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Tittel

Norges svovelkisforekomster
Skorovas forekomst

Forfatter	Dato	Bedrift
Steinar Foslie, Gjelsvik, Tore, Halls C. et al., ferriday I. L. et al.	19	

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Råstofftype	**Emneord**	
Malm/metall	Svovelkis	

Sammendrag

NORGES SVOVELKISFOREKOMSTER

AV

STEINAR FOSLIE

Skorovas forekomst.[1]

Forekomsten ligger SV for Tunsjøen og 650 m.o.h. I årene 1913—16 blev den undersøkt ved 2 stoller (*Nygruben* og *Gamlegruben*) og 20 diamantborhull og påvist å være meget betydelig.

Den er innleiret i skifrige grønnstene med flatt, undulerende fall, som danner en vid anticlinal. Denne har engang vært overleiret av et utstrakt intrusjonsfelt av trondhjemitiske og gabbroidale bergarter, som nu er bevart fra erosjonen bare rundt periferien, hvor de setter mot dypet.

Malmen har sitt utgående i en liten flat dalforsenkning på fjellsiden, og har vært gjenstand for en enorm oksidasjon, så vi her finner den største jernhatt, som kanskje er kjent i Norge. Ved utlutning av malmen har hengbergarten ved dennes utgående vært gjenstand for recente sammenstyrtninger, så den er opbrukket i store flak som dekker malmen, og gir inntrykk av en langt mindre malmmektighet enn den som virkelig eksisterer.

Malmen er en finkornig svovelkis, oftest med lav kobbergehalt. I Nygrubens stoll, som er drevet nær det utgående av hovedmalmen og går nesten utelukkende i malm, er denne usedvanlig rik på svovel og fattig på kobber, som det sees av nedenstående generalanalyser.

I borhullene er malmens sammensetning mere variabel, og kobberinnholdet er gjennemgående høiere. En midlere analyse fra alle borhull, omfattende bare malm med over 40 % S, anføres også nedenfor. Den gir det beste billede av malmlegemets midlere sammensetning.

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[1] Se også:

H. H. SMITH: Notes on Skorovas Deposit. Trans. Inst. Min. & Met. London 1922

J. H. L. VOGT: Gronggrubene og Nordlandsbanen. Norges Geol. Unders. Skr. nr. 72.

A. BUGGE: Skorovasfeltet i Grong. Tidsskr. f. Kemi og Bergvæsen, nr. 2 1922.

	Malm fra Nygruben (nær det utgående) %		Midlere analyse fra alle borhull %
S	51,32	50,97	46,40
Fe	45,35	45,42	41,35
Cu	0,288	0,30	0,98
Zn	null	spor	0,89
Pb	spor	spor	-
Ni, Co	null	0,08	-
As	0,005	0,042	0,04
Se	0,008	0,002	-
SiO_2	1,50	1,25	4,63
TiO_2	0,017	-	-
Al_2O_3	-	0,45	1,52
CaO	1,00	0,12	1,08
BaO	null	spor	-
MgO	0,47	0,30	1,32
P_2O_5	0,009	0,014	-
CO_2	spor	spor	-
O. H_2O	0,09	1,15	-
	100,06	100,10	98,21

Cr, Sb, Te, Bi, Mn, F og fritt C kunde ikke påvises i de to førstnevnte analyser.

Malmen fra Nygruben har ved brendingsforsøk vist sig å gi en fortrinlig avbrand (purple ore) med ca. 65 % Fe, 0,5—1 % S og 0,4 % Cu.

Også i enkelte av borhullene fantes betydelige mektigheter av malm med over 50 % S, men gehalten varierer forøvrig mellem 40 og 50 % S. Kobberinnholdet varierer temmelig meget, fra 0,2 til 4 % Cu, i de forskjellige partier av forekomsten, uten at nogen regel for fordelingen kan opstilles.

Innleirede grønnstenspartier, som må brytes sammen med kisen, beløper sig til bare omtrent 5 % av den hele masse.

Man har dessuten i en del av borhullene partier av opberedningsmalm med under 40 % S. De utgjør tilsammen omkring 1/10 av eksportmalmmengden, og medregnes ikke i de efterfølgende masseberegninger.

