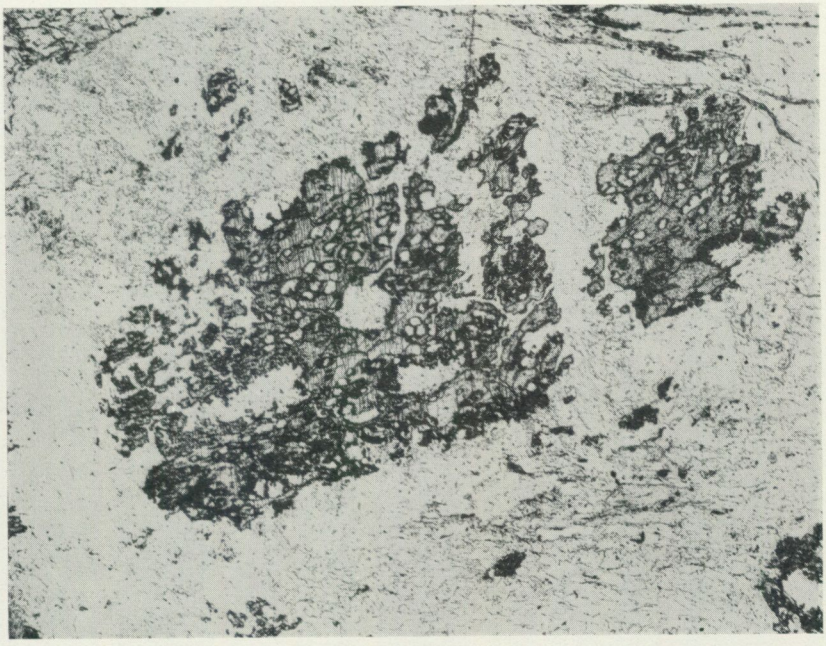


Fig. 16. Remnant of cyanite surrounded by pseudomorphing sericite in sericite-chlorite-quartz schist. 130 m level. × 12.

contacts between ultrabasic rocks and acid intrusives (1935). In composition the Kristineberg chlorite is an extreme, Al-bearing magnesium type, i. e. it is composed mostly of chlorite of clinochloritic or penninitic composition. Antigorite may be present but is not abundant. As to origin, however, the Kristineberg chlorite-rocks must be reckoned as metasomatic addition products (magnesium skarn).

The chlorite-rock is partly talc-bearing and shows transitions into soapstone and sometimes talc-schist. The soapstone and especially the talc-schist occur where the rock has been greatly disturbed tectonically and displaced, and it is considered to be somewhat later in origin than the chlorite-rock. Schistose chlorite-rock and soapstone are often met with at the contact to the zinc ore. Along the faults or fault breccias, which cut the zinc ore and the hanging complex, talc is often enriched even far away from the chlorite-rock.

A typical, dense, chlorite-rock has been analyzed (Table 18).

This rock is thus an almost pure chlorite and is composed of 98 % clinochlore. Impurities are disseminations of pyrite, sphalerite, rutile, and probably some apatite.

Refractive indices of the clinochlore are $N_{max}$ 1.587 and $N_{min}$ 1.579 (Na-light, T. Krokström). Average birefringence is 0.006. The mineral is optically positive. Owing to the finely fibrous structure, it was not possible to determine the axial angle. The interference colours are but slightly anomalous.

Towards the surrounding sericite-quartz schist, transitionary rocks occur,

**Table 18. Chlorite-rock. Crosscut 212, 170 m level.**
Analyst N. Sahlbom.

| | | | Composition of chlorite after deduction of iron-bearing rutile, sphalerite, and pyrite | |
|---|---|---|---|---|
| | | Mol. prop. | | Mol. prop. |
| $SiO_2$ | 30.32 | 5 048 | 30.9 | 5 145 |
| $TiO_2$ | 0.50 | 63 | | |
| $Al_2O_3$ | 17.67 | 1 733 | 18.0 | 1 766 |
| $Fe_2O_3$ | 2.69 | 169 | 1.6 | 100 |
| FeO | 2.49 | 347 | 2.5 | 348 |
| MnO | 0.30 | 42 | 0.3 | 42 |
| MgO | 33.41 | 8 286 | 34.0 | 8 433 |
| CaO | tr. | | | |
| $Na_2O$ | 0.40[1] | 65 | 0.4 | 65 |
| $K_2O$ | 0.52[1] | 55 | 0.5 | 53 |
| $P_2O_5$ | 0.17 | 12 | 0.1 | 7 |
| F | 0.00 | | | |
| Cl | tr. | | | |
| S | 0.94 | 283 | | |
| Cu | 0.00 | | | |
| Zn | 0.15 | 23 | | |
| Cr | 0.00 | | | |
| $H_2O+$ | 11.44 | 6 350 | 11.7 | 6 494 |
| $H_2O-$ | 0.08 | | | |
| | 101.08 | | 100.0 | |
| $-O_2$ (to S) | 0.4 | | | |
| | 100.68 | | | |
| Sp. gr. | 2.65[2] | | 2.61 | |

[1] S. Henriksson. — [2] O. Alvfeldt.

(*viz. chlorite schist*) with increasing content of silica, which causes the rocks to pass from an originally ultrabasic type into an acid variety rich in silica. The composition of the chlorite alters simultaneously due to enrichment in iron, and thus the mineral changes from clinochlore to prochlorite or ripidolite. This is common in the quartz-rich phases, which have a lower content of magnesium and a higher iron content. This alteration occurs successively and it is evident that a considerable chemical conversion and equalization has taken place.

The chloritite-soapstone zone follows, as mentioned above, on the hanging side of the zinc ore, but it has an uneven development and may also appear on the footwall side of the zinc ore, this being evidently due to the irregular development of the channelways for the metasomatic solutions. At the western and eastern ends of the $A_1$ ore thin layers of zinc ore continue outwards. These are also accompanied by wall rocks enriched in chlorite, which may continue also after the disappearance of the zinc ore itself. Toward the west, chlorite-extreme rocks occur along the $A_3$ ore, but they are rather irregular, indicating that the fissuring has not been so wide and thus the solutions were not afforded so much access as along the hanging-wall side of the $A_1$ ore.

It is evident that an extra enrichment of magnesium occurred at the forma-

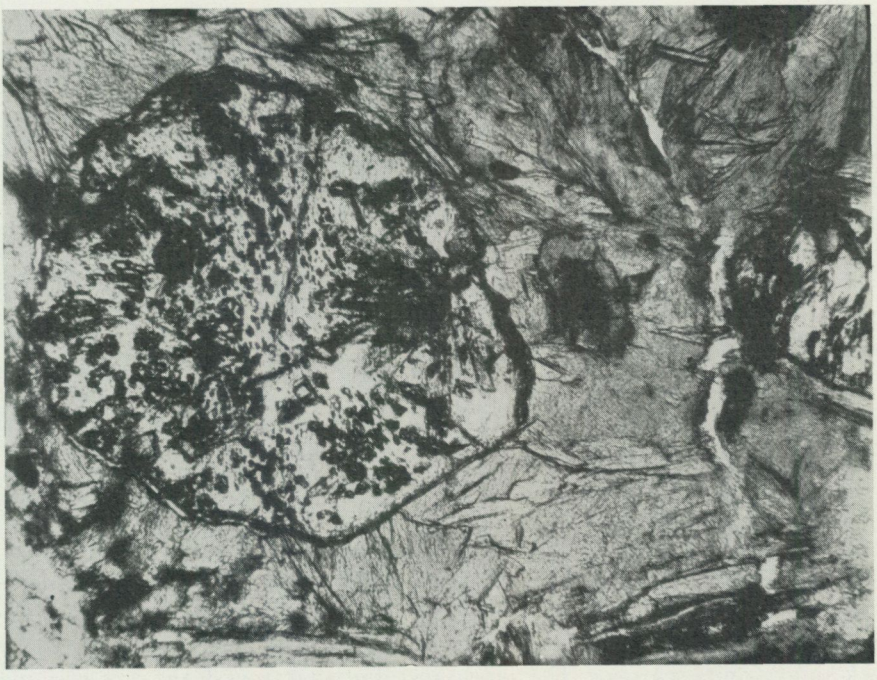


Fig. 17. Pseudomorph of talc probably after olivine in chlorite schist. Close to the $B_1$ ore, 170 m level. × 51.

tion of the zinc ore. Besides the chief magnesium minerals, chlorite and talc, other minerals occur sporadically, such as magnesite and tremolite which have been specially noticed on the 250 m level. Investigation of the zinc ore has made it clear that chlorite and talc are products of late crystallization; they even disturb and replace the sphalerite. It is probable that chlorite and talc are in part hydrothermal alteration products of earlier crystallized skarn minerals (cf. photo, Fig. 17), which, however, have been completely transformed. The formation of chlorite rock in its first phase is thus an alteration product of skarn minerals formed before or at the first crystallization of sphalerite. The sporadic occurence of tremolite within the footwall of the zinc ore serves to indicate this. It is also probable that some olivine crystallized primarily as talc-pseudomorphs with the crystal form of olivine have been locally observed within chlorite schist.

The pyritic sulphide ores were accompanied by or just preceded by an enrichment in biotite (and some actinolite), the biotite later on becoming unstable and for the most part altered to ripidolitic-prochloritic chlorite,[1] while the formation of the zinc ore, which is regarded as less high-hydrothermal, was accompanied by an alteration of earlier formed gangue minerals. A successive formation of gangue minerals probably occurred, beginning with relatively high-temperature minerals, while the parts of the solutions last to crystallize directly formed re-

[1] At the chloritization of actinolite a mineral is formed the composition of which is closer to that of clinochlorite.

latively low-temperature minerals, the minerals first crystallized being at the same time more or less altered.

The corroded appearance of the crystallization of chlorite and talc in relation to sphalerite indicates that they are at least partly recrystallized minerals, since the gangue minerals within certain parts of the footwall side of the zinc ore are evidently replaced by sphalerite.

According to what is known at present about the distribution of the extreme chlorite-bearing rocks, the extension of these rocks decreases towards the lowest levels contemporaneously with the approach of the ore-bearing zone toward the Jörn granite. It is as yet too early to say if this has anything to do with a decrease of the ore towards deeper levels.

## Remnants of quartz porphyry (albite-porphyry) within sericite quartz schist.

Within the south-western part of the mine area, remnants of albite-porphyry occur. The outermost part of the 170 m level exhibits some rather well-developed quartz-porphyries with visible albite phenocrysts. The rocks are more or less sericitized or biotitized with an enrichment in streaks or layers which make the rock appear quite schistose. The appearance and alteration of the rock is similar to the one described earlier from Hornträsket (p. 9). Judging from the structure of some of the rocks with well-developed euhedral albite phenocrysts, these appear to have been flows. It is not possible to say to what degree tuffs or tuffitic rocks may have been present.

The composition and degree of alteration of some of the rocks will be seen from the volumetric analyses of rock samples from the 170 m level (Table 19) far from the ores.

**Table 19. Quartz-porphyries (albite-porphyries), sericitized and biotitized. Per cent of volume.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Quartz | 38 | 33 | 37 | 41 | 40 | 42 | 50 |
| Albite phenocrysts | 18 | 19 | 3.3 | 15 | 11 | 3 | 3.8 |
| Albite in groundmass | 18 | 8 | 29 | 8 | 11 | 18 | 15 |
| Sericite | 16 | 29 | 11 | 23 | 27 | 19 | 9 |
| Biotite | 8 | 2.5 | 19 | 11 | 7.5 | 17 | 22 |
| Chlorite | 1.6 | 8 | 0.2 | 1.9 | 3 | | tr. |
| Pyrite | 0.1 | tr. | 0.4 | tr. | | 0.4 | |
| Apatite | 0.1 | | 0.1 | tr. | 0.2 | 0.2 | 0.2 |
| Rutile | 0.2 | 0.3 | | 0.1 | 0.3 | 0.1 | tr. |
| Epidote, orthite | tr. | | tr. | tr. | | tr. | |
| Sillimanite | | 0.2 | | | | | |
| Titanite | tr. | | | | | | |

No silicification of the rock has occurred, but biotitization is observable. This rock area is at the outer boundary of the sericite-biotite-quartz schists, which have their chief distribution south of Kristineberg.

The plagioclase of the rocks is an albite with the composition about $An_5$.

The phenocrysts are better preserved than the albite of the groundmass. Biotite and sericite are often intergrown. In the direction of the strongest absorption the colour of the biotite passes from greenish brown over turbid brown to violet brown. The biotite is altered to a chlorite varying between prochlorite and clinochlore.

## Ores.

As a result of mining operations, the following chief ore lenses have been distinguished:

The A ores, chiefly pyritic ore on the footwall side and zinc ore on the hanging-wall side, wich are developed as $A_1$ the chief ore body, with a complex *en échelon* continuous to the W, recently united under the name of $A_3$, with $A_4$ further to the W. The B ores: $B_1$ a pyritic ore S of $A_1$, chiefly developed as a quartzitic or dry ore in the eastern part; the $B_2$ ore, a relatively thin but continuous copperpyrite ore S of $B_1$; the $B_3$ ore, a pyritic and dry ore S of the western $B_2$ ore; The C ore is a pyritic ore low in copper E of $A_1$; The D ore is similar and is *en échelon* with and E of the C ore.

The sulphide ores of Kristineberg were deposited chiefly along fissure zones at the southern slope of a protruding wedge of a Jörn-granite anticline. The ores were mainly formed by replacement of the wall rocks, volume for volume, in a multiple wave of mineralization. Replacement is often so complete that the original structures have been quite obscured.

The ores may be divided into the following subspecies: pyrite ore with a low content of copper, often below 1 %; copper-pyrite ore (wet ore), which is a pyritic ore with chalcopyrite (Cu above 1 %); dry ore or quartzitic ore, which is a sericite-quartz schist or chlorite-quartz schist with a pronounced impregnation of chalcopyrite and pyrite; and zinc ore, which is composed chiefly of pyrite and sphalerite and which may pass over into a chalcopyrite-rich pyrite ore at its footwall. — There are also transitionary phases towards the wall rock.

### $A_1$ ore, pyritic ore.

The A-ores are complex ores, dominantly pyritic, but with a prominent pyrite-sphalerite ore generally situated on the hanging-wall side of the pyrite ores. The chief ore is the $A_1$ ore, which continues westwards with the irregular $A_3$ ore complex. Further to the W there is the pyritic $A_4$ ore.

The pyritic ore on the footwall side is usually much broader than the zinc ore on the hanging-wall side, at least at higher levels. In some places, however, the zinc ore widens at the cost of the pyrite ore. On the 170 m level the pyritic ore attains a length of 350 m and a maximal breadth of 15 m. It is narrowest in the central part, about $2\,^1/_2$ m being the smallest width. It is rather poor in copper here. A section of the $A_1$ ore with surrounding rocks is reproduced in Fig. 18.

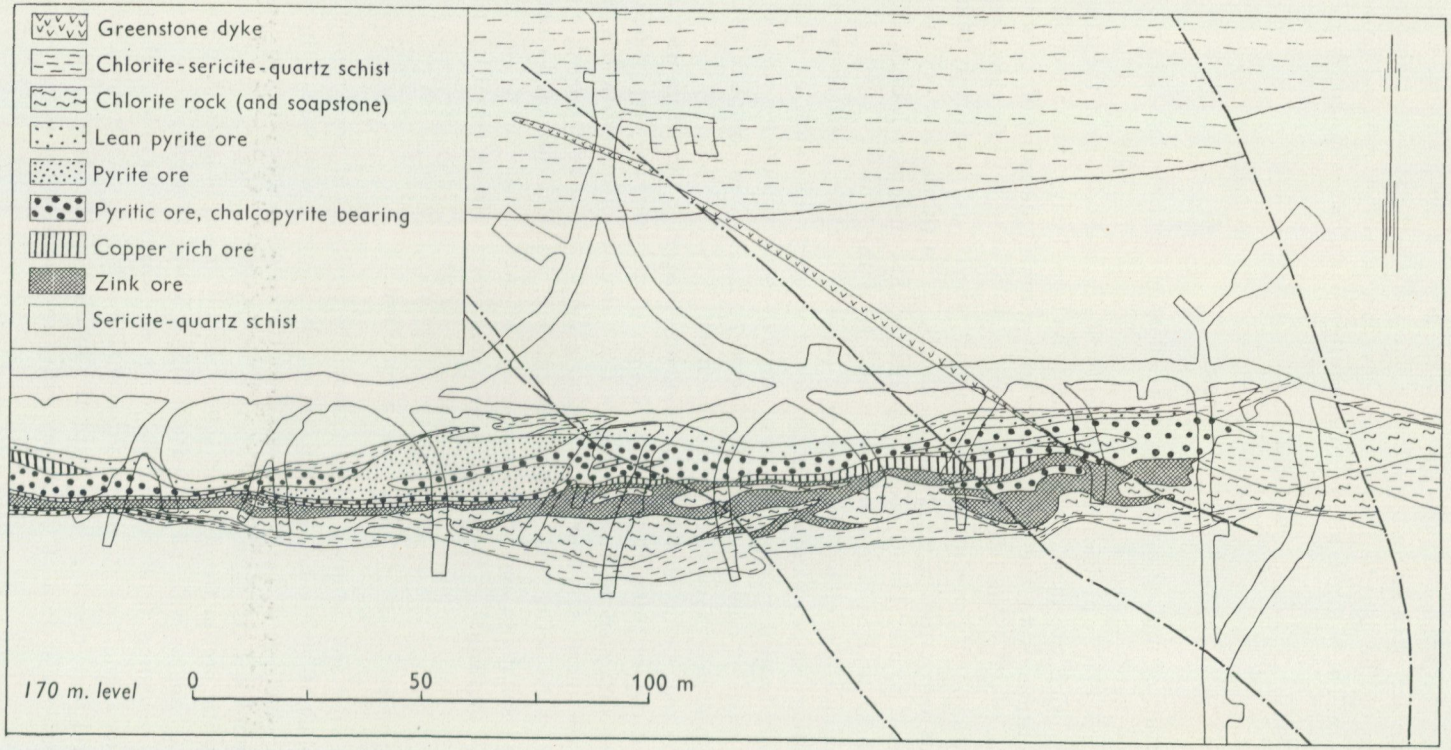



Fig. 18. Eastern and middle part of the $A_1$ ore, 170 m level. Sericite-quartz schist and sericite-chlorite-quartz schist are white.



Fig. 19. Chloritic pyrite ore with brecciating veins of chalcopyrite, which is accompanied by some quite dense chlorite. Crosscut 112, 90 m level. × 6.

The ore may be divided into three different types, *viz* a chloritic, rather lean ore on the footwall side, a rather solid pyrite ore in the middle, and a rather copper-rich ore on the hanging wall side at the contact to the zinc ore. Where this ore is particularly rich in chalcopyrite, it is generally thin, and it sometimes passes gradually over into copper-rich zinc ore. As shown by the 170 m map (Pl. 2), the distribution of the ores is rather irregular. There may also be pyritic ores in the zinc ore.

At the contact to the footwall a transitionary zone generally occurs with a rich impregnation of pyrite in a chlorite-sericite-quartz schist.

The gangue minerals common in the ore are chlorite, then quartz, and in addition sericite in some parts and actinolite in others. Sericite is thus common on the footwall side and actinolite on the hanging-wall side. Sometimes a little talc or tourmaline may occur, and sporadically epidote or some carbonate. Sericitized cyanite has been observed in one area, barite in another, and fluorite in a third. A little rutile occurs accessorily and also traces of apatite.

