

# GEOLOGY AND STRUCTURES OF THE RØSTVANGEN SULPHIDE DEPOSIT IN THE KVIKNE DISTRICT, CENTRAL NORWEGIAN CALEDONIDES\*

INGOLF J. RUI

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The Røstvangen mine occurs in a sequence of regionally metamorphosed sedimentary rocks and volcanic greenstones belonging to the Caledonides of central Norway. It is presumed to be of Cambrian age. The close spatial relationship between the greenstone and sulphide deposits in the Kvikne district in general suggests that the ore material was originally brought into the geological milieu from depth during the period of submarine volcanic activity. The structural control of the Røstvangen ore bodies indicates that a later remobilization, transport and subsequent redeposition of the sulphides in the present fold hinge position took place during Caledonian metamorphism and foldings.

*I. J. Rui, Institutt for geologi, Universitetet i Oslo, Blindern, Oslo 3, Norway.*

The Røstvangen mine is located approximately 25 km SSE of Kvikne parish in central Norway at about 62°23'N latitude, 10°22'E longitude.

Røstvangen is one of a number of rich, but small massive chalcopyrite-bearing pyritic ore deposits known from the Kvikne district. In addition there are countless small pyrrhotitic occurrences which are low or deficient in copper.

Copper mining started in the vicinity of Kvikne as early as in 1631 and ended finally in 1812. Røstvangen, however, was not discovered until 1905 and was worked from 1908. After an almost continuous period when construction work, improvements, and development work had been carried out at the newer Finnhaug, Hamdal, and Børsjøhø mines, located about 5 km WNW of Røstvangen, the relatively modern Røstvangen plant was finally abandoned in 1921 as a consequence of the worldwide economic crisis, and indirectly also because of the limited known ore reserves (Stubsjøen 1951).

## General geology

### *Regional setting*

The Kvikne district occupies a central position in the Caledonides of central Norway, and the strongly folded sedimentary and volcanic rocks of the area

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belong to the Gula Group, which is presumably the oldest part of the Cambro-Silurian stratigraphy of the Trondheim region (C. Bugge 1954, Wolff 1967, Rui 1972). The metamorphic state of the Gula Schists is usually rather high and in the Røstvangen–Kvikne area it corresponds to the highest B1.3 subfacies of the greenschist facies (Winkler 1967).

### *Stratigraphy and petrography*

The restricted Røstvangen area may be divided up successively into three lithological units:

The upper sedimentary unit.

The greenstone unit.

The lower sedimentary unit.

The right way up of the original bedding, however, has not been established.

The various rock types recognized at Røstvangen and also the mode of occurrence of the sulphide ores are essentially the same as those encountered at the Kvikne mines *sensu strictu* recently described in detail by Nilsen & Mukherjee (1972).

*The lower sedimentary unit.* – It consists chiefly of grey or greyish-brown coloured schists of argillaceous composition. The schists are composed essentially of quartz, biotite, chlorite, and varying but usually minor amounts of plagioclase and  $\pm$  muscovite. Scattered porphyroblasts of hornblende and garnet are frequently present, and the most common accessories are tourmaline, apatite, and leucoxene.

The common quartz-biotite schists are frequently interlayered with calc-silicate bands which may be up to a few cm thick and are composed mainly of quartz, hornblende, and clinozoisite, with minor amounts of plagioclase, chlorite, and garnet.

*The greenstone unit.* – This is essentially composed of green coloured hornblende schists frequently containing irregular patches and veinlets of secondary carbonate. The wide lateral extension and conformability to the enclosing mica schists suggest that the rocks are of primary volcanic origin.

The variable thickness of the beds from less than a metre to the extreme widths obtained in the western parts of the area is apparently the result of a combination of primary depositional nature and secondary thickening and thinning due to isoclinal folding.

The fine-grained schistose greenstones are composed chiefly of bluish-green hornblende and plagioclase, usually with some epidote/clinozoisite and carbonate, and accessory amounts of chlorite, biotite, apatite, sphene, ilmenite, and leucoxene. The chemical composition is basaltic (Table 1).

The greenstones, especially the thin horizons in the eastern part of the area (Fig. 1), are locally associated with a rather coarse-grained, rusty-brown weathering rock predominantly composed of garnet, quartz, and colourless cummingtonite. The cummingtonite is usually arranged in radiating aggregates. Most of the more than 100 claims of low grade pyrrhotite and pyrr-

Table 1. Chemical analyses of greenstones from Røstvangen and neighbouring areas.

