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Tittel

The Joma sulphide ore body, Nord-trøndelag, Norway, Report to NTNF May 1986

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Vokes, F.M.	30.05	1986	Grong Gruber AS

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Geologi		Jomafeltet Jomaforekomsten
Råstoffgruppe	**Råstofftype**	
Malm/metall	Cu,Zn	

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

Gir et sammendrag av strukturkartlegging i et 12 km2 stort område. I tillegg er det kommentert på malmforekomstens der malmens strukturer er kartlagt under jord.
Deformasjonseffekter på malmtykkelsen blir omtalt. Dertil blir forholdet mellom de tre grønsteinsbuene diskutert i forhold til muligheten til funn av nye forekomster.
Det gjøres en gjennomgang av malmens sideberg og de forskjellige malmtypene. Det deles i 4 typer.
Tilslutt gjennomgås antatt opprinnelig stratigrafi og dannelse av malmen.

FMV

THE JOMA SULPHIDE ORE BODY
NORD-TRØNDELAG, NORWAY

REPORT TO N.T.N.F. ON PROJECT MB 10.15042
MAY 1986

OUTLINE OF THE PROJECT

The project had as its aims an analysis of the structural setting, stratigraphy, petrography, mineralogy and chemistry of the Joma sulphide deposit and its surroundings.

The project is being reported on in two parts, Part I, a study of the structures by N.E. Odling and part II a study of stratigraphy, petrography, mineralogy and geochemistry, by A. Reinsbakken.

The project was funded jointly by Norges teknisk-naturvitenskapelige forskningsråd (NTNF) and Grong Gruber A/S and administered financially by SINTEF (B) Trondheim. Reinsbakken was engaged as project participant from May 1st 1984 to June 1st 1986, while Odling participated in the project while in possession of an NTNF Post-doctoral fellowship during the period June 1st 1984 to June 1st 1986.

The structural analysis by Odling was based on structural mapping at the scale of 1:5,000 of an area of approximately 12 km^2, involving the measurement of minor structures and mapping of lithological types in the greenstones. Finite strain was analysed for ten specimens of variolite bearing, pillowed metabasalt from the outer greenstone. The structure of the ore deposit was studied by underground mapping and minor structure measurement, concentrated in the newer, deeper parts of the mine. A total of 12 weeks were spent on surface mapping and 12 weeks on underground mapping from June to September in 1984 and 1985.

The stratigraphical, petrographical, mineralogical and geochemical study of the ore horizon by Reinsbakken involved the construction of 28 vertical and 5 planar sections of the ore body, extending those of Olsen (1984) to greater depth, and reclassifying the sulphide and country rock lithologies. To this end a number of the levels in the mine were mapped in detail during a total of six months spent at Joma. Fifteen deep drill holes from the surface to the ore horizon and six underground drill holes were logged and sampled for a total of 460 chemical analyses to study the hydrothermal alteration associated with the sulphide deposit. In addition, 72 samples of sulphide ore were analysed for base and trace metal content.

SUMMARY OF THE STRUCTURE OF THE JOMA AREA AND SULPHIDE DEPOSIT

Four phases of deformation have been identified in the Joma area. The main deformation phase, to which the generally flatlying penetrative schistosity and northwest trending, mineral lineation belongs, is D2. This phase is associated with the main nappe emplacement event and the formation of minor thrusts that form the lower contacts of the inner, middle and probably also the outer, greenstone units. F2 folds are occasionally seen to fold an S1 schistosity and F1 folds to which F2 folds are coaxial. Thus, D1 deformation is interpreted as an early stage of D2 deformation. Fold vergences and the outcrop pattern of pillow lavas indicate the presence of a major F2 fold in the middle greenstone with the Joma sulphide deposit located in the overturned limb. The fold and the ore horizon are both cut at depth by the thrust at the base of the middle greenstone.

The D2 structures are refolded by a northeast trending major F3 fold, the Joma synform. F3 fold axial planes and associated crenulation cleavage dip moderately to steeply northwest and fold hinges plunge gently northeast or southwest. Zones of L3 lineation plunge, trending obliquely across the greenstone units, imply a pre-D3 variation in the S2 schistosity surface interpreted as a 'ramp and flat' structure associated with the thrust at the base of the middle greenstone.