Pyrite is the dominant ore mineral. Chalcopyrite occurs very irregularly in the footwall ore, generally as brecciating veins in chloritic pyrite ore (cf. photo, Fig. 19). Chalcopyrite is finer grained than pyrite, which appears as single specks. Sphalerite occurs only as an accessory in the footwall ore, but it may be plentiful in the copper-rich hanging-wall ore.

Magnetite occurs sporadically as solitary grains or occasionally as impregnation strips. It is as granular as the pyrite, but the grain size is smaller, and it is generally more corroded than the pyrite.

**Table 20. $A_1$ ore, pyritic ore. Mineral composition in per cent of volume.**

| | Footwall ore | | | | | Middle ore | | | | | | | | Hanging-wall ore | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| Pyrite | 46 | 39 | 45 | 60 | 53 | 72 | 40 | 62 | 77 | 74 | 87 | 65 | 67 | 73 | 78 | 55 | 67 | 48 |
| Chalcopyrite | | 1 | 8 | 14 | 17 | tr. | 0.1 | 3 | 1.1 | 7 | 9 | 15 | 18 | 9 | 10 | 20 | 20 | 25 |
| Sphalerite | tr. | | 0.1 | 0.1 | | | | 0.1 | tr. | tr. | tr. | 0.3 | 0.3 | 5 | 0.6 | tr. | 2 | 2 |
| Quartz | 0.8 | 0.4 | 6.5 | 0.1 | 5.8 | 17 | 12 | | 7 | 5.4 | 1.2 | 1 | | | 3 | 1.9 | | 2 |
| Chlorite | 52 | 49 | 40 | 25 | 24 | 9 | 44 | 23 | 12.5 | 6 | 2.2 | 18 | 5.2 | 0.2 | 5 | 15 | 3 | 8 |
| Sericite | | 10 | | | | 1.5 | 3.2 | | 2 | 2 | 0.4 | 0.6 | | | | 8 | | |
| Actinolite | | | | 0.1 | | | | 8 | | 0.6 | | | 9 | 12 | 0.1 | | 0.4 | 15 |
| Talc | | | | 0.6 | | | | 3.9 | | | | | 0.5 | 0.8 | | tr. | 0.4 | tr. |
| Rutile | 0.2 | 0.6 | 0.1 | tr. | 0.1 | | 0.3 | tr. | | | 0.2 | 0.1 | tr. | tr. | | 0.1 | | |
| Apatite | | | 0.2 | tr. | 0.1 | | tr. | tr. | | | | | | | | | 0.1 | |
| Tourmaline | 1 | | | | | 0.5 | | | 0.4 | | tr. | | | | | | 0.1 | |
| Epidote (orthite) | | | 0.1 | | tr. | | 0.4 | | tr. | | | | | | | | | |
| Graphite & molybdenite | tr. | | | | | | | | | | | | | | tr. | | | |
| Carbonates | | | | 0.1 | | | | | | | | | | | | | 1 | |
| Magnetite | | | | | | | | | | | | | | | 0.3 | | 1 | |
| Bismuth mineral | | | tr. | | | | | | | | | | | | | | | |
| Vallerite | | | | | | | | | | | tr. | | | | | | | |
| Intermediate grain size: Pyrite (mm) | 2 | 2 | 2 | 0.5 | 0.5 | 2.5 | 2 | 1 | 1.5 | 2 | 1.5 | 2 | 0.5 | 1 | 1.5 | 1.5 | 1.5 | 2 |
| Chalcopyrite | | | | 0.1 | | | | 0.07 | 0.1 | 0.1 | 0.15 | 0.08 | 0.2 | 0.15 | 0.15 | | 0.3 | 0.6 |



Fig. 20. Chloritic pyrite ore with chiefly pyrite in dense, chloritic matrix, showing a streak rich in chalcopyrite. Crosscut 112, 90 m level × 1/6.

Now and then molybdenite accessorily occurs together with the gangue minerals. Scheelite has been observed three times close to quartz-tourmaline inclusions and twice alone. Vallerite may occur as very fine grains within chalcopyrite.

The pyrite grains[1] are sometimes slightly crushed, and may be replaced by chalcopyrite along fractures. Close to the zinc ore intergrowth of sphalerite in chalcopyrite or chalcopyrite in sphalerite sometimes replaces the pyrite. However, chalcopyrite generally occurs as a matrix to the pyrite grains together with gangue minerals. Even the gangue minerals may corrode the pyrite, especially chlorite but occasionally also sericite.

Veins of limonite have been observed penetrating chalcopyrite, and sometimes pyrite or sphalerite. A few times chalcocite has also been observed to brecciate and replace chalcopyrite. O. Ödman has also observed covelite to replace chalcopyrite.

Minute cavities have sometimes been observed in samples of pyrite ore.

Table 20 shows the mineral composition of some typical ore samples as seen in thin sections and polished sections. It is seen that the abundance of ore minerals is less in the footwall-ore than in the others. The content of chalcopyrite is low but very irregular. In the hanging-wall ore it is often abundant. Streaks rich in chalcopyrite may also occur in some parts of the intermediate ore section.

[1] The cubic form of the crystals is often evident.

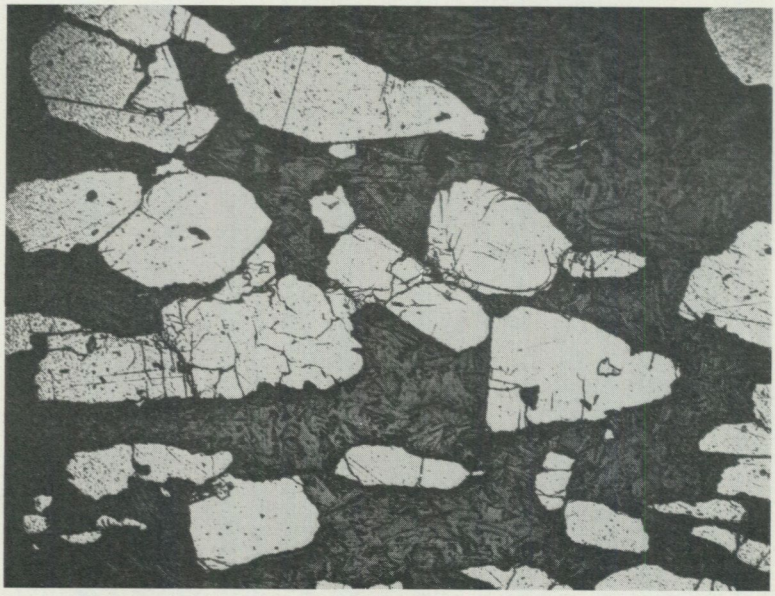


Fig. 21. Microphoto of chloritic pyrite ore. × 11.

The footwall-ore is often a granular pyritic ore rich in chlorite matrix; cf. Fig. 20 reproducing the photo of the ore in a crosscut, and Fig. 21 giving a microphoto of ore with large, irregular pyrite grains in a fine-grained matrix of chlorite. In this ore, chalcopyrite generally occurs as irregular veins here and there, so that only certain parts of this ore may be designated as copper-bearing pyrite ore. In some places the matrix between the pyrite grains is chiefly quartz instead of chlorite.

Copper-rich ore from the middle ore and hanging-wall ore is illustrated by the photos, Figs. 22 and 23, showing chalcopyrite as veins in pyritic ore or brecciating it. The latter represents a very copper-rich ore with a breccia-like appearance.

Figs. 24 and 25 show microphotos from the same copper-rich ore, with pyrite grains strongly corroded by chalcopyrite. The vein-like or breccia appearance of most of the chalcopyrite in the pyritic ores indicates that it is crystallized decidedly later than pyrite.

A section across the $A_1$ ore at crosscut 214 on the 170 m level shows sericite-quartz schist in the footwall followed toward the S by two metres of chloritic, lean pyrite ore, then sulphide ore with much chlorite followed by solid sulphide ore with streaks of chlorite, which becomes richer in chalcopyrite on the hanging-wall side towards the zinc ore. At the contact between the sulphide ore and the zinc ore there is generally a transitionary zone from chalcopyrite-rich ore with some sphalerite to a copper-rich zinc ore. Sometimes chlorite-schist, however, may separate the sulphide ore from the zinc ore.

The hanging-wall pyritic ore containing chalcopyrite generally has some

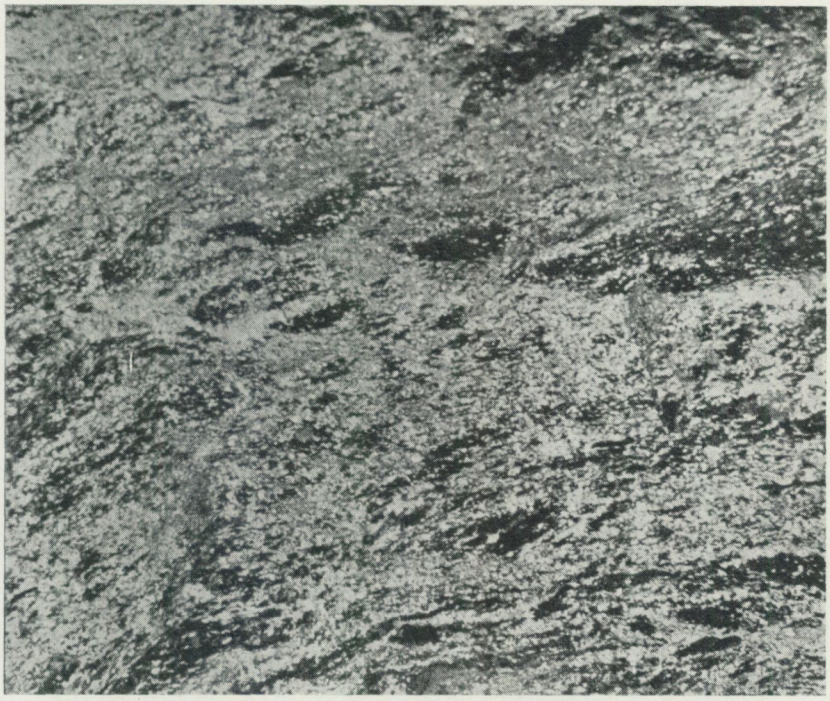
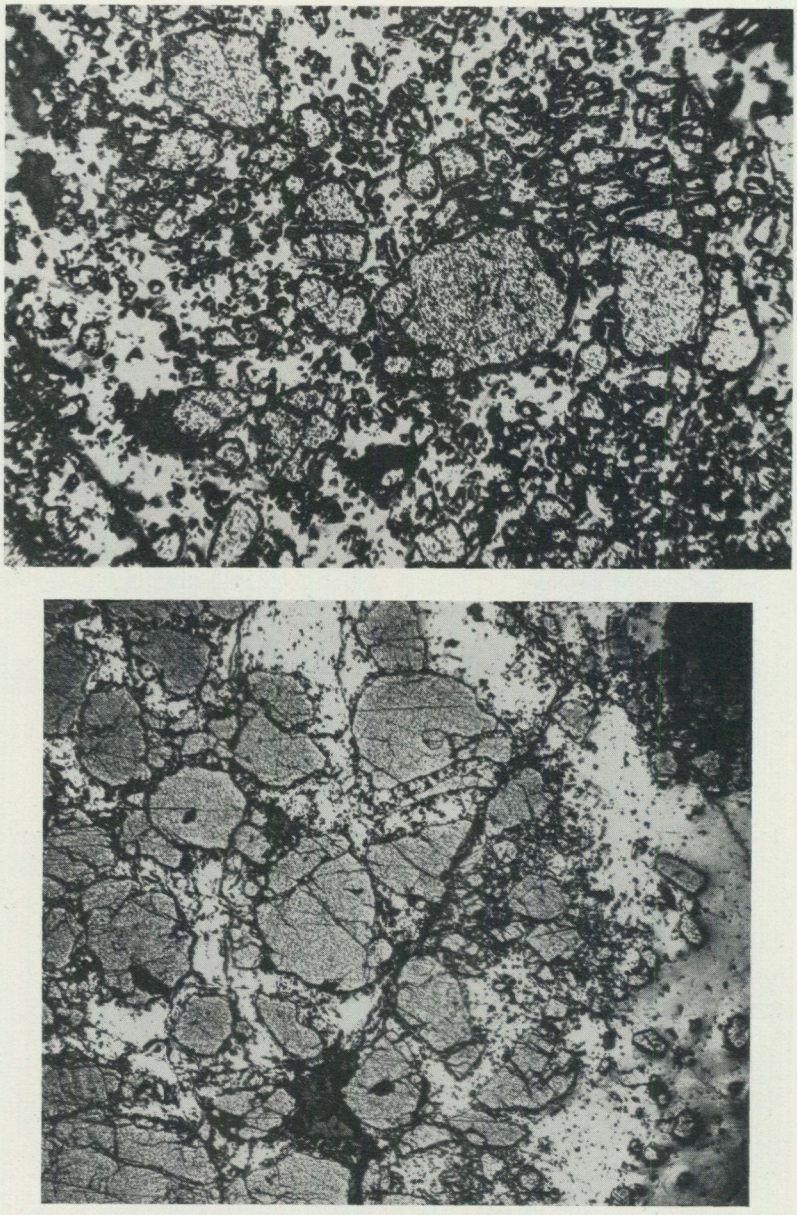


Fig. 22. The whitest streaks are chalcopyrite brecciating pyrite ore. Dark is chloritic matrix. × 5.



Fig. 23. Copper-rich ore. Chalcopyrite appearing as breccia. Crosscut 230, 170 m level.



Figs. 24 and 25. Chalcopyrite as matrix to pyrite which is corroded and partly replaced by the chalcopyrite. Crosscut 230, 179 m level. × 13 and 11.

actinolite which may preponderate over the chlorite. This amphibole may still be found within the zinc ore, but it is then more tremolitic in composition.

A sample from each section of the pyritic ore has been chemically analyzed, *viz* footwall ore, intermediate ore, and hanging-wall ore, as shown in Table 21.

**Table 21. Pyritic ores, $A_1$ ore.**
Analyst A. G. Hybbinette.

| Number<br>Position<br><br>Ore type | 153<br>Footwall ore<br>Crosscut 218<br>Chloritic sulphide ore | 139<br>Middle ore<br>Crosscut 156<br>Sulphide ore with actinolite | 150<br>Hanging-wall ore<br>Crosscut 228—230<br>Copper-rich sulphide ore |
|---|---|---|---|
| $SiO_2$ | 17.50 | 9.30 | 3.77 |
| $TiO_2$ | 0.13 | 0.07 | 0.02 |
| $Al_2O_3$ | 7.62 | 3.41 | 0.94 |
| Fe (total) | 30.99 | 36.08 | 42.10 |
| MnO | 0.07 | 0.10 | 0.01 |
| MgO | 6.71 | 5.13 | 1.13 |
| CaO | 0.03 | 1.09 | 0.06 |
| BaO | | | tr. |
| $Na_2O$ [1] | 0.03 | 0.07 | 0.03 |
| $K_2O$ [1] | 0.01 | 0.01 | 0.016 |
| $H_2O+$ | 4.00 | 2.33 | 0.58 |
| $H_2O-$ | 0.17 | 0.16 | 0.13 |
| $P_2O_5$ | 0.03 | 0.02 | 0.02 |
| S | 29.07 | 38.14 | 46.61 |
| Cu | 2.44 | 3.40 | 3.53 |
| Zn | | tr. | 0.49 |
| Pb | | | tr. |
| Cd | | | tr. |
| Hg [4] | | | 0.00003 |
| Mo | | | 0.003 |
| Co | | | 0.008 |
| Cr | tr. | tr. | tr. |
| As | tr. | | 0.006 |
| Se | | | 0.004 |
| Te | | | 0.002 |
| F | | 0.09 | 0.03 |
| Cl | | | 0.01 |
| B [2] | | 0.001 | |
| $+O_2$ | 1.55 | 0.90 | 0.50 |
| | 100.32 | 100.30 | 100.00 |
| Ag g/t | 33 | 38 | 38 |
| Au g/t | 0.4 | 2.3 | 1.8 |
| Sp. gr. [3] | 3.66 | 4.15 | 4.57 |
| Mineral composition: | | | |
| Pyrite | 49.7 | 64.9 | 81 |
| Chalcopyrite | 7.0 | 9.8 | 10.2 |
| Sphalerite | 0.1 | tr. | 0.7 |
| Molybdenite | | tr. | |
| Magnetite | | | 1.0 |
| Rutile | 0.1 | 0.1 | |
| Actinolite | | 9 | 0.2 |
| Quartz | 7 | 0.1 | 2.4 |
| Chlorite | 36 | 15 | 4.5 |
| Talc | | 1 | |
| Apatite | 0.1 | tr. | tr. |
| Epidote | tr. | | |
| Tourmaline | | 0.1 | |
| | 100.0 | 100.0 | 100.0 |

[1] S. Henriksson. — [2] K. E. Funcke — [3] O. Alvfeldt. — [4] G. Herlin.

**Table 22. Chemical analyses of actinolite and chlorite.**

| Actinolite: Analysis by Th. Berggren | | | Ripidolite: Analysis by N. Sahlbom | |
|---|---|---|---|---|
| | | Mol. prop. | | Mol. prop. |
| $SiO_2$ | 51.96 | 8 651 | 25.36 | 4 222 |
| $TiO_2$ | 0.40 | 63 | 0.50 | 78 |
| $Al_2O_3$ | 4.58 | 449 | 21.32 | 2 091 |
| $Fe_2O_3$ | 2.53 | 158 | 3.15 | 197 |
| FeO | 8.06 | 1 122 | 17.31 | 2 410 |
| MnO | 0.40 | 56 | 0.14 | 20 |
| MgO | 18.52 | 4 593 | 22.52 | 5 585 |
| CaO | 11.68 | 2 083 | 0.00 | |
| Hg [3] | 0.0006 | | | |
| BaO | 0.00 | | | |
| SrO | 0.00 | | | |
| $Na_2O$ [1] | 0.40 | 65 | tr. | |
| $K_2O$ [1] | 0.05 | 5 | tr. | |
| $H_2O+$ | 0.22 | 122 | 9.43 | 5 234 |
| $H_2O-$ | 0.02 | | 0.18 | |
| F | 0.92 | 484 | 0.00 | |
| Cl | 0.02 | 6 | 0.00 | |
| S | 0.15 | 47 | 0.00 | |
| $P_2O_5$ | 0.02 | 1 | 0.14 | 10 |
| Cu | | | 0.00 | |
| | 99.94 | | 100.05 | |
| -O (to F) | 0.39 | | | |
| | 99.55 | | | |
| Sp. gr. [2] | 3.00 | | 2.80 | |
| $\alpha$ | 1.622 | Straw-coloured | 1.613 | Bluish green |
| $\beta$ | 1.635 | Olive brownish green | | |
| $\gamma$ | 1.645 | Bluish green | 1.620 | Green |
| $\gamma-\alpha$ | 0.023 | | 0.004 | |
| $\gamma-\beta$ | 0.009 | | | |
| $2V\gamma$ | 97° | | Small | |
| $c:\gamma$ | 15.5° | | | |

[1] S. Henriksson. — [2] O. Alvfeldt — [3] C. Herlin.

As is usually the case, the footwall ore has the lowest content of ore minerals. It has been sampled out of a chalcopyrite-veined type, and all three ore types are richer in copper than the average ore.

The composition of the ore minerals is that common for Kristineberg, with pyrite preponderating over chalcopyrite and few other minerals. The copper-rich ore close to the zinc ore contains some magnetite, which otherwise is typical for zinc ore.

