# The Old Vigsnes copper mine at Karmøy, western Norway. Presentation of geophysical data

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Four different geophysical methods – the self potential, the charged potential (mise-à-la-masse), the VLF, and the gravity method – have been used together in the Old Vigsnes mine in the search for new ore. The combination of methods has proved to be useful and gives information on the boundaries of the worked ore bodies and where to look for a continuation of the ore.

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The pyrite deposits of Visnes, Karmøy, western Norway (Fig. 1) were discovered in 1865 and were immediately put into production. The 30 years that followed was a dramatic period for the Old Vigsnes mine (at Visnes); a booming production, which lasted for almost 25 years, was followed by 5 meagre years and production was discontinued in 1895. During the most productive years more than 550 men were working in the mine. The mining method used was to stope out the ore, leaving props for safety and as 'reserves' (which were used later). Early mining was close to the surface but the ore body was eventually followed to a depth of about 700 m. The Cu content of the ore was about 2% in the beginning, but this decreased gradually at depth, and the Cu content was only 0.4% when production was stopped. The distance to the neighbouring mine, Rødklev, is 800 m, and many attempts have been made to locate ore between the two.

The mining company A/S Sydvaranger bought the mining rights in 1972. The company started to empty the water-filled Old Vigsnes mine to see if any ore of economic importance had been left at depth and with the hopes of locating new ore bodies with the aid of modern geological and geophysical methods. Detailed geologic mapping has been done by J. Færden in the drifts on the different levels (Fig. 2).

Underground geophysical measurements were carried out in 1974, when several geophysical field variations around the deposit were mapped to get a better understanding of the ore complex. The geophysical methods used were the self potential method (SP), the charged potential method (CP) (mise-à-la-masse), the Very Low Frequency-EM method (VLF), and the gravimetric method. The results from these measurements are presented in this paper.

## Geology

The island Karmøy is situated off the west coast of Norway close to the town of Haugesund (Fig. 1). It belongs geologically to the south western part of the Caledonian orogeny in Norway. Several geologists have worked on Karmøy (Reusch 1888, Goldschmidt 1921, Broch et al. 1940, Geis 1961a, 1961b, 1962, 1963, Gvein 1973, unpublished geological map).

A summary of the geology is as follows: Paleozoic rocks overlie Precambrian gneisses. The eastern and lowest part of this formation is a greenschist with albite, epidote, and chlorite. Above the greenschist lies a thick zone of greenstone, gabbroic rocks, and amphibolite. Sandstone and conglomerate, which are the youngest Paleozoic rocks, occur at south Karmøy. Fossils dated to the transition between Ordovician and Silurian are found in this rock series (Broch et al. 1940) and the rocks on Karmøy have been correlated with the Caledonian development in the central Trondheim Region.

The thickness of the series (amphibolite, greenstone, and greenschist) is estimated to 6000 m on western Karmøy, and to 2500 m at Haugesund.

A series of mineralized zones with pyrite, pyrrhotite, chalcopyrite, sphalerite, and magnetite are found in certain bands within the green-

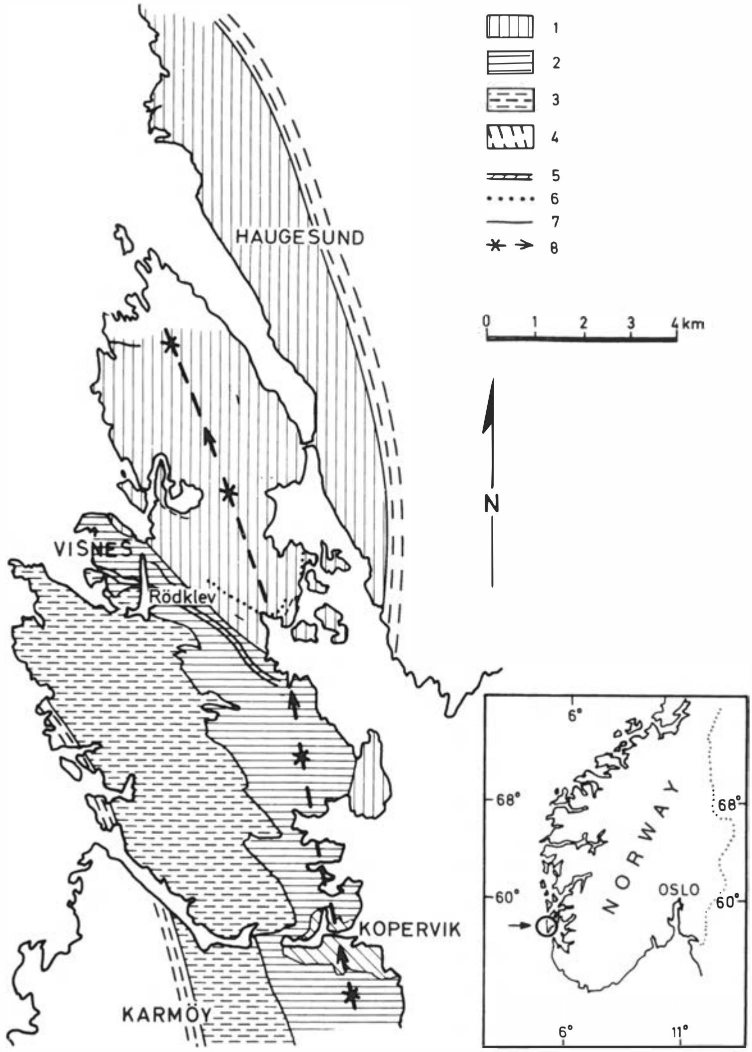


*Fig. 1.* Geologic map of Karmøy, western Norway (after Geis 1965). 1. Greenschist, 2. Greenstone, 3. Amphibolite, 4. Gneiss, 5. Vigsnes schist-zone, 6. Schist with quartz lenses, 7. Mineralized zone, 8. Axis of syncline.

stone, schists, and amphibolite series. One of them is the Vigsnes schist zone containing the largest known mines.

