The lead and zinc bearing veins at Tråk in Southern Norway

By

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Abstract.

The nearly vertical zinc and lead bearing veins that cut through Precambrian rocks near the Oslo region at Tråk in Bamle Southern Norway, are described. They can be followed for nearly 2.5 km. A younger introuded diabase is found in some of the veins. Ore minerals are sphalerite and galena with some pyrite and chalcopyrite. Quartz is the dominant gangue mineral.

Preface.

The present paper is a condensation of a thesis presented as partial fulfillment of the final degree requirements (bergingeniør) at the Institute of Geology, Technical University of Norway. The field work was done during the summer of 1963 and the laboratory work during the following winter under the quidance of professor dr. Jens A. W. Bugge.

I wish to thank professor dr. Frank M. Vokes for his helpful assistance with the manuscript and for improving my English.

The Tråk area lies in the southeast part of the county of Telemark in Southern Norway. (Fig. 1). For practical reasons the area was divided into two parts:

1. *Tråk central area,* about 8 sq. kilometers. This is the area where most of the zinc-lead deposits are concentrated.
2. *The Tråk area,* about 70 sq. kilometers, is roughly the area where the Tråk type of ore can be found.

The most detailed work has been done in the central area, as regards both the ore deposits and the general geology. The following account deals almost exclusively with the Tråk central area.

Introduction.

Altogether about two hundred prospecting claims have been registered in the Tråk area. There has not been time to find and study all of these in detail, so the work has been concentrated on the best known occurrences.

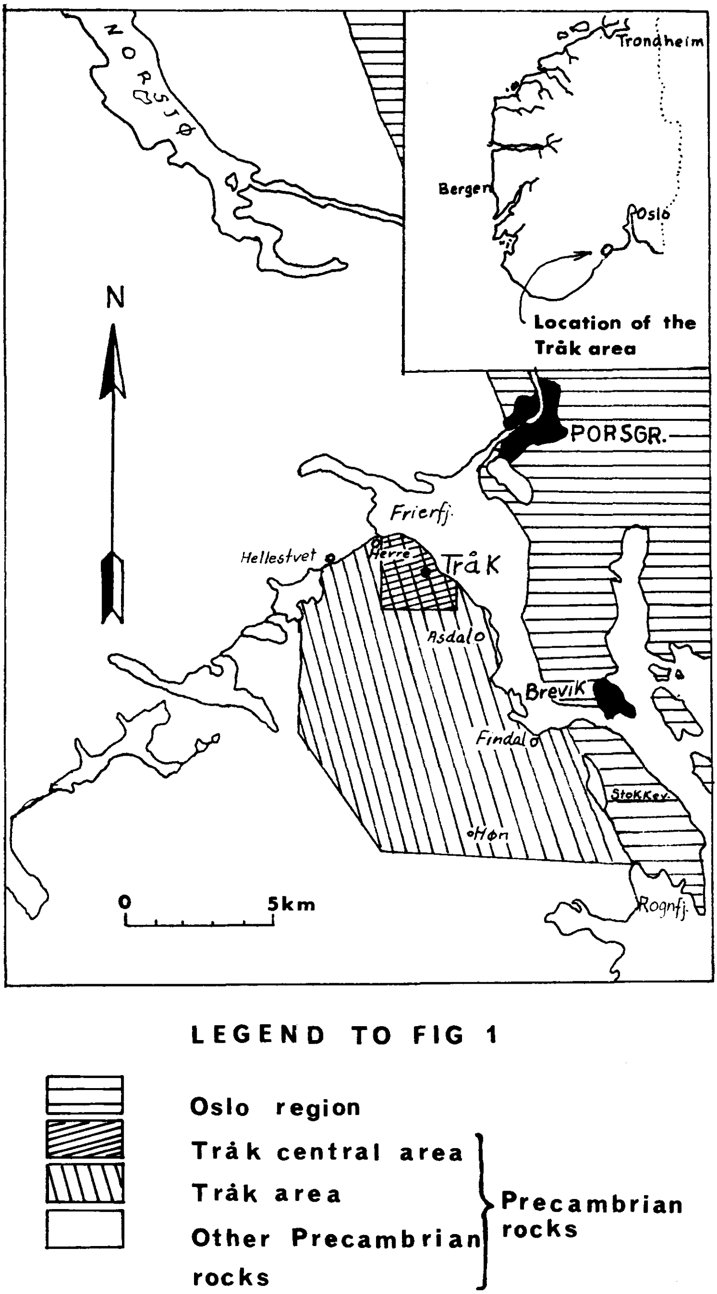


Fig. 1. Map showing the position of the Tråk area and Tråk central area.
Kart som viser beliggenheten til Tråkfeltet og Tråk sentralfelt.

The only previous publication that can be found regarding the ore bearing veins is that of J. H. L. Vogt (1907). Oftedal (1940) has made an optical spectrographic survey of the trace elements in minerals from the Tråk veins. Moorbath and Vokes (1963) have determined the lead isotope ratios in a sample of galena from one of the veins.

The Tråk area lies in the Kongsberg-Bamble area of the Southern Norwegian Precambrian, southwest of the Oslo region. To the north the area is bounded by rocks of the Telemark area. The following main rock types are found in the area:

Porphyritic granite (youngest).
Amphibolites and diabase.
Banded gneiss and quartzite (oldest).

The zinc and lead minerals are found in north-south striking veins which cut through these Precambrian rocks at almost right angles to their foliations. The veins are most likely of Permian age. Quartz is the main gangue mineral. Mining of the ore minerals was begun as early as 1543. Later the mines were worked sporadically up to 1908 when they were closed down at last. Altogether only a few thousand tons of ore have been taken out.

General geology.

Since the main work was done on the ore deposits and since these seem to have little or no genetic connection with the surrounding rocks, the geological mapping has been restricted to the central area. The map (*Fig. 2*) shows the geology of Tråk central area.

A. Bugge (1936) and J. A. W. Bugge (1943) have previously carried out geological and geological-petrological studies in the Kongsberg-Bamle area. More recently detailed studies have been made in the Bamle section by R. D. Morton and coworkers of the University of Nottingham. This sector includes the Tråk area, but the studies are as yet unpublished.

In this paper the rocks are described according to their most probable ages. These ages are based on Table No. 2 in J. A. W. Bugge (1960), and on my own observations.

The most probable succession is:

7. Diabase	Permian
6. Breccia	?
5. Sandstones	Cambrian

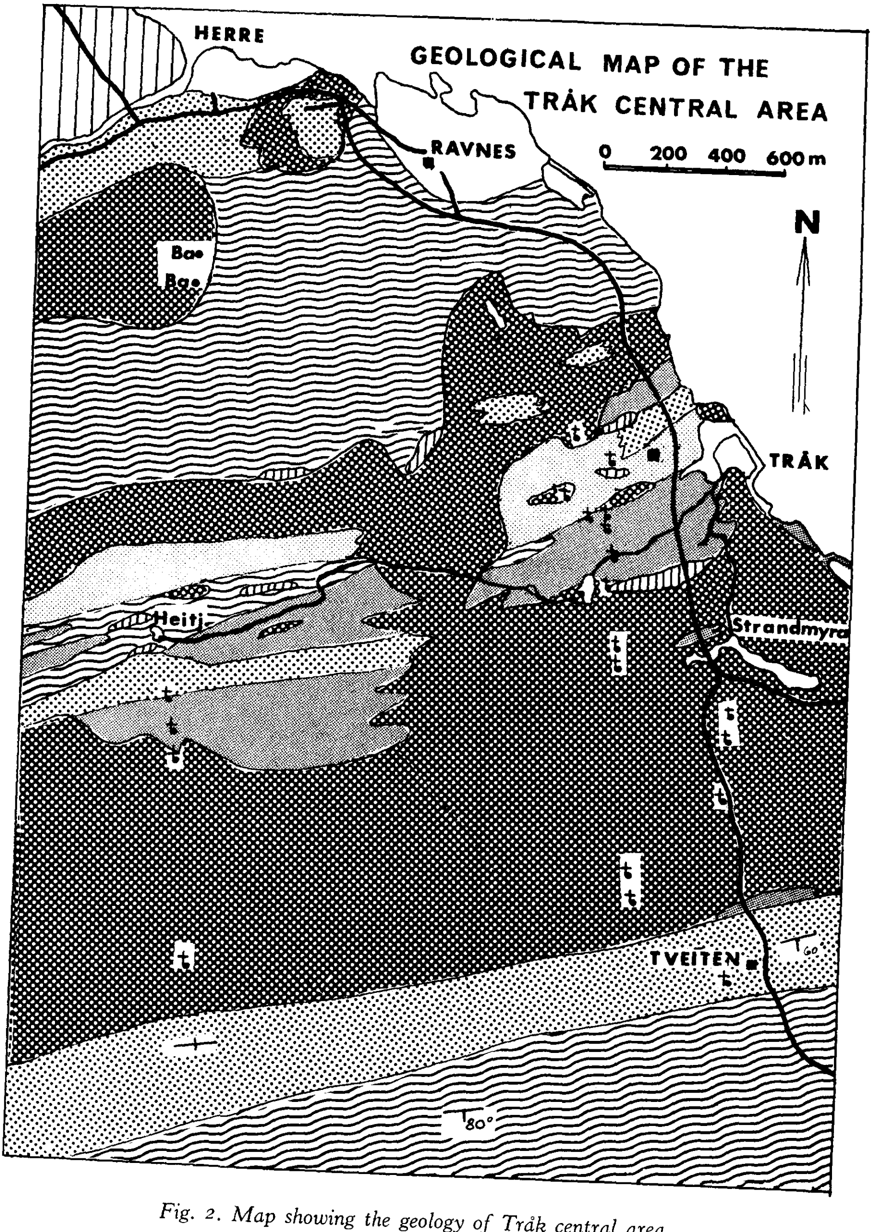
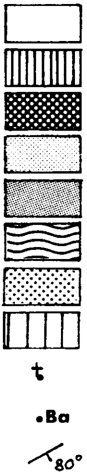