Locality	Savalen	Savalen	Børsjødø	Knausen	Røstvangen
Grid ref. 32V NQ	784117	785115	663197	782195	719179
SiO <sub>2</sub>	46.39	48.62	48.66	50.23	47.32
TiO <sub>2</sub>	0.94	1.03	1.46	1.16	1.02
Al <sub>2</sub> O <sub>3</sub>	14.50	14.69	14.29	15.04	14.29
Fe <sub>2</sub> O <sub>3</sub>	3.26	2.83	1.49	2.84	1.79
FeO	5.46	6.51	8.98	5.29	6.67
MnO	0.14	0.13	—	—	—
MgO	8.41	9.21	7.06	9.42	11.15
CaO	13.96	10.70	11.60	10.75	10.45
Na <sub>2</sub> O	2.35	2.94	2.76	2.54	3.45
K <sub>2</sub> O	0.15	0.13	0.12	0.11	0.17
P <sub>2</sub> O <sub>5</sub>	0.11	0.10	0.13	0.15	0.16
Ign. loss	3.75	1.79	2.71	1.99	2.30
Total	99.42	98.68	99.26	99.52	98.77
Sp.w.	3.07	3.02	3.02	3.01	2.98

hotite-magnetite mineralizations in the Røstvangen area are affiliated to this type of rock, whereas the Røstvangen ore bodies are tied to the border zone of the ordinary greenstone.

The garnet-cummingtonite rocks may have originated from ordinary greenstone through metasomatic alteration during regional metamorphism. The alteration, which apparently involves a general deficiency of calcium (Nilsen & Mukherjee 1972, p. 171), might have been favoured by the presence or introduction of sulphides. It is also possible that the rocks represent more primary iron and magnesia-rich deposits because of the regional, though discontinuous, association with greenstone.

Just to the south of the eastern pit and in a couple of other scattered localities along the greenstone border, bluish-grey-coloured magnetite-quartzites (with about 5–10%mt.) have been recorded. These occur as 2–3 dm, maximum 1–2 m, thick conformable beds located at or very close to the greenstone contact. The magnetite-quartzites might possibly be interpreted as original metamorphosed jaspilite beds.

*The upper sedimentary unit.* — It consists largely of grey-coloured subarenaceous schists essentially composed of quartz, biotite, and lesser amounts of muscovite. Minor constituents are plagioclase, chlorite, clinozoisite, garnet, and more scattered hornblende porphyroblasts. The most common accessories are apatite, tourmaline, and ores. Frequently noticed, usually near the greenstone border, are varieties rich in muscovite and peppered with dark porphyroblasts of biotite and garnet.

The ordinary grey schists sometimes contain thin quartzite bands or, more often, cm-thick greyish-white-coloured calc-silicate beds similar to those encountered in the lower sedimentary unit.