The first find of economic importance was the Old Vigsnes mine. The ore in the Old Vigsnes mine occurs in 5 steeply dipping elongated bodies, which have been mined to a considerable depth (maximum depth of the mine is 732 m). The ore bodies have varying width (20–40 m) and the thickness lies between 2 and 10 m. The geology in the mine is illustrated in Fig. 2. The ore in the mine is lying within a zone with chlorite schist and chlorite sericite schist in the greenstone formation (J. Færden, pers. comm. 1973).

## Instrumentation and measurements

Geophysical measurements were made at levels of 52, 83, 112, 160, and 260 m in the mine. Since the completion of this study, an additional two levels have been measured (360 and 460 m). The distance between each station on the levels was about 10 m. A millivoltmeter made by Norges Geologiske Undersøkelse was used for the SP measurement. Two non-polarizing $Cu/CuSO_4$ electrodes were used as potential electrodes. One was kept fixed at a base point at each level, and the other was moved along the adits. Potential differences were measured between the different levels, so all results refer

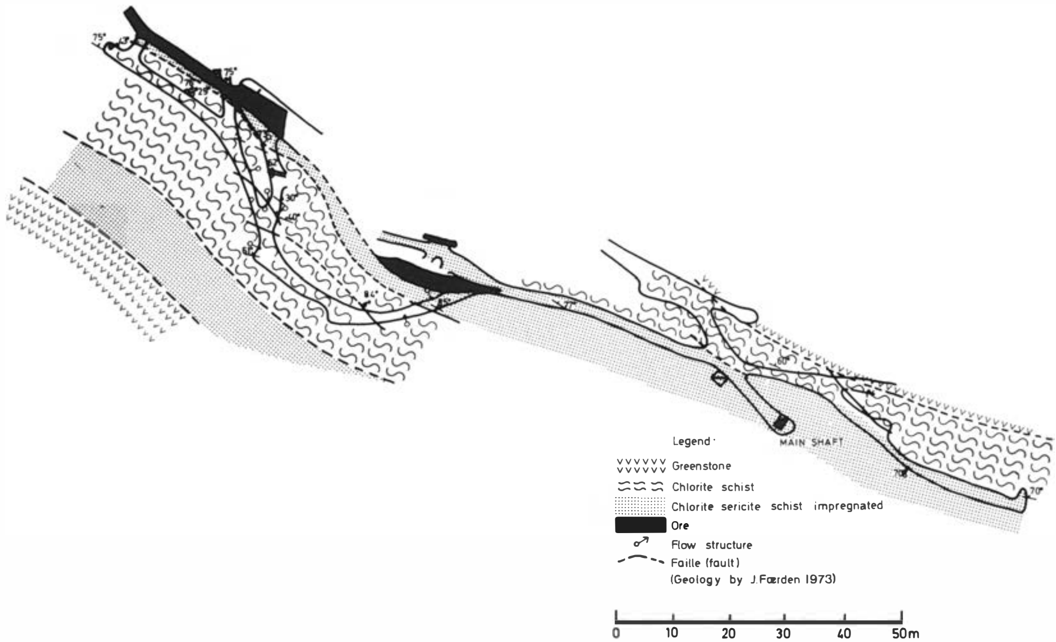


*Fig. 2.* Geologic map of level 83 m (after J. Færden 1973). For orientation, see Fig. 9.

to the same potential level. For this purpose a cable was lowered down the shaft.

Regarding the charged potential measurements, one current electrode was hammered into exposed ore at level 160 m (point E, Fig. 6), while the other electrode was placed (at 'infinity') in the ocean ca. 600 m away from the mine and normal to the strike of the ore bodies. The millivoltmeter used for the SP-measurements was used again here. A 12 volt battery supplied the current (ca. 1/2 A) needed for the CP measurements. The CP potentials refer to the same reference level as was used in the SP measurements. Additional SP and CP measurements were made in available drill-holes in the mine. These measurements gave valuable information and helped in the contouring of each level.

The VLF measurements were made with a Geonics EM – 16 (Paterson & Ronka 1971), and the transmitting station used was NAA, Cutler, Maine, freq. 17,8 kHz. Both the dip angle and imaginary component were measured. The primary field from NAA has a nearly ideal direction for electromagnetic induction in the ore lenses of the mine. The conditions for underground electromagnetic measurements are excellent, because nearly all metal installations, such as rails and rods, were removed when the mine was closed. Therefore, VLF field variations obtained in the drifts must be predominantly due to conductivity of the rest-ore. The compact pyrite ore in the mine is a very good conductor.

A La Coste Romberg gravity meter was used for the gravity measurements with a reading accuracy of 0.01 mgals. The measurements were reduced to the base of each level and no attempt was made to reduce the measurements to sea level. The reason for this was that little new information would be gained by reducing to sea level, since the different levels in the mine were all nearly horizontal and therefore represent convenient datum planes.