Fig. 2. Map showing the geology of Tråk central area.
Geologisk kart over Tråk sentralfelt.

LEGEND TO FIG 2



Not mapped and covered
Fine grained granite
Porphyritic granite
Ti-bearing amphibolite
Amphibolite and diabase
Gneiss
Quartzite
Telemark area
Zn–Pb mines
Barite deposits
Strike and dip

4.	Granites	Precambrian
3.	Amphibolite and Diabase	«
2.	Gneisses	«
1.	Quartzites	«

1. *Quartzites.*

Rather pure quartzites are to be found over the whole of the Tråk area. On the map (Fig. 2) there can be seen a rather wide and persistent belt of quartzites in the southern part of the central area. No clastic structure can be seen under the microscope, the quartzite being quite recrystallized, with a grain size from 0.05 to 0.2 mm. Muscovite is the main accessory, as small flakes orientated parallel to the foliation. A few small microcline grains can also be seen, as well as very well-rounded zircon grains.

At other localities in the central area pure quartzites can be found, but only as inclusions in granite. It is possible that these large quartzite inclusions in the granite are the remnants of quartzite layers that have been broken up and enclosed by the younger granite.

In the extreme north of the area, near Herre, there is a quartzite layer that borders against rocks of the Telemark area. This quartzite is pink in color and rather impure. A thin section from this layer showed a content of about 10 % albite. Chlorite, well rounded zircons, euhedral pyrite, microcline and calcite are found as accessories. The structure is strongly cataclastic, nearly mylonitic. Quartz grains are broken and recrystallized, and the plagioclase crystals are often bent and broken. The cataclastic structure is supposed to be a result of the «great friction breccia», (A. Bugge, 1936), which is only 300 m to the north. This breccia (or mylonitic zone) marks the southern border of the Telemark area.

According to A. Bugge (1936) the Tråk central area belongs to the Kongsberg area, where the rocks are made up largely of effusive members, no quartzite being described. It is now clear from the present and other recent studies that quartzite is well represented in the Kongsberg rocks of Tråk central area, even near the border of the Telemark area, and this should suggest that the Tråk central area partly belongs to the Bamble area.

2. *Gneisses.*

Banded gneiss is the dominant rock in the Tråk area as a whole. It is made up of alternating dark and light bands from a few cm up to several metres in thickness. The light bands are of granodioritic composition, while the dark bands are amphibolitic. (There is also a granitic type of gneiss, and this type carries rather much garnet.)

In the southern part of the Tråk central area banded gneisses occur south of the quartzite layer. The gneiss seems to be concordant with the quartzite, and observations from the field show that there is a gradual transition between the two types. This seems to suggest that both rocks were derived from sediments that were deposited by a normal sequence of sedimentation. If this is so the quartzite may be regarded as presenting a basal arenaceous unit which was overlain concordantly by sediments having alternating light (arenaceous) and dark (argillaceous) bands, deposited in deeper water.

Pegmatites are very common in the gneiss, especially in the southern part of the area. Minerals occourring in these pegmatites are microcline, plagioclase, muscovite, tourmaline, garnet, chalcopyrite and molybdenite. The ytterium phosphate, xenotime, was found in a thin section from one of the pegmatites. Determination of the type of plagioclase in the different types of gneisses shows rather sodic types, varying from An 10 to An 30.

3. *Amphibolites and diabase.*

The dark rocks, intermediate to basic, are mainly represented by amphibolites. They often carry rather much garnet. The amphibole mineral is a common hornblende, and the plagioclase is an andesine with An 34. Some free quartz is also found in the amphibolites. Accessories are chlorite, apatite and ore minerals. The results of field work suggest that these amphibolites occur mainly in banded gneiss zones and that they represent especially thick basic layers in the banded gneiss sequence. The mineral association is also rather similar in both the narrower and the thicker amphibolitic layers, exept for garnets in the thicker amphibolites.

In the central area is found a zone of ilmenite bearing amphibolite. The main mineral in this rock is a sericitized plagioclase (An 35). Other minerals include a dark green hornblende, biotite, ilmenite and apatite. Accessories are epidote, garnet and chlorite. The ilmenite is found as thin «schlieren» and bands, and a polished section showed that it is very pure. No lamellae of hematite and no magnetite could be seen. There is about 5 % ilmenite in the rock. There is known to be an ilmenite prospect in the central area. (Ref. S. Foslie, 1925, I, 539).

On the coast east of Tråk and at other places in the area, there occurs a diabase, also of Precambrian age. The texture is ophitic with lath shaped plagioclase crystals (An 60) which are rather badly sericitized. Other minerals are hornblende, chlorite, biotite and calcite.

4. *Granites.*

Two different types of granites can be recognized. The most dominant type is a coarse grained porphyritic granite. This type is the same as A. Bugge (1936) and J. Bugge (1943) have described as «coarse-grained Kongsberg granite» or «porphyritic granite». The phenocrysts of microcline attain maximum dimensions of about 15 mm. The granite also contain about 20 % of plagioclase, an albite with about An 7. Other minerals are biotite, muscovite, chlorite, garnet and euhedral zircon with especially sharp crystal faces. The granite itself shows intrusive relations to the other rocks. At a distance of 0.5 km south of Herre there were found included angular blocks of quartzite one or two dm in size, while along the main road about 0.8 km south of Tråk, blocks of banded gneiss 4—5 meters in size, can be seen incorporated in the granite. West of the central area, outside the map area of Fig. 2, just south of the dominant quartzite belt there is an «island» of porphyritic granite in the banded gneiss zone. Here the boundary between the granite and the gneiss seems to be very sharp. At the coast just east of Tråk can be seen the border between Precambrian diabase and granite. This border is sharp, and it is also possible to find sharp edged pieces and blocks of diabase in granite.

From the geological map (Fig. 2) it can be seen that two large areas of amphibolite, gneiss and quartzite lie surrounded by the main granite mass west of Tråk. The strikes of these layered rocks on either side of the band of granite separating the two areas are identical. This supports the idea that they are both parts of the same layered complex which the granite has broken through.

All this evidence indicates that the porphyritic granite is younger than the quartzites, gneisses, amphibolite and diabase.

The fine grained granite is not so well represented as the porphyritic granite. It is found as lens shaped bodies parallel to the foliation of the adjacent rocks. The largest body of this type is found 0.3 km south of Tråk. The main minerals are microcline, microcline perthite, quartz and an acid plagiaclase. Myrmekite also occurs. Accessories are biotite and zircon.

5. *Cambrian sandstones.*

In the southern part of the Tråk area, on the west side of Stokke-vann (See Fig. 1), there is a Cambrian sandstone lying concordantly below the alum shale of the Oslo region. There is one dark type and one light type. Th. Vogt (1924) has described this sandstone.

