Excursion 4

Metallogeny Associated with the Oslo Rifting

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In all, five different ore types will be demonstrated, starting within the plutonic rocks and moving successively outwards into the surrounding Precambrian areas. Localities to be visited are numbered, correspondingly, 1 to 5.

Deposits 1, 2, 3 closely connected to the Oslo plutonic rocks

Deposit No. 1. Intramagmatic veins carrying molybdenite can be well seen in and around *Sørumsåsen mine* (No. 12 in Plate 4), situated within the Drammen granite, close to the eastern margin of the Drammen cauldron (Bugge 1963).

The mine was worked over short periods up to 1945, the operations being concentrated on a 2 m-wide vein system carrying about 0.2% MoS_2. This vein system is part of a larger set of small veins occurring within a 200 m-wide zone that can be traced for about 800 m, from the main adit in the west to a point east of Skapertjern (Fig. 1). The individual veins usually have E–W to ENE–WSW strikes and vertical to steep northerly dips. They can in some cases be followed for 100 m along strike. Within the mining area the coarse biotite

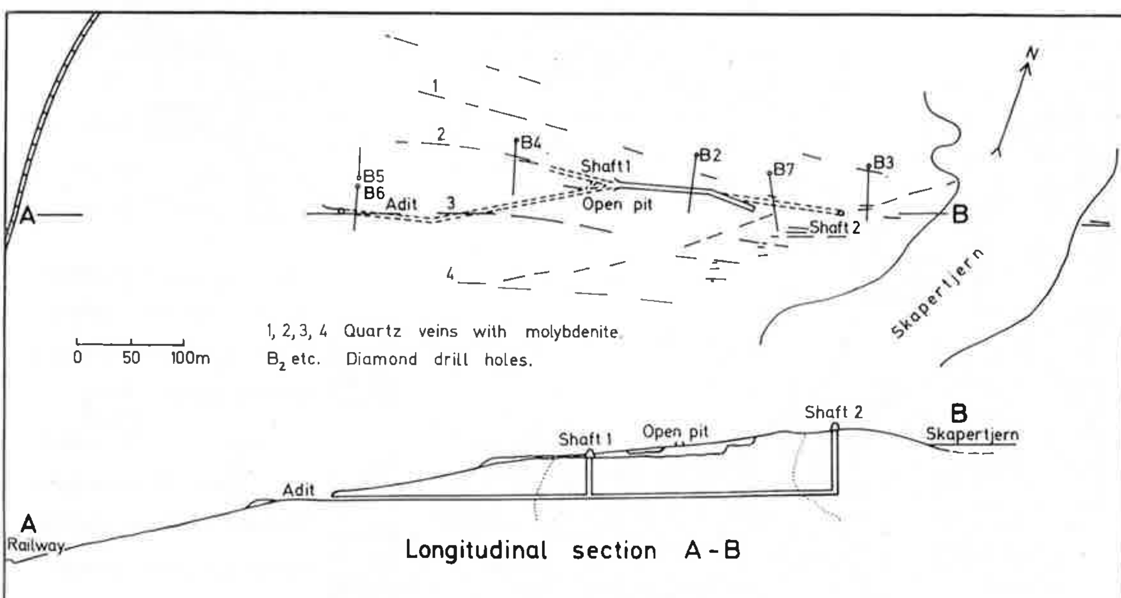
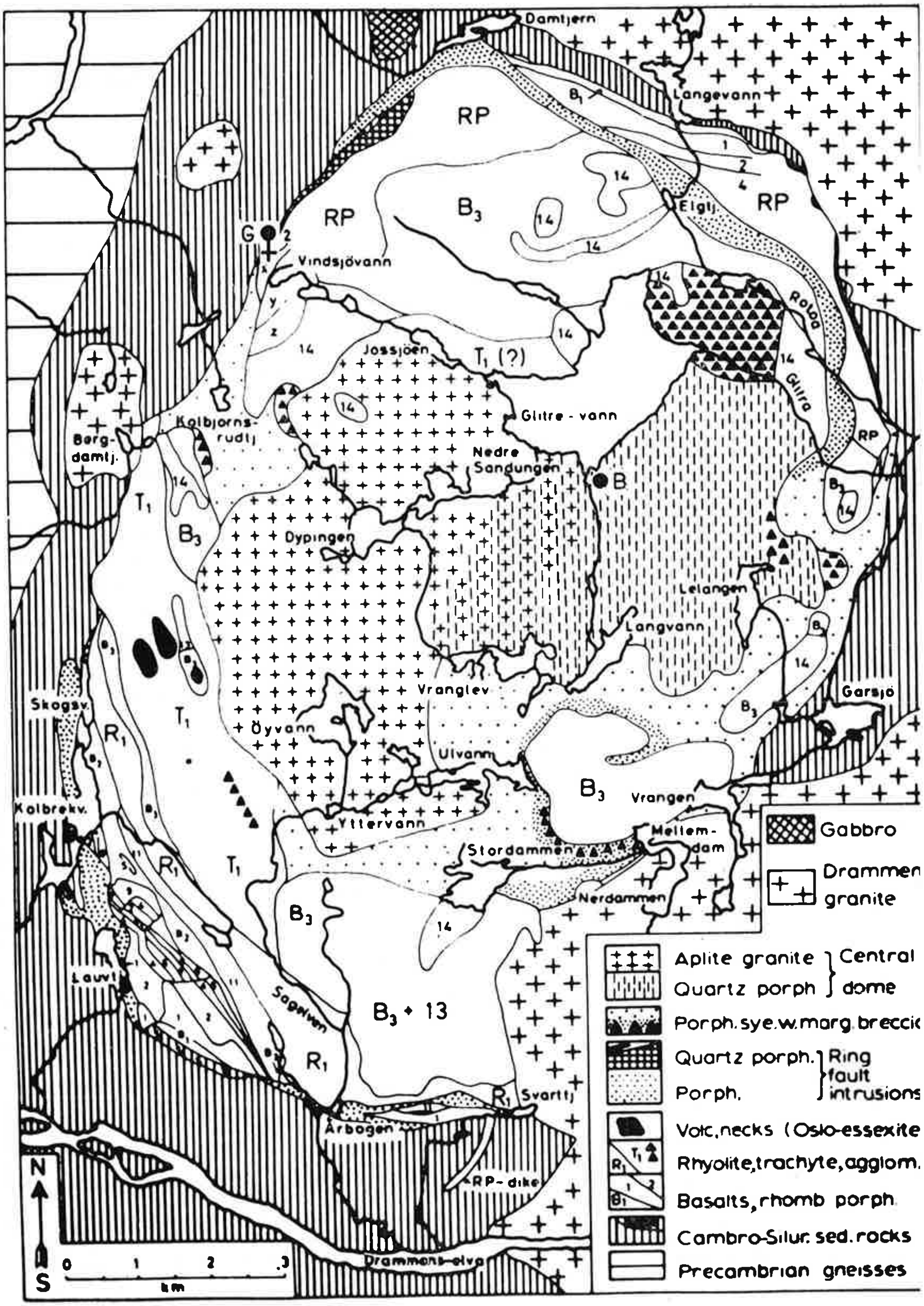


Fig. 1. Sørumsåsen molybdenum mine (abandoned) near Drammen. Sketch plan and section after A. Bugge (1963).