Chlorite, the dominating mineral of the gangue, varies somewhat in composition. It is prochloritic or ripidolitic in the footwall ore and gradually becomes richer in magnesium towards the zinc ore.

The actinolite of the middle ore and chlorite from the footwall ore of crosscut 218 have been analyzed (Table 22).

The highest and lowest refractive indices for the actinolite varies between 1.618 and 1.052. If the content of sulphur is calculated as pyrite, aluminium and silica as combined, titanium as joined with iron and magnesium, manganese



Fig. 26. Typical zinc ore. Dark gray is inclusions of chloritic rock, white is granular pyrite, and the grayish groundmass is composed of very fine-grained sphalerite together with talc and some chlorite. × 1.



Fig. 27. Typical zinc ore. The bright coloured stripes in the middle are rich in pyrite. × 1/10.

and alkalies with calcium, fluorine and chlorine with water, the proportions 8.34: 5.29: 1.99: 0.64 are obtained instead of the theoretical 8 : 5 : 2 : 2. The amphibole as well as the chlorites within the ore is relatively dry, i. e. they are deficient in water. The content of fluorine in the amphibole is high and it is thus reminiscent of the actinolite from Pierrepont according to Kunitz and Ford (N J Min, BB 1930).

The chlorite is a typical ripidolite from the footwall side of the ore (crosscut 218). It possesses a somewhat anomalous gray (yellowish black) birefringence. Chlorite from the footwall side of the ore at another crosscut has the same indices of refraction. The chlorite from the actinolite-bearing ore, which lies in the intermediate ore, is richer in magnesium with refractive indices as follows: $\alpha$, $\beta = 1{,}580$. This mineral is thus closer to pennine in composition.

### $A_1$ ore, zinc ore.

The zinc ore occurs chiefly along the hanging-wall side of the A ore. It is a pyrite—sphalerite ore, in which the pyrite generally preponderates. The pyrite is granular and easily detectable, while the sphalerite is fine-grained and generally occurs as a groundmass, between the pyrite grains, together with the gangue and other sulphides. As the sphalerite is also very light in colour it is not readily perceivable. The zinc ore, on the other hand, is easily recogniz-



Fig. 28. Transition from pyritic ore, undermost, to dense zinc ore uppermost. The intermediate part is rich in chalcopyrite. × 1/14.

able because of its special gray tone. It generally contains balls and slabs of a dense, chloritic rock. The ore itself is more fine-grained and lighter in colour than the pyrite ore. The groundmass thus consists not only of sphalerite, but also of much talc, while the dark chlorite chiefly occurs as ball-like inclusions.

The photos, Figs. 26 and 27, show common types of ordinary, more or less stripy zinc ore, in which the chloritic slabs and the granular pyrite are conspicuous while sphalerite and talc are concealed in the groundmass. The photos, Figs. 28 and 29, show transitions from granular pyritic ore to dense, light-coloured zinc ore, and from chloritic sulphide ore to dense, grayish zinc ore.

The zinc ore is often irregular; it is sometimes thin and sometimes thick, and often split, particularly at the ends. It may also be intrusive into the sulphide ore sending offshots into that ore. Thin apophyses of zinc ore often occur separately on the hanging-wall side. At the contact to the hanging wall some very large, porphyritic pyrite crystals have been observed.

The wall rock on the hanging-wall side is generally dense chlorite with transitions towards soapstone. This rock may be disseminated with sphalerite and pyrite. Such a rock also occurs here and there within the ore with all stages of impregnation of the sulphide minerals. The small balls, slabs, or *schlieren* of chloritic rock, which were seen in Figs. 26 and 27, can reach large dimensions and may divide one part of the zinc ore from the other. It is rarer for such a rock to



Fig. 29. Transition from chloritic sulphide ore, with bright-coloured, brecciating chalcopyrite (undermost) to dense, pale grayish zinc ore (uppermost). The undermost part of the zinc ore is rich in chalcopyrite. The contact with the pyritic ore is here rather sharp. × 1/17.

contain so much sphalerite as to be looked upon as ore. The formation of the zinc ore, especially the hang, evidently originated at a lower temperature than the chalcopyrite-bearing pyrite ore and it could not so completely replace the wall rock as the latter. The hang of the zinc ore has thus plenty of slab-like inclusions of altered rocks. It may also appear as apophyses in cracks in surrounding rock or ore.

The inclusions in the zinc ore have often been rounded or bent by later movements along it.

To show variations in the composition of the zinc ore, Table 23 has been compiled from typical ore samples (polished sections and thin sections).

The prominent ore minerals in mean order of abundance are pyrite, sphalerite, chalcopyrite, and galena. Magnetite is also rather common. Rich zinc ore can be richer in sphalerite than pyrite and in this case the sphalerite always appears as a groundmass to the pyrite grains.

Sphalerite often more or less replaces pyrite. The photo, Fig. 30, shows a common type of zinc ore with corroded pyrite in a groundmass of homogeneous sphalerite. The pyrite may also appear as almost square grains. It is, however, seldom quite euhedral. When fractured the pyrite could more easily be replaced by late-crystallizing sulphide minerals.

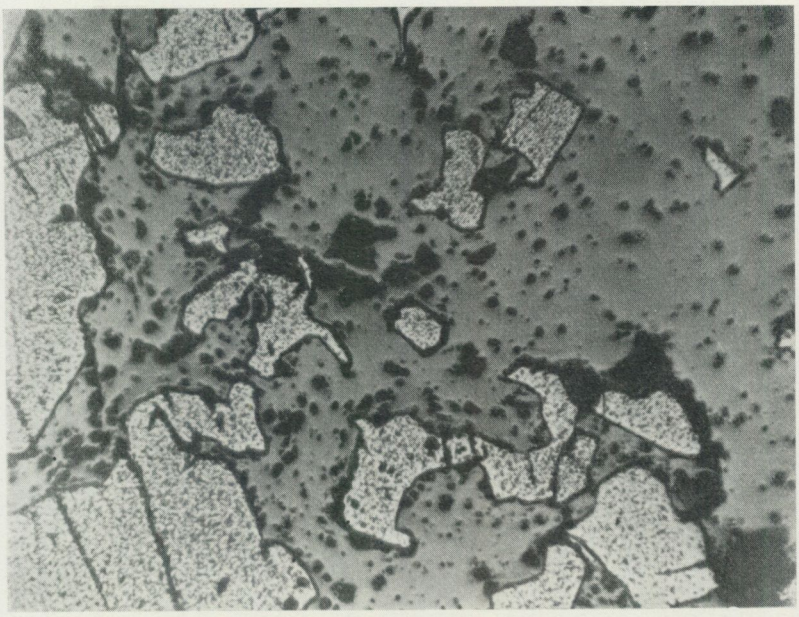


Fig. 30. Zinc ore. Pyrite with groundmass of sphalerite. The pyrite is strongly corroded and replaced by sphalerite. × 50.

The zinc ore is sometimes rather crushed, and in those cases even the pyrite appears as small grains or aggregates of small grains. This crushing of the ore is late in origin and may have originated at the same time as the slickensiding of the hanging-wall rock. In homogeneous zinc ore the intermediate grain size of pyrite is about 1 mm, and in crush-brecciated ores it is about 0,3 mm in size. Other sulphide grains and gangue minerals are of about the general size of 0,1 mm with much variation. Because of a mosaic-like intergrowth, the ore may often contain small sulphide grains of the magnitude 0,02 mm. In very crushed zinc ore, the general size of the ore grains may be of this order of magnitude.

Chalcopyrite and sphalerite often occur mutually within each other, the included mineral then appearing, in a similar form, whether it be chalcopyrite or sphalerite. When the percentage of zinc is high the chalcopyrite thus occurs within the sphalerite, while the opposite takes place in copper-rich ore. In zinc ore poor in copper the chalcopyrite appears as very fine grains within the sphalerite.

Galena generally appears as breccia-like inclusions within the sphalerite or chalcopyrite. It often seems to have crystallized contemporaneously with these minerals, but sometimes it replaces them. As breccia-like grains of sphalerite or chalcopyrite can also be seen within galena, it may be deduced that all three minerals for the most part crystallized contemporaneously. The microphoto, Fig. 31, shows sphalerite and galena jointly replacing pyrite.

**Table 23. Zinc ore. $A_1$. Mineral composition. Vol. %.**

| Number of sample... | 219 | 242 | 264 | 255 | 253 | 241 | 225 | 237 | 279 | 235 | 236 | 226 | 239 | 152 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crosscut or stope.... | 6 | 222 | 172 | 106 | 106 | 222 | 2 | 216 | | 216 | 208 | 116 | 212 | 218 | 212 |
| Level..... | 85 | 170 | 130 | 90 | 90 | 170 | 150 | 170 | 170 | 170 | 170 | 90 | 170 | 170 | 170 |
| Hanging-side ore .... | | | x | x | | | x | | | x | x | x | | | x |
| Footwall ore ..... | | | | | x | x | | | x | | | | x | x | |
| Pyrite ..... | 20 | 32 | 30 | 48 | 46 | 25 | 53 | 34 | 12 | 42 | 59 | 41 | 40 | 54 | 41 |
| Sphalerite ..... | 55 | 50 | 50 | 41 | 36 | 36 | 35 | 33 | 32 | 31 | 30 | 29 | 27 | 27 | 27 |
| Chalcopyrite ..... | 0.4 | 1 | 0.2 | 4.6 | 1.4 | tr. | 1 | 5 | 0.2 | 3.5 | 0.1 | 0.4 | 8 | 0.3 | tr. |
| Galena ..... | 0.3 | tr. | 2.9 | 0.1 | | 0.6 | 0.5 | 1.1 | 3.5 | 1 | tr. | 2 | 1.7 | 2 | 1.7 |
| Magnetite ..... | | | tr. | 1.3 | 2.5 | | 0.1 | 3 | 6 | 1.5 | 0.9 | 0.2 | 0.3 | 0.1 | 0.8 |
| Tetrahedrite ..... | | | 0.1 | | | | | | 5 | | | | | | |
| Bismuth ..... | | | tr. | | | tr. | | | 0.1 | | | | | | |
| Chalcocite ..... | | | | | | | | | | | | | | | |
| Smithsonite etc. ..... | 1 | 0.1 | | | 0.1 | | | | tr. | | | 0.1 | 3 | | 3.5 |
| Chlorite ..... | 8 | 4 | 12 | 4 | 1 | 8.3 | 0.4 | 4 | 15 | 7 | 9 | 11 | 10 | 2.6 | 16 |
| Talc ..... | 8 | 8 | 4.4 | 1 | 12 | | 10 | 18 | 26 | 6 | 1 | 15 | 10 | 14 | 10 |
| Quartz ..... | 4 | 4.7 | 0.3 | | | 30 | | | | | | | | | |
| Apatite ..... | 0.1 | 0.2 | tr. | | | 0.1 | | | 0.1 | | | 0.2 | | tr. | |
| Rutile ..... | | | | | | | | | | | | 0.1 | | | |
| Tremolite ..... | 0.2 | | | | | | | 1.9 | 0.1 | 8 | | | | | |
| Tourmaline ..... | | | tr. | | | | | | | | | | | | |
| Colour of sphalerite... | grayish brown | yellowish brown | pearl brown | pearl brown | dark brown | light-coloured | dark brown | brown | pearl brown | dark brown | light-coloured | light-coloured | pearl brown | dark brown | pearl brown |
| Groundmass ..... | ZnS | ZnS | ZnS | ZnS | ZnS | ZnS + quartz | ZnS | | talc chlorite | ZnS | — | ZnS + gangue | — | ZnS | gangue + ZnS |
| Ore type ..... | compact | compact | granular | compact | breccia-like granular | breccia-like granular | compact | breccia-like | slabby | breccia-like | breccia-like | granular ball-bearing | dense, breccia-like | breccia-like | layered, breccia-like |
| Medium size of small ore grains ..... | 0.05 | 0.05 | 0.1 | 0.06 | 0.06 | 0.02 | 0.08 | 0.03 | 0.08 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 |

| Number of sample | 244 | 243 | 233 | 249 | 245 | 246 | 148 | 151 | 250 | 179 | 247 | 248 | 251 | 274 | 147 | 304 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crosscut or stope | 224 | 222 | 214 | 228 | 224 | 226 | 212 | 228 | 230 | 170 | 226 | 228 | 232 | | 212 | 2 |
| Level | 170 | 170 | 170 | 170 | 170 | 170 | 170 | 170 | 170 | 130 | 170 | 170 | 170 | 170 | 170 | 75 |
| Hanging-side ore | | x | | x | x | | x | | | x | x | | | x | | |
| Footwall ore | | | x | | | x | | x | x | | | | x | | x | |
| Pyrite | 36 | 43 | 55 | 37 | 43 | 48 | 48 | 39.8 | 50 | 27 | 59 | 55 | 58 | 48 | 50 | 46 |
| Sphalerite | 25 | 25 | 22 | 22 | 20 | 18 | 19 | 17 | 16 | 17 | 14 | 11 | 6.9 | 2 | 18 | 37 |
| Chalcopyrite | 1.5 | 0.9 | 5.5 | 0.2 | 7 | 5 | 0.5 | 2 | 1.7 | 1.1 | | 3.6 | 8 | 16 | 18 | 1.2 |
| Galena | 2.5 | 0.2 | 0.5 | 0.7 | 1 | 1 | 5 | 1 | 0.3 | 0.2 | 1.3 | 0.4 | | | 0.4 | |
| Magnetite | 2 | | 1 | | | | 1 | tr. | 1 | | | | | 11 | 1 | 0.8 |
| Tetrahedrite | | | | | | | | tr. | | | | | | | | |
| Bismuth | | | | | | | | tr. | | | | | | tr. | | |
| Chalcocite | | | | | | | | | | | | | | tr. | | |
| Smithsonite etc. | | | | | | | 2 | tr. | | | 0.5 | | | | 0.4 | |
| Chlorite | 5 | 8.9 | 10 | 16 | 15 | 8 | 24 | 20 | 10 | 44 | 5 | 16 | 27 | 19 | 9 | 6 |
| Talc | 28 | 22 | 6 | 24 | 14 | 20 | tr. | 20 | 21 | | 20 | 14 | | 4 | 1 | 3 |
| Quartz | | | | | | | | | | 10.5 | 0.2 | | | | 0.1 | |
| Apatite | tr. | | | 0.1 | tr. | | 0.1 | 0.1 | | tr. | tr. | tr. | 0.1 | tr. | 0.1 | |
| Rutile | | | | | | | 0.1 | 0.1 | | 0.2 | | | tr. | | tr. | tr. |
| Tremolite | | | | | | | 0.3 | | | | | | | | 1 | 6 |
| Colour of sphalerite | light-coloured | brown | brown | pearl brown | brown | pearl brown and dark brown | brown | yellowish brown | yellowish brown | | light-coloured | light-coloured | brown | | brown | dark brown |
| Groundmass | — | talc | — | talc chlorite | — | ZnS + talc | ZnS + chlorite | talc | talc + ZnS | chlorite | ZnS + talc | talc chlorite | — | — | ZnS + $CuFeS_2$ | ZnS |
| Ore type | dense, breccia-like | breccia-like | dense | breccia-like schistose | slabby | dense, slabby and brecciated | brecciated | granular, ball-bearing | breccia-like schistose | breccia-like ball-bearing | granular breccia-like | slabby | breccia-like, | granular | breccia-like ball-bearing | granular |
| Medium size of small ore grains | 0.02 | 0.05 | 0.03 | 0.03 | 0.03 | 0.02 | 0.08 | 0.04 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.1 | 0.03 | 0.1 |

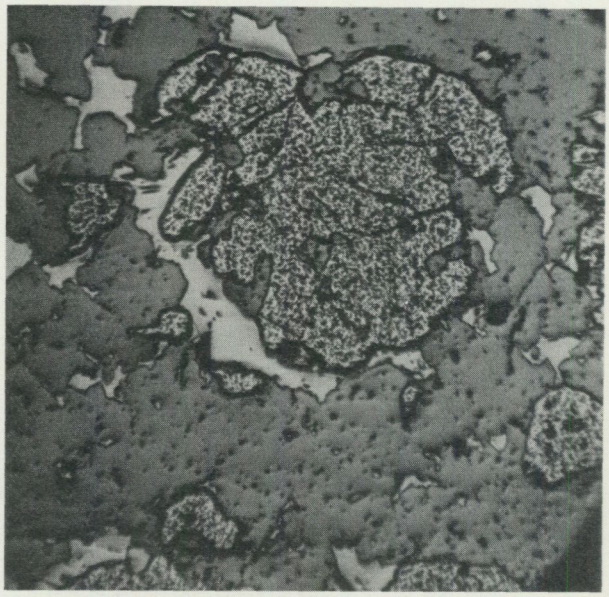


Fig. 31. Sphalerite and galena replacing pyrite. × 35.

Zinc ore relatively rich in lead along the hanging wall has often some content of tetrahedrite. The intergrowth of this mineral with galena generally indicates that they crystallized contemporaneously. As the photo, Fig. 32, shows they often crystallized a little later than sphalerite. Very small, bright white grains or lamella-like grains of bismuth or bismuthite sometimes appear within galena and occasionally also within chalcopyrite or tetrahedrite.

Sphalerite, chalcopyrite, and galena appear to be similar in the replacement of pyrite. Some gangue minerals, particularly talc and chlorite which often replace pyrite, may also replace the other sulphide minerals mentioned above. Zinc ore, rich in gangue minerals, thus often has a strongly corroded sphalerite with very irregular outlines and rather small grain size. Magnetite, however, is the ore mineral which is most strongly corroded by the silicate minerals. It is generally anhedral and often poikiloblastic.

The general order of crystallization may have been approximately the following: Pyrite and magnetite – – – chalcopyrite – sphalerite – – galena – – chlorite-talc. Sphalerite continued to crystallize also after chalcopyrite. Chlorite and talc are partly hydrothermally altered minerals which originally may have crystallized before the ore minerals. As very few remnants of such earlier minerals have been observed, it is hard to say to what degree this may have occurred. The later gangue minerals (chlorite and talc) received other crystal forms than the earlier ones and the original material was generally more or less transferred. It is probable that much of the chlorite (chlinochlorite, penninite, antigorite) and talc crystallized directly.

In Table 13 the ore types are arranged according to decreasing content of

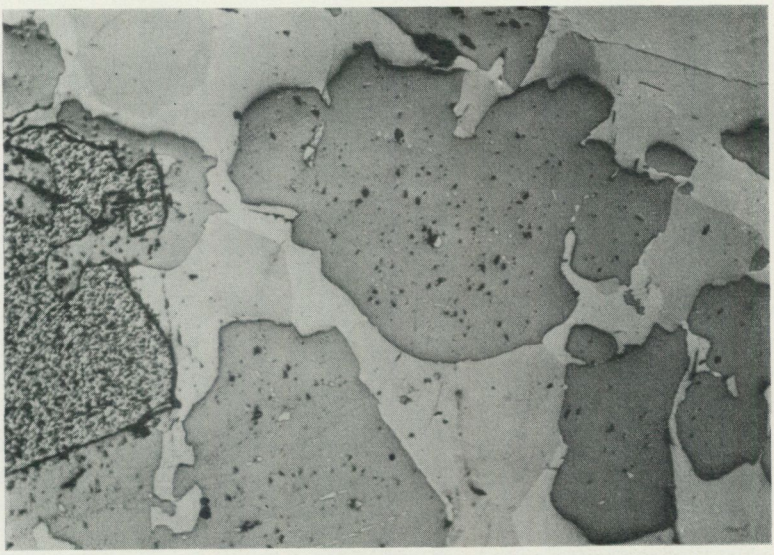


Fig. 32. Galena (white) and tetrahedrite (pale gray) replace sphalerite, which itself replaces pyrite. × 35.

sphalerite. Since the mineral composition in these analyses is calculated from polished sections and thin sections, the composition of large inclusions in the ore could not be included in the analyses. Accordingly the composition of the ores in the table are higher in ore minerals than (mined) ore is in general. The table shows if the sample was taken out of hanging-wall ore or footwall ore, what is the colour of the sphalerite sample, which are the chief minerals of the groundmass, and the average size of the grains of the groundmass. The type of ore is also given, *viz* if it is breccia-like, contains balls or slabs of chloritic rock, if it is dense (quite fine-grained) or granular.