6. *Breccia (Permian age ?).*

About 0.5 km west of the southern part of Stokkevann (Fig. 1), near the main road, occurs a breccia. It appaers as a small, elliptical «island» that covers about 2500 sq. metres in the gneiss complex. The breccia fragments are of gneiss with a granodioritic composition and have sizes from microscopic fragments up to 5 cm. Without detailed studies it is difficult to determine the age and genesis of this interesting rock. The matrix is mostly calcite, but also chlorite, epidote and the ore minerals pyrite, chalcopyrite and pyrrhotite were found.

Ramberg and Barth (1966) have described evidence, in the form of breccia and other features, of Eocambrian volcanic activity in southern Norway, especially in the Fen area and its surroundings. Similar breccias are described from other localities covering a wide area in southern Norway, which are (tentatively) ascribed to the same period.

The breccia near Stokkevann might be one of the Eocambrian types mentioned above, but it is most reasonable to believe that it was formed in connection with the Permian explosive activity in the Oslo region.

7. *Diabase of Permian age.*

Permian diabase can be found all over the Tråk area as vertical dykes with thicknesses from a few centimetres up to about two metres. The same dykes also occur in the ore bearing veins in the area. The diabase has a typical ophitic structure with lathlike, zonar plagioclase (An 70). Other minerals are calcite (as amygdaloids), chlorite, biotite and about 10% of ore minerals, mostly magnetite.

Quaternary geology.

The whole Tråk area lies mainly below the upper marine limit. As mentioned above, the ore bearing veins strike northsouth, and grooves, narrow valleys and long narrow lakes are also aligned in the same direction. This topography has been formed by fluvioglacial action, brecciation and/or alteration connected with the vein structures having faciliated erosion by the melt waters. Field evidence of this action can be observed in the form of water-eroded channels aligned N-S along the vein direction. That this erosion was fluvio-glacial and not glacial is also shown by the fact that the dominant movement of the ice-sheet was from NW to SE. (Holtedahl, 1960). It was only during the break-up of the ice that fluvial action could begin deeping channels along the structurally controlled N-S direction.

The opposite phenomenon, that the veins occur as ridges, is also observed, but this is not frequent. In these cases the veins consist dominantly of hydrothermal quartz so that they are more resistant to erosion than their wall rocks.

Tectonics.

J. H. L. Vogt (1907) has interpreted the mineralized veins as faults parallel to the boundary of the Oslo region. Measurements show that this boundary in the area from Rognsfjord towards Porsgrunn has a strike of 175^g. The joint rose (*Fig. 3*) shows the joints from Tråk central area and the area to the south. It has been constructed from aerial photographs. As the diagram shows, two main joint systems can be distinguished. The dominant joint direction is the one striking between 170^g—200^g. It is this direction which coincides with the mineralized veins in the central area. By studying the aerial photographs it can be seen that the north-south striking joints become less frequent towards the west. A reason for this might be that the joints are parallel faults connected with the

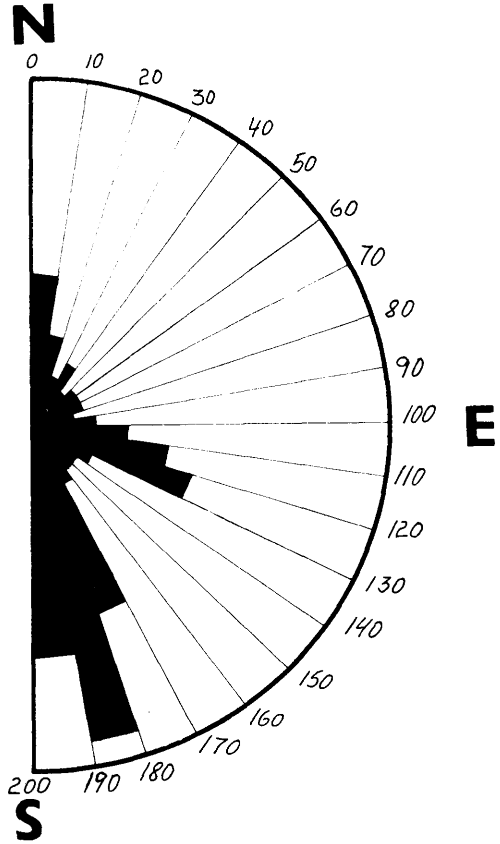


Fig. 3. Joint rose from Tråk central area and the area just south of Tråk central area.
Sprekkerose fra Tråk sentralfelt og området rett syd for Tråk sentralfelt.

subsidence of the Oslo region and consequently they become less frequent away from the boundary of the Oslo region.

The other, minor, joint system strikes at 125^g, and the two systems make an angle of about 60^g with each other. According to observations in the field and J. H. L. Vogt (1907) who was down in the mines, there are no faults crossing the lodes. These observations indicate that the mineralized joints are the younger and that the other joint system may be a result of an earlier tectonic period. This minor joint system may possibly be related to tension cracks connected with the main fault zone between the Telemark region and the Kongsberg-Bamble area. This fault zone has a strike of about 70^g, and the southern part, the Kongsberg-Bamble area, has moved to the southwest (270^g). This movement could produce tension cracks having a strike direction of about 120^g, which is the direction of the minor joint system.

The tectonic movements in the northern part of the area have been very intense. Marked cataclasis can be observed in thin sections from the northern part of the central area.

Fig. 4 shows the mines and claims in the area. During the mining period three main lodes were exploited.

No. I. *Tråk main lode* is the lode that connects mines No. 10, 2, 1, 3, 4 and 4a.

« II. *Heitjern lode* is the lode that connects mines No. 5, 6, the claim about 120 m north of mine No. 5 and the claim about 0.7 km south of mine No. 6.

« III. *Tveiten lode* is the lode that connects the claim near Strandmyra to mine No. 7 and to the mine and claim near Tveiten farm.

It is not proven that the lodes are continuously mineralized, but it is reasonable to assume that the mines and claims along the lodes mentioned above are connected by a fissure or fissures that are more or less mineralized. Since it is about 60 years since the mines were closed down and probably a much longer time since the most intense prospecting was carried out in the area, little or nothing can be seen of the many small prospecting holes and claims. Traces of prospecting activity can often be seen, but mostly this has been later covered by earth and vegetation, so it is not possible to determine wheter mineralization was present or not. However, since the lodes are assumed to connect the mines in the old mining reports, and since the field observations also support this, it is reasonable to suppose that the lodes really are fissures that connect the mines and claims and that these are more or less mineralized.

The mineralization seems to be concentrated in the porphyry granite, but is also present in the amphibolite and quartzite. This is possibly a result of the relative competency of the various rocks. The granite is more competent than the banded gneiss.

Lode No. I, Tråk main lode, has a strike of 193^g, and most of the mineralized veins along the lode show practically the same strike direction. However, in general the individual vein directions lie more or less to the east of the lode direction. Ten veins have been measured, and four of these show a direction 4^g to the east of the lode direction. Two veins show the

LEGEND TO FIG 4

— — — —	Major joints
—·—·—·—	Minor joints
(no)	Mine or claim with strike of vein
Ba	Barite deposit with strike of vein

Mines and claims

1	Kværnhusåsen
2	Havna I (Central shaft)
3	Amundskås
4	Tråkfjell
4 a	Tråkfjell adits
5	Heitjern I
6	Heitjern II
7	Tveitendalen
8	Ravnes claim
8a	Utkikken claim
9	Little Tråk
10	Havna II (Tråk shaft)

lode direction, and two veins show big variations to the east (19^g and 29^g). The vein in the claim by the brook north of mine No. 1 and a vein in mine No. 2 show a rather big variation to the west.

It seems certain that there have been movements along the direction of the lode.

The direction of the mineralized veins should indicate a relative movement of the eastern block to the south. Such a movement should give rise to tension openings of a similar pattern to that actually formed by most of the veins along the lode.

The veins are in general vertical or dipping steeply to the west.

On lodes No. II and III similar tectonics as on lode No. I can be observed.

In the mining report J. Cockburn (1908) points to an increase in the mineralization in the lode near the contact between different rock formations. This can not be observed at the surface, but it could be reasonably related to the contact between rocks of differing competencies. Mines No, 1, 10 and 6 are probably examples of this.