Damtjern
Langevann
RP
B1
1
2
4
14
B3
Elgtj.
G
Vindsjövann
x
y
z
Jossjöen
T1 (?)
Kolbjorns-rudtj
Glitre-vann
Rolaa
Glitra
Berg-damtj.
Nedre Sandungen
B
T1
B3
Dypingen
Lelangen
Langvann
Vranglev
Garsjö
Skogsv.
R1
Öyvann
Ulvann
Vrangen
Kolbrekv.
Yttervann
Mellem-dam
Stordammen
Nerdammen
Lauvt
Sagelven
B3 + 13
Svarttj
Årbogen
RP-dike
Drammens-elva
N
S
0 1 2 3
km
Gabbro
Drammen granite
Aplite granite
Quartz porph
Central dome
Porph. sye. w. marg. breccia
Quartz porph.
Porph.
Ring fault intrusions
Volc. necks (Oslo-essexite
Rhyolite, trachyte, agglom.
Basalts, rhomb porph
Cambro-Silur. sed. rocks
Precambrian gneisses

granite contains dykes and irregular segregations of aplite and quartz–porphyry with both sharp and gradational contacts with the granite.

Molybdenite occurs irregularly distributed in thin quartz and clay gouge veins rarely exceeding 3 cm in width. Accessory vein minerals are pyrite, scheelite and fluorite. The clay gouge veins are locally transitional to the quartz veins along their strike. The quartz veins often show a gradually decreasing molybdenite content when traced along strike away from the clay gouges. Molybdenite is only in rare cases found as impregnations in the country rock, mainly in aplite.

The vein systems are transected by diabase dykes with a maximum width of 10 metres. The dykes often show concentrations of molybdenite along their contacts where they cut molybdenite-bearing veins.

Diamond drilling has shown that the ore-bearing veins continue at least 100 m beneath the surface and also indicates that the vein systems have an easterly plunge.

Deposit No. 2. The possible porphyry-type molybdenum mineralization within the Glitrevann cauldron northwest of Drammen. (A. Geyti & H. K. Schønwandt, unpubl. results) (No. 14 in Plate 4). This is situated within a late, stock-shaped, multiple intrusion consisting of aplitic granite and quartz-feldspar porphyry (Fig. 2). These rocks show some resemblance to the quartz-porphyries and aplitic granites encountered within the Finnemarka and Drammen biotite granite massifs. However, there is so far little evidence for a common source for, and a simultaneous deposition of, molybdenite within the apical parts of the biotite granite and within the subsided near-surface or subvolcanic porphyries within the Glitrevann cauldron.

Fieldwork by Geyti and Schønwandt (pers. comm. 1976), has shown that the molybdenite mineralizations are connected to alteration zones in the central intrusions. The aplitic granite is a fine- to medium-grained leuco-granite containing a maximum of 5 vol.% biotite. The quartz-feldspar porhyry is an aphanitic rock with phenocrysts up to 4 mm in size, in a dark grey or grey matrix. This colour difference of the matrix allows two varieties of porphyry to be distinguished, a dark variety located in the east, and a lighter variety located to the west. The boundary between the quartz–feldspar porphyry and the aplitic granite is sharp, not gradational as shown on the map (Fig. 2).

Two types of alteration have so far been recognized (Fig. 3):
1) a quartz–sericitic alteration; 2) an argillitic alteration.

A quartz–sericitic alteration zone is well developed in the area as wallrock alteration in connection with fissures. The paragenesis used in the field to define this zone is sericite + quartz ± molybdenite. The quartz–sericite ratio

Fig. 2. Geological map of the Glitrevann cauldron, north-west of Drammen. (After C. Oftedahl 1974. Norges Geologi, Tapir Forlag, Trondheim). G: Glomsrudkollen. B: Bordvika.

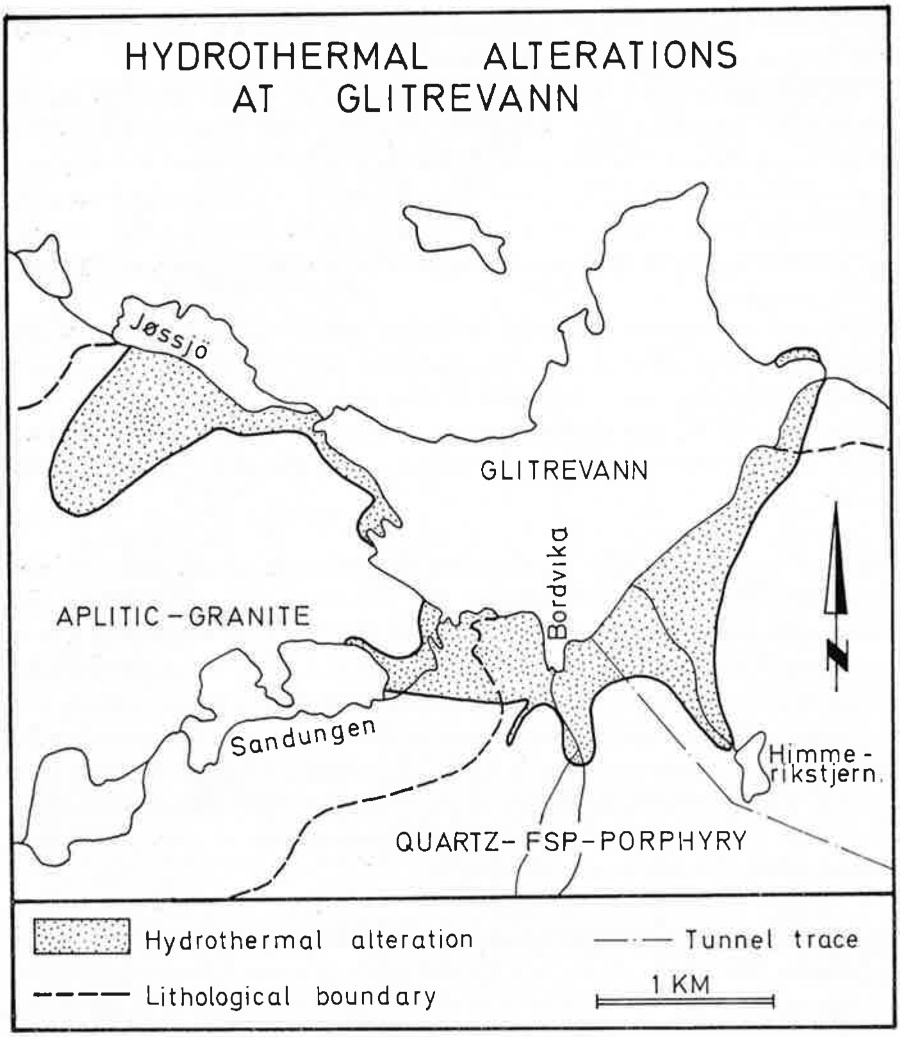


Fig. 3. Wall-rock alteration zones associated with possible porphyry-type molybdenite mineralization in the Glitrevann cauldron. (Map by A. Geyti & H. K. Schønwandt, Aarhus University). See also Fig. 8.

varies between the two extremes, complete sericitization and complete silicification. Sericitized rocks are soft and yellow-white, with pyrite occurring both as vein fillings and disseminations in the altered rocks. Silicified rocks are steel-grey, hard and brittle, with pyrite occurring only as vein fillings. In both cases the feldspar phenocrysts are completely altered.