Ved undersøkelsesarbeidene er det nu påvist, at forekomsten består av to utpregede kislinealer med akseretning mot SSV og nesten horisontalt forløp inn i fjellsiden. På grunn av det

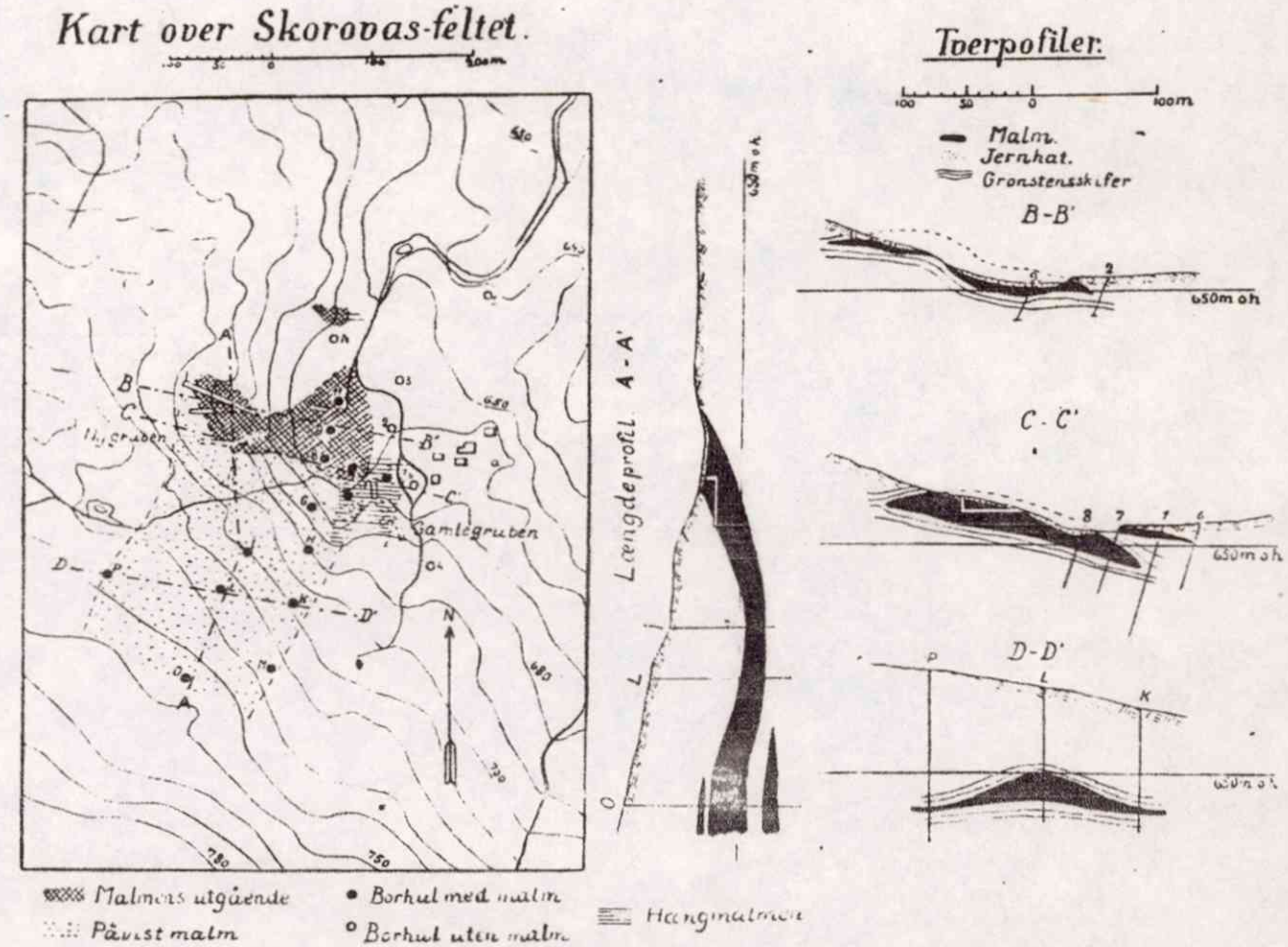

Fig. 13.

flate østlige fall dekker malmens utgående et stort område i bunnen av den nevnte dalsenkning og fjellskråningen, og utgjør her en mere eller mindre tykk erosjonsrest, der som nevnt er dekket av en optil 5 m. mektig rustmasse, dels in situ, dels transportert.

Videre nordover synes efter forfatterens undersøkelser den fremdeles rustne fjellskråning å være malmens oprinnelige liggflate, som nu er blotlagt. Man skulde derfor ikke kunne vente malm av betydning her, iallfall ikke tilhørende samme malmlineal.

Malmlinealen er hittil påvist omtrent fra borhull 9, hvor malmen i dalbunnen har en resterende tykkelse av 9 m. og til det sydligste borhull O over en samlet aksial lengde av ca. 300 m. I to tverrprofiler, B—B' og D—D', er dens bredde temmelig godt kjent, og utgjør ca. 190 m. Forøvrig er malmlinealens østre grense over den nevnte lengde nokså nøie fastslått, og viser sig å forløpe temmelig regelmessig. Derimot har antallet av borhull ikke vært tilstrekkelig til en nøiaktig fastsettelse av den vestre grense. I henhold til de ovennevnte 2 fullstendige profiler i nesten 200 m. innbyrdes avstand forutsettes foreløbig, at også den vestre grense har et lignende regelmessig forløp, så linealens midlere bredde kan settes til 190 m.