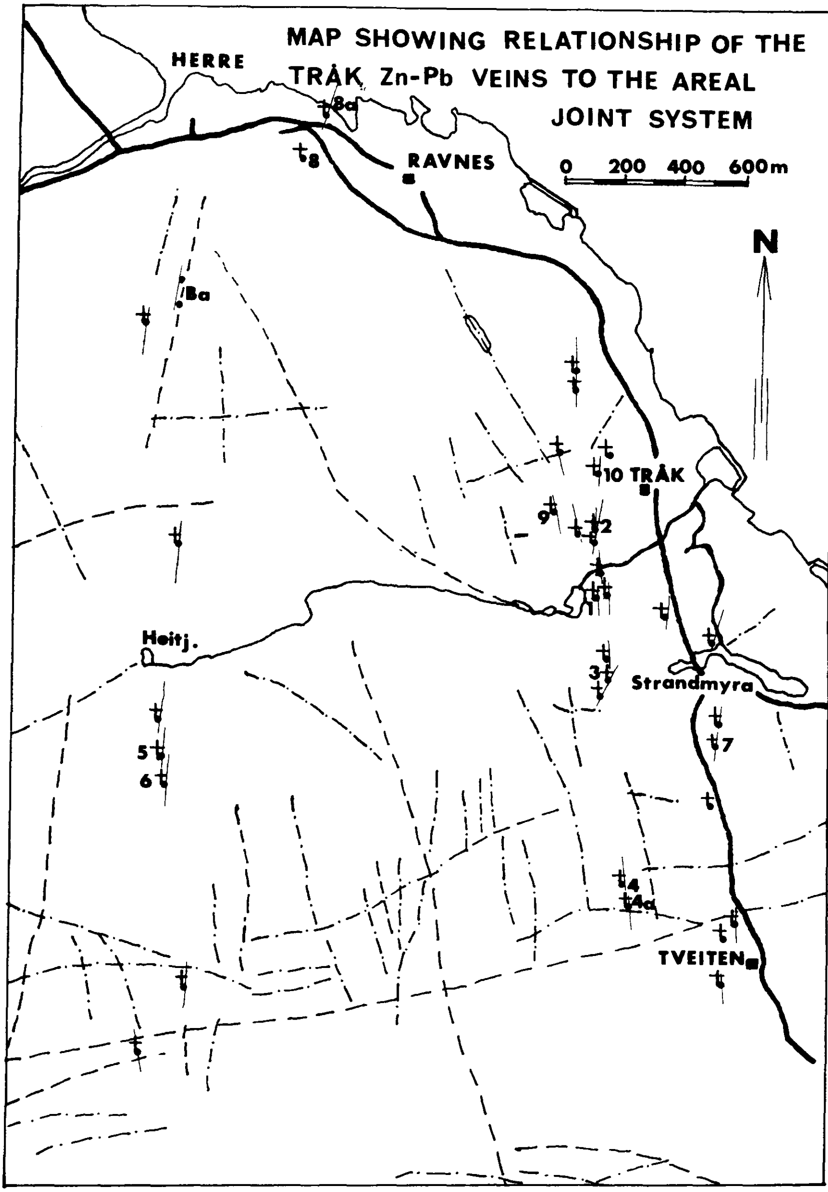


Fig. 4. Map showing relationship of the Tråk Zn — Pb veins to the areal joint system, and the position of the chief deposits.

Kart som viser forholdet mellom Zn — Pb gangene og sprekkesystemenes på Tråk og beliggenheten til de viktigste forekomstene.

Observations show a very clear brecciation of the wall rock, and both in large specimens and in thin sections breccia fragments of varying sizes may be seen. These are always altered by hydrothermal activity, the secondary minerals being chlorite and sericite.

In thin sections it can also be seen that there has been more than one movement along the faults. The gangue mineral, quartz, is mainly seen as euhedral crystals, but zones with mylonitic and recrystallized quartz are usual. *Fig. No. 5* shows a broken euhedral quartz crystal in an aggregate of recrystallized quartz.

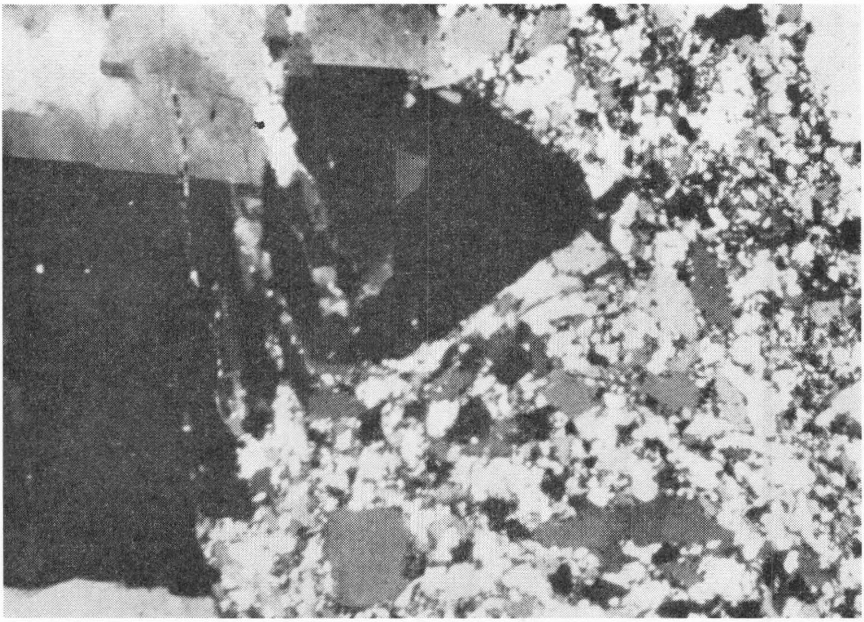


Fig. 5. Vein quartz with mylonitized and recrystallized zone (on the right hand side). + Nic. · 30.

Gangkvarts med en mylonitisert og rekrystallisert sone på den høyre del av fotoet. + Nic. · 30.

The mineralization.

General.

In addition to the previously mentioned publication by J. H. L. Vogt (1907), there is available an old report from the mines by J. Cockburn (1908) which is to be found in the archives of the Geological Survey of Norway (NGU).

The sphalerite and galena occur in the quartz matrix as individual mineral aggregates with sizes from about one mm up to three cm, and as continuous mineral bands with varying thickness, but in general under five cm. J. H. L. Vogt (1907) who visited the mines while they were being worked, mentioned that the mineralization could be followed for up to 2.5 km in lode No. I. He also states that locally the lode carries no ore minerals at all, but in general it is more or less mineralized. The thickness of the veins is very variable. At one place in mine No. 3 it is four metres, but in general it is from about 2 metres down to one decimetre.

In some of the veins occurs a younger intrusive diabase, probably of late Permian age.

There occur two veins that are quite different from the general type in the area. The one is a baryte-bearing vein, 0.5 km south of Herre, and the other is a siderite-bearing vein, outside the central area, 3 km SSW of the baryte-bearing vein.

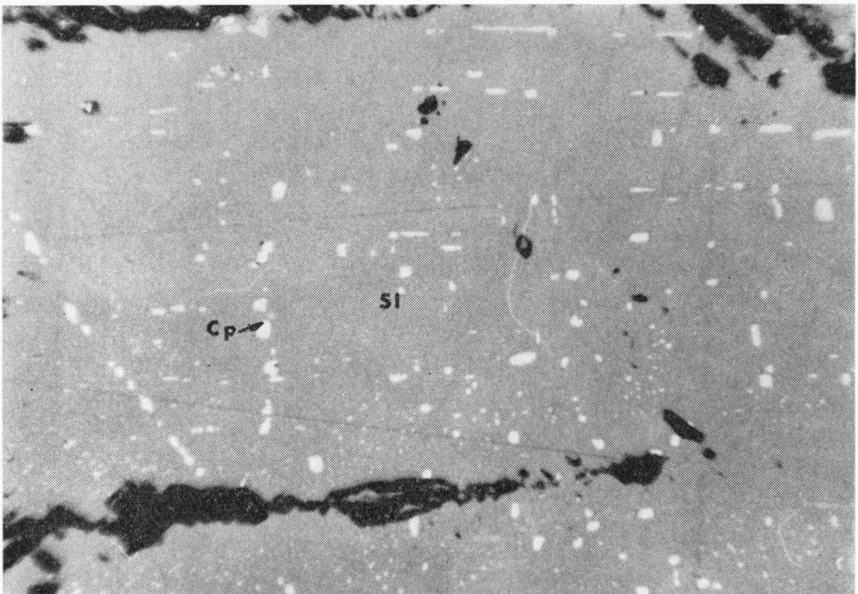


Fig. 6. Sphalerite with oriented drops of exsolved chalcopyrite. Sl = sphalerite, Cp = chalcopyrite. Parallel reflected light. · 190.

Sinkblende med orienterte dråper av avblandet kobberkis. Sl = sinkblende, Cp = kopperkis. Parallelt reflektert lys. · 190.