## Data presentation

Horizontal maps have been constructed at each level for each of the different methods. In all maps tentative contours were drawn with dashed lines in order to complete the field picture. Although the measurements in some instances only make up fragments of the field, we feel

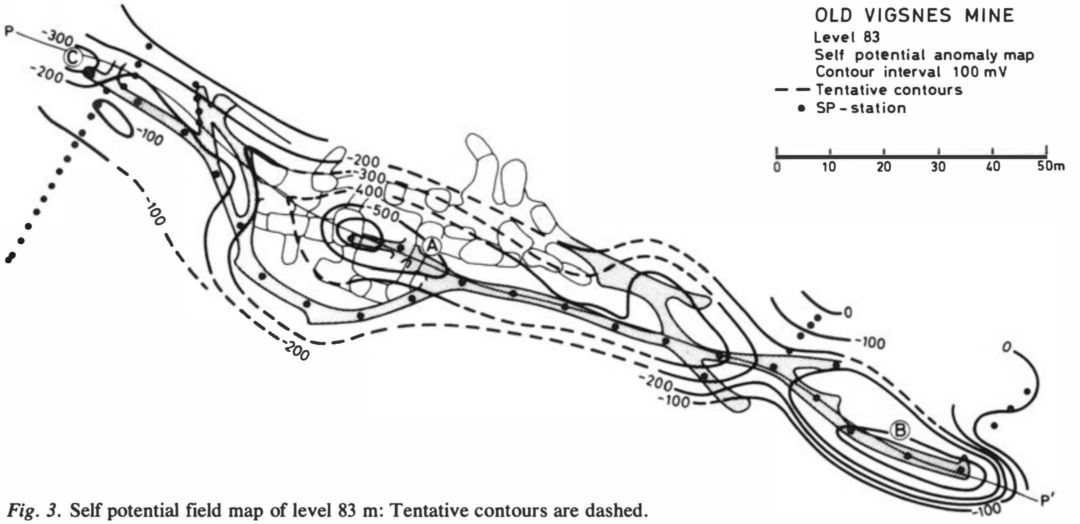


*Fig. 3.* Self potential field map of level 83 m: Tentative contours are dashed.

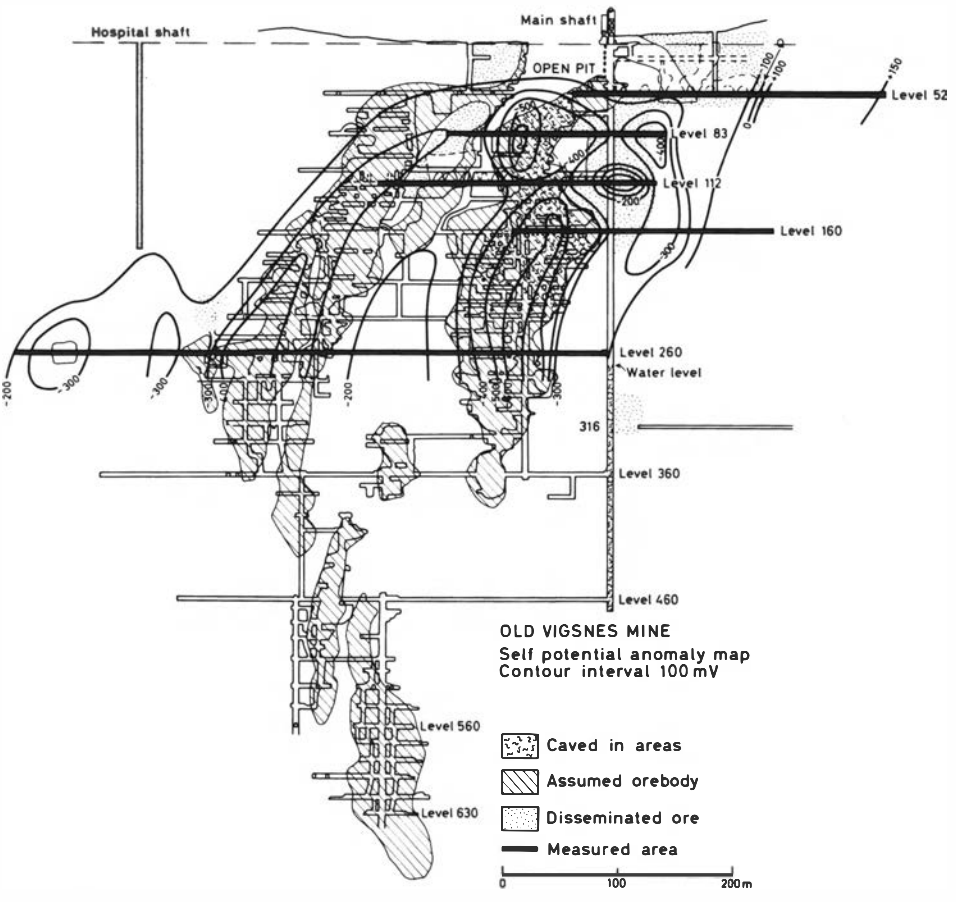


*Fig. 4.* Depth section along the strike and dip of the ore bodies showing the self potential field. Potential is taken along the line PP, Fig. 3, and corresponding lines on different levels.