From the folded L2 lineation patterns, finite strains and the distribution and orientation of D3 deformation, D3 and D2 deformations are sub-coaxial and dominantly simple shear. D3 deformation is therefore interpreted as a late stage in the nappe emplacement event.

D4, the latest phase of deformation, is confined to minor structures adjacent to the upper thrust boundary with the overlying Gjersvik nappe. D4 structures show an antithetic relationship to D3 structures such that as D3 deformation decreases intensity, D4 structures become dominant. These structures are thought to form as a result of compression caused by the formation of the Joma synform.

All deformation phases identified in the Joma area are present in the Joma massive sulphide deposit. D2 structures, with which the penetrative schistosity in the greenstones and textural layering in the sulphides is associated, show a variation in style corresponding to a composition change across the ore body. In the east, where the sulphides are chalcopyrite and pyrrhotite rich and contain intercalated silicate layers, isoclinal F2 folds with amplitudes of 100 to 300 m are developed. The folds show thickened hinges in which the silicate layers have suffered intense folding and disruption, and thinned limbs along which thrusting has led to the emplacement of thin slivers of sulphide into the greenstone country rocks. In the eastern section of the ore body the sulphides are massive and pyrite-sphalerite dominated. Here intense thrusting has led to the development of numerous tectonic lenses within which slides are marked by thin, laterally persistent, silicate and carbonate layers. The tips of thrust lenses pass westwards into the hinges of F2 folds. Due to abundant thrusting, the majority of sulphide-greenstone contacts are now tectonic and a phase of thrusting, pre-dating D2, correlated with D1, is indicated by the folding of such tectonic contacts in F2 fold hinges. D2 deformation increases markedly with depth as the ore horizon approaches the lower thrust contact of the middle greenstone. The obliquity of the S2 schistosity to the sulphide-greenstone contacts implies a southeasterly directed sense of movement on the majority of the thrust contacts.

D2 structures are refolded during D3 and F3 folding is most intense in the western section of the ore body. As in the country rocks, F3 folds are discontinuous and occur in lens-shaped zones of intense folding. Within the sulphides, reactivation of the D2 thrust planes during D3 has caused a flattening of the F3 axial planes and rotation of F3 fold hinges towards the D2 thrust planes and the L2 lineation direction, respectively. Abundant D3 fractures and veins in the adjacent greenstones form two sets, the first subparallel to the F3 axial and the second, subparallel to conjugate shears to the D2 thrust planes. They indicate tensional stresses in the greenstones during D3 deformation, thought to be caused by the competency contrast between greenstone and sulphide.

THE EFFECTS OF DEFORMATION ON THE ORE THICKNESS

The results of two phases of deformation on the Joma ore body has been to greatly modify the original tabular form of the ore horizon and intense early (D1-D2) deformation has resulted in dramatic changes in thickness over short distances. Tectonic thickening has occurred in the hinge zones of F2 folds and, to a lesser extent, F3 folds, in the western section of the ore body. Vertical thickening occurs in the steep limbs of F3 folds due to change in attitude of the ore horizon. Thinning of the ore horizon occurs in the limbs, especially short limbs, of F_2 folds in the western section, and at the edges of thrust lenses, in the eastern section of the ore body.

The structural styles of the two fold phases can be used as a guide to changes in ore thickness and to locate zones of thick ore. In the eastern section of the ore body, massive pyrite-sphalerite sulphides have developed thrust lenses whose edges trend northwest parallel to the L2 lineation. They tend to be arranged en echelon so that, traversing the ore body in a southerly direction, successive lenses occur at increasingly greater depths to the southwest i.e., in a direction perpendicular to the trend of thrust lenses. In the western section of the ore body, chalcopyrite-pyrrhotite ores with intercalated silicate horizons, have led to the development of large scale F2 folds.

Their thickened hinges form rod-shaped zones trending parallel to the L2 lineation and plunging gently northwest or southwest. Zones of exaggerated ore thickness in steepened F3 limbs trend perpendicular to F2 hinges, plunging gently northwest. Where these two hinge trends intersect, pod-like areas of greatest ore thickness occur. Since F3 folding is confined to the western section, these pods occur in this part of the ore body.