As a rule, the footwall side of the zinc ore is relatively rich in chalcopyrite, while the hanging-wall side is generally poor in copper, but may be rich in galena although without any transition to lead ore. The hanging-wall ore is generally lighter in colour than the footwall ore, due to a groundmass richer in talc. The sphalerite of the hanging-wall ore is often lighter in colour than the sphalerite of the foot-wall ore, but that is a rule with many exceptions.

The zinc ore rich in lead often contains some tetrahedrite and occasionally traces of rarer minerals, such as bismuth. The copper-rich footwall ore occasionally shows traces of chalcocite replacing chalcopyrite.

The common gangue minerals are chlorite and talc. These minerals dominate in the hanging-wall ore and they may sometimes also be the only gangue minerals of the footwall ore, although quartz is often prominent here just as in the pyritic ore close by. In this latter case the type of the chlorite is less magnesium-dominant and it may even be repidolitic in composition, as against the otherwise dominant clinochlorite-penninitic type of the zinc ore. Together

with the last-mentioned chlorite an antigoritic chlorite may also occur, sometimes intergrown with clinochlorite or penninite.

A small amount of a carbonate sometimes occurs in the groundmass, e. g. between sphalerite grains. It generally seems to be a zinc carbonate, but occasionally dolomite or magnesite also occurs.

The sphalerite is usually rather light-coloured in shades of yellow, yellowish brown, and brown. Because of the small grain size and the intergrowth with other minerals it is often hard to see the exact colour of the sphalerite and to determine the relative iron content of it. In order to determine variations in composition of the sphalerite, five different varieties have been chosen for analyses. The sphalerite grains have been crushed and the best material picked out, but because of the mineral's poikiloblastic growth it has not been possible to get it quite free from inclusions of chalcopyrite, galena, pyrite, talc, chlorite, or quartz. In order to show the composition of pure sphalerites these inclusions have been deducted in the lowermost part of Table 24. The spec. gravities were determined by G. Broström and F. Wickman.

**Table 24. Sphalerites picked out of zinc ore. $A_1$ ore. Per cent of weight.**
Analyst A. G. Hybbinette.

| | 277<br>Pale yellowish brown | 169<br>Yellowish brown | 264<br>Pale brownish | 219<br>Grayish brown | 304<br>Brown |
|---|---|---|---|---|---|
| S | 32.66 | 33.70 | 32.9 | 32.55 | 33.05 |
| Zn | 64.5 | 62.8 | 62.8 | 59.2 | 57.0 |
| Fe | 1.36 | 2.60 | 3.04 | 3.50 | 7.70 |
| Cd | 0.20 | 0.18 | 0.20 | 0.22 | 0.18 |
| Cu | 0.08 | 0.05 | 0.13 | 1.87 | 0.17 |
| Pb | 0.04 | tr. | 0.42 | 0.45 | tr. |
| Bi | tr. | tr. | tr. | tr. | tr. |
| MnO | 0.02 | tr. | tr. | 0.05 | 0.09 |
| $SiO_2$ | 0.95 | 0.1 | 0.9 | 1.20 | 1.15 |
| $Al_2O_3$ | tr. | tr. | tr. | 0.1 | < 0.2 |
| MgO | 0.15 | 0.1 | tr. | 0.30 | 0.80 |
| CaO | tr. | tr. | | tr. | tr. |
| $P_2O_5$ | tr. | tr. | | tr. | tr. |
| | 99.96 | 99.55 | 100.39 | 99.44 | 100.34 |
| Sp. gr. | 4.14 ± 0.04 | | | 4.14 ± 0.04 | 4.04 ± 0.04 |
| Calculated composition of pure sphalerite | | | | | |
| ZnS | 97.6 | 96.8 | 94.7 | 96.2 | 86.3 |
| FeS | 2.2 | 3.0 | 5.1 | 3.5 | 13 |
| MnS | | | | 0.1 | 0.2 |
| CdS | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

No. 304 is the darkest sphalerite observed in the ore. Yellowish brown to pale brown sphalerites are the most common. The weight percentage of iron in the Kristineberg sphalerites thus varies between 1 % and 8 %, 2 to 3 % is the most common proportion. The content of cadmium seems to be almost

constant — 0.2 % — and manganese is low, about $\frac{1}{100}$ of the iron content. The traces of Bi is probably due to very small grains of bismuth, which have occasionally been observed in polished sections. Small crystals of sphalerite observed within the mine outside the ore body, e. g. in quartz segregations, have all been light-coloured, generally pale yellowish brown. Such a pale yellowish brown sphalerite crystal with spec. gravity 4.1 was analyzed and found to contain: Zn 65.4 and Fe 0 4 % (Boliden Laboratory, Boliden). It is thus lower in iron than the light-coloured sphalerites of the ore.

Three different samples of zinc ore have been chemically analyzed (Table 25).

The chlorites of these ore samples are clinochlorite or penninite, but No. 147 has also some antigoritic chlorite. This mineral occurs partly individually as thin prisms or flakes and partly as a rim around the penninite-clinochlorite. The antigorite constitutes merely about $^1/_2$ of the rock.

The zinc ore on the 250 m level is somewhat more irregular than on the upper levels, and it is not distinctly separated from the pyritic ore. Sometimes it has a variable gangue mineral composition. Besides the common ore type with chlorite and talc as dominant gangue minerals, dolomite or magnesite occurs locally as matrix between the ore grains. Occasionally, tremolite and dolomite are the chief gangue minerals. The tremolite may occur alone or together with chlorite and talc. Tremolite and dolomite sometimes replace pyrite, but they themselves can be replaced by chalcopyrite, sphalerite, or galena, while chlorite and talc replace all these minerals.

The dolomite occurs irregularly. It may appear plentifully in which case it is cut by brecciating veins of ore minerals. The carbonate is occasionally cut by veinlets of limonite, which brecciate the outer parts of the dolomite and now and then cut the entire mineral, resulting in replacement of a great part of it. The dolomite may be more or less dissolved and precipitated, replacing other minerals close by. It seems probable that the perculating solutions producing the secondary limonite took part of the material from the iron-bearing sulphides and precipitated limonite as veinlets in the carbonate at the same time as some of this mineral was dissolved. Tremolite has not been influenced by the limonitic alterations. It is pale in colour and generally occurs as spherulites. A partial analysis of material picked out shows the following contents (in percentage of weight): $SiO_2$ 52.4, FeO 3.4, MgO 23.1, CaO 13.7, and $Al_2O_3$ 1.4 % (Boliden Laboratory, Boliden). It is a rather common type of tremolite.

The zinc proportion of the $A_1$ ore increases downwards. The zinc area of this ore is thus distinctly greater on the 250 m level than on the 170 m. The zinc content of the former is more than three times as large as the copper content of the ore. On the deepest level reached, 490 m, the zinc content of the ore seems to be still greater according to present knowledge.

### $A_3$ ore.

The western limit of the $A_1$ ore is rather irregular and fingers out in thin streaks. In the prolongation towards the W or WNW an uneven ore zone continues *en échelon* with imcompletely connected ores, formerly known as the

**Table 25. Analyses of zinc ores.**

| Analysis by | 147 B. Helger | 151 A. G. Hybbinette | 148 A. G. Hybbinette |
|---|---|---|---|
| Ore type | Copper-rich zinc ore | | Lead-rich zinc ore |
| Occurrence | Footwall ore Crosscut 212 | Footwall ore Crosscut 228 | Hanging-wall ore Crosscut 212 |
| $SiO_2$ | 3.49 | 10.64 | 6.99 |
| $TiO_2$ | 0.07 | 0.06 | 0.13 |
| $Al_2O_3$ | 1.2 | 2.25 | 3.4 |
| Fe total | 32.07 | 27.45 | 25.51 |
| MnO | 0.05 | 0.03 | 0.10 |
| MgO | 3.44 | 6.80 | 6.67 |
| CaO | 0.26 | 0.06 | tr. |
| BaO | 0.06 | | |
| $Na_2O$ [1] | 0.01 | 0.20 | 0.05 |
| $K_2O$ [1] | 0.02 | 0.024 | 0.01 |
| $H_2O$ + | 1.41 | 1.50 | 2.10 |
| $H_2O$- | 0.41 | 0.10 | 0.28 |
| $P_2O_5$ | 0.02 | 0.02 | 0.01 |
| S | 40.60 | 34.80 | 34.12 |
| Zn | 9.39 | 12.20 | 12.90 |
| Cu | 5.62 | 1.71 | 0.18 |
| Pb | 0.38 | 1.30 | 6.25 |
| Cd | tr. | tr. | 0.03 |
| Hg [3] | 0.0017 | 0.0021 | 0.001 |
| Ag | | 0.008 | 0.01 |
| Bi | | 0.006 | |
| Mo | | 0.001 | |
| As | | 0.003 | |
| Se | | 0.002 | |
| Te | | 0.004 | |
| Co | | 0.002 | |
| $CO_2$ | 0.16 | tr. | 0.49 |
| F | | 0.09 | |
| | 98.69 | 99.26 | 99.23 |
| + $O_2$ to Fe | 0.6 | 0.6 | 0.8 |
| | 99.29 | 99.86 | 100.03 |
| Sp. gr. [2] | 4.43 | 3.97 | 4.10 |
| Mineral composition: | | | |
| Pyrite | 56.5 | 50 | 50 |
| Chalcopyrite | 16.2 | 5.0 | 0.6 |
| Sphalerite | 14.2 | 18.9 | 18.9 |
| Galena | 0.4 | 1.5 | 7.2 |
| Tetrahedrite | | tr. | |
| Bismuth | | tr. | |
| Bismuthite | | tr. | |
| Magnetite | 1.5 | 1.4 | 2 |
| Smithsonite a o carbonates | 0.4 | | 1.2 |
| Barite | 0.1 | | |
| Rutile | tr. | 0.1 | 0.1 |
| Chlorite | 8.5 | 12 | 18 |
| Talc | 1 | 11 | 2 |
| Quartz | 0.1 | | |
| Actinolite | 1 | | |
| Apatite | 0.1 | 0.1 | tr. |
| | 100.0 | 100.0 | 100.0 |

[1] S. Henriksson. — [2] O. Alvfeldt. — [3] C. Herlin.

$A_2$ and $A_3$ ores but now combined as the $A_3$ ore. These ores are best known on the 170 m level, where they have been followed by drifts and by diamond drilling. They extend *en échelon* with about 3 m intermediate width and rather irregular outlines.

The easternmost body is chiefly a zinc-bearing pyritic ore with a variable and low content of copper. The middle of the ore is the richest with an intermediate content of about 4 % Zn and 1 % Cu. To the west, the ore is chiefly pyritic, but with a thin horizon of zinc ore along the hanging wall. The westernmost ore is a pyritic ore (with about 40 % S) low in copper and zinc.

The wall rock is chiefly quartz-chlorite schist sometimes altered into chlorite rock. As the ore zone here is thinner than along the $A_1$ ore, because of less extensive fissuring, the alteration of the wall rock has not gone so far, and the development of extreme Mg-minerals along the hanging-wall side is not so complete as along the large $A_1$ ore.

### $A_4$ ore.

The $A_4$ ore is a pyrite ore, about 130 m W of the $A_3$ ore, surveyed from the surface down to the 90 m level. It has an eastern—western extension of about 145 m with an average width of 8 m. The dip is about 39° to the S, and the pitch about 45° to the SW.

The ore is rather irregular in composition, with intercalations of sulphide-bearing sericite-chlorite schist. The zinc content is inconspicuous, and the copper content is generally also low, but there are some minor streaks rather rich in chalcopyrite on the foot-wall side of the ore. Locally small lumps rich in chalcopyrite have also been encountered in the middle part of the ore close to the surface. In average, however, the useful ore has a copper content of a few tenth of one percent, while the sulphur content will be somewhat above 30 %. The ore is denser and richer in pyrite on the hanging-wall side.

The commonest gangue minerals are quartz, sericite, and chlorite.

Between the ore and the surrounding quartz-sericite schist there is a quartz-chlorite schists, about one m wide, on the hanging-wall side, and a quartz-sericite-chlorite schist on the foot-wall side of the ore. There are also some sulphide disseminations or bands of copper-bearing pyritic ore on this side of the main ore body.

Much concretions of quartz-tourmaline veins have been met with on the foot-wall side of the $A_4$ ore.

The upper part of the ore is much weathered.

### $B_1$ ore.

The pyritic B-ores form a group of three chief ores on the hanging-wall side of the $A_1$ ore. The $B_1$ and $B_3$ ores are intermixtures of pyrite ore and dry ore, while the $B_2$ ore is pyritic, of considerable length in depth but shorter at the surface.

The $B_1$ ore is a sulphide ore complex horizontally situated about 130 m to the S of the A ore. It is chiefly developed as a quartzitic ore or dry ore in the



Fig. 33. Typical chalcopyrite-rich, quartz-rich dry ore. 170 m level. × 1/5.

eastern part and as a chalcopyrite-bearing pyrite ore in the western part, which really consists of several steep layers of pyritic ore separated by banks of sericite-quartz schist (or chlorite quartz schist).

### Quartzitic ore or dry ore.

The dry ore in the eastern part is a heterogeneous ore consisting of mixtures of quartzitic, copper-rich ore with banks of sericite or chlorite quartz-schists disseminated with pyrite, and some streaks of pyritic ore. The compact, pyritic ores are lower in chalcopyrite than the typical quartzitic ore, which is often rich in chalcopyrite and sometimes contains 5 % Cu over an area of a couple of metres. The content of gold is seldom above 1 gr/t on the upper levels. On the 250 m level the content of gold is often higher and megascopically visible flakes of gold have been seen there.

The content of sulphur varies between the high content of the compact pyritic ore and the low content of the quartz schist disseminated with pyrite, and brecciated by chalcopyrite veinlets (with about 10 % S). The content of zinc is low and unimportant (on an average below 0.1 % Zn). The richest ore is a chalcopyrite breccia in quartz schist of a type reproduced in the photo, Fig. 33.

The dry ore is generally composed of a mixture of chalcopyrite-brecciated quartz schist poor in micaceous minerals, with pyrite-rich streaks in sericite- or chlorite-quartz schist which often contains segregated masses of quartz.

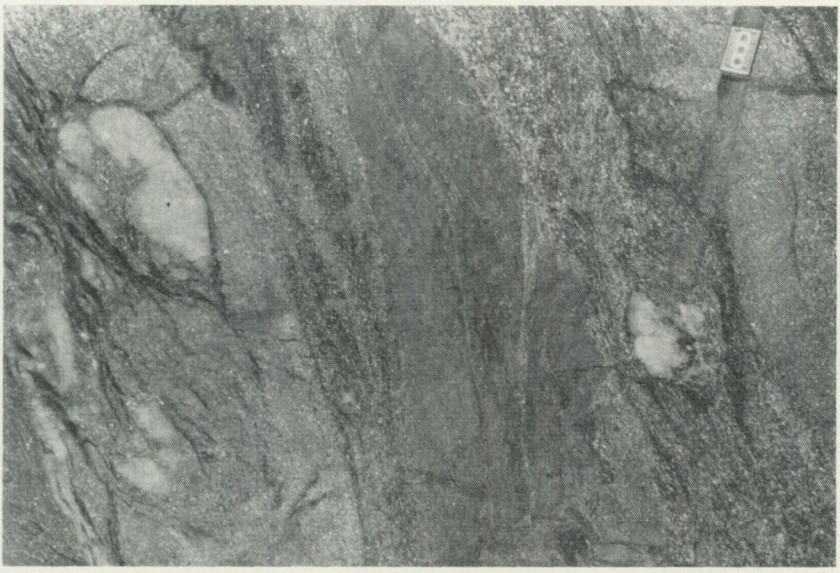


Fig. 34. Dry ore with almost pure quartz schist strips and quartz concretions. 90 m level. $\times 1/9$.

Chalcopyrite may also be enriched at the borders of the quartz concretions. The photos, Figs. 34 and 35, show such inhomogeneous ores. There are solitary, large pyrite crystals in the copper-rich parts, while pyrite predominates completely over chalcopyrite in the pyritic streaks.

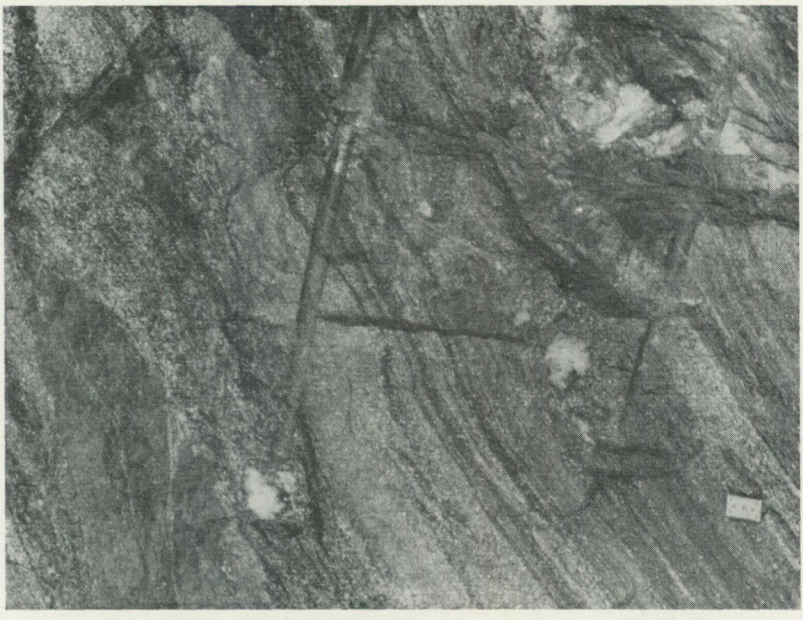


Fig. 35. Quartz-rich, pyrite-banded, lean dry ore. 90 m level. × 1/16.