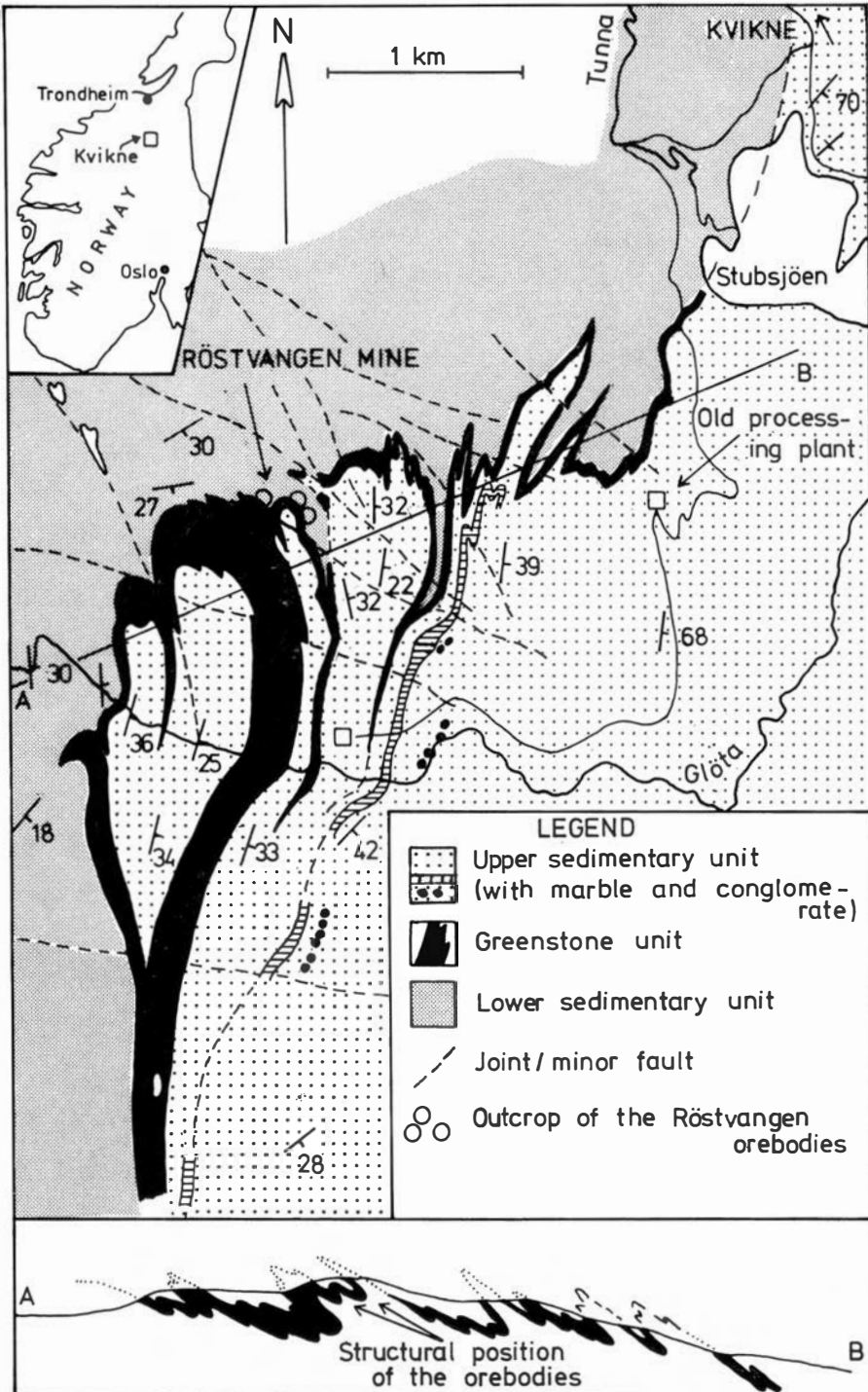


Fig. 1. Geological map of the Røstvangen area, Kvikne district. Cross-section A-B is shown below.

The rather pure horizon of calcite marble in the central part of the area is about 15–20 m thick, but gradually becomes thinner northwards where it finally wedges out. Dark grey to black, in part graphite-bearing, schists and polymict conglomerates are associated with the marble in places.

### *Structures*

The most conspicuous tectonic structures in the Røstvangen area are the repeated tight to isoclinal folds which are well manifested by the outcrop pattern of the greenstone unit (Fig. 1). These regional folds are overturned to the west and usually show a moderate eastwardly dipping of the original bedding. The dipping is usually parallel or subparallel to the dominating secondary schistosity of the rocks.

On the mesoscopic scale the marble horizon and the interbedded, more competent calc-silicate bands in the sedimentary sequences give an impression of the intense development of similar type folds. The interlayered calc-silicate bands frequently show detached fold hinges. The preferred orientation of minor fold axes dips about 20° towards SSE (Fig. 2B).

The area is dissected by numerous joint zones and/or minor faults which have a preferable strike about NW-SE. They are often well expressed in the topography as elongated marshes and small lakes or low scarps.

## **Ore geology**

### *Types of ore*

The massive ore bodies at Røstvangen mine are chiefly composed of fine to medium-grained aggregates of sub- to euhedral pyrite embedded in a matrix which comprises mainly chalcopyrite, pyrrhotite, and minor amounts of sphalerite. In addition there are local concentrations of massive magnetite ores low in sulphides, and of high-grade chalcopyrite-pyrrhotite ores.

During the working period three qualities of ores were obtained from the mine by cobbing (Hofstad 1922):

High-grade ore (pyrrhotitic) – ca. 8.5% Cu, 35% S	(70 t)
Export ore (pyritic) – ca. 2.4–3.4% Cu, 42–46% S	(212 000 t)
Processing ore (pyritic) – ca. 1.7% Cu, 30% S	(176 000 t)

According to Foslie (1926), the average grade from bulk production was 2.65% Cu, 43% S and lesser than 1% Zn. Chemical analysis of the ore shows about 0.01% As and only traces of Pb, whereas given silver and gold figures range from 10–80 ppm and 0.3–2.0 ppm, respectively.