THE CONTINUATION OF THE GREENSTONE UNITS IN THE LEIPIKVATTNET NAPPE AND FURTHER ORE OCCURRENCES

The structural analysis of the Joma area has shown that the repetition of the three greenstone units is tectonic and that the Joma massive sulphide deposit is cut by a thrust located at the base of the middle greenstone. The L2 mineral lineations approximate the shear direction and the relationship between S2 schistosity in the greenstones and the tectonic sulphide-greenstone contacts indicates that the middle greenstone has been translated in a southeasterly direction. The remainder of the Joma deposit should therefore be situated within the Leipikvattnet nappe to the west of the presently known ore body. To investigate the continuation of the three greenstone horizons beyond the presently mapped area, their outcrop has been traced on the 1:50,000 maps of the Huddingsvatnet and Røyrvik areas.

To the south of the Joma area, the Leipikvattnet nappe forms a steeply dipping belt trending north-northeast. The inner greenstone outcrops in a thin strip adjacent to the main thrust with the overlying Gjersvik nappe. Thin graphitic phyllite layers within the greenstone probably represent the location of minor thrusts connecting with the lower contact of the inner greenstone lens in the Joma area. The outcrops of the middle and outer greenstone units thin southwards and can be traced for approximately 10 and 7 km respectively. Both units show folding on their structurally upper contacts and all three greenstone units show smooth unfolded lower contacts. Since these are known to be the location of thrusts in the cases of the inner and middle greenstone units, it is thus likely that the lower contact of the outer greenstone is also tectonic.

As the lower thrust contacts are unfolded, the folding of the upper contacts is coeval with thrusting and therefore D2 in age.

In the extreme south, the rocks between the three greenstone units are composed of thin intercalated layers of graphitic phyllite, quartzitic phyllite and greenstone. This interlayering is probably due to attenuated isoclinal F2 folding and small scale thrusting. The layering trend can be used to trace the southern continuation of the thrusts at the bases of the middle and outer greenstone units, showing that they gradually converge with the main thrust at the base of the Gjersvik nappe.

To the west, the Leipikvattnet nappe trends generall eastwest and is folded by an open F3 antiform trending northeast and plunging gently southwest. As in the area to the south of Joma, the inner greenstone forms an almost continuous, thin strip of outcrop, adjacent to the main thrust contact with the Gjersvik nappe. The outcrop of the outer greenstone can be followed, progressively thinning westwards. The middle greenstone, in contrast, passes westwards into a series of thin, en echelon lenses trending obliquely to the inner greenstone and major thrust. It is probable that these lenses are tectonic in character and they are interpreted as a series of imbricate minor thrusts underlying the inner greenstone. West of Gåsvannet, the middle greenstone is again represented by a single thin greenstone layer.

Several occurrences of sulphide impregnation associated with carbonate horizons and one occurrence of massive sulphide, are known at Borvasselv, in the imbricated greenstone layers to the east of Gåsvannet. The sulphides are associated with lithologies similar to those found in the Joma massive sulphide deposit (carbonate and chlorite schist). They also lie to the west of the main deposit, the predicted direction for the location of the missing portion of the sulphide body, and are separated from the main deposit by a series of thrusts. They therefore represent the best candidate for the section of the Joma massive sulphide deposit which was separated from the main body by thrusting at the base of the middle greenstone.

LITHOLOGY OF THE WALL ROCKS

The hosting greenstones of the Røyrvik Group metavolcanites show a variety of textures and structures. Although these rocks have undergone a strong pervasive metamorphic recrystallisation and penetrative foliation, remnants of pillows, pillow-breccias and hyaloclastites occur, indicating deposition in a submarine environment. A detailed investigation of the three greenstone units of the area indicates that the lower and middle greenstones (Orklumpen and Joma, respectively) originally belonged to the same volcanite complex, which has been repeated by isoclinal folding and thrusting.

The Joma deposit itself occurs within the middle greenstone, at the interface between two local volcanite units. The older, pre-ore volcanites, in the structural hangingwall, comprise a sequence of massive flows and high level intrusions (Group A), enveloped in a pillow lava and pillow-breccia sequence (Group B). The younger volcanites (in the structural footwall) consist of a thinner pillow lava and pillow breccia unit (Group C_1) which grades, both stratigraphically upwards and laterally into a sequence of well-layered to laminated volcaniclastic rocks (Group C_2). The layered pyroclastic rocks contain minor layers of grey and dark grey graphitic phyllites and carbonates, grading upwards into layered quartz rich rocks and graphitic phyllites ('ribbon cherts').