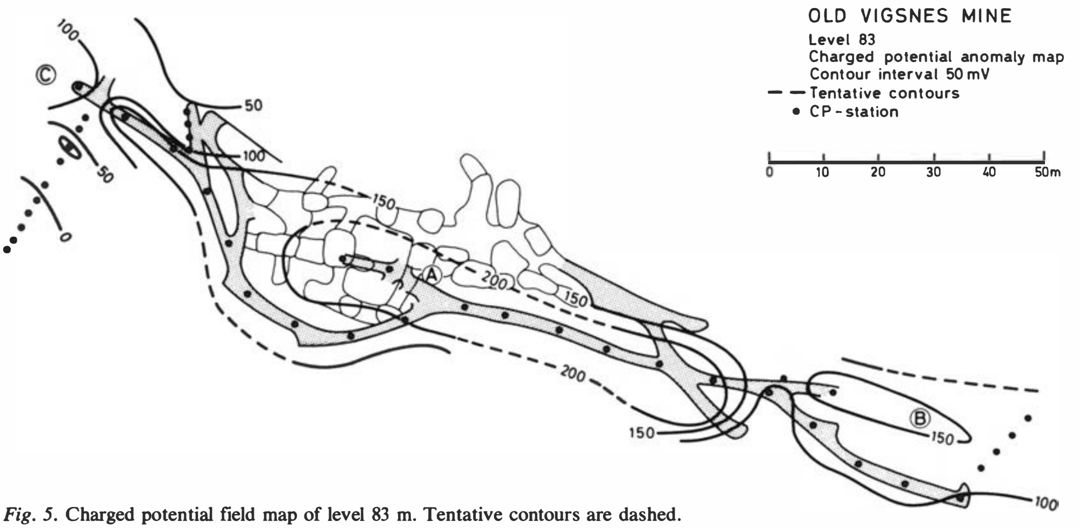


*Fig. 5.* Charged potential field map of level 83 m. Tentative contours are dashed.

that the tentative contours are a reasonable approximation to the actual conditions.

In this paper, maps from level 83 m are presented. This was an arbitrary choice, and the other levels present the same amount of information. We present, however, only one level because of limit of space.

A depth section along the ore lenses has been compiled for each method. This section is contoured on the basis of the horizontal maps from each level. An 'anomalyline' (PP', Fig. 3) was drawn through the ore bodies along the main stopes, and the values along this line were projected on to a plane which had the same dip and azimuth as the ore lenses.

## The self potential method

Fig. 3, which presents the SP results at level 83 m, shows three low potential zones: SP 83A, B, and C. The areal coverage is good because a few diamond drill holes have also been measured. The low potential areas seem to follow the stopes rather closely, indicating that the ore remnants have enough conductance to produce a considerable SP anomaly (minimum – 629 mV at anomaly A).

The depth section along the ore lenses is shown in Fig. 4. The SP contours follow the stoped out area closely and in some detail. The major anomaly trend may continue upwards to the right, east of the main shaft. East of the main shaft at level 112 m is a small area with relatively high self potentials. However, this area may bypass the ore body and does not prohibit a possible continuation of the field. The collapsed area in the middle of the mine (down to 160 m) with much void space shows up as an area with small variations in the potentials.

## Charged potential method (mise-à-la-masse)

The equipotential lines of the current concentrations at level 83 m follow rather closely the drift where the ore has been stoped out (Fig. 5). Three zones with high potentials – CP 83 A, B, C – were found corresponding to the low potential zones of the SP map (Fig. 3). Anomaly CP 83 C seems, however, to be lying further from the drift than the corresponding SP anomaly. The CP 83 C anomaly in the stope indicates a possible continuation of ore to the west.

The depth section of the CP field is presented in Fig. 6. The maximum current concentration is centered around the electrode point (E at level 160 m),and good current connections are found from the electrode downwards to level 260 m, despite the fact that most of the ore in the area is stoped out.

The high potential zone around the current supply point seems to bend upwards to the east of the main shaft. A local area is found east of