### *The form and structure of the ore bodies*

The Røstvangen mine consists of a series of elongated, lenticular small bodies of massive ore mutually arranged in an overlapping *en échelon* pattern. The plunge of the major axes of the ore bodies coincides perfectly well with the preferred orientation of the minor fold axes and linear structures of the country rocks (Fig. 2).

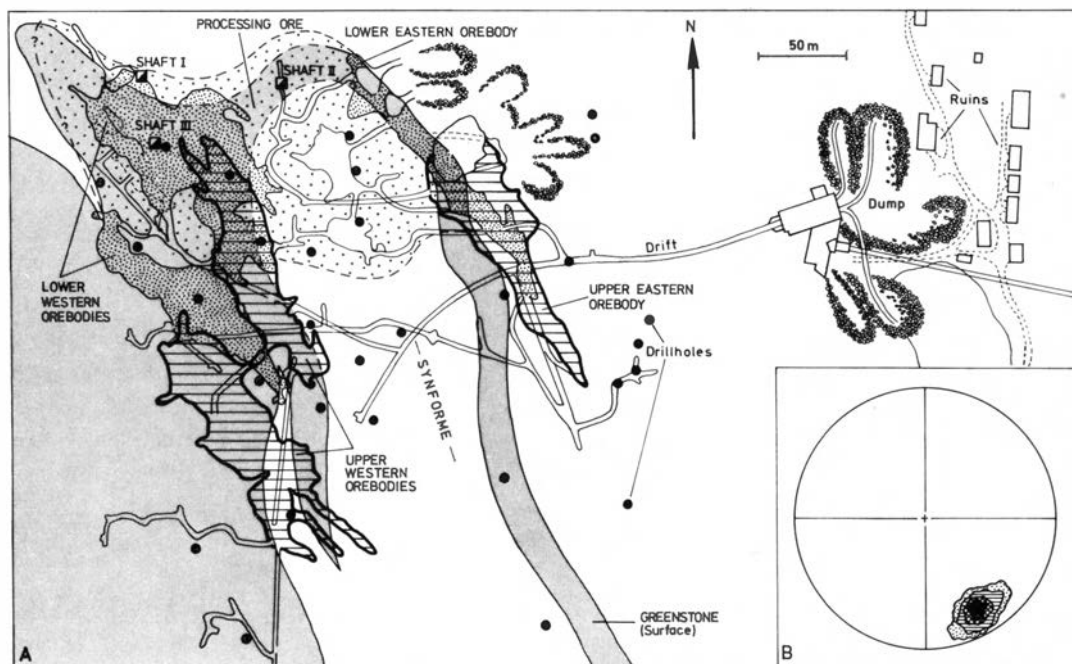


Fig. 2. (A) Geological map of the surroundings of the Røstvangen Mine showing the outcrop of the greenstone unit (grey) in relation to the horizontal projection of the mine workings. (B) Fold axes from the area to the north of the river Glöta and to the west of the marble horizon. Equal area projection, lower hemisphere. Contours: 5%–10%–30%–50% with max. 59% pr. 1% of area. 56 observations.

The individual ore-shoots have been mined out separately for about 150–200 m in length with widths usually varying between 15 and 60 m. The thickness normally ranges from about 2 m (cut-off ca. 0.3–0.5 m) up to a local maxima of about 15 m.

The lower western ore bodies and also the lower eastern ore body are located at the junction between the greenstone and lower sedimentary units and are interconnected through an interjacent zone of heavy pyrite impregnation (processing ore). The upper eastern ore body in turn is deposited in the same stratigraphical position and, according to Hofstad (1922), is only separated from the lower eastern ore body by local thick masses of massive magnetite ore in the upper overlapping parts (Fig. 3).

The spaces between the upper and lower western ore bodies are largely occupied by greenstone which rapidly wedges out eastwards. The distances between the overlapping lenses gradually diminish upwards (towards NNW) and according to Thonstad (1919) and Hofstad (1922) finally unite in the upper levels.

In the outcrops a clear folded connection is apparent between the upper and lower eastern ore bodies (Fig. 3). Whether or not there is a similar connection between the upper and lower western ore bodies is more speculative, but it does not seem unreasonable.