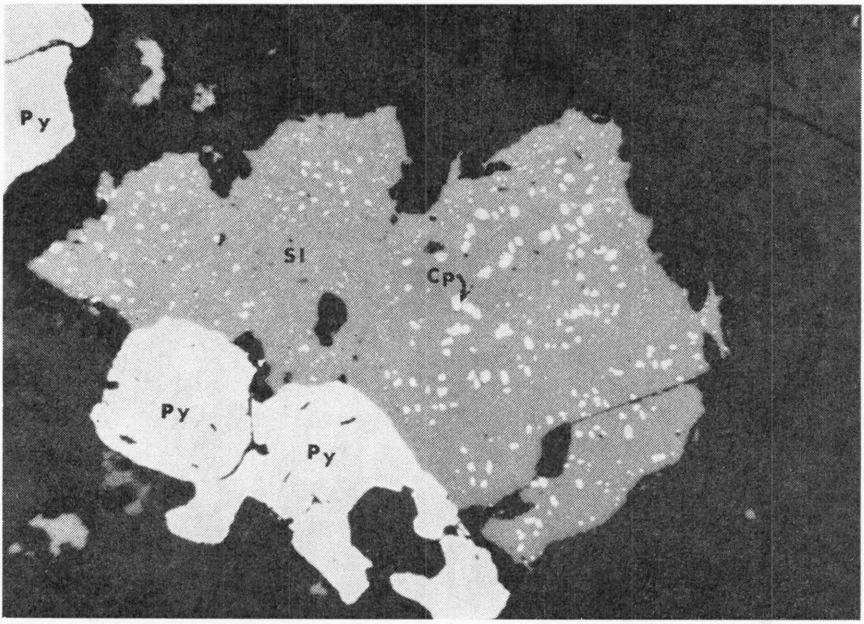


Fig. 7. Sphalerite and pyrite surrounded by gangue mineral, zonally distributed chalcopyrite in the sphalerite. Sl = sphalerite, Cp = chalcopyrite, Py = pyrite. Parallel reflected light. · 75.

Sinkblende og svovelkis omgitt av bergartsmineral med sonar avblandet kobberkis i sinkblenden. Sl = sinkblende, Cp = kobberkis, Py = svovelkis. Parallelt reflektert lys. · 75.

J. H. L. Vogt suggests the following sequence of events: «The veins were first opened and then filled with quartz and sulphides. Later, other veins opened and some of the old veins reopened, and an intrusion of diabase followed. Still later the original veins were again opened, in a few places, and a late generation of baryte was deposited.»

Ore minerals.

The main ore minerals from Tråk are sphalerite, galena, chalcopyrite and pyrite.

Sphalerite is the most important mineral, occurring as a pale green and a pale brown type. The streak is light yellow brownish. Under the ore microscope in polished section the sphalerite has a grey-white to weak red inner reflection. According to I. Oftedal (1940) the sphalerite from Tråk only contains 2 % Fe. No pyrrhotite is found in the sphalerite. The sphalerite occurs mostly as independent sub- to anhedral individuals about one mm to one cm in size. It is also found as inclusions in galena and pyrite.

The most important mineral occurring in the sphalerite is exsolved chalcopyrite. Sometimes galena is seen as inclusions and, rarely, pyrite. The chalcopyrite in the sphalerite occurs as drops of various sizes (Shown in *Figs. 6* and 7). Fig. 6 shows that the exsolved chalcopyrite drops occur as lenses and prisms, and they are often oriented in distinct lines, which follow crystallographic directions in the sphalerite. *Fig.* 7 shows a large area of sphalerite with exsolved chalcopyrite having a seriate arrangement in which the largest drops occur scattered near the centres of the sphalerite grains.

Galena occurs as rather big sub- to anhedral grains often concentrated in bands. In mine No. 9 a few euhedral cubes of galena were found. Sometimes it also is found as minor inclusions i sphalerite, chalcopyrite and pyrite. *Fig. 8* shows an euhedral crystal of pyrite included in galena, which

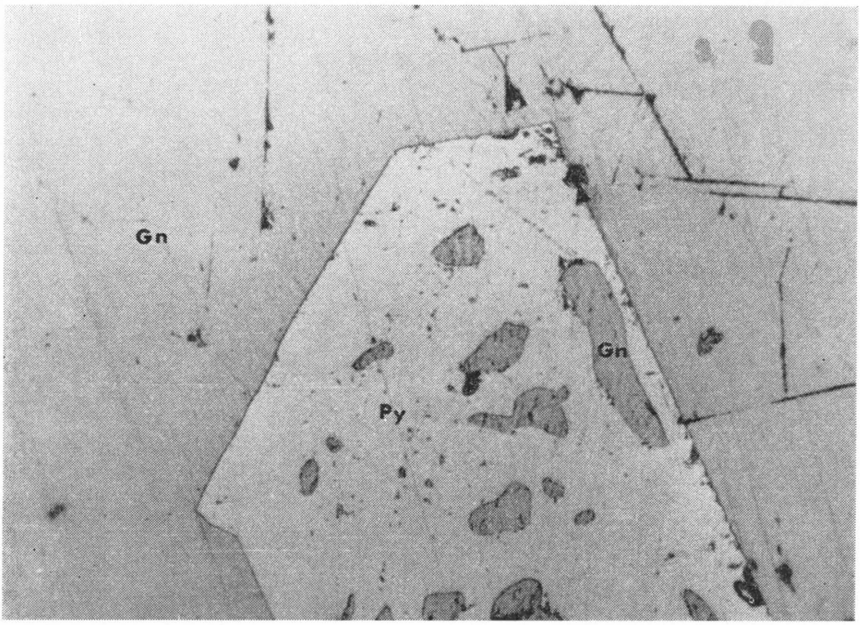


Fig. 8. Euhedral pyrite crystal in galena with galena inclusions. Py = pyrite, Gn = galena. Parallel reflected light. Immersion. · 480.

Euhedral svovelkiskrystall i blyglans med blyglansinneslutninger. Py = svovelkis, Gn = blyglans. Parallelt reflektert lys. Immersjon. · 480.

also occurs as inclusions in the pyrite. Both sphalerite and chalcopyrite are also found in galena.

Chalcopyrite is also mainly found as independent anhedral individuals, but it also occurs to a large extent as drops in the sphalerite. It is not studied whether the independent individuals are exsolutions or not. Chalcopyrite can also be seen as small grains in galena and rarely in pyrite. Sphalerite and pyrite are not found in the chalcopyrite.

Pyrite occours in most of the Tråk type of ore in variable amounts. It is especially plentiful in mine No. 9, «Lille-Tråk», an the prospecting claim 200 m north of this mine. The pyrite occurs mainly as euhedral striated cubes.

Siderite is found in a vein 850 m west of the SW part of the central area. (Outside map area of Fig. 2). It has a specific gravity of 3.84 g/cm^3, which indicates a rather pure siderite. It contains a little chalcopyrite.

Magnetite and hematite occur in a vein with Tråk type of ore 1.5 km west of the SW part of the central area near the lake of Hellestvedt (Fig. 1). Goethite and malachite are found in minor amounts as secondary minerals.

Trace elements.

Earlier analyses of silver in galena were carried out in the laboratory of Kongsberg silver mines (report by J. H. L. Vogt, 1904) and in England, 1906—1908, by the companies who bought the products (report by J. Cockburn, 1908).

I. Oftedal (1940) has made the following trace element determinations in galena and sphalerite from Tråk:

Galena: Ag 0.1 %, As 0.1 %, Sb 0.05 %, Bi 0.1 %.

Sphalerite: Cd 0.1 %, Mn 0.1 %, Fe 2 %, In 0.001 %, Co 0.1 %, Cu 0.1 %

During the present investigation, Ag, Cd, Fe and Cu were determined by X-ray fluorescent sprectrography and by optical spectrograph. The optical spectrographical determinations of Ag and Bi in galena and Fe and Cu in sphalerite were carried out in the geochemical laboratory at N. G. U. (Norges Geologiske Undersøkelse). Cd in sphalerite was analyzed in the same laboratory by X-ray spectrography (analyst for both optical and X-ray analyses: Magne Ødegård).

Galena.