**Table 26, $B_1$ ore, Volumetric analysis.**

| | Dry ore Eastern ore | | | | | | Wet ore Western ore | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 185 | 161 | 312 | 28 | 313 | 186 | 1162 | 1142 | 165 | 142 | 310 | 144 | 104 | 162 | 11 |
| Pyrite | 60 | 20 | 72 | 40 | 39 | 17 | 57 | 57 | 89 | 91 | 58 | 45 | 71 | 59 | 73 |
| Chalcopyrite | 5.8 | 8 | 11 | 14 | 17 | 20 | 0.2 | 2.2 | 2.2 | 2.5 | 4 | 8 | 10 | 15 | 20 |
| Sphalerite | tr. | tr. | 0.1 | 0.1 | 1.9 | tr. | 0.3 | 0.1 | | 0.2 | 0.1 | | tr. | 0.9 | tr. |
| Molybdenite | tr. | | tr. | tr. | tr. | 0.5 | | | | | | | | | |
| Quartz | 4 | 58 | 4.3 | 12.5 | 18 | 50 | 10 | 7.6 | 5 | 4 | 36 | 7 | 12 | 9.3 | 4 |
| Chlorite | 29 | 12 | 9 | 33 | 24 | 12.5 | | 0.5 | 0.8 | 1.2 | 0.9 | 30 | 3.9 | 0.2 | 1 |
| Sericite | 1 | 1.7 | 3.5 | | tr. | | 32 | 1 | 1 | 1.1 | 1 | 9.7 | 3 | 15 | 2 |
| Rutile | 0.2 | 0.2 | | 0.4 | 0.1 | tr. | 0.5 | | | | tr. | 0.2 | 0.1 | 0.1 | tr. |
| Apatite | | tr. | tr. | | | | tr. | | | | | 0.1 | | | |
| Epidote (orthite) | | 0.1 | | | tr. | | | | | | | tr. | | | |
| Tourmaline | | | tr. | | | | | 0.6 | 2 | tr. | | | | 0.5 | |
| Limonite | | | tr. | | | | | | | | | | | | |
| Marcasite | | | | tr. | | | | | | | | | | | |
| Grain size: | | | | | | | | | | | | | | | |
| Pyrite (in mm) | 1.2 | 2 | 2 | 0.6 | 1.5 | 1 | 2 | 2 | 1 | 1.2 | 1 | 1.5 | 2 | 2 | 2.5 |
| Chalcopyrite | 0.1 | Coarse breccia | 0.2 | 0.15 | 0.4 | Coarse breccia | 0.1 | 0.1 | 0.07 | 0.1 | 0.1 | | 0.25 | | 0.2 |

**Table 27. Copper-rich dry ore. Drift 201, 170 m level.**
Analyst A. G. Hybbinette.

| | | Mol. prop. | Mineral composition | |
|---|---|---|---|---|
| $SiO_2$ | 40.89 | 6 808 | Pyrite | 32.5 (per cent of |
| $TiO_2$ | 0.12 | 19 | Chalcopyrite | 16.6 weight) |
| $Al_2O_3$ | 3.51 | 344 | Quartz | 37.8 |
| Fe total | 22.89 | 4 099 | Chlorite (ripidolite) | 11 |
| MnO | 0.04 | 6 | Sericite | 2 |
| MgO | 1.58 | 392 | Rutile | 0.1 |
| CaO | < 0.03 | | Sphalerite | tr. |
| BaO | 0.02 | 1 | Apatite | tr. |
| $Na_2O$ [1] | 0.05 | 8 | Epidote | tr. |
| $K_2O$ [1] | 0.18 | 19 | Molybdenite | tr. |
| $H_2O+$ | 1.15 | 638 | | 100.0 |
| $H_2O-$ | 0.04 | | | |
| S | 23.17 | 7 227 | | |
| $P_2O_5$ | 0.02 | 2 | | |
| Cu | 5.76 | 906 | | |
| Zn | tr. | | | |
| Pb | tr. | | | |
| | 99.42 | | | |
| $O_2$ to Fe | 0.6 | | | |
| | 100.02 | | | |
| Sp. gr. [2] | 3.43 | | | |
| Ag | 19 gr/t | | | |
| Au | 4.3 gr/t | | | |

The matrix enclosing the sulphide minerals varies between chlorite-quartz schist, sericite-quartz schist, and rather pure quartz schist. The chlorite-sericite-quartz schist often contains an abundance of large quartz concretions. In the compact parts of the dry ore the common gangue minerals are quartz (dominating), chlorite, and sericite. Besides these and the usual accessory, rutile, following minerals occur sporadically: cyanite, tourmaline, talc, apatite, biotite, epidote, and rarely garnet, andalusite, sillimanite, and plagioclase.

The predominant ore minerals are pyrite and chalcopyrite. Molybdenite occurs more frequently in the dry ore than in any other Kristineberg ore and is often megascopically visible. An ore sample from the 90 m level shows a Mo content of 0.56 %. Generally it occurs only in traces. Graphite has also been observed at a few localities.

Table 26 shows the composition of ore samples from the $B_1$ ore with the dry ore in the left columns.

A typical section through the dry ore complex of the $B_1$ ore is best seen in crosscut 235 in the ESE part of 170 m level: Schistose sericite-chlorite-quartz schist occurs in the footwall to the N, followed to the S by sericite-quartz schist which passes over into chloritic pyrite ore with brecciating veins of chalcopyrite. This rock becomes rich in segregations of quartz, which often have rather chalcopyrite-rich rims. The ore passes over into a sericite-chlorite-quartz schist riche in concretions of quartz and streaks of sulphide impregnations with pyrite dominating over chalcopyrite. Some quartz concretions also contain tourmaline.

[1] S. Henriksson. — [2] O. Alvfeldt.

The width of the chalcopyrite-bearing ore is about 8 m. The footwall is here composed of chloritic ore and the hanging wall of quartzitic ore. Towards the hanging-wall side the ore passes over into quartz-rich sericite-chlorite-quartz schist with streaks of pyrite and but little chalcopyrite. This is followed by a rather white quartz schist containing a little sericite and chlorite and poor in sulphides, then by a two-metre-wide lean pyritic ore which is a branched continuation of a pyritic ore on the hanging-wall side of the dry ore farther westwards. The sericite-quartz schist on the hanging-wall side of this ore-streak toward the $B_2$ ore is rather rich in spherulites of cyanite described earlier (cf. photo, Fig. 15).

A typical, particularly rich, quartz-rich ore of the footwall side (170 m level) has been chemically analyzed, Table 27.

The analysis also shows traces of As, Cd, Co, Cr, Ga, Ni, and Sb according to spectrometric investigations.

### Pyritic ore or wet ore.

The western continuation of the $B_1$ dry ore is chiefly a pyritic ore of the usual Kristineberg ore type, poor in zinc. It is divided into several parallel but irregular layers, some of which are too thin to be stoped. An easterly part of this ore close to the dry ore is reproduced from a detail map, Fig. 36. The transition toward the dry ore is thus indistinct and very uneven. Just as there are strips of pyritic ore in the dry ore there are also lenses of dry ore within the pyritic western ore. Toward the W, the layers of pyritic ore generally thin out successively, although some are continued *en échelon* before the ore zone peters out. The $B_1$ ore is not productive in its whole length because of the thin layers of it, especially in the westernmost part.

This ore is generally a rather compact, pyritic ore with a content of copper far below that of the dry ore. The percentage of sulphur is somewhat lower for the whole western complex because of the inclusions of lenses of dry ore and wall rock. As elsewhere in the pyritic ores of Kristineberg, the content of chalcopyrite is irregularly distributed. One sample of compact ore may thus be almost devoid of chalcopyrite while another may be rich. The content of gold is not high and that of zinc quite insignificant.

The mineral composition of the ore is seen to the right in Table 26. Chalcopyrite generally occurs in the interstices between pyrite grains. Pure brecciating veins of chalcopyrite, which may occur in the dry ore, do not appear in the pyritic ore. Rutile and sphalerite only occur accessorily. In a south-eastern continuation of the ore, marcasite was observed as an alteration product of pyrite. In this ore streak the pyritic ore locally passes into a zinc-bearing ore.

As a fissure filling in the $B_1$ ore there occurs a white, chalk-like mineral, Kribergite (Du Rietz 1945). It is a water-bearing, aluminium-hydrate-sulphate-phosphate of secondary origin. Its composition is about 2 $Al_2O_3$ ($P_2O_5$, $SO_3$) 5 $H_2O$, but it is not quite constant. Intermediate refractive index is 1.484, birefringence 0.002, and sp. gr. 1.92. Crystal symmetry is low.

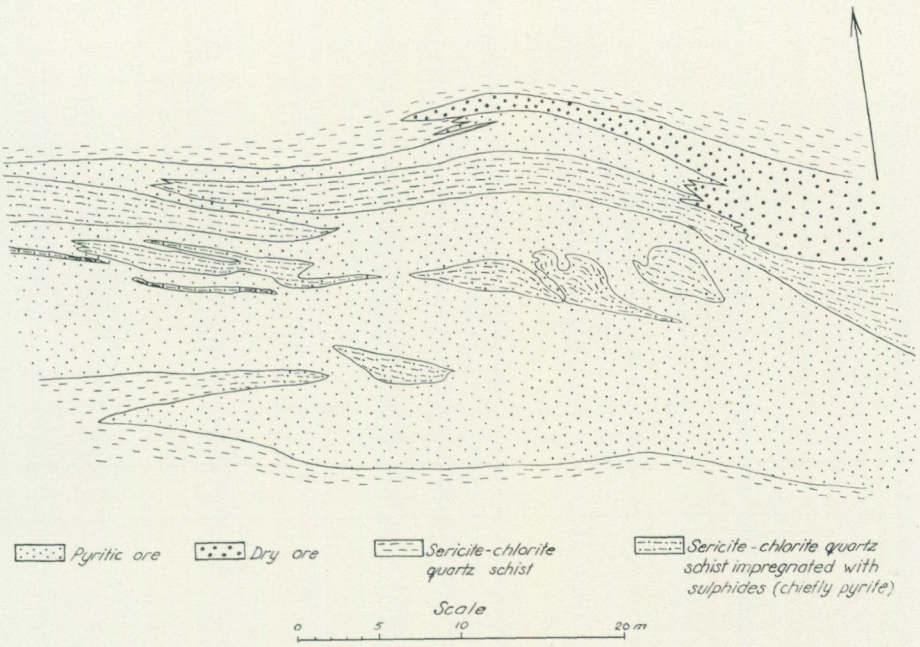



Fig. 36. An easterly part of the $B_1$ pyritic ore close to the dry ore showing irregular development of the ore (cutting into wall rock and partly replacing it with some inclusions of it floating in the ore). Stope 3, 61 m level.

### $B_2$ ore.

The $B_2$ ore is an extensive, lengthy, and uniform ore body with an average width of almost 4 m. It is rather narrow at the surface, but it is considerably extended on the 170 m level.

The $B_2$ ore strikes somewhat obliquely in relation to the $B_1$ ore. Its eastern part is thus far away from the $B_1$ ore (on the 170 m level about 60 m from it) while it almost touches it in the westernmost part. The prolongation of the $B_2$ ore towards the WNW thus almost points towards the $A_3$ ore and it may consequently be a continuation of the same zone of weakness (or fissuring). The $B_2$ ore has a straight and even course as compared with the $B_1$ ore, the eastern part of which is uneven with a main northern branch of dry ore and a southerly branch of pyritic ore, the direction of which does not differ very much from the course of the $B_2$ ore.

The composition of the ore is fairly constant. It is a pyritic ore with a moderate chalcopyrite content averaging 40 % S, 1.6 Cu, and 0.9 gr/t Au. As usual the content of copper is rather variable.

The wall rock surrounding the ore is generally a sericite-quartz schist or sericite-chlorite-quartz schist which may pass over into a chlorite-quartz schist at the margin of the ore. Gangue minerals in the ore are therefore chiefly quartz, sericite and some chlorite. The ore is a compact pyrite ore with chalcopyrite as small grains close to or surrounding the pyrite, but when accumulated as veins

it forms the groundmass around the pyrite grains. Other ore minerals are scanty. Sphalerite and rutile occur as accessories. Quite sporadically molybdenite, marcasite, limonite, or pyrrhotite have been observed as solitary grains. Pyrrhotite does not otherwise occur within the Kristineberg ore with the exception of a rare occurrence as fine microscopic grains within chalcopyrite (observed in one polished section within the $A_1$ ore). Besides the above-mentioned dominating gangue minerals quartz, sericite and ripidolitic chlorite, and apatite occur accessorily, and cyanite, talc, calcite, or tourmaline occasionally.

A large sample from the western part of the ore has been analyzed, Table 28. This ore sample is exceptionally low in copper, the content being about $^1/_3$ of what is usually the case.

**Table 28. $B_2$ ore. Crosscut 237, 170 m level.**
Analysis by the Boliden Laboratory, Boliden.

| | | Mol. prop. | Mineral composition | |
|---|---|---|---|---|
| $SiO_2$ | 14.42 | 2 398 | Pyrite | 78.5 weight % |
| $TiO_2$ | 0.10 | 16 | Chalcopyrite | 1.6 |
| $Al_2O_3$ | 2.86 | 281 | Sphalerite | 0.2 |
| Fe total | 37.2 | 6 662 | Quartz | 12 |
| MnO | 0.08 | 11 | Sericite | 4 |
| MgO | 0.63 | 156 | Chlorite | 3 |
| CaO | 0.24 | 43 | Cyanite | 0.6 |
| $Na_2O$ | tr. | | Rutile | 0.1 |
| $K_2O$ | 0.39 | 41 | Apatite | tr. |
| $H_2O+$ | 0.58 | 322 | | 100.0 |
| $H_2O-$ | 0.05 | | | |
| $P_2O_5$ | 0.02 | 1 | | |
| S | 42.4 | 13 225 | Sp. gr. | 4.17 |
| Se | 0.002 | | | |
| Cu | 0.56 | 88 | | |
| Zn | 0.11 | 17 | | |
| Co | 0.09 | 15 | | |
| As | 0.03 | 4 | | |
| Ni | 0.00 | | | |
| Pb | 0.00 | | | |
| | 99.74 | | | |
| $O_2$ to Fe | 0.2 | | | |
| | 99.94 | | | |
| Ag | 3 gr/t | | | |
| Au | 0.1 gr/t | | | |

Along the hanging-wall side between the 150 and 170 m levels, about 1 dm outside the rim of the ore, a thin coating of metallic copper was observed on a flat surface of the sericite-chlorite-quartz schist. It forms irregular plates about 1 mm thick (which became very much oxidized in the air)[1]. Somewhat higher up, but in the same position, on about the 150 m level close to the main ore, a thin layer with impregnation of chalcopyrite and pyrite was discovered, where the chalcopyrite was strongly brecciated by chalcocite. Sometimes chalcopyrite occurs only as inclusions within the chalcocite. Small grains of this

[1] Quite locally metallic copper has also been observed in quartz concretions on the footwall side of the C and D ores.

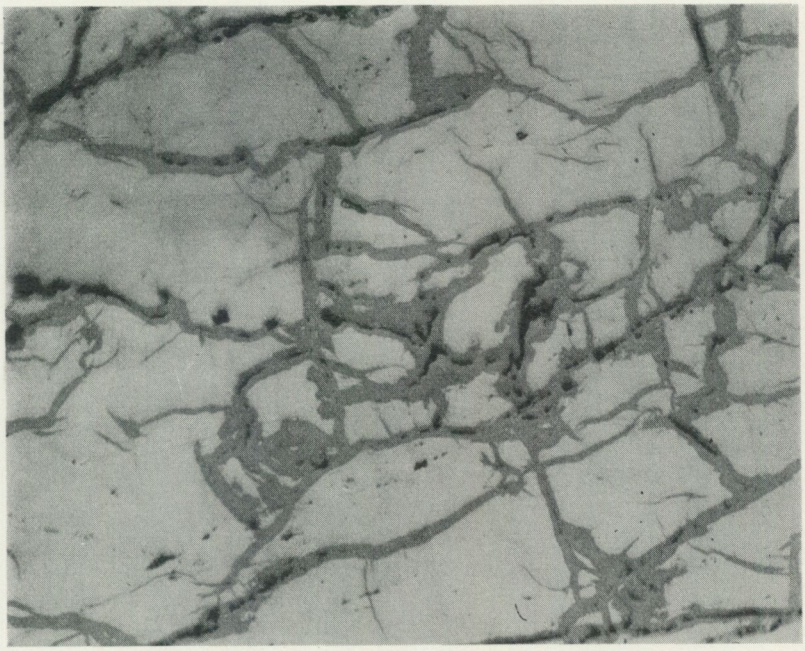


Fig. 37. Veinlets of chalcocite brecciating chalcopyrite. × 140.

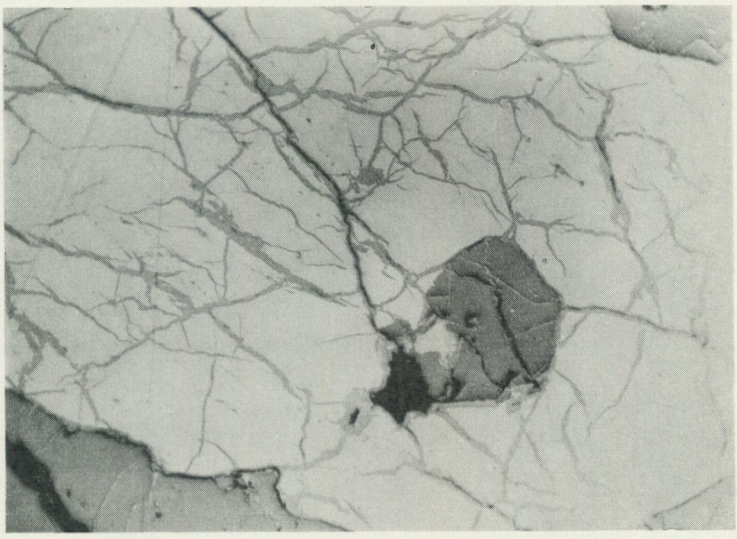


Fig. 38. Chalcocite as veinlets brecciating chalcopyrite and sphalerite. The sphalerite is not so extensively brecciated as the chalcopyrite, and the veinlets are thinner. The sphalerite is often surrounded by a thin coating of chalcocite against the chalcopyrite. × 120.

mineral were also found without any trace of remaining chalcopyrite. Usually the chalcocite appears as a network of veinlets through the chalcopyrite grains, as shown by the photos, Figs 37 and 38. Sometimes limonite occurs together with



Fig. 39. Chalcocite brecciating chalcopyrite and enveloping it in the surrounding gangue minerals and pyrite. Limonite appears in the middle of the veinlets or at the contact toward other minerals. × 120.

chalcocite, either as thin veinlets in the chalcocite (cf. Fig. 39) or on the border against surrounding gangue minerals.

Chalcocite has also been observed in the hanging-wall ore of $A_1$ pyritic ore brecciating chalcopyrite or chalcopyrite and sphalerite.

The chalcocite seems to be isotropic, but its appearance and its association with limonite shows that it is a low-temperature alteration product of chalcopyrite. The sulphides have been leached out of outcrops of the ore and the dissolved copper content has then been precipitated along fissures and slickensides chiefly along the borders of the ores. Through the action of oxidizing solutions an enrichment of copper sulphide has occurred at the expense of some iron sulphide, which has been oxidized and precipitated as limonite. Some copper has also been precipitated as metal. Along the hanging side of the $A_1$ zinc ore the schistosity and the slickensiding of the wall rock is great, and percolating solutions from above have reached the 250 m level showing much secondary precipitation of limonite (cf. p. 87).

### $B_3$ ore.

The $B_3$ ore is situated south of the western part of the $B_2$ ore. It is a mixture of dry ore and pyritic ore, and it generally has a rather quartz-rich groundmass. It is smaller than the $B_1$ och $B_2$ ores, and it generally has a lower content of sulphur than those two ores. The content of copper is often low, but it is the ore richest in gold at Kristineberg. A local section over a width of two metres shew a content of 46 gr/t Au. The extent of the ore is less on the 170 m level than on the upper levels, but it is more extensive again on the 250 m level.