On a regional scale there is a horizontal variation in the quartz/sericite ratio which diminishes towards the periphery of the quartz alteration zone. Moreover, alteration at the periphery becomes more structurally controlled. At the periphery, a few, metre-wide zones with total sericitization penetrate the country rocks for several hundred metres, while at Bordvika, in the central part of the alteration zones, the typical alteration occurs as centimetre to decimetre-wide silicified zones around quartz veins. In the water tunnel this alteration shows a typically irregular stockwork pattern.

The quartz–sericite zone is largely controlled by faults. The most conspicuous is the northwest-striking fault, running through Jøssjø and Vindsjø. Along this fault zone there is a long, narrow belt of massively altered rock. Vertically the alterations are only found below 475 m a.s.l.

Argillitic alteration is seen in the water-tunnel southeast of Bordvika as centimetre to decimetre-wide veins filled with white to grey clay.

The molybdenite is found as flake-like crystals along veins inside the quartz-sericitic alteration zone and as fine-grained impregnations in totally altered and sheared rock in which it is impossible to discern the original texture. The molybdenite imparts a dark colour to the altered rock.

Minor molybdenite is associated with pegmatite in the aplitic granite. This type of mineralization resembles the occurrences of MoS_2 in the Drammen granite mentioned above.

Deposit No. 3. Contact metasomatic sulphide mineralizations have been worked in the past at several places along the western margin of the Glitrevann cauldron northwest of Glitrevann. The largest of these workings was that at the *Glomsrudkollen Mine* (No. 15 in Plate 4), which was in operation during the period 1880–1910. The early exploration activity here took place at several localities along apparently favourable limestone zones some 1200 m long and about 10–30 m wide.

The folded Cambro-Silurian rocks in the area have been thermally affected by the stock-shaped biotite granite to the northwest and by the ring dykes injected along the margin of the Glitrevann cauldron. The sediments have mainly undergone contact metamorphism in the hornblende-hornfels facies (see Fig. 2).

Recent investigations by F. Pedersen (1976) have shown that the sphalerite-dominated mineralizations occur within skarn-altered parts of a steeply dipping Lower Silurian limestone zone, having a NE-SW strike, i.e., a strike parallel with the cauldron boundary. The limestone zone is bordered by the quartz porphyry ring dyke to the east and overlies stratigraphically Ordovician argillaceous and calcareous hornfelses to the west.

Subsidence (1000 m) of the Glitrevann cauldron caused the intrusion of the ring dyke and the down-dragging of the ore-bearing limestone. Both the skarn alteration and the ore deposition post-date the ring dyke intrusion.

The mineralized skarn bodies have an irregular shape and are especially well developed in areas where the limestone has been transected by faults, fractures and locally porphyry dykes. The main ore body, located 200 m SW of L. Maurtjern, occurs as a crescent-shaped plate situated along the bedding of the altered limestone. The axial plunge of the body is from surface to 35 m level 45° NE and between 35 m and 74 m level 30° SW. The content of sphalerite seems to diminish at the deepest level, i.e. 74 m.

Most of the ore-bearing solutions were introduced subsequently to the main skarn alterations. Early metasomatic alteration gave rise to a light brown garnet-clinopyroxene skarn that is encountered several places in the mining area, but which is usually low in ore minerals. This skarn type consists of light brown garnet and smaller amounts of green clinopyroxene in a matrix of calcite and quartz. Usually the skarn shows a banded texture due to alternating garnet and clinopyroxene layers. This texture apparently reflects the original sedimentary layering of the altered host-rocks. Brecciation and fracturing of both the early skarn and the limestone followed, prior to a new influx of solutions. These solutions gave rise to retrograde alteration of early garnet-clinopyroxene skarn and skarnification of unaltered parts of the limestone, leading to development of amphibole-, chlorite-, epidote-, quartz- and calcite-bearing skarns with green to dark brown colours. The main ore deposition was related to the end of this period, which was characterized by repeated fracturing. The ore minerals occur as fissure fillings, as metasomatic veins and as massive concentrations due to the replacement of interstitial calcite in the late skarns and unaltered limestone. The ore minerals locally show selective replacement of calcite-rich layers in the limestone, leaving calcareous hornfels beds unreplaced.

The ore-forming period started with the deposition of hematite and, somewhat later, also of granular magnetite. Some of these Fe-oxides are probably also products of the retrograde skarn alteration. Most of the hematite has been pseudomorphosed by lamellar magnetite during the influx of more sulphide-rich solutions.

Subsequently to the fracturing of the magnetite ore, the main sulphide deposition followed, giving rise to sphalerite ore with subordinate amounts of pyrrhotite, chalcopyrite, pentlandite, mackinawite, galenobismuthinite, bismuthite, siegenite and millerite. During a somewhat later mineralizing stage chalcopyrite, pyrrhotite and sphalerite with minor amounts of argentiferous pentlandite, pentlandite, gold and pyrite were deposited.

The massive sphalerite ore comprising the main ore body at Glomsrudkollen mine is connected with the amphibole-calcite skarn. Generally it can be stated that the zinc content in this skarn type increases porportionally with the degree of alteration of the early garnet-clinopyroxene skarn.

On textural and mineralogical grounds, Pedersen (1976) distinguished the following ore types (Table 1):

A. Sphalerite-dominated ores.

Ore-type 1. Replacement and fracture fillings in garnet-bearing marble.

Ore type 2. Fracture fillings in garnet-clinopyroxene skarn.

Ore type 3. Fracture fillings and replacement in garnet-clinopyroxene-epidote-calcite skarn (Transition zone).

Ore type 4. Replacement in amphibole-calcite-(epidote) skarn. (The main ore body).

Ore type 5. Replacement and fracture fillings in garnet–amphibole–chlorite skarn.

B. Chalcopyrite-pyrrhotite-sphalerite ore.
Ore type 6. In garnet-amphibole-epidote skarn.
C. Magnetite ore with fracture fillings of sphalerite and pyrite.
Ore type 7. In amphibole-chlorite-calcite skarn.

Ore types 1 and 6 are only found on the mine dumps, while the others can be studied at the surface around the main incline shaft. Fig. 4 shows the main geological features at this locality. A schematic cross-section of the Glomsrudkollen mine, characterized by the central amphibole-calcite skarn bordered by garnet-clinopyroxene skarn, is also given in this figure.

Fluorite and scheelite can be encountered locally in larger concentrations. Scheelite seems to be situated in the brecciated parts of the garnet-clinopyroxene skarn, while fluorite has a more irregular distribution.