Ag. Fifteen analyses of specimens of galena from various parts of the Tråk area carried out at Kongsberg in 1904, seven carried out in England in 1907, and eleven carried out in Trondheim in 1963, are shown graphically in the histograms in *Fig. 9*. The silver content in the specimen analyzed at N. G. U. was 0.02 %. Both the Kongsberg, N. G. U. and the present results are much lower than the analyses done in England, and

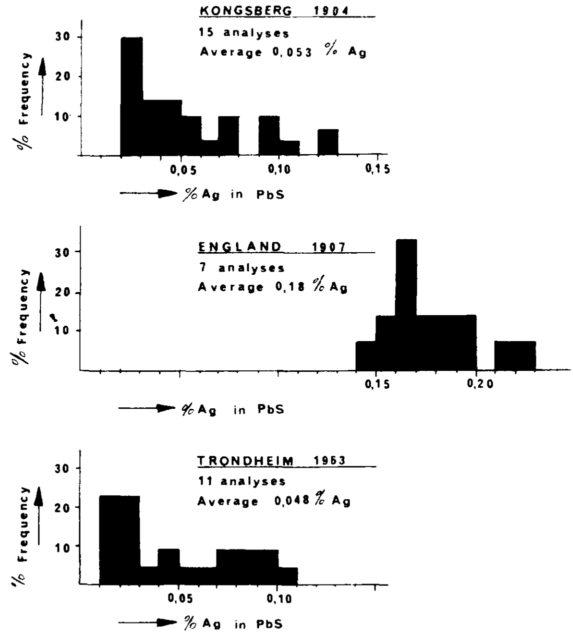


Fig. 9. Histograms showing silver content in galenas analyzed in different laboratories.
Histogrammer som viser sølvinnholdet i blyglans som er analysert ved forskjellige laboratorier.

it is reasonable to believe that these are most correct. The silver content in galena from Tråk should then range from 0.02 to 0.10 % with an average of 0.05 %.

Bi. The specimen analyzed at N. G. U. gave no indication regarding bismuth and the Oftedal's value was 0.1 %. Determination in galena by X-ray fluorescence was not possible because of coinciding lines of Pb and Bi. However, Bi could even be detected in sphalerite, presumably occurring in galena impurities. Oftedal (1940) found a content of 3 % Bi in galena from the prospecting claim of Stulen (= Sandåen, Foslie 1924, I. 528) which lies outside the Tråk area, about 20 km north of Skien and on the border of the Oslo region. Galena with octahedral cleavage is found at Stulen, but is not observed in Tråk. However, ore from

Stulen studied by X-ray fluorescence shows lower Bi content than many of the specimens from Tråk. It is then reasonable to believe that the Bi content in the galena from Tråk approximates, or is higher than, the Oftedal value of 0.1 %.

Sphalerite:

Cd. X-ray fluorescence determination of cadmium was performed on only two specimens of sphalerite, and both show about 0.15 % Cd. One specimen analyzed at the laboratory of N. G. U. shows 0.15 % Cd.

Fe. Oftedal (1940) found 2 %. The present results from N. G. U. show 1.6 % in total. Nearly 0.1 % Fe is calculated as being bound to exsolved chalcopyrite in this specimen, and the iron content in sphalerite will then be 1.5 %. These results agree with the rather pale sphalerite that is generally found in the area.

In. Oftedal (1940) found 0.05 % in Tråk sphalerite. He mentions that a brown type of sphalerite (the oldest) from the vein of Lassedalen, Kongsberg silver mines, carries much gallium and very little indium, while the green sphalerite from the same vein appears to be poor in gallium and rich in indium. As mentioned there also is a pale green type of sphalerite at Tråk, but there is no color description of the sphalerite from Tråk analyzed by Oftedal. Gallium is not found in the sphalerite from Tråk.

Co. Oftedal (1940) found 0.05 % Co in Tråk sphalerite, and the present investigations show trace amounts.

Cu. Oftedal (1940) found 0.1 % and the same per cent was found at N. G. U.

Lead isotopes.

Moorbath and Vokes (1963) have made lead isotope determinations of 35 Norwegian and two Swedish galenas. Included among these is one determination from one of the veins at Tråk. This sample gave a «negative age». Three samples of galena from the silver-bearing veins at Kongsberg also shoved negative ages. Moorbath and Vokes state: «Vogt's account of the sequence of events implies a Permian origin for the Tråk veins, which thus, both in geological characters and in age of deposition, are almost identical with Bugge's veins of the first generation in the Kongsberg area. The similarities in the lead isotopic composition of the two galenas (30 and 33) reinforces the geological evidence.»

Gangue minerals.

Quartz is undoubtedly the dominant gangue mineral, and it occurs mainly as euhedral crystals with sizes from about one mm up to one or two cm. The crystals do not show undulating extinction and this implies that the veins have not been stressed subsequent to the crystallization of the quartz.

Chlorite is very often found as inclusions with a spherulitic or vermicular form and a radial structure. The chlorite is pleochroic in shades of green and the spherulites range in size from 0.01 to 0.15 mm. In one of the claims it was found quartz crystals («ghost quartz») that were riddled with chlorite spherulites. The spherulites are concentrated at crystal faces which formed at an early stage of the growth of the crystal. In general the chlorite occours very rarely in this form, mostly it occurs in small rosettes in quartz as shown in thin section in *Fig. 10*. Chlorite occurs the same way in the Kongsberg silver mines and is described by Neumann (1944).

Fig. 10. Vein quartz with spherulitic chlorite inclusions. + Nic. · 190.
Gangkvarts med sfæriske klorittinneslutninger. + Nic. · 190.

Calcite occurs in very small amounts. It is only found as minute veinlets in the orebearing veins, and it is reasonable to believe that the calcite is mainly younger than the quartz.

Zircon occurs as an accessory in the vein material and it is possible that the few crystals that are found are mainly unaltered crystals from replaced breccia fragments of wall rocks in the veins.

Barite is found in only one thin section of the gangue mineral, but barium has been determined by X-ray fluorescence from a few other gangue samples. Barium has also been determined in the same way in the previously described breccia in the southern part of the Tråk area, 0.7 km west of the southern part of Stokkevann and near the main road (Fig. 1). In all samples where Ba was determined, Sr is also present. Barite is found in quantity near Herre in the north of the central area (Fig. 2).

Diabase.

The petrography of the diabase is described in the section on the geology of the area.

In lode No. 1 diabase can be found continuously over a distance of one km. At Tråkfjell, i . e. mine No. 4, it is not observed. The following thicknesses at lode No. 1 were measured:

Mine	No.	10 Tråk shaft	about	0.3 m
«	«	2 Havna I	«	0.5 m
«	«	1 Kvernhusåsen	«	1.0 m
«	«	3 Amundskås	«	1.7 m
«	«	4 Tråkfjell	absent	

Diabase is not found in lodes No. II and III, but occurs at some other prospecting claims in the area.

The diabase occurs both centrally in the veins and along their walls.

The diabase itself is never intersected by ore, and it seems clear that it is younger than the ore mineralization in the veins. An observation from mine No. 1 appears to confirm this. (*Fig. 11*). The drawing shows a section through a minor vein with sphalerite, chalcopyrite, quartz, wall rock (granite) and diabase with flowage structure. The quartz crystals that penetrate into the diabase seem to be quite unaltered by it, but they are coated by a film of chlorite. In some places a quite decomposed rock is found in the veins. It is possible that this is altered diabase. This rock contains chlorite, sericite, aggregates of newly formed feldspar and magne-

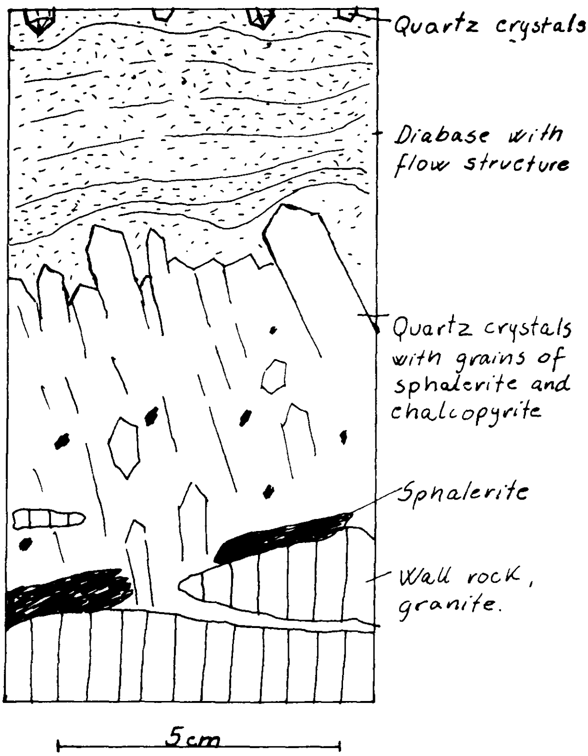


Fig. 11. Sketch of a tiny vein from mine No. 1 showing how the later intruded diabase occurs.
Skisse av en liten gang fra gruve No. 1 som viser hvorledes den senere intruderte diabas opptrer.

tite. Galena is found both in contact with the rock and in it as impregnations.