On this level the ore is relatively richer in copper and sulphur than on the upper levels, and the content of gold has also increased. The western part of the ore on this level contains some streaks with magnetite impregnation.

The $B_3$ ore is rather uneven with varying percentages, especially of copper. The dry ore is usually richer in copper than the pyritic ores. The zinc content is inconspicuous and generally below 0.1 %. The dry ore varies between chlorite-quartz schist or sericite-quartz schist impregnated mostly with pyrite and quartz schist with brecciating chalcopyrite and an impregnation of pyrite. There are often concretions of quartz and also regular pyritic ore with quartz matrix. Quartz dominates among the gangue minerals, and chlorite[1] is more abundant than sericite. Actinolite has occasionally been observed.

The pyrite ore variety is generally not so compact as in the similar ores described above.

The ore is often split up at the eastern and western limits and there are often inclusions of wall rock within the ore.

A complete chemical analysis has been made of a large sample of ore from the 170 m level, Table 29.

**Table 29. $B_3$ ore, pyritic ore. Crosscut 229, 170 m level.**
Analysis by A. G. Hybbinette.

| | | Mol. prop. | Mineral composition | |
|---|---|---|---|---|
| $SiO_2$ | 30.54 | 5 085 | Pyrite | 69.0 weight % |
| $TiO_2$ | 0.02 | 3 | Chalcopyrite | 0.2 |
| $Al_2O_3$ | 0.09 | 9 | Magnetite | 0.1 |
| Fe total | 32.39 | 5 801 | Quartz | 30.0 |
| MnO | 0.01 | 1 | Sericite | 0.5 |
| MgO | 0.04 | 10 | Chlorite | 0.2 |
| CaO | tr. | | Rutile | tr. |
| $Na_2O$ [2] | 0.03 | 5 | Apatite | tr. |
| $K_2O$ [2] | 0.02 | 2 | Sphalerite | tr. |
| $H_2O+$ | 0.10 | 56 | Molybdenite | tr. |
| $H_2O-$ | 0.17 | | | 100.0 |
| $P_2O_5$ | 0.01 | 1 | | |
| S | 36.12 | 11 266 | | |
| Cu | 0.04 | 6 | | |
| Zn | tr. | | | |
| Mo | 0.001 | | | |
| Co | 0.005 | 1 | | |
| Cr | 0.01 | 2 | | |
| Hg [4] | 0.0004 | | | |
| Ni | tr. | | | |
| As | 0.01 | 1 | | |
| Se | 0.003 | | | |
| F | 0.01 | 5 | | |
| | 99.62 | | | |
| $+O_2$ to Fe | 0.2 | | | |
| | 99.82 | | | |
| Au | 0.7 gr/t | | | |
| Sp. gr. [3] | 3.90 | | | |

It is a quartz-rich pyrite ore almost free from copper, also low in gold.

[1] Ripidolite or diabantite. — [2] S. Henriksson. — [3] O. Alvfeldt. — [4] C. Herlin.

### C and D ores.

The western limit of the C ore is situated *en échelon* on the south-eastern side of the boundary of the $A_1$ pyritic ore, while the D ore follows *en échelon* on the south-eastern side of the C ore. Both these ores have been investigated by drilling from the surface, and the C ore has also been investigated on the 170 m level as well as the western part of the D ore.

The C and D ores are surrounded by an aureole of sericite-chlorite-quartz schist which locally passes into rocks rich in chlorite and talc.

The matrix between the sulphide grains of the ore is generally dominantly quartz with chlorite (generally ripidolite but with variations toward clinochlorite, delessite, or diabantite), but sometimes also sericite. Traces of apatite, biotite, talc, rutile, and remnants of probably olivine and pyroxene have been observed. A characteristic feature of these ores, particularly the C ore, is represented by streaks and bands of magnetite impregnation. Magnetite is anhedral and fine-grained with a grain size much smaller than that of the pyrite. The impregnation is locally so abundant that magnetite is more plentiful than pyrite. Magnetite impregnation may be lacking. In order of crystallization magnetite may be later than pyrite, as it often corrodes the latter to some extent or even replaces it along the borders.

The C and D ores are lean pyritic ores with a low content of chalcopyrite. The copper content may locally be as high as 1 %, but it is usually below 0.1 %. About the same is true of sphalerite. In the western part of the D ore the zinc content may locally be high, e. g. in one drill hole 7.2 % Zn and 1.4 % Cu for a width of 3.1 m, while otherwhere it is often lacking.

Judging from electric measurements at the surface, the D ore attains an extension of almost 300 m, with a width of about 3 m according to the drill holes, while the area of the C ore is somewhat less. From the surface to the 170 m level the width of the C ore is more than doubled. The average content of sulphur at the same time increases from about 31 % to 35 % S, but the content of Cu is still low. The western part of the D ore is also higher in sulphur on the 170 m level. In average it is slightly lower in sulphur than the C ore. The area is a little larger than at the surface.

The C and D ore have not yet been investigated on the 250 m level.

## Tectonics.

Most of the rock complexes within the mine area are quite schistose. It is only the best preserved parts of the granite porphyry that show a homogeneous, non-schistose structure. The ores also acquire a plate-like appearance through orientation of the flat inclusions and the micaceous gangue minerals.

The rock complexes dip to the S in the eastern and middle part of the mine area and to the SSW in the western part (the strike of the $A_3$ ore is toward N 63° W). The angle of the dip is somewhat variable with values between 30° to the S and 90°. An average for the different levels is about 52° for 90 m

level, 55° for 130 m level, 57° for 170 m level, the angle becoming somewhat steeper for deeper levels. The dip of the ore bodies is generally conformable with the dip of the schistosity of the walls rocks. The pitch of the fold axis of both folds and linear structure of the rocks and the ores is also conformable, and the pitch is most easily derived from the linear structure of the schists. The pitch of the fold axis is generally uniform but with minor undulations. The dip of the pitch thus varies between 20° and 65°, and the direction of it between S 80° W and S 40° W. Transverse folding has been observed in a few places. An average of the pitch and linear structure for the upper levels of the mine gives the following values: 90 m level 36° S 59° W, 130 m level 37° S 58° W, and 170 m level 42° S 61° W. On the 250 m level it is somewhat steeper than on the 170 m level and it is yet steeper on the 490 m level.

The direction of the pitch observed in the quartz schist by the $A_3$ ore is on the average about 10° more westerly (about S 70° W on the 170 m level) than by the $A_1$ ore.

Fissuring: Under strong pressure with shearing, probably developed at the end of the late folding during the developement of the Revsund granite complex, some zones of weakness yielded to pressure and were opened to shearing and fracturing. Such zones of weakness may for instance be the contact between the volcanics and the Jörn granite, and especially the projection of the anticline of Jörn granite into the albite porphyries at Kristineberg will have been an area where the stress resulted in a zone of fracturing.[1] These fissures in the outer aureole of the local Revsund massive were probably opened by the ore solutions coming from the Revsund granitization. The predilection of the albite porphyry for fracturing is explained by its brittleness as compared with the granite porphyry.

The $A_1$ ore represents the area of greatest fissuring. The complexity of this ore shows that its fissures or zone of fissuring has been opened or widened several times. The strong alteration of the wall rocks is due to the size of the fissure zone with a resulting greater flow of solutions, and to renewed flows of ore solutions.

The $A_3$ ore represents a long but rather thin zone of fissuring. The composition of the ore is analogous with that of the $A_1$ ore, which indicates that about the same type of solutions precipitated the ore though under less favourable circumstances, resulting in an uneven and thinner ore and also less alteration of the wall rock.

The direction of the $B_2$ ore points towards the $A_3$ ore, and the original fissure may have been a continuation of the $A_3$ fissure zone, but the composition of the $B_2$ ore indicates that its zone of fissuring must have been filled and solidified during the first phases of ore deposition since the zinc ore is lacking as well as the rather extensive alterations of the wall rocks, which characterize the A ores.

[1] This position of the ore at the prolongation of a Jörn granite anticline may be compared with the location of the Boliden ore in a dragfold in the porphyry close to the contact with the overlying slate (Ödman 1940).

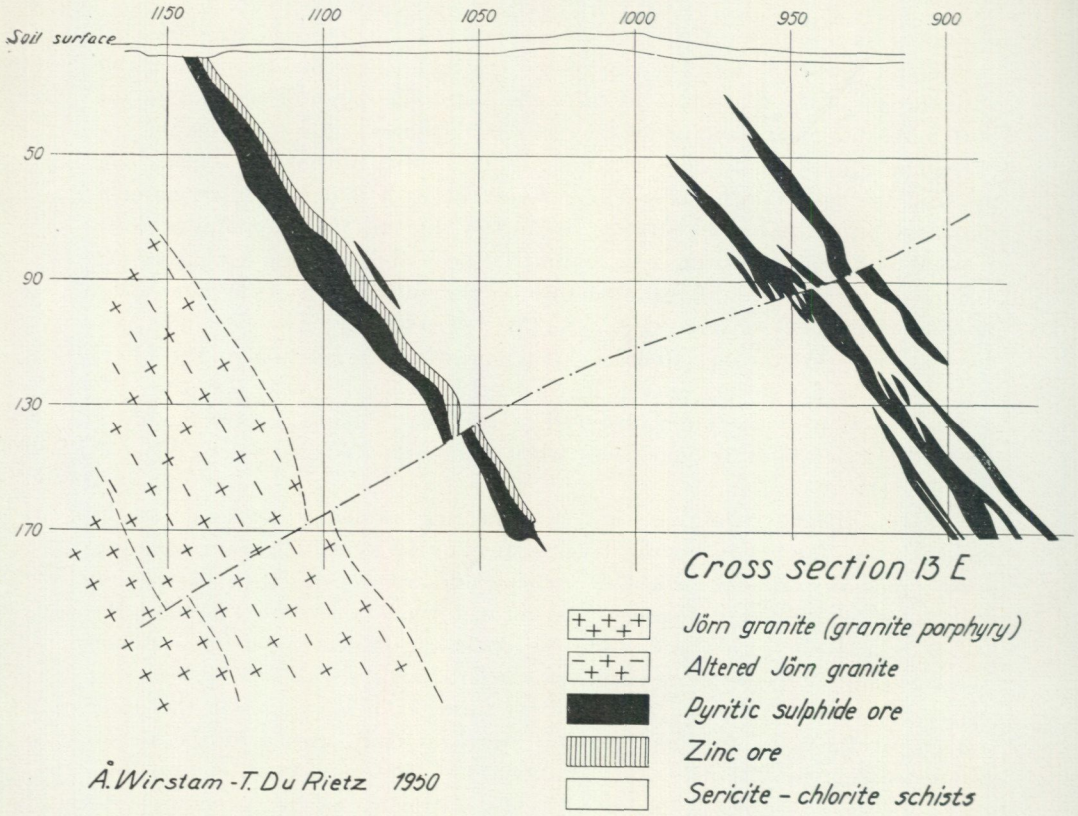



Fig. 40. Cross section along the co-ordinate 1085.

The $B_1$ ore, similar to the $B_3$ ore, represents an uneven complex of fissuring with several parallel fissures, which were not so persistent as that of the ores mentioned above.

The C and D ores represent thin fissures following the $A_1$ zone *en échelon* towards the E. These fissures and those of the $B_1$ ores have but locally yielded to the final solutions.

Of all the ores, the A ores have the most complete sequence of ore formation, and of these ores the $A_1$ is the one most regularly developed. Most uniform is the pyritic part of it, as the zinc ore is somewhat irregular owing to a crystallization during a lowering of temperature, so that the last part of it has cut into both the wall rocks and the pyritic ore. The distribution of chalcopyrite within the pyrite ore is also irregular and it often appears as veins in the pyrite ore or else brecciates it. It must have been deposited after the bulk of the pyrite. Its textural appearance, its behaviour in relation to sphalerite, and its intergrowth with that mineral indicates that it was formed at about the same time, although sphalerite also continued to crystallize.

The ends of the $A_1$ ore peter out in finger-like forms. In the western limit on the 170 m level it is rather uniform, but it splits up into two upward branches,

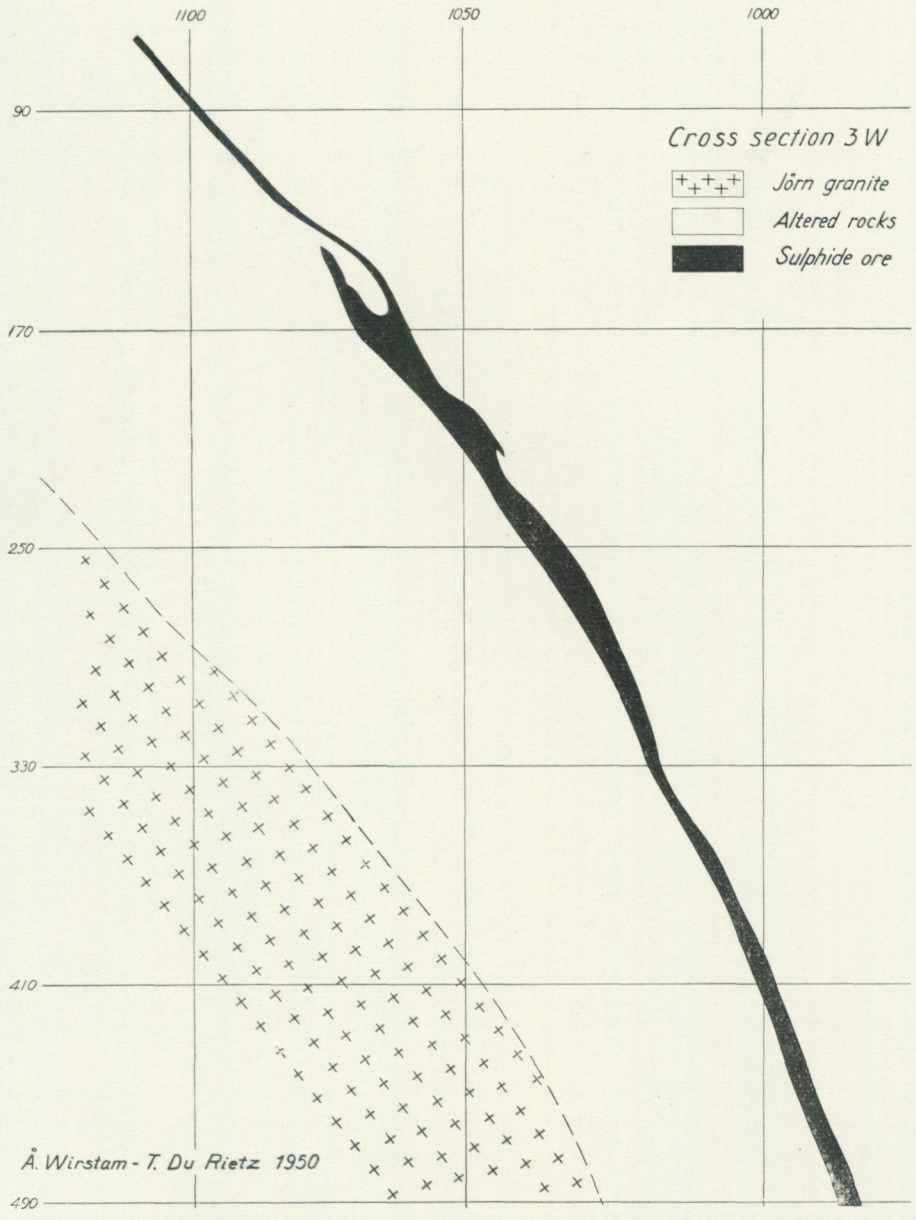



Fig. 41. Sketched cross section along the co-ordinate 785.

as is seen on 130 and 90 m levels. The zinc ore, too, has here divided into two wedges.

In the eastern limit of the $A_1$ ore the zinc ore sends off a thin apophysis to the east on the southern side of the ore.

The $B_1$ ore is very irregular. The eastern dry ore has relatively diffuse boundaries between ore and wall rock and locally it passes over into pyritic ores.

The transition towards the western pyritic ore is also diffuse and uneven. The latter is a complex of thin ore bodies lying parallel to one another or *en échelon*, which is also true of the vertical view of them as shown in the cross section, Fig. 40.

Faults: Many faults and fractures cross the mine area, generally in a north-western to south-eastern direction. Small fracture lines may also have other directions as seen especially within the granite porphyry area.

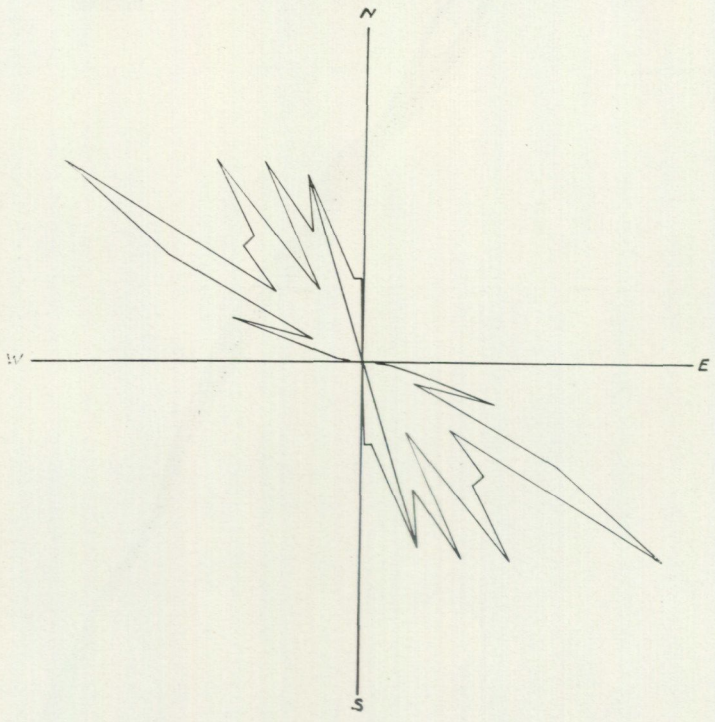



Fig. 42. Diagram showing frequency of directions of faults within the mine area (1943). The radiating line towards the NNW shows the intermediate direction of the largest fault.

The diagram of Fig. 42 shows the directions of most of the fault lines in the horizontal plane observed within the area. The direction of the biggest fault has been marked out as a radiating line. This, which on the 90 m level cuts the ores in the middle of the area, passes on the east side of the A ore on the 170 m level while it cuts the eastern parts of the $B_1$ and $B_2$ ores. Its dip is about 72° to the E on the 170 m level, and 66° to the E on the 90 m level. It is often developed as a fault zone of parallel planes with more or less crushed rock between, but sometimes the rock between two such planes may be seen to be quite undisturbed. The displacement is then divided between the various (two or three) fragmentary faults, so that the complete displacement will be the same and rather constant — 8 m — *i. e.* the western side is offset 8 m towards the S as compared with the eastern side. In the vertical sense, the displacement is

the same. The glide striae thus on the average dip 45° toward the SE or SSE on the slickensided walls. Other faults with measureable displacement all show movements in the opposite direction, *i. e.* the western side has been displaced to the N. A few such faults with a displacement of one metre or so have been observed. All of them run in a more northwesterly direction. There are thus three distinct fault systems on the 170 m level and two insignificant ones, which are all displaced in the same direction and do not quite equalize the displacement of the large fault. The westernmost one is the largest with an offset of about 2 $^1/_2$ m. The directions of the striae seem to dip slightly less than in the large fault.