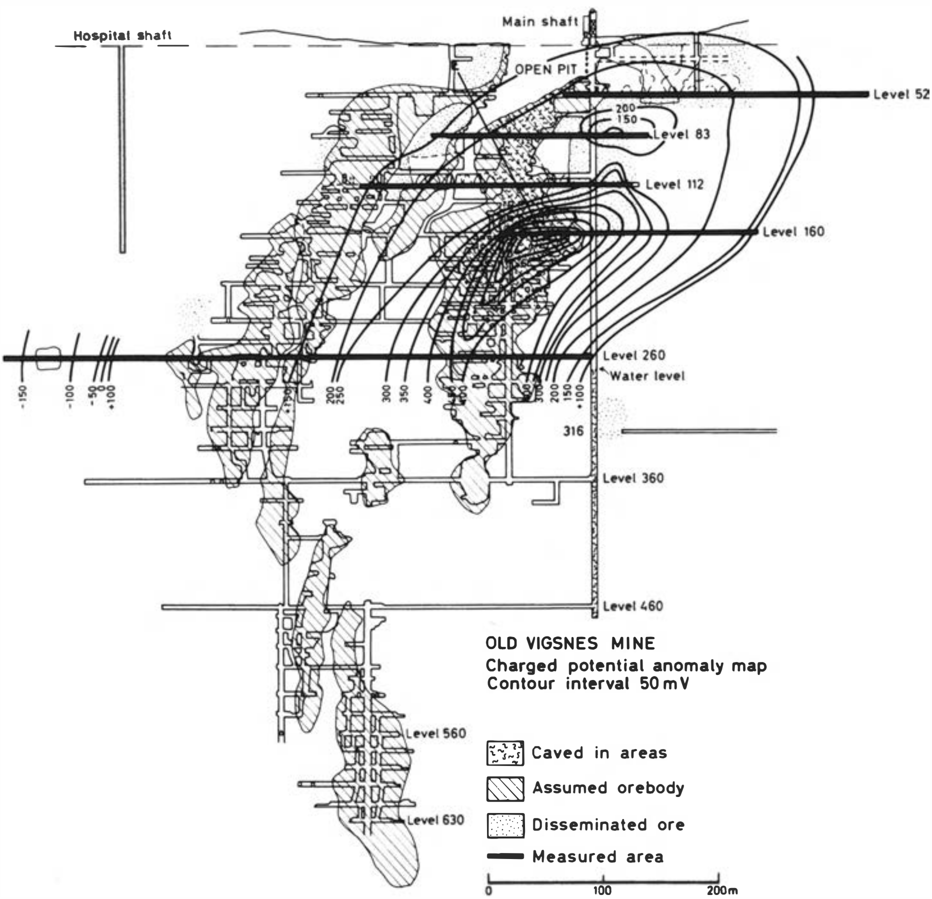


*Fig. 6.* Depth section showing the charged potential field. The same projection procedure as in Fig. 4.

the main shaft at level 83 m where there is a somewhat lower potential. The collapsed and void area from level 160 m and upwards seems to stop a current connection between the western part of the mine and the central part. The potential in this part of the mine stays nearly constant, thereby indicating that the western part is one large body. West of the 'Hospital shaft' is another steep potential gradient indicating that we are leaving the western body.

# The VLF method

The VLF field induces secondary current concentrations along the boundaries of conducting ore bodies. These currents cause secondary EM fields of the same frequency as the primary field, which will give vertical components in the neighbourhood of ore bodies. As the induced currents have to return through the lower part of the conducting ore body, the sign of the vertical field component will change somewhere in the middle of the body. The primary field decreases exponentially, with increasing depth, but the decrease seems to be rather slow, since the VLF signal has been detected several hundred meters underneath the surface. Therefore, as a first approximation, the primary field can be assumed homogenous. The sketches Fig. 7 (cross section) and Fig. 8 (longitudinal section) show the variations of the dip angle field component which is to be expected around a circular current concentration. The cross section shows that the sign of the dip angle field changes if:

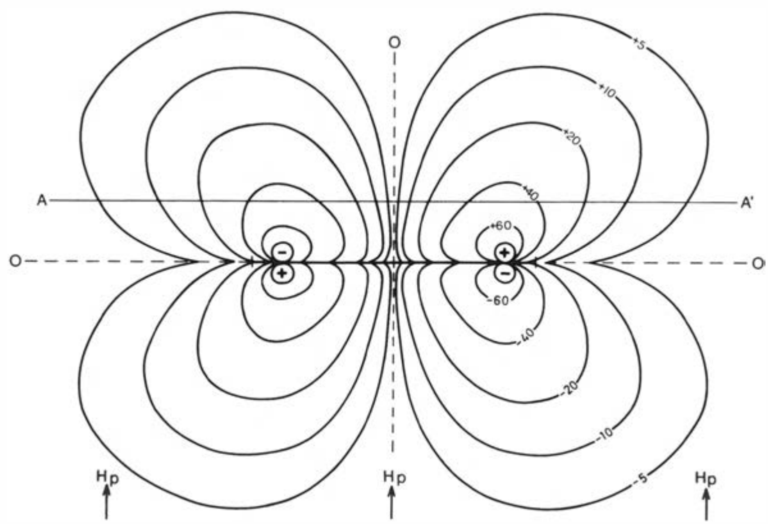


*Fig. 7.* Sketch showing the VLF dip angle in a section across a conducting sheet.

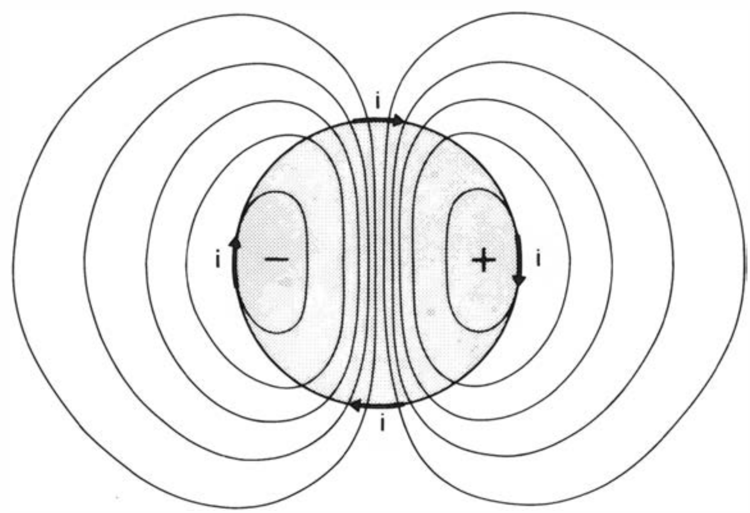


*Fig. 8.* Sketch showing the VLF field component parallel to the conducting sheet in Fig. 7 (taken along AA', Fig. 7).

1) an adit is passing through the ore body from the hanging wall to the foot wall,

2) a shaft or raise (e.g. $A–A_1$ in Fig. 7) is passing along an ore body in the hanging wall or in the foot wall. The sign change occurs when passing the central part of the body. The longitudinal section shows that measurements in the country rock on the mine levels may give important information concerning the possible shape and extension of an ore body.

The VLF results at level 83 m in the mine are presented in Figs. 9 and 10, which show the variations in the dip angle field and imaginary field component respectively around the rest-ore in the stopes. The results are in good agreement with those shown in Fig. 7. The following characteristics should be mentioned:

Both the dip angle and imaginary field components are negative in the hanging wall of the ore body.