J. H. L. Vogt (1907) has observed a small fault in the diabase in mine No. 1 so there have been tectonic movements after the diabase was emplaced.

Conclusion.

From the description of the vein material it can be concluded that the Tråk veins are «ore-bearing quartz breccia veins» since quartz is the dominant gangue mineral.

The diabase which is mainly found in lode No. I can be said to be younger than and independent of the mineralization.

From the microscopic study of the ores it is difficult to come to a certain conclusion regarding the order of deposition of the different ore minerals. It can be seen that sphalerite and pyrite are not found in chalcopyrite, and that chalcopyrite is found in pyrite in only one place. In a specimen from Mine No. 1 the order pyrite, chalcopyrite, sphalerite and galena (youngest) can be seen. In a prospecting claim 0.6 km south of Herre the order appears to be pyrite, sphalerite, galena, while in a tiny vein at the west side of the road 0.4 km south of Tråk, the order is pyrite, galena and chalcopyrite. From these micro- and macro-observations it can be assumed that pyrite is the oldest ore mineral. Later chalcopyrite, sphalerite and galena were deposited. From the few observations it is not possible to state the order of deposition of these minerals, but galena seems to be the youngest ore mineral. Quartz was deposited during the whole of the mineralization, especially in the final stages. Barite siderite and calcite are supposed to be the latest minerals deposited. (See appendix).

Lode No. I, with mines No. 10, 2, 1, 3, 4 and 4a, is the only one showing diabase. Sphalerite is the dominant mineral in the northern part and it decreases remarkably to the south. Galena increases to the south, and chalcopyrite seems also to increase in the same direction. Little pyrite is found in this lode, but it is concentrated to the north. No regularity can be seen in the silver content of the galena.

Lode No. III, with mine No. 7 and Tveiten mine, carries much galena and chalcopyrite in the southern part and more sphalerite to the north.

Lode No. II, with mines Nos. 5 and 6, and the prospecting claim 0.7 km south of mine No. 6, seems to be poorer in metallic minerals than lodes Nos. I and III.

In the Sortebogen area southeast of Tråk central area (see appendix) the three lodes show a similar distribution of the ore minerals. The eastern lode is rich in galena and chalcopyrite, and poor in sphalerite, while the middle lode carries more galena than sphalerite and the western lode is the richest in sphalerite.

In general much chalcopyrite is exsolved in sphalerite when chalcopyrite is well represented in the vein as independent individuals.

General features concerning the trends of the mineralization from north to south in the area as a whole cannot be distinguished. However, in the individual lodes there seems to be much sphalerite to the north and more galena and chalcopyrite to the south. From east to west there is clearly a concentration of chalcopyrite and galena in the east and decrease of these minerals towards the west with a parallel increase of sphalerite.

According to Lindgren (Mineral Deposits, 1933) the Tråk deposits should be classified under intermediate temperature conditions on the basis of the type of ore minerals and vein mineral. This means the mesothermal zone corresponding with temperatures from 200°—300° C. Generally Lindgren estimates the depth under the actual surface at which the mineralization took place as being from 1.5 to 4 km. J. H. L. Vogt (1907) suggested a depth of about 2.5 km below the surface at the time of mineralization. This suggestion is based on the total thickness of the overlying Permian lavas, Paleozoic sedimentary rocks and Precambrian rocks. It should be noted that gallium is not determined in the sphalerite from Tråk, and a low gallium content indicates a relatively high formational temperature (Oftedal, 1940).

The lead isotope results support the theory that the Tråk veins and some of the veins at Kongsberg silver mines have genetic relationship and that both types most probably have genetic connections with the igneous activity in the Oslo region during Permian times.

Appendix.

Description of the deposits. (Fig. 4).

Lode No. I includes the mines Nos. 4a, 4, 3, 1, 2 and 10. This is the lode where there has been most mining activity. The ore taken out carried 13—18 % sphalerite and 1—5 % galena. These numbers are taken from the mining report (J. Cockburn, 1908). Quartz is the dominating vein mineral and a little chlorite occurs enriched in breccia fragments and parallel to crystal faces of vein quartz.

In the following description the mines will be described in order of size for each lode.

Mine No. 1. Kværnhusåsen.

This mine is also called Tråk main mine, it is the biggest in the area and it has a 65 m deep shaft. The mine lies in a complex of fine grained granite, porphyritic granite and amphibolite. A movement along the line of the lode can be seen, but it is difficult to see a distinct border.

The mineralization is reported as containing up to 18 % sphalerite and 3 % galena. A profile of the vein from west to east just north of the shaft shows:

Wall rock, amphibolite.
Ore-bearing vein 0.5 m.
Diabase 1.0 m.
Ore-bearing vein 0.2 m.
Wall rock, fine-grained granite.

The ore minerals both from the dumps and the vein are rather coarse grained. Sphalerite and galena are well represented, but relative little chalcopyrite is found, in the form of independent grains and as exsolutions in sphalerite. Pyrite occurs also in rather small amounts.

The silver content in the galena is about 0.05 %. Bi and Cd are also present in small amounts in the ore determined by X-ray fluorescence.

Zircon and barite occur only as accessory gangue minerals.

The wall rock is rather fresh, but the breccia fragments are all strongly decomposed and consist mainly of chlorite and sericite.

Mine No. 3. Amundskås.

The ore from this mine was taken out both as open pit and underground mining. The ore is very similar to the ore in mine No. 1, and the mined ore is reported to carry about 13 % sphalerite and 5 % galena.

A profile over the vein from west to east just north of mine No. 3 shows:

Wall rock, porphyritic granite.
Ore-bearing vein 0.2 m.
Diabase 1.5—2.0 m.
Ore-bearing vein 1.0—1.5 m.
Wall rock, porphyritic granite.

Here, as in mine No. 1 the ore is split by the later intruded diabase. Chalcopyrite and pyrite are, as in mine No. 1 not well represented. A pale green sphalerite is found in the ore.

Silver in galena is determined to about 0.02 %.

Mine No. 2. Havna I (Central shaft).

This mine is mainly surrounded by porphyritic granite, but also amphibolite.

The mined ore carried about 15 % sphalerite and 1 % galena.

A profile across the vein in the prospecting claim 30 m southwest of the shaft from west to east shows:

Wall rock, porphyritic granite.
Ore-bearing vein 2.0 m.
Calcite vein 0.15 m.
Diabase 0.5 m.
Wall rock, porphyritic granite.

Here the diabase only occurs at the east side of the ore-bearing vein.

There is little chalcopyrite exsolved in the sphalerite, and only a few individual grains are found. Very little pyrite is also found.

Mine No. 10. Havna II (Tråk-shaft).

The shaft lies between porphyritic granite and amphibolite. The mined ore carried 15 % sphalerite and 1 % galena. A profile over the shaft from west to east shows:

Wall rock, porphyritic granite.
Ore-bearing vein 2.0 m.
Diabase 0.4 m.
Wall rock, amphibolite.

As for mine No. 2 the diabase is at the east side of the ore-bearing vein.

Chalcopyrite is only represented i small amounts, but pyrite is rather well represented in this mine.

Silver is not determined in galena, but the content is supposed to be rather low since a x-ray fluoresence determination of the ore, mixed galena and sphalerite, shows very small amounts silver.

Mine No. 4. Tråkfjell.

This mine or prospecting claim, lies in porphyritic granite, and there has never been ordinary mined on it.

The vein is rather narrow, 0.2—0.5 m, but it is rather rich in sphalerite, galena and some chalcopyrite. There is relatively more galena and chalcopyrite and less sphalerite in this mine than the other mines on lode No. I.

The sphalerite also carries more exsolved chalcopyrite.

Diabase is not present in the vein.

The silver content in galena is about 0.02 %.

Mine No. 4a. Tråkfjell adits.

This mine is the oldest known mine in the area. Two level adits were driven along the vein direction in a eastwest striking narrow valley. It lies also in porphyritic granite, and diabase is absent.

The ore is much like the ore in mine No. 4, but polished section of a pale green sphalerite shows only small amounts of exsolved chalcopyrite.

In the galena silver is determined to 0.10 % which is rather high compared to all the other mines in the area.

Lode No. III lies east of lode No. I, and there are two mines of significence here. These are Tveiten mine and mine No. 7. No diabase occurs, and the gangue minerals are the same as in lode No. I.