The oblique direction of the faults towards the NNW and NW indicates that the greatest pressure that caused the displacements and which earlier was directed more from the N and from the S, later on twisted with the strongest direction of pressure from the SSE and NNW. The small faults with offsets in the opposite direction probably originated at the same time as one-sided shear planes. The fact that they disappear wedge-like against the large fault indicates that they originated as a resistance against the greater movement. It is probable that the displacement of the equilibrium was caused by the ore depositions and that it was equalized later on by fault movements.

The schistosity of the hanging wall of the $A_1$ ore is continued by a slight (longitudinal) fault to the W and to the E.

The rock material within the faults consists of more or less crushed pieces of the wall rocks. A little chloritic schist occurs at the surface of the glide walls. Real clay faults are not common. Within the granite porphyry calcite coatings occur on many cracks and fissures.

A chemical study of many samples from the larger faults has disclosed no enrichment in precious metals, but merely the same composition as the surrounding rocks.

Where the faults cut through the chlorite-talc rocks, a disruption, contortion, and crushing of these has occurred. Since these rocks are weak, soft, and flexible and glide easily, especially where much talc is present, some extra displacements sideways from the fault have often occurred which have occasionally also contorted the zinc ore. The fault zone is often wider there and may have minor branching faults. Chlorite-talc material has often been squeezed further away from the mother rock, along the fault.

## Mineral paragenesis.

The minerals known to occur within the mine area have been collected in Table 30. The minerals are graded according to their frequency.

The mineral paragenesis is represented by highly hydrothermal minerals, at the boundary to pneumatolytic, successively down to low hydrothermal and vadose ones. According to W Lindgren's classification, the Kristineberg ore type belongs to the mesothermal pyritic deposits (hydrothermal replacements of crushed and sheared zones with strong alteration of the surrounding rocks)

**Table 30. Minerals within the ore zone.**

(++++ Very common, +++ common, ++ rather common, + uncommon, . rare)

| Ore minerals | | Gangue minerals | |
|---|---|---|---|
| Pyrite | ++++ | Quartz | ++++ |
| Chalcopyrite | ++++ | Sericite | ++++ |
| Sphalerite | ++++ | Fuchsite | . |
| Galena | +++ | Biotite | ++ |
| Tetrahedrite | ++ | Chlorite: Antigorite | + |
| Molybdenite | ++ | Chlorite: Penninite | + |
| Chalcocite | + | Chlorite: Chlinochlorite | ++++ |
| Marcasite | + | Chlorite: Delessite | ++ |
| Pyrrhotite | . | Chlorite: Prochlorite or ripidolite | ++++ |
| Bismuthite | . | Cyanite | +++ |
| Vallerite | . | Andalusite | + |
| Arsenopyrite | . | Sillimanite | + |
| Argentite? | . | Garnet | . |
| Covellin? | . | Actinolite | +++ |
| Dyscrasite? | . | Tremolite | ++ |
| Lead-antimony sulphide (undetermined) | . | Tourmaline | +++ |
| Copper | + | Plagioclase (remnant) | + |
| Bismuth | + | Olivine? (remnant) | . |
| Gold | . | Pyroxene? (remnant) | . |
| Graphite | + | Talc | +++ |
| Magnetite | +++ | Serpentine | . |
| Hematite | . | Titanite | + |
| Limonite | ++ | Epidote (zoisite) | ++ |
| Ilmenite | . | Orthite | + |
| Rutile | ++++ | Apatite | +++ |
| Smithsonite | + | Zircon | ++ |
| Scheelite | ++ | Calcite | ++ |
| | | Dolomite, Ankerite, Magnesite | + |
| | | Barite | + |
| | | Fluorite | + |
| | | Prehnite | + |
| | | Gibbsite | . |
| | | Kaolinite | . |
| | | Kribergite | . |
| | | Gypsum | . |

with slight transitionary phases towards both hypothermal and epithermal paragenesis.

As solitary remnants from original albite-porphyry acid plagioclase occurs. Quartz may also partly be a relic mineral, but it is recrystallized. Apatite and zircon are also recrystallized remnants.

Epidote, orthite, and titanite are early alteration minerals and are rather unstable. They have therefore generally disappeared.

Andalusite, cyanite, tourmaline, scheelite are relatively high temperature predecessors to the ore formation. Sericite and biotite are to the greatest part early predecessors to the ore formation. Sillimanite is a local alteration product of cyanite (and probably also of andalusite). Cyanite and especially andalusite have at a late stage been greatly altered to sericite.

The pyrite ore was accompanied by a strong enrichment of biotite, which — as the temperature fell — was altered to a chlorite relatively rich in iron. Chlorite may also have been formed directly during the late crystallization of

the pyrite ore. Within the B ores sericite is often second to chlorite, the sericite being formed particularly in the quartz-rich ores.

The large copper-rich pyrite ore ($A_1$ ore) is also accompanied by actinolite, while the zinc ore is accompanied by magnesium-rich chlorite and by tremolite, especially in the copper-rich footwall zinc ore and locally also by dolomite or magnesite. Chlorite and talc may be regarded partly as alteration products of magnesium-rich skarn minerals formed earlier. They were to the greatest part formed directly during the crystallisation of the late zinc ore.

The lack of cubanite[1] associated with chalcopyrite and the almost complete lack of pyrrhotite indicates that the temperature of origin of the chalcopyrite-bearing ore was not very high. As magnetite occurs together with iron-poor sphalerite, it is evident that it was not a scarcity of iron that caused the crystallization of an iron-poor sphalerite and the lack of pyrrhotite. The ever present accessory rutile is also typical for hydrothermal sulphide ores where the original titanite and Ti-bearing biotite are no longer stable.

Among the ore minerals, chalcocite, marcasite, copper, and limonite are late and secondary minerals and prehnite, gibbsite, kaolinite, kribergite, and possibly barite, gypsum, and some carbonate are late and secondary among the gangue minerals.

## The chemical exchange.

In order to estimate the chemical exchange during the alterations one must compute the probable composition of the originally dominating volcanic rock. A recalculation of the analysis of the partly altered albite-porphyry from Hornträsket is most convenient. Table 31 gives the composition of the albite-porphyry, the »reconstructed» original porphyry, and the analyses of the altered rocks. To this has been added a calculated analysis of an average andalusite-sericite-quartz schist (with 51 % quartz, 28 % sericite, 15 % andalusite, 5 % albite, and 1 % rutile + pyrite = apatite).

A comparison of the analyses discloses that the andalusite-sericite-quartz schist of the zone formed nearest the Revsund granite in the S is characterized chemically by an increased content of aluminium and potassium and a lowered content of sodium (and of lime). The content of iron and magnesium is low.

In the next zone to the N, the cordierite-quartz schist, an addition of magnesium is evident while the content of iron is still low. The potassium content has increased still more — also the water content — while sodium has been lowered. The addition of sulphur is now more noticeable.

The quartz schists of the Kristineberg area have, besides the addition of some magnesium and potassium, received an increased content of iron, which is bound chiefly to sulphur. The aluminium content of these rocks is not high. Sodium is insignificant.

[1] cf. Schneiderhöhn—Ramdohr, 1931.

**Table 31. Analyses of quartz-porphyry and altered rocks, per cent of weight.**

| | 1 Calculated primary quartz-porphyry | 2 Quartz-porphyry (albite-porphyry) altered (Table 1) | 3 Calculated andalusite-sericite-quartz schist | 4 Cordierite-biotite-quartz schist (Table 10) | 5 Sericite-quartz schist (Table 17) | 6 Quartz schist (Table 17A) | 7 Chlorite (ripidolite) = Chlorite schist without sulphides (Table 22) | 8 Chloritite (Table 18) |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 76.5 | 70.20 | 72.5 | 74.30 | 74.8 | 75.32 | 25.36 | 30.32 |
| $TiO_2$ | 0.5 | 0.70 | 0.5 | 0.55 | 0.34 | 0.30 | 0.50 | 0.50 |
| $Al_2O_3$ | 12.0 | 13.50 | 20.8 | 12.79 | 6.1 | 8.02 | 21.32 | 17.67 |
| $Fe_2O_3$ | 1.3 | 1.95 | 0.7 | 1.38 | 8.1 | 5.54 | 3.15 | 2.69 |
| FeO | 1.5 | 3.79 | 0.1 | 0.68 | | 1.42 | 17.31 | 2.49 |
| MnO | 0.1 | 0.10 | | 0.02 | 0.01 | tr. | 0.14 | 0.30 |
| MgO | 0.1 | 2.44 | 0.1 | 2.97 | 0.65 | 3.18 | 22.52 | 33.41 |
| CaO | 1.0 | 0.78 | 0.3 | 0.11 | 0.79 | 0.42 | 0.00 | tr. |
| BaO | 0.0 | tr. | | 0.06 | | tr. | | |
| $Na_2O$ | 5.7 | 4.04 | 1.0 | 0.46 | 0.31 | 0.26 | | 0.40 |
| $K_2O$ | 0.8 | 0.92 | 2.5 | 3.29 | 1.51 | 1.26 | | 0.52 |
| $H_2O$ | 0.2 | 1.52 | 1.2 | 1.80 | 0.84 | 1.10 | 9.43 | 11.44 |
| $P_2O_5$ | 0.3 | 0.30 | 0.1 | 0.09 | 0.09 | 0.19 | 0.14 | 0.17 |
| F | | | | 0.07 | | | | |
| Cl | | | | | | 0.19 | | 0.94 |
| S | | | 0.2 | 0.85 | 6.9 | 4.08 | | |
| Cu | | | | | 0.02 | tr. | | 0.15 |
| Zn | | | | | 0.20 | | | |
| $CO_2$ | | | | | 0.06 | | | |
| $SO_3$ | | | | 0.15 | | | | |
| $B_2O_3$ | | | | | | 0.02 | | |
| Niggli values | | | | | | | | |
| Si | 460 | 325 | 456 | 474 | 1066 | 630 | 40 | 47 |
| al | 43 | 36.5 | 77 | 48 | 51 | 39 | 20 | 16 |
| fm | 15 | 38.5 | 5 | 35 | 19 | 48 | 80 | 83 |
| c | 6 | 4 | 2 | 1 | 12 | 4 | 0 | 0 |
| alk | 36 | 21 | 16 | 16 | 18 | 9 | 0 | 1 |
| mg | 0.05 | 0.44 | 0.2 | 0.8 | 0.75 | 0.8 | 0.66 | 0.9 |
| k | 0.09 | 0.13 | 0.6 | 0.83 | 0.76 | 0.75 | | 0.45 |

The chlorite of Table 22 represents the extreme rock at the footwall of the large ore, while the chloritite (Table 18) represents an extreme rock at the hanging-wall contact. To the chlorite schist of the footwall belong — besides chlorite (Table 22) — sulphides and sometimes quartz. Both these types of chlorite thus represent the magnesium metasomatism with the iron-rich phase at the footwall (the association of the pyrite ore) and the magnesium-rich phase at the hanging wall (the association of the zinc ore). These late hydrothermal products have to a great extent obtained their silica content in a dissolved form, while the water and aluminium contents have greatly increased. The ore itself has, however, a low content of aluminium, indicating that aluminium and magnesium to a certain degree have been deposited as an aureole around the ores.

All analyses of the ores have been collected for chemical comparison of the different ore types, Table 32.




Fig. 43. Diagram of Niggle values of Table 31.

Fig. 43 is a variation diagram of the Niggli values al, alk, fm, mg, c, k, arranged according to the order in Table 31 (from unaltered volcanic to the most metasomatically altered product of the mine). Since silica is too variable, it being almost wholly carried away in the chlorite rocks, it could not be included in the figures. Al is the most uniform component, increasing slightly in the zones nearest the Revsund granite and decreasing somewhat in the final stage of ore formation. Alkalies and lime almost disappear in the last stage, while the femic components (fm, mg) increase especially in the last stage. K $\left(\frac{K}{Na}\right)$ shows variations analogous to mg, which often is the case in magnesium metasomatosis.

Generally speaking, the Kristineberg region is characterized by a strong metasomatic alteration of a volcanic complex, which originally was of a dominantly sodic composition. The mass of Revsund granite at Säter, from which centre the metasomatic alteration emanated, has a nearest aureole where the metasomatic mineral development is relatively high temperatured, whereas the mineral development at the mine area farther from the centre of granitization[1] is rela-

[1] Granitization within the Skellefte District has recently been comprehensively described by S. Gavelin (Geol. Fören. Förhandl. 1947).

**Table 32. Collection of ore analyses, per cent of weight.**

| | Dry ore | Chloritic sulphide ore | Pyritic ore | Pyrite ore | Copper-rich, pyritic ore | Copper-rich pyritic ore, actinolite-bearing | Copper-rich zinc ore | Zinc ore | Zinc ore, rich in lead. |
|---|---|---|---|---|---|---|---|---|---|
| | $B_1$ | $A_1$ | $B_2$ | $B_3$ | $A_1$ | $A_1$ | $A_1$ | | |
| $SiO_2$ | 40.89 | 17.50 | 14.40 | 30.54 | 3.77 | 9.30 | 3.49 | 10.64 | 6.99 |
| $TiO_2$ | 0.12 | 0.13 | 0.10 | 0.02 | 0.02 | 0.07 | 0.07 | 0.06 | 0.13 |
| $Al_2O_3$ | 3.51 | 7.62 | 2.86 | 0.09 | 0.94 | 3.41 | 1.23 | 2.25 | 3.4 |
| Fe | 22.89 | 30.99 | 37.20 | 32.39 | 42.10 | 36.08 | 32.07 | 27.45 | 25.51 |
| MnO | 0.04 | 0.07 | 0.08 | 0.01 | 0.01 | 0.10 | 0.05 | 0.03 | 0.10 |
| MgO | 1.58 | 6.71 | 0.63 | 0.04 | 1.13 | 5.13 | 3.44 | 6.80 | 6.67 |
| CaO | tr. | < 0.03 | 0.24 | tr. | 0.06 | 1.09 | 0.26 | 0.06 | < 0.10 |
| BaO | 0.02 | tr. | | | | tr. | 0.06 | tr. | tr. |
| $Na_2O$ | 0.05 | 0.03 | tr. | 0.03 | 0.025 | 0.07 | 0.01 | 0.20 | 0.05 |
| $K_2O$ | 0.18 | 0.01 | 0.39 | 0.02 | | 0.01 | 0.02 | 0.024 | 0.01 |
| $H_2O$ | 1.15 | 4.00 | 0.58 | 0.10 | 0.58 | 2.33 | 1.41 | 1.50 | 2.10 |
| $P_2O_5$ | 0.02 | 0.03 | 0.02 | 0.01 | 0.016 | 0.02 | 0.02 | 0.02 | 0.01 |
| S | 23.17 | 29.07 | 42.40 | 36.12 | 46.61 | 38.14 | 40.60 | 34.80 | 34.12 |
| Cu | 5.76 | 2.44 | 0.56 | 0.04 | 3.53 | 3.40 | 5.62 | 1.71 | 0.18 |
| Zn | tr. | tr. | 0.11 | tr. | 0.49 | tr. | 9.39 | 12.20 | 12.90 |
| Pb | | | 0.00 | | | | 0.38 | 1.30 | 6.25 |
| Cd | | | | | | | tr. | tr. | 0.03 |
| Mo | | | | 0.001 | 0.003 | | | 0.001 | |
| Co | | | 0.09 | 0.005 | 0.008 | | | 0.002 | |
| Cr | | | | 0.01 | | | | | |
| Bi | | | | | | | | 0.006 | |
| As | | | 0.03 | 0.01 | 0.006 | | | 0.003 | |
| Se | | | 0.002 | 0.003 | 0.004 | | | 0.002 | |
| Te | | | | | 0.002 | | | 0.004 | |
| $CO_2$ | | | | | | | | | 0.49 |
| F | | | | 0.01 | 0.03 | 0.09 | | 0.09 | |
| Cl | | | | | 0.01 | | | | |
| Ag gr/t | 19 | 33 | 3 | | 38 | 38 | | 78.7 | 96 |
| Au gr/t | 4.3 | 0.4 | 0.1 | 0.7 | 1.8 | 2.3 | | 0.8 | 2.8 |

tively low temperatured. The alteration of the whole region is characterized by a more or less complete removal of sodium and partly also of lime and an addition of potassium, magnesium, sulphur, and iron.

During a somewhat later and more locally developed alteration phase connected with the issuing of the ore solutions at the zone of fissuring at Kristineberg, an additional enrichment of iron, magnesium, and sulphur occurred. In the first stage of this alteration an addition of aluminium and probably also of potassium (high content of biotite) and some calcium (amphiboles and carbonates) occurred. Most of the pyrite ore was precipitated during this stage. During the gradual progress of the metasomatic alteration with a slow lowering of the temperature, most of the copper-zinc ore was precipitated. During the early part of this stage, biotite and amphibole were stable, but during the latter part, characterized by a decreasing content of copper and an increasing content of zinc and lead, the gangue minerals became still more magnesium-dominant due to a decreasing content of iron and aluminium and a removal of lime and potassium. The biotite and amphibole developed earlier were chloritized and the extreme magnesium mineral, talc, was also formed. In consequence of the decreasing temperature, new fissures had been formed on the hanging-wall side of the $A_1$ ore, where zinc ore, still pyrite-bearing but almost free from chalcopyrite and with a dominant matrix of talc, had crystallized.

During a later stage with a still lower temperature, the disturbed tectonic equilibrium of the rocks was counterbalanced by faults and distortion of some of the rock complexes.

During a decidedly later stage, the ore at the surface was more or less weathered while the ore below was attacked locally by solutions coming from above. Pyrite was altered to limonite and chalcopyrite to chalcocite, and locally copper, too, was precipitated. According to an investigation by E. Grip (1944), a weathered ore breccia occurs at the outcrop below the moraine, while erratic boulders of this weathered ore are to be found in the moraine. This weathering was thus chiefly pre-Glacial. Most of the pyrite and chalcopyrite in the weathered ore was dissolved while gold increased somewhat. The dissolved substances were precipitated mainly along fissures, cracks, and slickensides at the margins of the ore bodies.

## Summary.

A complex of chiefly acid, sodium-dominant lavas and tuffs was exposed to intensive folding with intrusion of the syn-orogenic, Old Archaean Jörn granite.

During the formation of the coarsely porphyritic, later Archaean Revsund granite, the volcanic complex was uplifted,[1] sheared and strongly metasomatically altered, the result being that the volcanic complex, for the most part, was altered to sericite quartz schist. The metamorphism was zonally developed in relation to the Revsund granite. Near S of the granite, andalusite-seri-

[1] S. Gavelin (1939), E. Grip (1941) have earlier described the tectonic evolution of the Revsund granite epoch of the regions east of Kristineberg.

cite-quartz schist was formed, passing over northwards into cordierite-biotite-sericite-quartz schist. These zones were formed under the highest temperature and the universal pressure for the field. The forming of an andalusite-bearing zone next to the granite is due to the absence of magnesium metasomatism there as compared with the aureoles farther north, which also show an increase in the addition of sulphur. Northwards, the cordierite becomes unstable and the rocks pass over into biotite-sericite-quartz schists, the earlier products containing remnants of cordierite. Around Kristineberg, biotite becomes unstable and most of it is altered to chlorite. Chloritic sericite-quartz schists dominate. Northwards, the effect of the metasomatism is seen to become weaker and more and more remnants of the original volcanics are found, besides the dominant albite-porphyry also alkali-intermediate porphyry, dacite, and porphyrite.

The Jörn granite (biotite trondhjemite) in the E is developed as a granite porphyry at the contact to the volcanics. The western border of this granite is also metasomatically altered.