Pedersen (1976) concludes that the Glomsrudkollen mineralization is genetically connected with a transverse system of faults and fractures that can be traced southeastwards to the Glitrevann molybdenum mineralization, where they control the quartz-sericitic alteration envelope in the peripheral parts of the alteration zone. Recent underground mapping by one of the authors

Table 1. Mineral parageneses in the Glomsrudkollen mine (Pedersen 1976)

Minerals / Ore types	1	2	3	4	5	6	7
Hematite					o	oo	
Magnetite				oo	o	oo	oooo
Sphalerite	oooo	oooo	oooo	oooo	oooo	ooo	oo
Chalcopyrite	o	o	o	o	oo	ooo	oo
Mackinawite		o	o	o	o	o	o
Pyrrhotite	o	o	o	o	o	ooo	o
Pentlandite	o	o	o	o	o	o	
Galenobismuthinite	o	o	o	o	o	o	o
Bismuthite		o			o		
Gold						o	
Siegenite	o	o	o				
Millerite	o	o	o				
Ag-pentlandite					o	o	
Pyrite	oo	o	oo	oo	oo	ooo	oo
Marcasite		o	o	o	o	oo	
Limonite			o	o	o	o	ooo
Covelline						oo	
Garnet	oo	oooo	oo		oooo	oo	o
Clinopyroxene		ooo	oo		o		
Amphibole	oo	oo	ooo	oooo	ooo	ooo	ooo
Epidote	oo	oo	oo	oo	oo	ooo	o
Chlorite	oo	oo	ooo	oo	ooo	o	ooo
Talc			oo		oo		
Plagioclase		oo	oo	o	oo		
Quartz	oo	oo	oo	ooo	ooo	o	oooo
Calcite	oooo	oo	ooo	oooo	ooo	oooo	oooo

oooo Main constituents
ooo Subordinate constituents
oo Minor constituents
o Accessory constituents

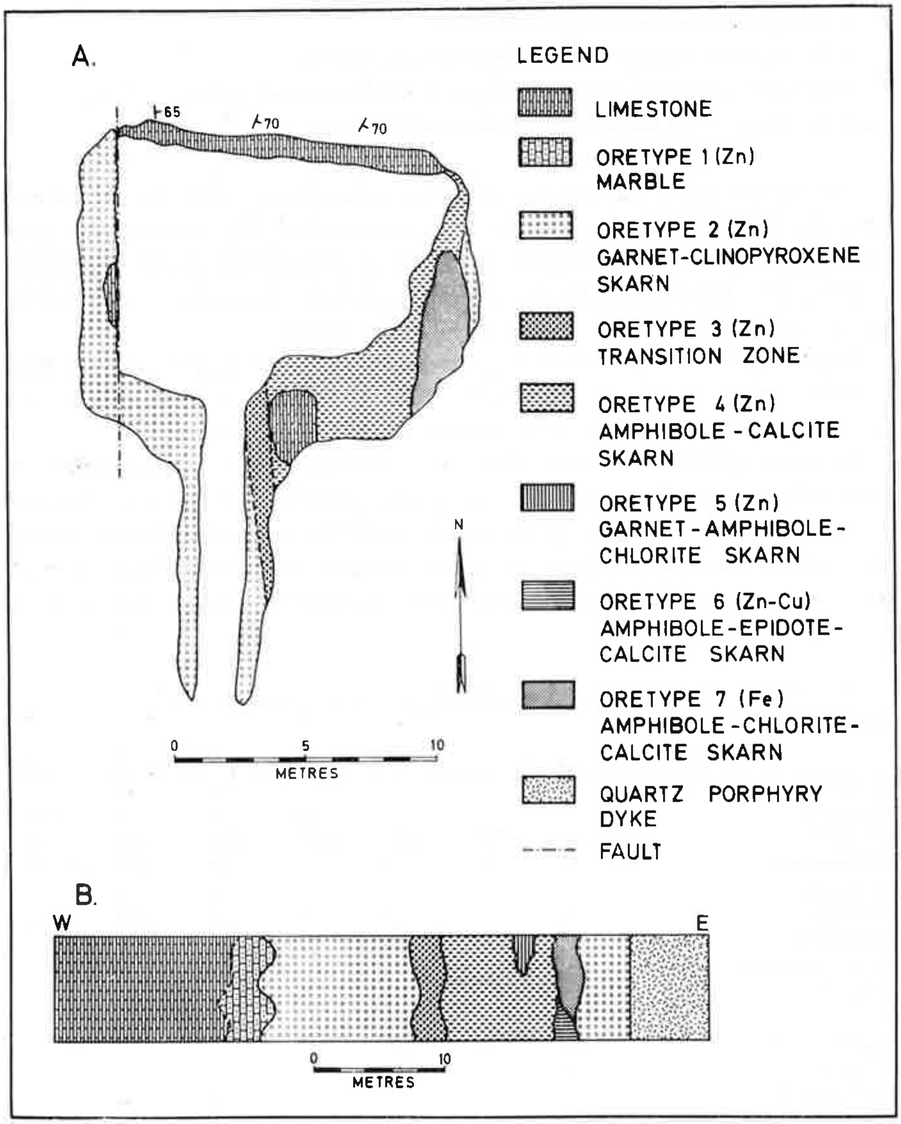


Fig. 4. Glomsrudkollen Mine. A) Geological plan around collar of incline shaft. B) Schematic vertical section at this locality. (After F. Pedersen, unpublished thesis, Aarhus University, 1976.

(P.M.I.) has, however, given indications that the main sphalerite mineralization is controlled rather by a system of strike-slip faults than by transverse faults.

In the lower adit at Glomsrudkollen, a 2m-wide quartz-sericite-fluorite vein has been met with in a transverse fault far outside the main ore body. This may possibly constitute the continuation of the Glomsrudkollen-Glitrevann fault-zone; if this is so, then the relation between the Glomsrudkollen Zn- and Glitrevann Mo-mineralization, proposed by Pedersen (1976), is somewhat uncertain.

Vein deposits Nos. 4 and 5 in Precambrian areas outside the Oslo graben

Numerous vein deposits of Precambrian age have been worked in the past in areas peripheral to the Palaeozoic rocks of the Oslo graben. By far the most famous mining district is that situated to the west of the south-central part of the Oslo Region, known as the Kongsberg district.

The deposits are situated in Precambrian rocks which comprise N-S striking, banded gneisses of dioritic to amphibolitic composition with considerable intrusions of granite (Kongsberg granite) and hyperite (Vinor amphibolite or diabase). The ore-bearing veins are subdivided into early quartz-breccia veins dominated by base metal sulphides or fluorite and late calcite veins characterized by their content of native silver and Ni-Co arsenides. So far, only the silver-bearing veins, mainly located west and northwest of the town of Kongsberg, have been of economic importance. Recently, however, one of the fluorite-dominated quartz-breccia veins has received attention as a possible fluorspar source (T. Vrålstad 1976, unpubl. results). This deposit is located in Lassedalen valley and can be traced for about 3.5 km westwards from Olsrud in Saggrenda, 6 km SSW of Kongsberg town.

Deposit No. 4. This Lassedalen breccia zone (No. 23 in Plate 4) (Fig. 5), which shows only small lateral displacements, has an east-west strike and a steep southerly dip (65–80°). The zone is usually 15–30 m wide, but locally attains a width of nearly 80 m. It has a rectilinear strike but shows in some places changes or bifurcations from the main E-W direction. The changes in strike have apparently exercised a considerable control on the localization of larger concentrations of fluorite.