In the foot wall both components are positive.

The 'cross over' seems to be close to the foot wall contact of the ore body in the stopes.

Both components decrease successively at both ends of the body.

Fig. 11 represents VLF anomalies observed at the different levels above level 260 m in a depth section along the lenses about 10 m into the

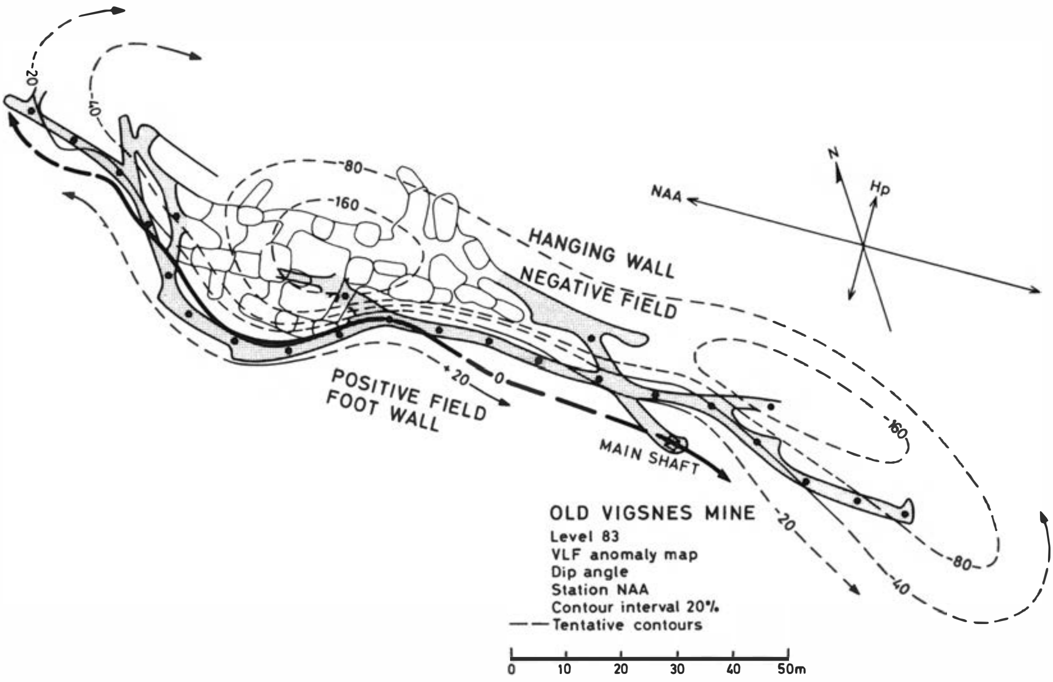


*Fig. 9.* VFL dip angle map of level 83 m. Arrow NAA shows direction to transmitting station.

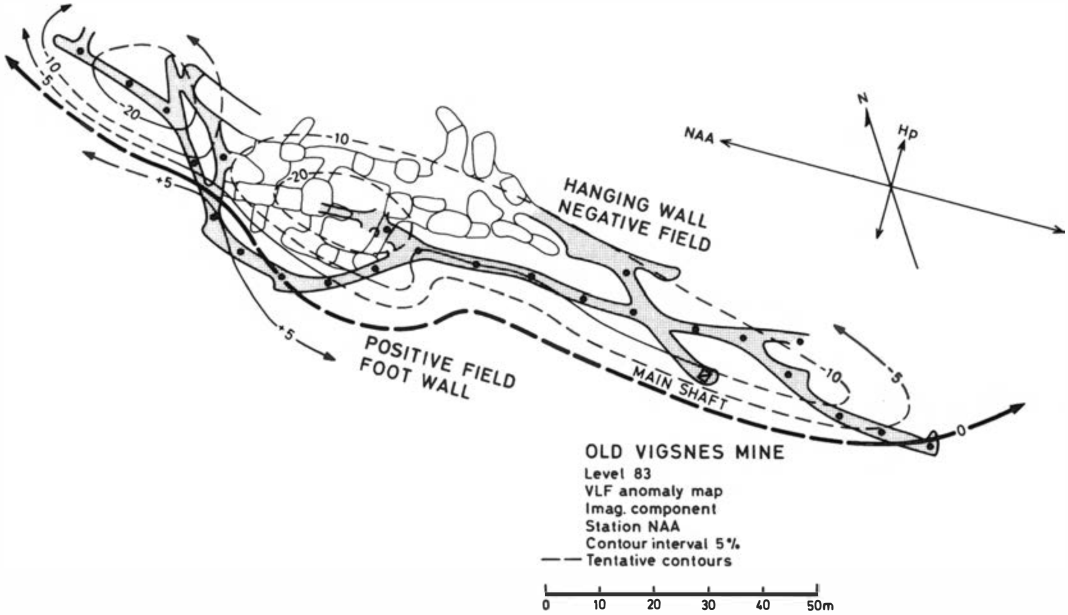


*Fig. 10.* VFL imaginary component map of level 83 m. Arrow NAA shows direction to transmitting station.