I det sydligste borhull O finnes den største mektighet som hittil er påvist i denne malmstokk, nemlig 30 m. ren malm. Dertil kommer at en ny malm blev påvist 10 m. videre i det liggende, og med 10 m. mektighet. Denne nye malm, som bare er kjent i de sydligste borrhuller O—M, medregnes ikke i beregningen av påvist malm.

Undersøkelsene er ikke tilstrekkelige til å fastsette det hele malmlegemes midlere mektighet med nogen større nøiaktighet, men på grunnlag av de kjente mektigheter i 13 borhull og observasjoner i Nygruben og forskjellig røsker, kan den settes til minst 10 m. i middel for den hele bredde. Deri er da ikke innbefattet den nye malmstokk i borhull O, heller ikke opberedningsmalmene med under 40 % S eller de viktigste skiferinnleiringer i malmen.

Det midlere malmareal, *loddrett pa akseretningen*, blir da omkring 1 900 m^2. Med en utvinning av 4,25 tonn pr. m^3 kan altså denne malmlineal gi omkring 8 000 tonn pr. løp. m. i akseretningen.

Over og utenfor den østre del av denne malm, 10—15 m. i hengen, er der en annen malmlineal, som er påvist i Gamlegruben og i 4 borhull. Aksen er visstnok parallell hovedmalmens. Den er ennu temmelig litet undersøkt, men synes å ha en bredde av omtrent 60 m. med en midlere mektighet av kanskje 3 m. Hittil er den bare påvist i en aksial lengde av 50 m.

I forhold til hovedmalmen er den påviste malmmengde her temmelig ubetydelig, og da som nevnt dens dimensjoner ennu er usikre og forekomsten viser adskillige uregelmessigheter, innbefattes den ikke under påvist malm.

Som påvist malm beregnes derfor bare hovedmalmstokken inntil et tverrprofil gjennem borrhull O. Som sannsynlig malm kan vi trygt regne en fortsettelse av 100 m. i aksial retning. Produksjonsevnen pr. løp. m. er her naturligvis meget usikker, men på grunn av den store mektighet i borhull O, den nytilkomne malmstokk i liggen og en del bidrag fra hengmalmen vil man her antagelig kunne regne med 10 000 tonn pr. løp. m.

Påvist malm 300 · 8 000.... 2 400 000 *t.*
Sannsynlig malm 100 · 10 000 1 000 000 -
Mulig malm .... *Særdeles betydelig.*

The Skorovass Pyrite Mine, Grong area

by Tore Gjelsvik.

For the XXI International Congress, T. Gjelsvik (1960) has prepared a paper on the Skorovass deposit, which is referred to for details. Only a short extract is given here.

The *Skorovass* deposit belongs to the same group as *Løkken,* being a base metal-bearing pyrite deposit in spilitic greenstone. It is the only one so far brought into production in the Grong area.

The greenstone formation at Skorovass can be subdivided into three parts (See Fig. 17):

1. at the base, banded, limy greenschists of clearly sedimentary origin, containing blue quartzites with thin "vasskis" (sedimentary pyrite) bands.

2. alternating greenstone flows and pyroclastics, some of which are keratophyres.

3. the upper part, within which the deposit is situated, mainly spilitic flows (amygdales commonly noted) and some thin, intercalated keratophyre beds.

A band of trondhjemite separates parts 1 and 2 and forms an extensive contact zone of hybrid greenstones. The top of the mountain north of the mine village consists of gabbro containing a small deposit of nickeliferous pyrrhotite.

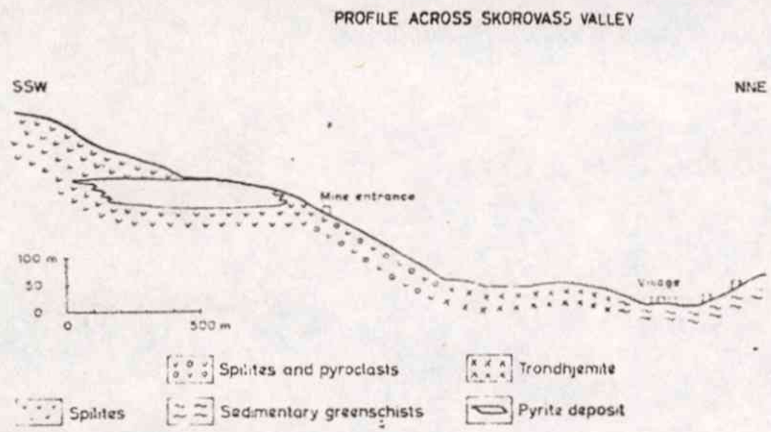

Fig. 17.