The breccia is filled by quartz, calcite and fluorite with minor amounts of pyrite, sphalerite and chalcopyrite. These minerals occur as more or less monomineralic veins and lenses, and as a cementing medium between country rock fragments. They have been deposited at several stages, each connected with repeated brecciation or fracturing. Quartz is always present, while calcite, fluorite and sulphides are more erratic in their occurrence. The country rock fragments often show silicification, while the breccia is at several places transected by decimetre-wide clay veins.

The footwall side of the Lassedalen structure consists of sheared gneisses with a transition zone towards the main breccia characterized by abundant vugs and by deposition of laminiform calcite (argentine). This breccia type can also locally be observed along the hanging wall. The main fluorite concentrations are located within the central and hanging wall part of the breccia, in which the degree of fracturing and mineral deposition shows great variations.

The economically important fluorite mineralizations, occurring as veins and lenses with a pinch-and-swell pattern, can be followed more or less continuously, for about 1 km. The largest swells can reach a width of 10–13 m for a distance of 200–250 m along strike. The fluorite content in these bodies varies in the range 40–80% CaF_2. In addition, fluorite occurs as dense

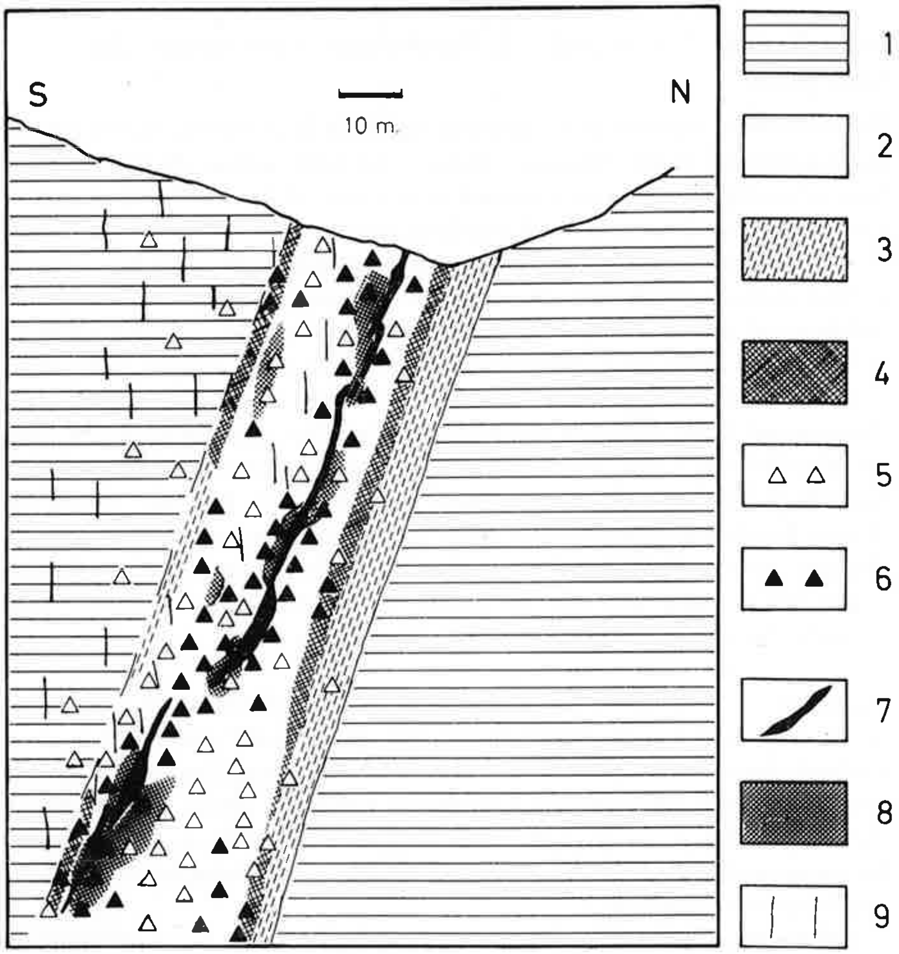


Fig. 5. Idealized vertical cross-section through the Lassedalen fluorite-bearing breccia zone. 1. Precambrian gneisses. 2. Brecciated gneisses. 3. Sheared gneisses. 4. Breccia containing laminiform calcite and abundant vugs. 5. Breccia with low content of introduced minerals. 6. Breccia with high content of introduced minerals. 7. Fluorite veins and lenses. 8. Dense fluorite. (After T. Vrålstad, unpublished report, Norsk Hydro A/S).

disseminations, containing 20–30% CaF_2, along and near these massive veins and lenses.

The great majority of the fluorite has a green colour, although local, concentrations of white and colourless types have been noted, while subordinate amounts of blue and violet fluorite are encountered most places within the Lassedalen structure.

The junction between the main breccia and the fractured country rock in the hanging wall is more diffuse than that on the footwall side. The fractured gneisses contain only minor concentrations of fluorite as veinlets and weak disseminations.

Deposit No. 5. The Kongsberg Silver Mines were in operation from 1623 to 1955, during which time nearly 1400 tonnes of pure silver were produced from about 130 larger and smaller mines.

The mines were worked on *Ag-bearing calcite veins.* Ore shoots along the veins were apparently controlled by their intersection with concordant sulphide-bearing zones, the so-called *fahlbands,* in the Precambrian country rocks. These fahlbands are schistose zones composed of biotite-garnet, sericite, chlorite, garnet-amphibole or garnet-chlorite-biotite schists. They usually have a rusty appearance due to weathering of disseminated sulphides, mainly pyrite and pyrrhotite. Other disseminated ore minerals occurring in subordinate amounts are chalcopyrite, sphalerite, pyrite, arsenopyrite, cobaltite, galena, magnetite and ilmenite. Chalcocite and bornite occur more rarely. The fahlbands are interwoven with narrow veins and lenses of quartz, often carrying fracture fillings of the above-mentioned sulphides. The most important of these zones are the Overberget and Underberget fahlbands, running northwards from a point southwest of Kongsberg. The great majority of the mines are connected within these two zones. The Overberget fahlband is 180–900 m wide and reaches a length of about 10 km along strike.

The silver-bearing veins usually strike about east-west and normally dip steeply towards the south. However, southerly dips of 45° are common in the northern part of the Overberget zone and in places elsewhere the dip can be steep to the north. The calcite veins are very narrow, from a few millimetres upwards. The average width is about 5–10 cm. The dimensions along strike and dip rarely exceed 100 m. The veins often appear in sets, which show a distribution resembling a 'fiederspalten' vein system, usually with a northerly plunge. There exist, however, numerous single veins that cannot be incorporated into this 'fiederspalten' system. The individual veins are often surrounded by parallel and crossing fissures, resulting in a mineralized zone or a mineralized breccia.

Some of the early quartz-breccia veins located within the fahlbands have been permeated by the same solutions that gave rise to the later Ag-bearing calcite veins. These modified veins, called '*main veins*' by C. Bugge (1917) were often very rich in silver. They carried large quantities of laminiform calcite and abundant vugs.