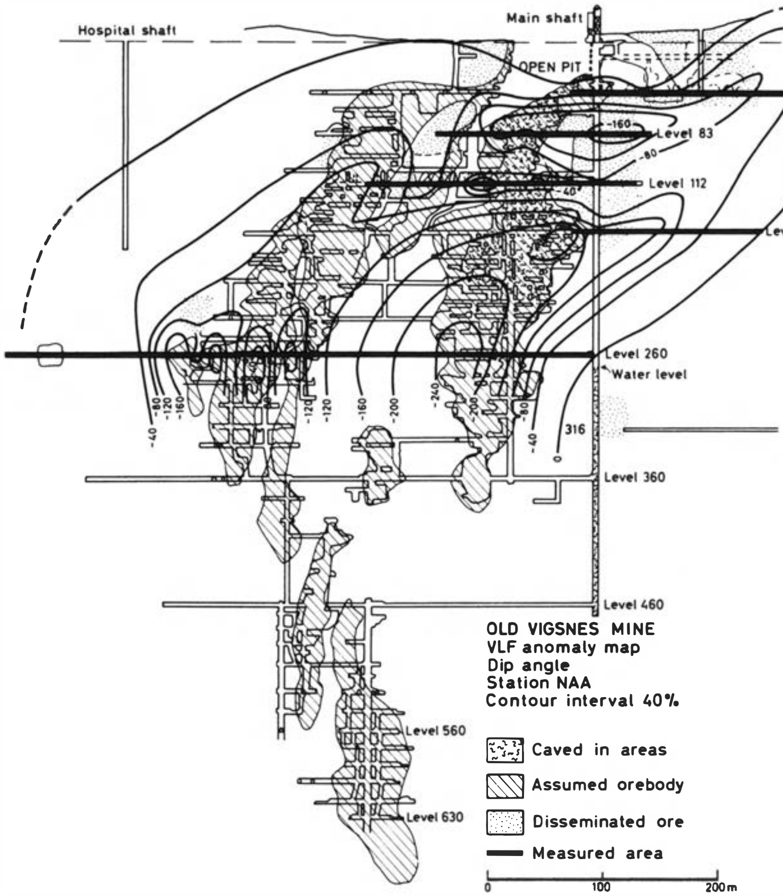


*Fig. 11.* VFL field (dip angle) depth section parallel the ore lenses section represents the field 10 m into the hanging wall.

hanging wall. The section presents the variations in the dip angle field, and we note that:

The general shape of the VLF field is in good agreement with the theoretical distribution shown in Fig. 8.

The equi-lines circumscribe the ore bodies and give evidence on the direction of the axis of the ore lenses.

The VLF field seems to indicate that the conducting ore lenses are very deep (at least more than 500 m) as the sign of the field does not change above level 260 m (Fig. 8).

Later investigations on the deeper levels 360 m and 460 m have shown a change of sign of the imaginary component near level 360, indicating a possible depth of the lenses of ca. 700 m.

# The gravity method

Fig. 12 shows the gravimetric results for level 83 m. The anomalies are pseudo-Bouguer anomalies reduced to each level as datum plane. In order to get real Bouguer anomalies one simply should add a constant for each level.

Three anomalies (G 83 A, B, C) are found. G 83 A which is a maximum, corresponds to CP 83 A and SP 83 A. G 83 B is also a gravity maximum and G 83 C a minimum, and we notice a rather strong gradient west of C.

The interpretation of underground gravity data is dependent upon several factors. A gravity maximum can be caused by mass excess under the measured station or by mass deficit above the station. Likewise, a gravity minimum can be caused by mass deficit under the station or

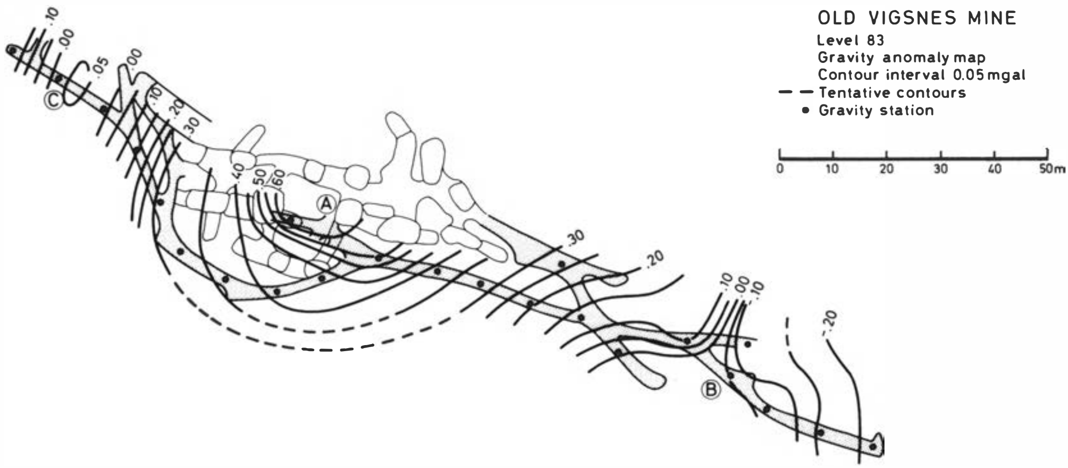


*Fig. 12.* Gravity anomaly map of level 83 m. Datum plane is lowest point of level 83 m. Tentative contours are dashed.