The greenstones show a metabasaltic (spilitic) composition with mixed MORB-WPB affinities. A significant difference between the pre- and post-ore lavas is, however, apparent. For example, the post-ore lavas show distinctly lower contents of TiO_2 and Zr at similar Cr contents relative to the pre-ore lavas. Thus the former show a N-MORB and the latter an E-MORB or WPB affinity. The Røyrvik Group metavolcanites appear to have formed in an oceanic, near continent, probably off-axis setting.

<u>The pre-ore metavolcanites</u> in the vicinity of the ore horizon are uniform, moderate to pale green coloured and schistose. They have, however, undergone extensive chemical and mineralogical changes due to the intense, pervasive, hydrothermal alteration. Original volcanic textures and structures have been partially or completely destroyed during extensive albitization, chloritization, sericitization and sulphidization. Chemical changes have involved a dramatic decrease in both Ca, Mg and to a lesser extent K, a considerable increase in Fe, Na, S and minor increases in Al.

A detailed study of the mineralogical and chemical variations in the host rocks at Joma has distinguished six lithologies within the pre-ore volcanites. They show zonal patterns in both their mineral and elemental distributions which are typical of intense hydrothermal alteration patterns found within 'feeder zones' forming the rootzone to volcanogenic massive sulphide deposits. The pre-ore host-rock lithologies are, in order of increasing degree of alteration, B_1 to B_6. In addition the individual units may be divided into subunits (e.g. B_{6a-d}).

B_1 - Undifferentiated massive and pillowed greenstones.
B_2 - Albite-bearing sericite schists.
B_3 - Albite-bearing chlorite schists.
B_4 - Chlorite-actinolite schists.
B_5 - Albitites.
B_6 - Chlorite schists.

Marginally to the ore body and stratigraphically upwards in the original sulphide-silicate pile, the chlorite schists become more Mg rich and distinctly pyrite- and carbonate-bearing in the form of disseminations and individual layers. This is enriched in Zn and contrasts with the Cu enriched chlorite schist stratigraphically below.

Compared to the host metabasalts, both the albitite and chlorite schist show significant chemical variations. Mg has apparently been depleted from the albitite while the chlorite schist shows a significant enrichment in this element. Na is enriched in the albitite and depleted in the chlorite schists; Ca is depleted and Fe is enriched in both these units. These significant chemical variations can be interpreted as indicating a hydrothermal alteration origin for the albitite and the deposition of the chlorite schist, in part, as Fe-Mg-Cu rich syn-depositional layers of tuffaceous (?) bottom mud. The Ca leached from the lavas below could have been held in solution and later deposited as extensive, concordant carbonate layers within the Zn rich pyritic ore in the upper parts of the sulphide stratigraphy.

ORE TYPES AT JOMA

The following ore minerals have been recognized in Joma.
Major minerals; pyrite, pyrrhotite, chalcopyrite, sphalerite and magnetite. Minor and trace minerals; cubanite, tetrahedrite, mackinawite, vallerite, galena, arsenopyrite, cobaltite, ilmenite, rutile, native Au, electrum and amalgam.

The ore at Joma has been subdivided into four main massive, and two disseminated, ore types, based on the textural, mineralogical and chemical characteristics. The four major ore types are:

Type I: Fine grained grained to flinty pyritic ore. Contents of both Cu and Zn are moderate.

Type II: Fine to medium grained pyrite-pyrrhotite-chalcopyrite ore.
Carries layers of disseminated amphibole and of amphibole schist, chlorite schist, magnetite ore and dark, recrystallised chert. Usually Cu rich.

Type III: Chalcopyrite-pyrrhotite breccia ore.
Typically carries fragments (clasts) of chlorite schist, carbonate, magnetite ore and fine grained pyrite ore (Type I). Durchbewegt. Cu rich.

Type IV: Medium to coarse grained pyritic ore. Contains carbonate and chlorite as both matrix and as individual layers. Generally rich in Zn and devoid of Cu.

The two main disseminated ore-types are 1) dark, Fe rich chlorite schists containing disseminations and layers rich in chalcopyrite and pyrrhotite, 2) pale albite-white mica schists, rich in pyrite-quartz-calcite veins and disseminations, often rich in Zn and minor Pb.