The vein system encountered in the Justits mine (Fig. 6) follows a so-called '*strike vein*', i.e. a fissure originating from faults parallel with the strike of the fahlbands and mineralized with calcite and locally also with zeolites and adularia. The 'strike veins' were rarely silver-bearing, but cross-cutting calcite veins showed high silver contents close to them and usually narrowed and tapered off with increasing distance from them. Neumann (1944) pointed out that the regular enrichment of silver in the neighbourhood of the strike veins is mainly a matter of tectonic control of the deposition.

The '*rotten veins*' (råtaganger, Lattengänge) of the fahlband zones have been described by C. Bugge (1917). These veins are mylonitized dislocation fissures, striking about east-west and dipping 45°–60°. They are filled by a clayey mass

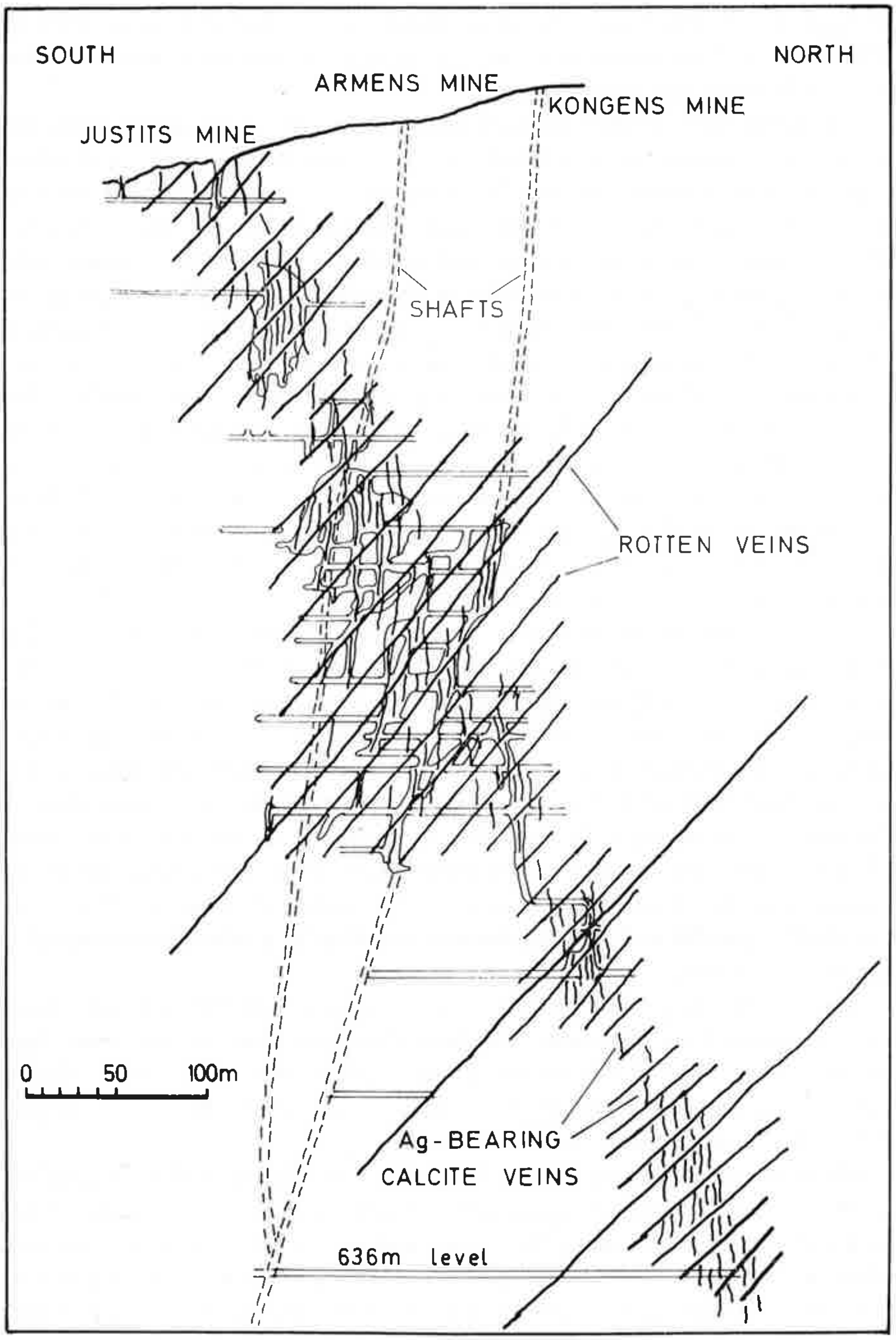


Fig. 6. Schematic vertical N–S section through the Justits mine, Overberget fahlband, showing veins and fissures. Section drawn in plane of strike vein. (After C. Bugge 1917, and H. Neumann 1944).

consisting of mainly chlorite, kaolinite and some illite. Silver is also usually encounterd in the vicinity of the veins. Neumann (1944) considered that the 'rotten veins' represented loci of maximum stress concentration (shearing – faulting). The effects of the stress diminish gradually on both sides of the 'rotten veins' and die out. The numbers and sizes of the calcite veins also decrease proportionally with distance from the 'rotten veins'.

In addition to calcite, the silver-bearing veins consist of quartz, fluorite, barite, zeolites, adularia, axinite and coalblende. The major ore minerals are pyrite, sphalerite, pyrrhotite, native silver, chalcopyrite, galena, argentite, Ni–Co arsenides and sulphosalts of silver (mentioned in order of decreasing abundance).

The minerals can be assigned to three separate parageneses:

1) An early quartz–coalblende–fluorite–axinite–pyrite paragenesis;
2) an intermediate calcite–barite–fluorite–sulphide–native silver–Ni-Co arsenide paragenesis;
3) a late calcite–zeolite paragenesis. Ruby silver is encountered on rare occasions.

All these parageneses have usually been precipitated in the same vein fissure, but locally they can also form separate fillings.

The silver deposition stage can be further subdivided into an early calcite–barite–sphalerite–chalcopyrite–galena stage, an intermediate fluorite–native silver stage and a late calcite–pyrrhotite–chalcopyrite–Ni-Co arsenide–sphalerite stage. These subdivisions are, however, very closely related to each other and Neumann (1944) considered it logical to regard them as forming a single event. The deposition of these minerals probably took place in the temperature range 200°–400°C.

The native silver occurs mostly in three different ways (Neumann 1944): 1) As 'matrix silver' (fyllingssølv) interstitial to other minerals and having shapes that are mainly determined by the outlines of the surrounding minerals. 2) As filiform silver, at Kongsberg called 'thread silver'; i.e., curved bundles of threads which have often grown together. Thread silver has been given various names, e.g. 'hair silver', 'tooth silver' and 'moss silver'. The latter is made up of aggregates of smaller threads orientated in all directions. 3) As crystals limited by well-defined crystal faces. Among these types the 'matrix silver' was probably the most commonly occurring form.

So far, the genesis of these silver veins and their localization within the fahlbands has not been fully explained, though the problems have been discussed in several publications. Further research is obviously needed, although the inaccessibility of the deposits at the present time renders this difficult.