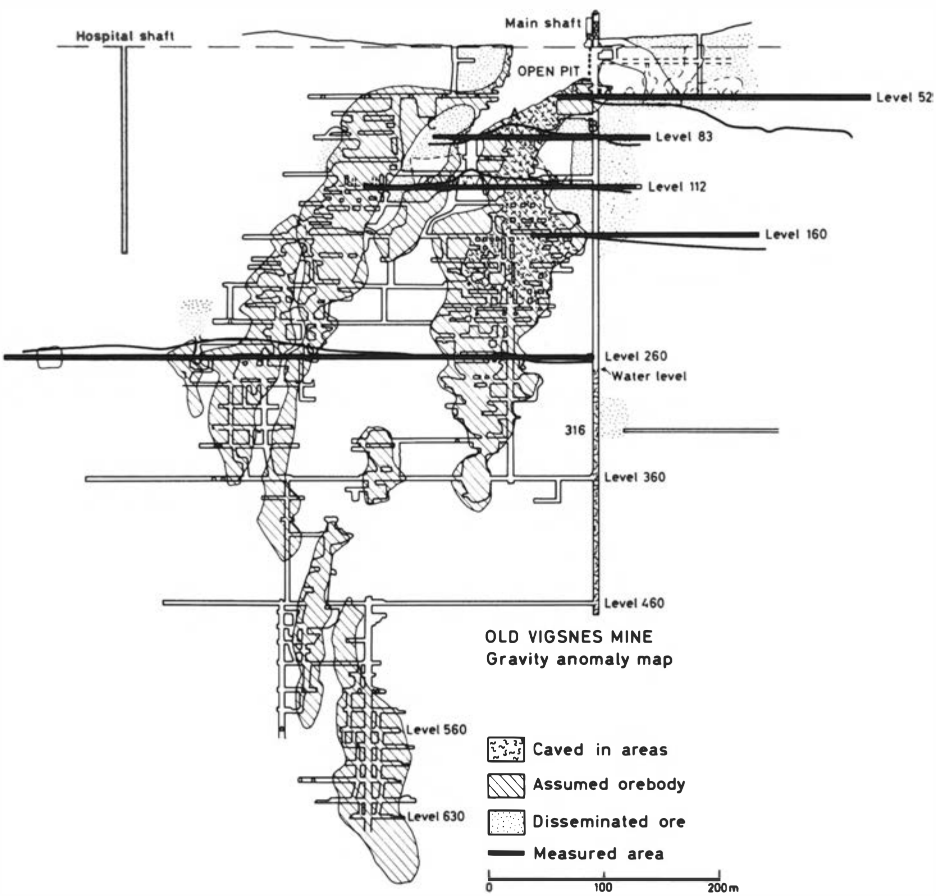


*Fig. 13.* Depth section showing the gravity anomaly at different levels. The anomalies are reduced to the different levels in which they were measured. In order to get Bouguer anomalies one should add a depth dependent constant for each level.

by mass excess above the station. If one looks at the depth section (Fig. 13), then it is rather obvious that G 83 A is caused by a void above the maximum since most of the area above anomaly A is either caved in or an open pit. G 83 C may be caused by ore remnants above the minimum, and G 83 B which is a relative maximum may be caused by dense underlying masses.

The depth section (Fig. 13) shows gravity profiles along the different levels. The gravity generally rises towards the west. The maxima at levels 83 m and 112 m are probably due to the open pit and the void spaces above these levels. The minimum to the east at level 52 m may indicate dense rocks above the drift. The maximum at level 260 m may reflect voids above, but since large stoped out areas are also found below the anomaly it may be due to dense masses under the measured level.

## Concluding remarks

None of the electrical measurements are able to distinguish between compact (economic) ore or pyrite impregnations in narrow (not economic) bands.

The measurements on all levels have shown the position and direction of the ore horizon, thus guiding the geologist in planning an underground drilling programme.

The electric fields appear to give information on the direction and probable depth extension of the conducting ore bodies.

The gravity measurements have given information on voids and possible ore concentrations below or above a given level. These measurements may in some cases distinguish between compact ore or impregnations, where electrical measurements give no resolution.

This study indicates that the combination of the four methods may yield information that is important in selecting the most promising drilling prospects.

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## References

Broch, O. A., Isachsen, T., Isberg, O. & Strand, T. 1940: Bidrag til Skudenes-sedimentenes geologi. *Nor. Geol. Unders. 155,* 41 p.

Geis, H.-P. 1961a: Strukturelle iakttagelser ved noen norske kisforekomster. *Nor. Geol. Tidsskr. 41,* 173–196.

Geis, H.-P. 1961b: Früh hologene Sulfidlagerstätten. *Geol. Rdsch. 50,* 46–52.

Geis, H.-P. 1962: Zur Spilitbildung. *Geol. Rdsch. 51,* 375–384.

Geis, H.-P. 1963: Aus dem Übergang vom Oberbau in den Unterbau. *Geol. Rdsch. 52,* 184–188.

Geis, H.-P. 1965: 100 Jahre Vigsnes Kobberverk. *Tidsskr. for Kjemi, Bergv. og Metallurgi 8–9,* 194–202.

Goldschmidt, V. M. 1921: Die Injektionsmetamorphose im Stavanger-Gebiete. *Skr. Nor. Vidensk. Akad. i Christiania,* Mat.-Naturvidensk. Kl. 1920, no. 10.

Logn, Ø & Bølviken, B. 1974: Self potentials at the Joma pyrite deposit, Norway. *Geoexploration 12,* 11–28.

Paterson, N. R. & Ronka, V. 1971: Five years of surveying with the very low frequency-electromagnetics method. *Geoexploration 9,* 7–27.

Reusch, H. 1884: Fjeldbygningen ved Viksnes kobbergrube på Karmøen. *Nyt Mag.f. Nat. 28,* 97–106.

Reusch, H. 1888: *Bømmeløen og Karmøen med omgivelser.* Christiania 1888.