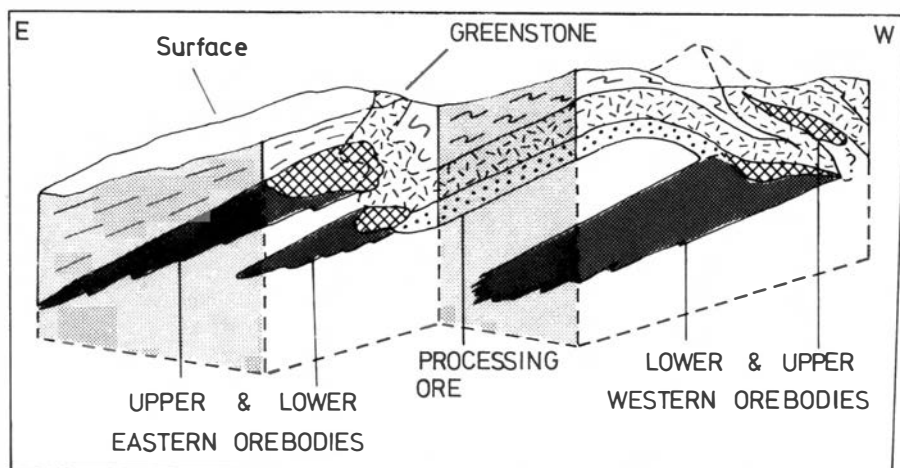


Fig. 3. Sketch showing the supposed mutual relationship between the Røstvangen ore bodies.

The ore walls are usually rather sharp and conformable to the schistosity of the enclosing country rocks. The massive ore, however, may in places apparently truncate or replace the wall rocks in the border zone between the greenstone and the micaschist (Fig. 4). The ore zone as a whole is located near and is probably structurally controlled in fold hinge position along the border zone between the greenstone unit and the lower sedimentary unit.

The apparent termination of the Røstvangen ore bodies towards depth may be caused by minor NW–SE running faults. It is a well known fact from a number of Norwegian sulphide ore deposits that the massive ores gradually wedge out towards small scale faults, but reappear in a similar way on the opposite side of the fault plane (Foslie 1926, Aasgaard 1927).

#### *Wall rocks*

The study of wall rocks was confined to the limited, but well exposed outcrop of the upper eastern ore body (Figs. 3 and 4).

The greenstone immediately bordering the ore body in the west appeared to be similar in thin section to ordinary greenstones from other localities. Chemical analysis of one single greenstone sample taken from near the ore wall (see Fig. 4), however, is somewhat higher in alkalies and magnesia than the other samples (Table 1).

The main constituents of the light grey-coloured micaschists enveloping the eastern part of the ore body are quartz, biotite, and muscovite. Biotite occurs as both matrix mineral and as larger porphyroblasts together with garnet and scattered hornblende prisms. In addition there are minor amounts of chlorite, clinozoisite, apatite, tourmaline, and ores.

A distinctive zone of bleached schist, about 10–20 cm thick, occurs immediately at the border between the micaschist and the massive pyritic ore

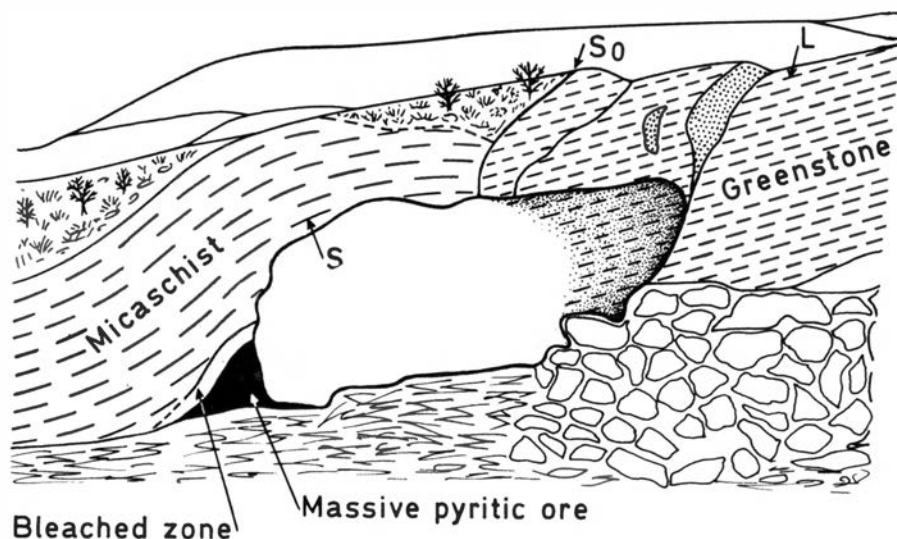


Fig. 4. The outcrop of the upper eastern ore body viewed towards the south. The secondary schistosity (S) of the micaschist is conformable to the massive ore, but is at an obtuse angle to the greenstone contact (So). Note that this lithological border is cut by the old mine workings which may indicate a similar discordant relationship of the massive ore zone itself. Linear structures (L) in the greenstone are parallel to the major axis of the ore bodies.