Road log (Excursion 4, see Fig. 7)

Start from Sundvollen Hotell, drive southwards on road 285, along the eastern shore of the lake Tyrifjorden, passing Downtonian sandstones and Permian

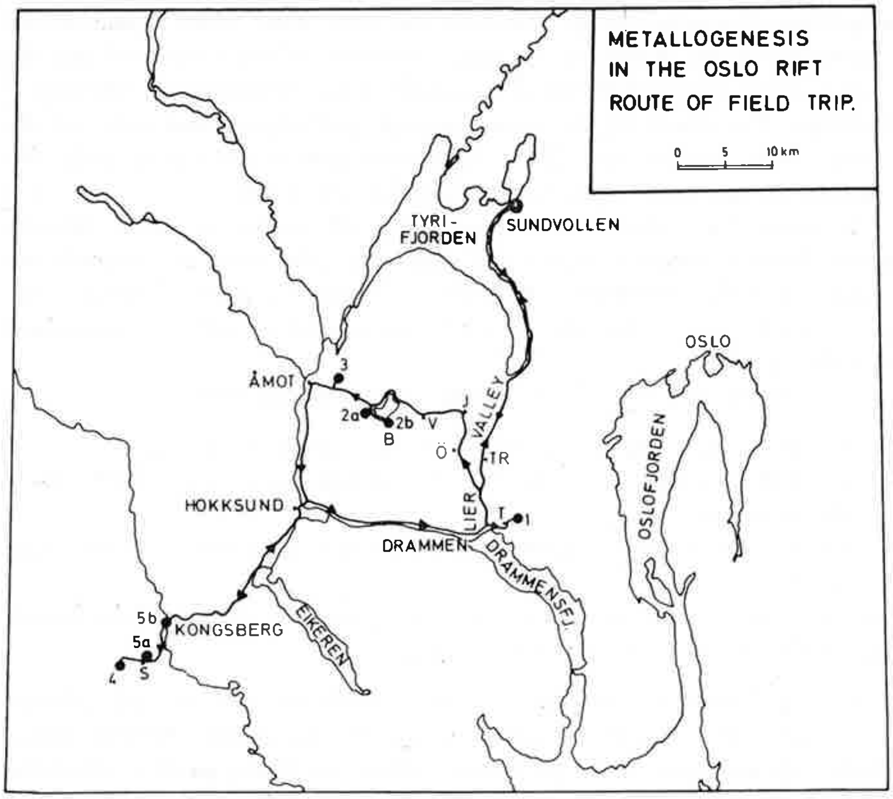


Fig. 7. Map showing the excursion route. Tr: Tranby, T: Tuverud, Ö: Øksnes, J: Justad, V: Veslesetra, S: Saggrenda, B: Bordvika.

lavas forming a pronounced escarpment to the east. The contact of the Drammen granite is crossed at Tranby (38 km).

First stop at Tuverud on the east side of the Lier River, near the Drammensfjord (45 km). 15 min. walk *to Loc. 1, the Sørumsåsen mine.* At this locality intramagmatic molybdenite-bearing quartz and clay veins can be seen and their relations to the biotite granite, with aplitic facies, quartz porphyries and diabase dykes, can be studied. A well-worn path leads upwards from 'Grubevegen' in a modern residential area and crosses an old, disused railway line (Oslo–Drammen). The path crosses the open pit between Shaft 1 and Shaft 2 (Fig. 1) on a bridge, from which a general view of the narrow, worked vein system can be obtained. To the north of the old stopes, just before the bridge is reached, are extensive dumps from which good specimens of the mineralization can be collected.

Return down path, leaving it to the left to descend into the mouth of the open pit just east of Shaft 1 (Fig. 1). Good exposures of Permian diabase dykes cutting the vein system at low angles.

Return to the path, follow it back across the old railway line (approximately corresponding to the outer, eastern, margin of the Drammen cauldron) to Grubevegen.

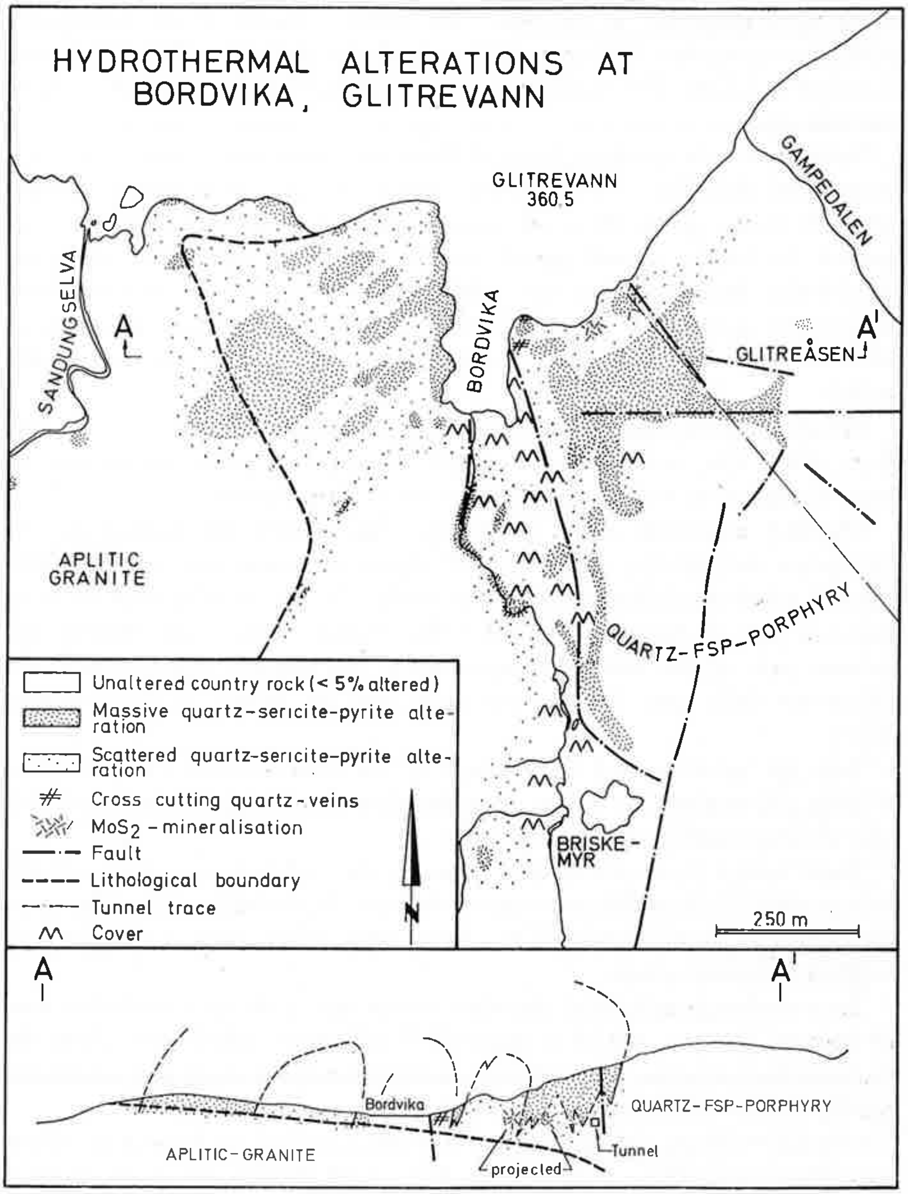


Fig. 8: Hydrothermal alteration at Bordvika, Glitrevann, Locality 2 b in Fig. 7. See also Fig. 3. (Map by A. Geyti & H. K. Schønwandt).