Tveiten mine.

This mine lies just southwest of Tveiten farm. It is surrounded by quartzite and the mined ore is reported as carrying 10 % sphalerite and as much as 10 % galena. Chalcopyrite is also well represented both as independent individuals and as exsolutions in sphalerite. Pyrite is not found.

The vein is rather narrow, but rich in sphalerite and fine-grained galena.

Silver in galena is determined as 0.02 %.

Mine No. 7. Tveitendalen.

This mine is surrounded by porphyritic granite. The ore mined is reported as carrying 5 % sphalerite and 1 % galena. There is also rather much chalcopyrite in this mine, and it is like the type from Tveiten mine.

Lode No. II is about 1.5 km west of lode No. I. This lode has never been mined on any scale, and it is therefore more difficult to give a detailed study. The orebearing vein seem to be from 0.5 to 1 m thick, and the ore is supposed not to be as rich as in lode No. I and III.

At mines Nos. 5 and 6, i.e. Heitjern I and II, shafts have been sunk, and at the mine 0.7 km south of mine No. 6 a level adit has been driven in about 40 m to the north.

Diabase is not found in the lode.

The galena is rather fine-grained, and the sphalerite carries little exsolved chalcopyrite. Pyrite and chalcopyrite are also found in the ore. The vein mineral is mainly quartz with very little chlorite.

Other deposits in the Tråk area.

«The Little Tråk lode»: Mine No. 9 and the prospecting claim 0.2 km to there north are rather different from the other mines in the area.

A diabase decomposed into chlorite, sericite and a fine-grained aggregate of feldspar is connected to the vein.

The ore minerals are pyrite, galena, sphalerite, chalcopyrite and siderite. There is rather much pyrite, which occurs as coarse striated euhedral crystals with both cubic and pyritohedral form. The sphalerite looks darker than in the other deposits and rather much chalcopyrite is exsolved in it. Chalcopyrite is also well represented as independent individuals. Both sphalerite and chalcopyrite are found in pyrite and this is not seen in other specimens from the Tråk area. Galena is found both in contact with and in the decomposed diabase. The silver content in the galena is about 0.02 %.

The gangue carries so much chlorite that it is quite dark.

Prospecting claim No. 8a, Utkikken near Herre is a narrow vein in porphyritic granite. The ore is galena, sphalerite and chalcopyrite, and it is much like the ore in mine No. 4.

The Sortebogen north-south striking lodes are found near Sortebogen between Asdal and Findal (fig. 1). These three lodes, with altogether 14 prospecting claims, are not studied in this work, but in a unpublished report by Fr. Schutz (1914) the following information is to be found.

The eastern lode (No. 1) near the sea consists of two prospecting claims carrying galena, chalcopyrite and pyrite.

In the hills about 0.7 km west of lode No. 1, lode No. 2 is found with 5 claims carrying galena and sphalerite, with galena as the dominant mineral.

Lode No. 3 is only 50 metres west of lode No. 2 with 7 prospecting claims on it. In this lode the ore minerals sphalerite and galena are found with sphalerite as the dominant mineral.

Barite and siderite mines.

A barite mine is found 0.5 km south of Herre. This deposit is mentioned by J. H. L. Vogt (1907), and Th. Vogt (1924) has given a detailed description of the barite crystals from this barite vein.

The vein direction is 215^g, thickness about 2 m and the surrounding rock is porphyritic granite.

Barite is the dominant mineral and there are a few small pyrite crystals. The barite crystals are well developed, clear to pale blue and brownish. They appear in many different forms and can reach sizes up to 6 cm. Strontium is determined by x-ray fluoresence, so it is possible that also celestite is present.

According to J. H. L. Vogt (1907) lead and zinc sulphides are also found in the same vein and these were deposited before the barite.

About 3 km SSW of the barite deposit, outside the Tråk central area a vein filled with siderite occurs. The vein direction is 220^g, thickness 1.8 m and the surrounding rock is porphyritic granite. Siderite is the dominant mineral. Just a little quartz and chalcopyrite are found.

The vein direction of both the barite vein and the siderite vein are practically the same, and they have possibly been mineralized at the same time as late minerals in the Tråk mineralization.

Sammendrag.

I dette arbeidet er Tråk sink og blyforekomst som ligger i grunnfjellet nær Oslofeltet i Bamle i Syd-Norge beskrevet.

Beskrivelsen er et sammendrag av «Det store eksamensarbeid i malmgeologi», utført ved Geologisk Institutt, Norges Tekniske Høgskole 1963—64.

Tråkforekomstene som periodevis er blitt drevet helt fra 1543 ble sist lagt ned i 1908.

Malmen opptrer i nord-sydgående steiltstående parallelle ganger som skjærer grunnfjellsbergartenes foliasjon i omtrentlig rette vinkler. Gangene kan følges i opptil 2.5 km i strøkretningen. Det er ikke påvist at mineraliseringen er sammenhengende i gangene, men det er rimelig å anta at forekomstene er knyttet sammen med sprekker som er mer eller mindre mineraliserte.

Malmmineralene er sinkblende, blyglans, kobberkis og svovelkis. I sinkblenden som inneholder bare 1.5 % Fe er det som regel rikelig med kobberkisavblandinger. Sinkblenden inneholder ca. 0.15 % Cd. Blyglansen fører ca. 0.05 % Ag.

Det dominerende gangmineral er kvarts. Ellers finnes også litt kloritt, kalkspat og tungspat.

Flere av gangene er ledsaget av en yngre intrudert diabas.

Mineraliseringsrekkefølgen synes å ha vært: svovelkis — kobberkis — sinkblende med kobberkisavblandinger — blyglans. Kvarts er avsatt under hele mineraliseringen og spesielt mot slutten. Tungspat, siderit og kalkspat er de yngste mineralene.

I de enkelte gangene ser det ut til at det er mest sinkblende mot nord og mer blyglans og kobberkis mot syd. Fra øst mot vest er det en tydelig konsentrasjon av kobberkis og blyglans i øst og mindre av disse mineralene mot vest med en parallell økning av sinkblendeinnholdet.

Det er antydet at forekomstene ble dannet i temperaturområdet 200—300° C. på et dyp av 1.5—4 km.

Forekomstene har sannsynligvis genetisk sammenheng med den eruptive virksomheten i Oslofeltet fra Perm.

Til slutt i dette arbeidet finnes et tillegg der de enkelte forekomstene er beskrevet.

References.

Bugge, A. 1936. Kongsberg-Bamle-Formasjonen. Norges Geol. Undersøk. No. 146.

Bugge, J. A. W. 1943. Geological and petrographical investigations in the Kongsberg-Bamle Formation. Norges Geol. Undersøk. No. 160.

— 1960. Skarn iron deposits in the Arendal district. International geol. congr. XXI session. Editor Joh. A. Dons.

Foslie, S. 1925. Syd-Norges gruber og malmforekomster. Norges Geol. Undersøk. No. 126.

Holtedahl, O. 1960. Geology of Norway. Norges Geol. Undersøk. No. 208.

Lindgren, W. 1933. Mineral deposits. McGraw-Hill Book Company, Inc. New York and London.

Moorbath S. and *Vokes F. M.* 1963. Lead isotope abundance studies on galena occurrences in Norway. Norsk Geol. Tidsskr. Bd. 43, h. 3.

Neumann, H. 1944. Silver deposits at Kongsberg. Norges Geol. Undersøk. No. 162.

Oftedal, I. 1940. Untersuchungen über die Nebenstandteile von Erzmineralien Norwegischer zinkblendeführender Vorkommen. Vid. Akad. Skr. 1. Mat. Nat. Klasse. No. 8.

Ramberg I. and *Barth T. F. W.* 1966. Eocambrian volcanism in southern Norway. Norsk Geol. Tidsskr. Bd. 46, h. 2.

Vogt, J. H. L. 1907. Uber die Erzgänge zu Traag in Bamle. Zeitschr. für praktische Geologie, Juni/Juli.

Vogt, Th. 1908. Schwerspat aus Norwegischen Vorkommen. Norsk Geol. Tidsskr., Bd. 1, h. 9.

— 1924. Beretning om undersøkelser i somrene 1924—1928. Norges Geol. Undersøk. No. 133.

Unpublished sources:

Cockburn, J. 1908. Traag mines ltd. Report No. 621, Bergarkivet Norges Geol. Undersøk.

Schutz, Fr. 1914. Sortebogen blyglans og sinkblendeforekomster. Report No. 186. Bergarkivet, Norges Geol. Undersøk.