(Fig. 4). The simple composition of the bleached zone is quartz, muscovite, and abundant sulphides – chiefly pyrite. This rock is also frequently found in the old dumps, which suggests a more general extension underground.

The bleached zone more than likely originated through metasomatic alteration of the micaschist immediately enveloping the ore. Whether this alteration is caused by aggressive ore-bearing fluids or resulted by sulphide-silicate reactions at the ore contact during the regional metamorphism is not clear. Anyway, wall-rock alteration is apparently not very extensive at Røstvangen mine.

#### *The origin of the ores*

When discussing the origin of the ores, the close spatial relationship between sulphide mineralization and greenstone must be of fundamental importance. With few exceptions the countless old mines and prospects within the Kvikne district, the Røstvangen area included, are located immediately on one or other side of the greenstone contact. A similar close relationship between massive sulphide deposits and submarine volcanic sequences is well known and frequently described from all over the world.

Because of the general absence of any potential intrusive source rock within the area, the ore metals and sulphur were probably largely derived from depth during the short period of basaltic volcanic activity and deposited on the sea floor together with the present greenstone lavas and/or tuffs.



In their present metamorphic state there are few evidences left in the rocks to prove whether the sulphides were originally concentrated in certain layers or zones, or were more sparsely disseminated throughout the greenstones. The apparent stratabound character of the Røstvangen deposit (Fig. 3), however, may indicate that originally there was a concentration of sulphides near the greenstone contact.

Both the Japanese Kuroko type of ores and the exhalative sedimentary ores described by Oftedahl (1958a) combined with subsequent redistribution of the sulphides during the folding, may explain how the Røstvangen ores formed. The Kuroko ores, however, are apparently related to more complex volcanic events than the ore deposits in the Kvikne district (Horikoshi 1969).

The frequent dependency of the massive sulphide ores on regional tectonic structures may indicate a more general and probably also a more extensive redistribution of the original sulphides (massive or disseminated) in regionally metamorphosed, eugeosynclinal areas. One of the most remarkable examples is the geometry of the extremely elongated Stekenjokk ore bodies in the Swedish Caledonides. It is determined by two regional major fold phases (Zachrisson 1971). In apparently the same regional structures just across the international border, the major Norwegian Joma sulphide deposits occur. They are located centrally in the 'Joma arch' (Oftedahl 1958b). Similarly the two parallel, about 2.5 km long, ruler-shaped Killingdal ore bodies in the Røros district are located in fold hinge position, close to the border between greenstone and phyllite (Rui 1973). The general conformability between linear structures and massive sulphide ores in the Norwegian Caledonides has been demonstrated earlier by Vogt (1952).

The restricted location of the Røstvangen ores in fold hinges as elongated massive ore-shoots which coincide with the preferred orientation of local as well as regionally distributed fold axes and linear structures, is also a rather clear example of structural control. The Segen Gottes mine in Kvikne, which together with Røstvangen mine constitute two of the more important ore deposits in the Kvikne district, is apparently dependent on the very same tectonic phase (Nilsen & Mukherjee 1972, p. 158).

The structural control of the ore bodies indicates that the sulphides (massive or disseminated) originally associated with the extrusives were remobilized and removed into favourable structural areas during regional metamorphism and folding. Transport of the sulphides has probably been favoured by the presence of metamorphic solutions which may have been capable of extracting the sulphides from the rocks (Park & MacDiarmid 1964, pp. 31–33).

Sulphide-bearing solutions generated chiefly along the greenstone border may have travelled along the border zone depositing the sulphides in fold hinge pressure minima without causing particular wall-rock alteration (Røstvangen). Solution generated within and in equilibrium with the greenstones, however, may have resulted in the sulphides being deposited at the border to

the chemical contrasting micaschists, thereby causing a more or less extensive wall-rock alteration. The common garnet–cummingtonite–anthophyllite bearing wall rocks at the Kvikne mine (Nilsen & Mukherjee 1972) suggest that wall-rock alteration and ore formation took place coincidentally with the peak of regional metamorphism.

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