Drive via Lierbyen to the road running north along the west side of the Lier Valley. This valley is deeply filled by glacial and fluvio-glacial deposits and good examples of these may be seen along this road. To the left of the road the high ground is first underlain by the Drammen granite (to Øksnes) followed by Cambro–Silurian sedimentary rocks.

Leave this road just beyond Justad (64 km) where permission must be obtained to use the logging-road leading up to lake Glitrevann and beyond.

Drive up logging-road to the west. The eastern margin of the Glitrevann cauldron is crossed at Veslesetra (72 km) and the dam controlling Glitrevann is passed at 74 km. The cauldron is here dominated by Permian basalt flows (see Fig. 2).

Drive around the northern shores of Glitrevann (Drammen's water reservoir) to Bordvika (B on Fig. 2, see also Figs. 3 and 8) (82 km). At Bordvika, in road-cuts and on the dumps from the water-tunnel supplying Drammen, one can inspect the highly altered quartz–feldspar porphyries associated with the molybdenite deposition. The main alteration is a silicification, at times very intense, but argillization along fractures, joints, etc., is also quite pronounced. MoS_2 and pyrite may be seen in some of the dump material and occasionally in situ.

Return along the logging-road to the west. At locality 2 a, Fig. 7, on the SW shore of the lake, massive quartz–sericite alteration in aplitic granite may be seen, dominated by sericite. MoS_2 can be found along fissures.

Continue westwards along the logging-road, leaving the western bay of Glitrevann and driving along the NE shores of Jøssjø and Vindsjø (NB! There is a locked road boom (barrier) at Jøssjø. The key must be obtained from Børresen A/S at Justad in advance.) This stretch of the road, through the western part of the cauldron, passes along the possible Glomsrudkollen – Glitrevann fault zone. The country rocks here are mostly rhomb porhpyry flows.

Turn left up as a small logging-road at the north-western shore of Store Vindsjø and continue for 200 m up to the mine dumps outside the 74 m level adit of *Glomsrudkollen mine*, *Fig. 7*, *loc. 3.*

These dumps cover the contact between the cauldron ring dyke and the metamorphic Cambro–Silurian rocks to the west. In the adit is exposed garnet–clinopyroxene skarn transected by shear zones which carry a chlorite and argillitic alteration gouge.

Turn northeastwards from the mine dumps and walk up a small dirt road or path on the east side of a topographic depression which runs along the cauldron fracture zone. After 200 m, weakly mineralized skarn and unreplaced marble can be studied around a small shaft, 15 m west of the path.

Continue walking and turn left on to another path of the bottom of a little escarpment, caused by a E–W running thrust-fault dipping 30° north. Further uphill the lower parts of a spoil heap are crossed. Some small workings on sphalerite-bearing garnet–clinopyroxene skarn are found above this dump. Here metasomatic alteration of marble, banded argillaceous and calcareous hornfels, and of a felsic dyke can be observed.

100 m uphill from the escarpment an old cabin, situated on rhomb porphyry, is reached. To the south-west, in a small gorge, pyrite–magnetite-bearing skarn is located in several prospects along the cauldron-marble contact. 30 m towards the north-east, in a small open-pit, the quartz–porphyry ring dyke and sphalerite mineralization in garnet and/or amphibole skarn along its contact, are exposed.

Between the cabin and the mine dumps outside the 23 m level adit, on the left side of the path, several prospects have been worked on skarns developed along local transverse faults and along borders between marbles and argillaceous hornfelses. The hornfelses contain garnet nodules and epidote veins and aggregates which are due to contact-metamorphic and metasomatic reactions. On the mine dumps, beautiful samples of mineralized skarns replacing marbles can be collected.

Further along the footpath up to the main incline shaft, 700 m NE of 74 m level adit, good exposures of the quartz–porphyry ring dyke are seen. Different types of sphalerite-dominated ores and associated skarn assemblages can be studied around the shaft collar (Fig. 4).

Continued walking northwards will lead up to several old mines and prospects, just north of Maurtjern, showing the same geological features as found along the Glomsrudkollen mine.

Leaving the Glomsrudkollen dumps and drive westwards, downhill (steep in parts!) to the main road (route 35) at Åmot. Along this stretch, there are good exposures of folded Ordovician and Cambrian black shales, interlayered with limestones. In the lowest part, Permian mænaite (syenite) sills can be seen.

At Åmot turn left (south) along route 35 to near Hokksund, where route E76 is joined (96 km). Follow route E76 south across the Drammens river at Hokksund. As far as the vicinity of Krekling (110 km) the road follows approximately the sub-Cambrian peneplain at the border between the Cambro–Silurian to the east and the Precambrian, forming hilly lowlands, to the west. At Krekling the road turns more westerly and soon descends into the valley of the Numedalslågen (river) and the historic town of Kongsberg (120 km).

Drive through Kongsberg, taking route 10 towards Notodden. After leaving the southern outskirts of Kongsberg, the road ascends the southern side of the Kobberbergs river, passing to the south of the extensive dumps at the portal of the Overberget adit of the Kongsberg Silver mine (Saggrenda).

At 127 km, a small logging-road leaves route 10 to the south, crossing the river and climbing up the southern slopes of the valley in an easterly direction. This road passes through a farm (close the gates!) and leads over to the smaller Lassedalen (valley) parallel to, and south of, Kobberbergs river valley. Stop at the buildings of the disused *Lassedalen fluorspar mine* (130 km) (*Loc. 4*).

The Lassedalen valley is eroded along the fluorite-bearing breccia zone described earlier in this section (see Fig. 5) but exposures are very scarce in the near vicinity of the old mine. However, the mineralization and wall-rocks may be inspected on dumps below (east of) of the mine shaft (incline) and at another shaft, some 200–250 metres up the valley to the west.

Scattered exposures of the mineralized breccia zone may be seen on the southern bank of the river in the vicinity of Neste prospect, some 2–300 metres downstream (eastwards) of the Lassedalen mine shaft. The adit at Neste, located in the south bank of the stream, just below a small waterfall, has good underground exposures of the mineralized breccia and is safe for the first 30 m or so.

Further downstream (2–300 m below Neste) is located the old working (adits and open pit) of Nedre (Lower) Lassedalen mine. Access to these workings is not too easy, and parts of them must be entered with extreme caution.

From Lassedalen, return to the main road (route 10) by the logging-road through the farm and drive back, eastwards towards Kongsberg.

If desired, a visit may be paid to the Kongsberg adit (Overberget) portal at Saggrenda (Loc. 5a). Although the silver mines are no longer working, tourist-type underground trips, in small wagons pulled by diesel locomotive, are run regularly during the summer months. These trips are more of mining historical than of direct geological interest.

The excursion may, however, be profitably terminated with a visit to the Silver Works Museum in Kongsberg, Loc. 5b (142 km). Apart from the excellent technical exhibits from the old mines, the Museum houses a unique collection of specimens of native silver and other minerals which is well worth a prolonged study. Also of special interest in the present connection is the collection of mine plans, maps and models of the vein systems.