Both the volcanics and the Jörn granite are cut by greenstone dikes and quartz-tourmaline veins, which are particularly abundant in the mine area.

The quartz-tourmaline veins are regarded as forerunners to the ore formation. Scheelite is associated with them. At about the same time quartz-concretions with or without cyanite were formed.

The Kristineberg deposit is situated in a pronounced zone of weakness in the volcanic complex close to the contact of the Jörn granite at the southern slope of a projection of a Jörn-granite anticline. The fracturing of this zone probably began before the formation of the Revsund granite, as the first fractures were filled with greenstone dikes and quartz-tourmaline veins. Later on, a stronger fissuring occurred in this area, the surrounding rocks becoming metasomatically altered with a formation of much biotite skarn and deposition of pyrite ore in fissures and as replacement of the wall rocks. The next ore-bearing solutions were rich in copper and zinc and the skarn formed at the same time was rich in magnesium and calcium. The skarn formed in the copper-rich ore was richer in iron than that formed in the zinc ore. The formation of zinc ore overlapped that of copper ore. During the crystallization of the zinc ore, the temperature fell successively and the earlier skarn minerals were no longer stable and were more or less altered, especially the biotite. The zinc ore last to form contained gangue minerals extremely rich in magnesium, *viz* clinochlorite-penninite-antigorite and talc. Quartz is completely absent. While the pyritic ore is mainly a replacement ore, the chalcopyritic and sphaleritic ores are both replacement and displacement formations Cf. S. Gavelin (1939) and O. Ödman (1941).

Owing to the alteration processes and the deposition of ore the equilibrium of the rock complexes was disturbed and the area was cut by faults.

During a much later stage the ore was weathered on the surface and a little material was precipitated below in fractures close to or in the ore bodies.

The sulphide ores at Kristineberg are almost free from pyrrhotite and arseno-

pyrite, which is unusual for the ores of the Skellefte District. The pyritic ore at the footwall side of the $A_1$ ore is the biggest in Kristineberg. This ore may be divided into a chloritic ore on the footwall side, a compact pyritic ore in the middle, and a thin, chalcopyrite-rich ore on the hanging-wall side at the contact with the zinc hanging ore. The zinc ore is always more fine-grained than the pyritic ore. The sphalerite generally forms the matrix of the pyrite grains; it is rather light in colour, giving the ore a grayish hue partly owing to the presence of much talc in the groundmass. Chlorite rock often forms balls and *schlerien* in the ore. The footwall part of the zinc ore is often rich in chalcopyrite, while the hanging-wall side may be rich in galena. A little tetrahedrite is associated with galena. Magnetite is rather common in the zinc ore. The zinc ore sometimes shows intrusive contacts with the pyritic ore.

The $A_1$ ore is continued *en échelon*, to the W by the similar, but thin and more irregular $A_3$ ore, and to the E by the C and D lean, pyritic ores.

The $B_1$ ore is a complex pyritic ore to the S of the $A_1$ ore. Its eastern section is a copper-rich quartz-bearing ore, continued by thin layers of pyritic ore to the W. Th $B_2$ ore is a persistant chalcopyrite-bearing pyrite ore about 4 m wide south of the $B_1$ ore, and the $B_3$ ore is a smaller one of about the same type as the $B_1$ on the south side of the western part of the $B_2$ ore.

All ores point to the S with an average dip of about 55°, and the pitch is to the W or WSW averaging about 42°, but steeper on the lower levels than on the higher.

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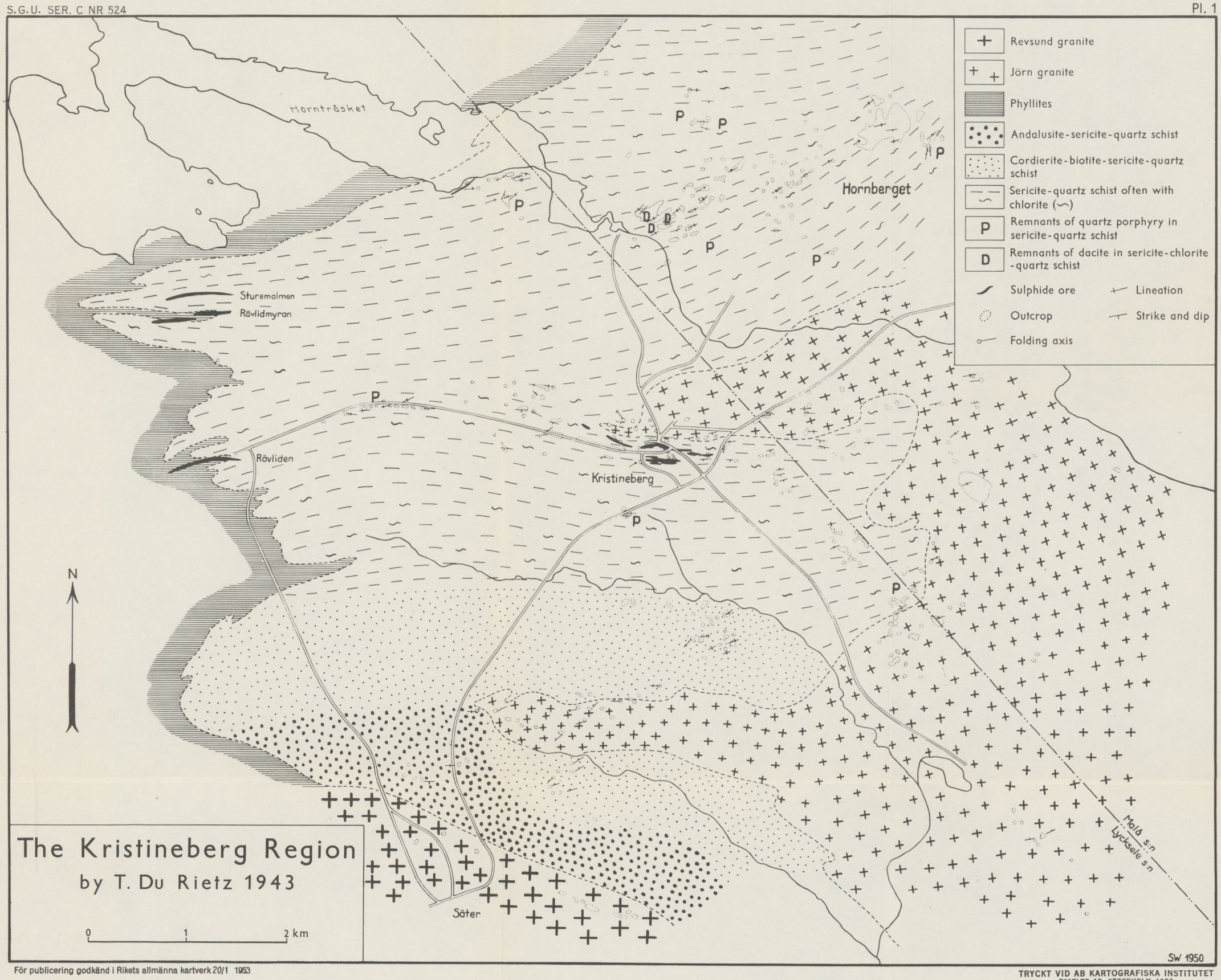
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by T. Du Rietz 1943

SW 1950

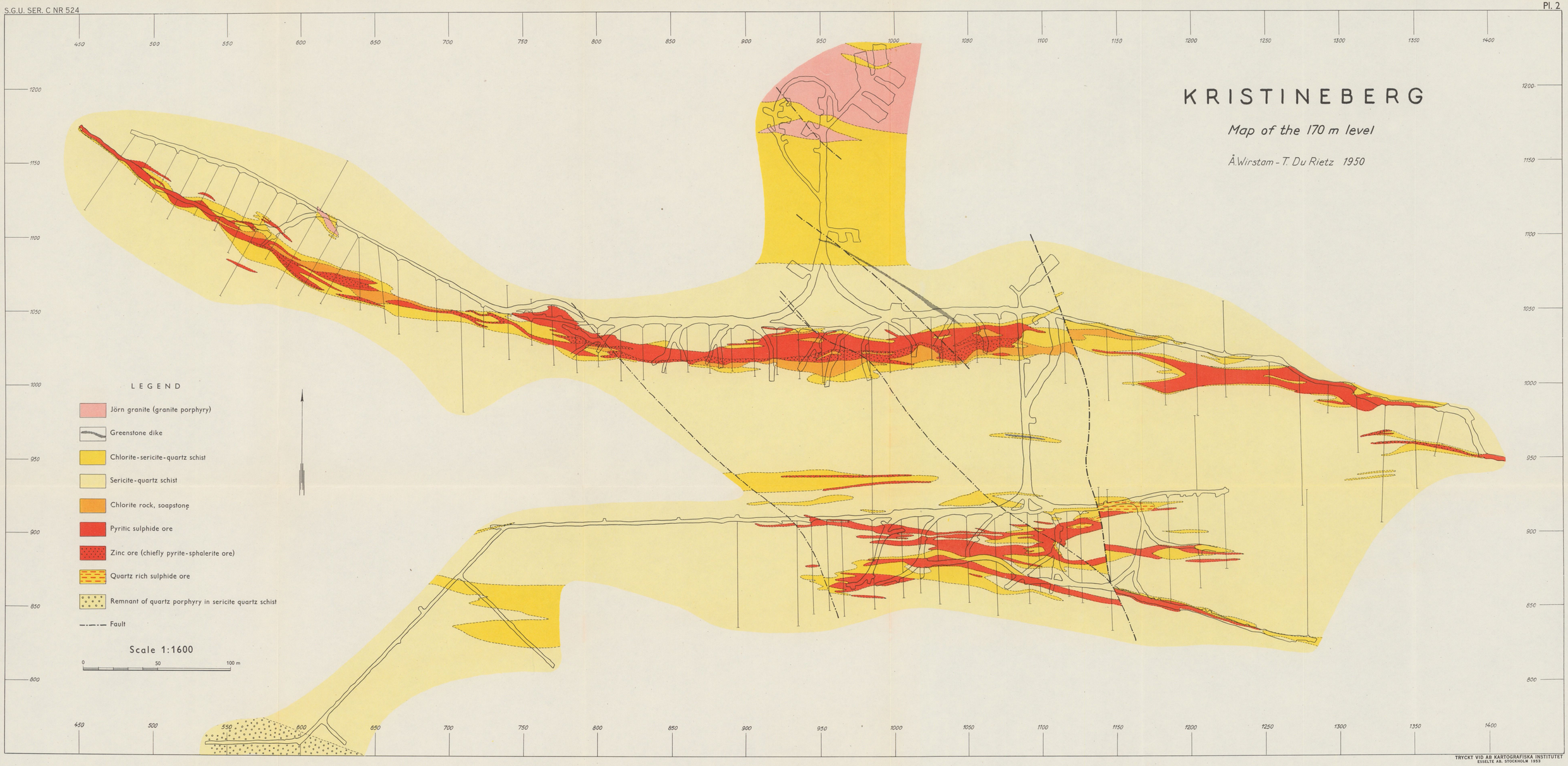
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# KRISTINEBERG

*Map of the 170 m level*

*Å. Wirstam - T. Du Rietz 1950*

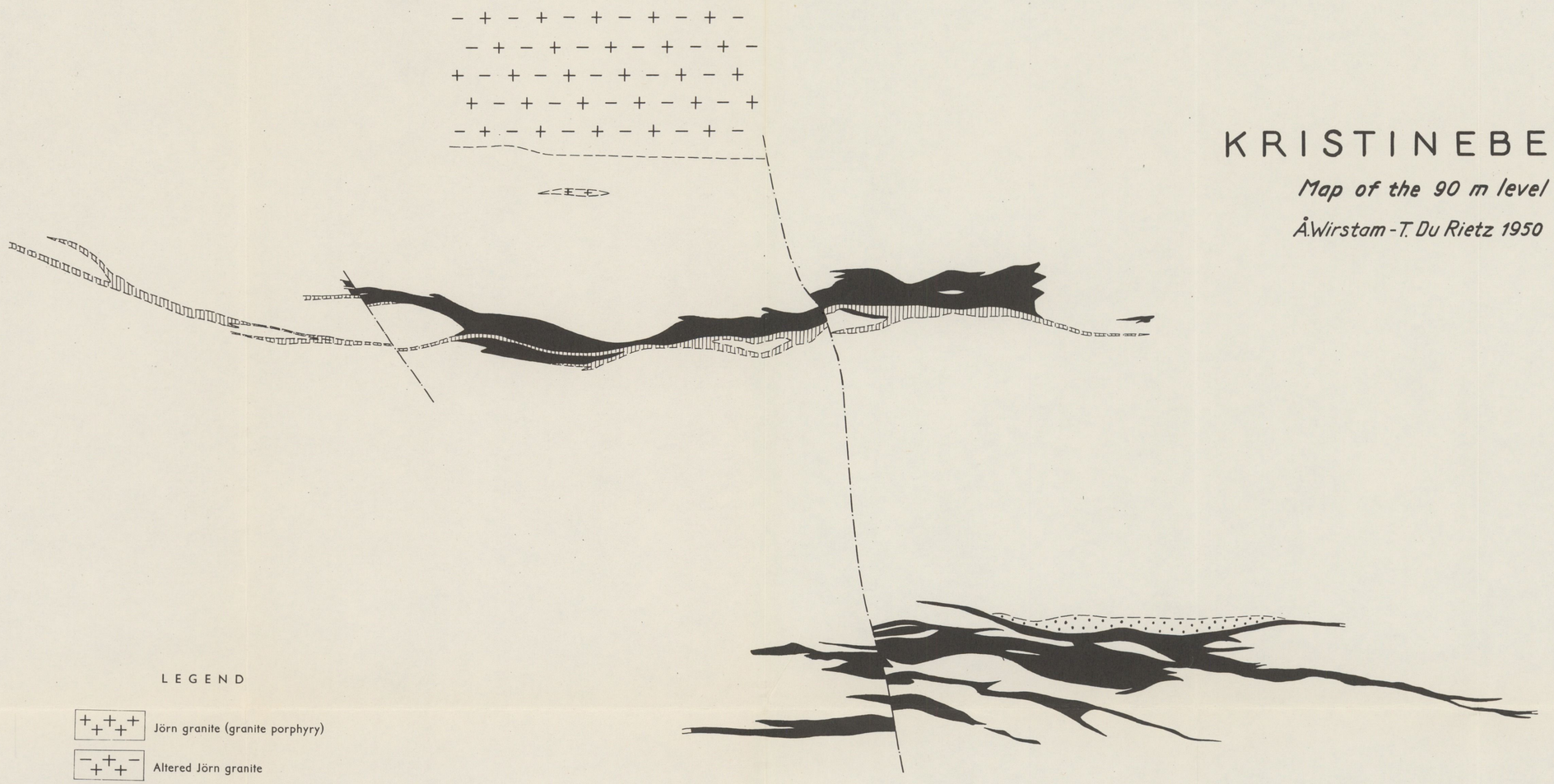



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# KRISTINEBERG

*Map of the 90 m level*

*Å. Wirstam - T. Du Rietz 1950*



LEGEND

- Jörn granite (granite porphyry)
- Altered Jörn granite
- Pyritic sulphide ore
- Zinc ore
- Quartz rich sulphide ore
- Sericite-chlorite schists

Scale 1:1600

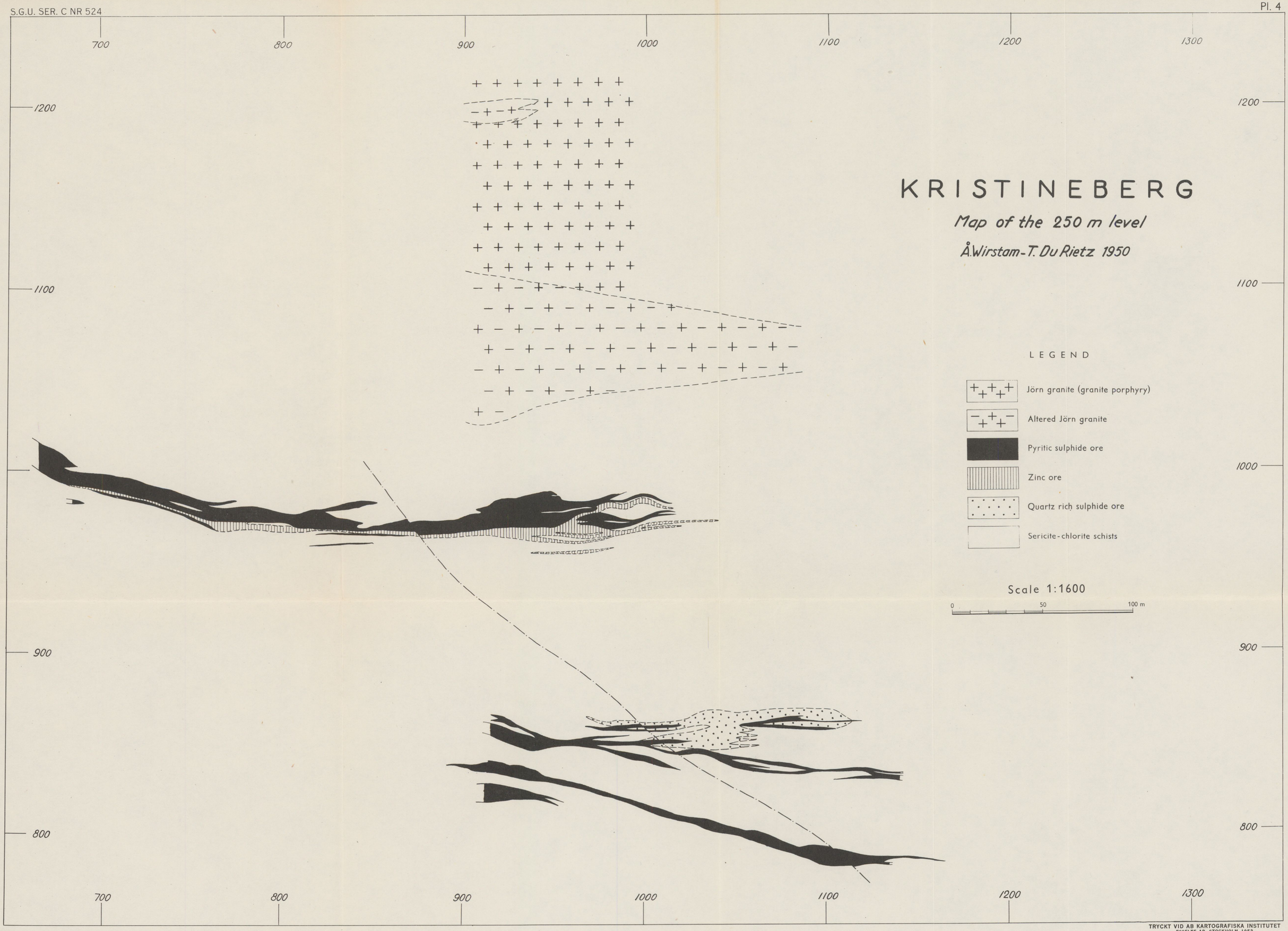
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# KRISTINEBERG

*Map of the 250 m level*

*Å. Wirstam-T. Du Rietz 1950*




LEGEND

- Jörn granite (granite porphyry)
- Altered Jörn granite
- Pyritic sulphide ore
- Zinc ore
- Quartz rich sulphide ore
- Sericite-chlorite schists

Scale 1:1600

0 50 100 m

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