Cu, Zn and specific gravity analyses of the massive ores have been shown to be valuable in distinguishing the above mentioned types. When these analyses are plotted in a triangular diagram as

$$\frac{\text{Cu sample}}{\text{Cu average}},\ \frac{\text{Zn sample}}{\text{Zn average}},\ \text{and}\ \frac{\text{specific gravity sample}}{\text{specific gravity average}}$$

the data points of the different ore types define distinct areas or clusters . The Cu-rich ore facies (ore types II and III) are confined to the western and southern parts of the ore zone and the thicker Zn-bearing pyritic ore facies (type IV) to the northeast and eastern parts.

The fine grained, flinty, pyritic ore facies (type I) appears roughly to separate the two main ore facies, the Cu- and the Zn rich ores.

Concerning the genesis of the chalcopyrite-pyrrhotite breccia ore, Olsen (1980) suggested the presence of a primary FeS phase which originally was, or has since recrystallized to, pyrrhotite. The competency contrasts between the silicate- and the sulphide-layering and the presence of large quantities of both chalcopyrite and pyrrhotite in these layers has probably been the governing factor in the formation of these tectonic breccia ores. Pyrrhotite and chalcopyrite, and for that matter also sphalerite, are minerals which, due to their internal structures (lattice planes along which gliding can occur), are readily mobilized and redistributed by tectonic shearing movements associated with the 'durchbewegung' phenomena.

Chalcopyrite, pyrrhotite, quartz-calcite and to lesser degrees sphalerite, chlorite, albitite and epidote are also typically mobilized along D_3 'piercement' structures and late cross-cutting fracture fillings, adjacent to the Cu rich massive sulphide ores at Joma.

ORIGINAL STRATIGRAPHY

A palinspastic reconstruction based on the distribution of ore types and mineralization in relation to host rock lithologies and hydrothermal alteration, including the recognition of a 'feeder zone', has led to the establishment of the following succession surrounding the ore body:

Top 1) Pale, epidote- and calcite-bearing post-ore greenstones and minor magnetite-bearing, dark recrystallized chert and limestone.

2) Massive, generally pyritic ore with interlayers and lenses of limestone and chlorite schist. The following ore types can be recognized, probably in a vertical sequence (top to bottom);
a) medium to coarse grained pyritic ore (Type IV),
b) fine grained to flinty pyritic ore (Type I),
c) fine to medium grained, Cu rich pyrite-pyrrhotite chalcopyrite ore (Type II).

3) Cu rich, pyrrhotite-chalcopyrite breccia ore (Type III).

4) Dark, Fe chlorite schists (B_6) rich in disseminations and layers of chalcopyrite-pyrrhotite.

5) Feeder zone lithologies (B_1-B_5, see p. 8).

Base 6) Moderate green, chloritic greenstones with epidote knots and pyrrhotite disseminations; minor pyrite veining.

FORMATION OF THE ORE BODY

Considerable evidence has accumulated to indicate that all the lithologies described above, except for some of the chalcopyrite-pyrrhotite breccia ores, were formed prior to D_1-D_2 and are, therefore, probably syn-depositional in origin. The sequence of events appears to have been:

1) Formation of a feeder-zone with associated hydrothermal alteration phenomena, including depletion of Mg and Ca and formation of pyrite-bearing albitites and pale albite-white mica-chlorite-actinolite schists. The feeder-zone forms the roots to the massive ores and the channels through which the metal-bearing fluids have ascended on their way to the sea floor.

2) Deposition of chemical sediments (tuffaceous muds?) immediately overlying and adjacent to the feeder zone.

3) Deposition of massive Fe-sulphides at the sea water-pillow lava interface immediately above and adjacent to the feeder zone. The sulphide ores grade from an early Cu rich layer, represented by the present layered Cu rich sulphide-, silicate- and magnetite rich ore, into a more Zn rich and Cu poor, pyritic top layer. The occurrence of carbonate and chlorite schist layers within the upper levels of the massive pyritic ore shows that the deposition of sulphides was not continuous.

4) Relative positions and bulk chemistries of these layers were maintained during the subsequent deformation and metamorphism except for the tectonic origin of the chalcopyrite-pyrrhotite breccia ores and minor chalcopyrite-pyrrhotite concentrations in later veins and fracture filled mobilizations.

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