Vertical SSW–NNE profile across the Skorovass valley showing the ore-body and main wall-rock types.

The pyrite deposit consists of one large body and a number of small satellites in close proximity. The former is 600–700 m long and 200–300 m wide, and of very irregular shape, perhaps best described as a system of closely spaced and interconnected lenses, with the largest dimension parallel to the strike, which is north-south. (See sections, figs. 18 and 19.) The small ore bodies are generally flat lenses, conformable to the schistosity of the enclosing greenschists. The big ore body, too, is generally conformable. In the tapering bifurcations, however, cross-cutting contacts are frequently observed. Rapid lateral termination of even thick ore zones is noted at several places.

In the sedimentary greenschists, small, isoclinal folding is observed, but generally the series appears only slightly folded and a flat dip towards east prevails in the mine area. Post ore faulting occurred, resulting in small displacements and abundant slickensiding of ore fragments.

Owing to a distinct variation in grain size and proportions of the minerals, the ore is commonly banded, again in conformity with the schistosity of the greenstones. The most pronounced banding is caused by zinc-rich layers. Usually, the ore is massive and fine grained, but in the northern direction it grades into a coarse grained, low grade type. The ore minerals are pyrite, chalcopyrite and sphalerite, with subordinate amounts of tennantite, magnetite, arsenopyrite and

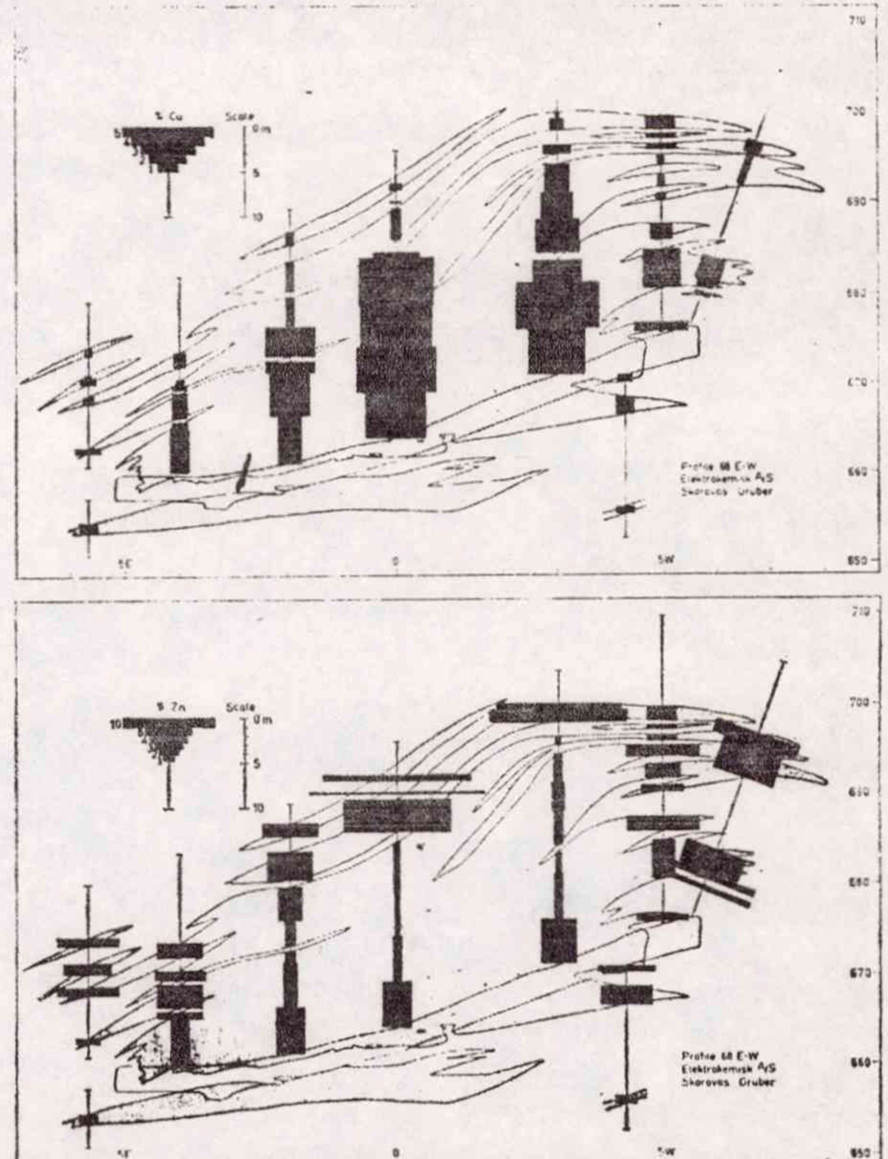

Fig. 18.

E–W vertical section through the Skorovass ore-body showing distribution of Cu (upper figure) and Zn (lower figure) values.

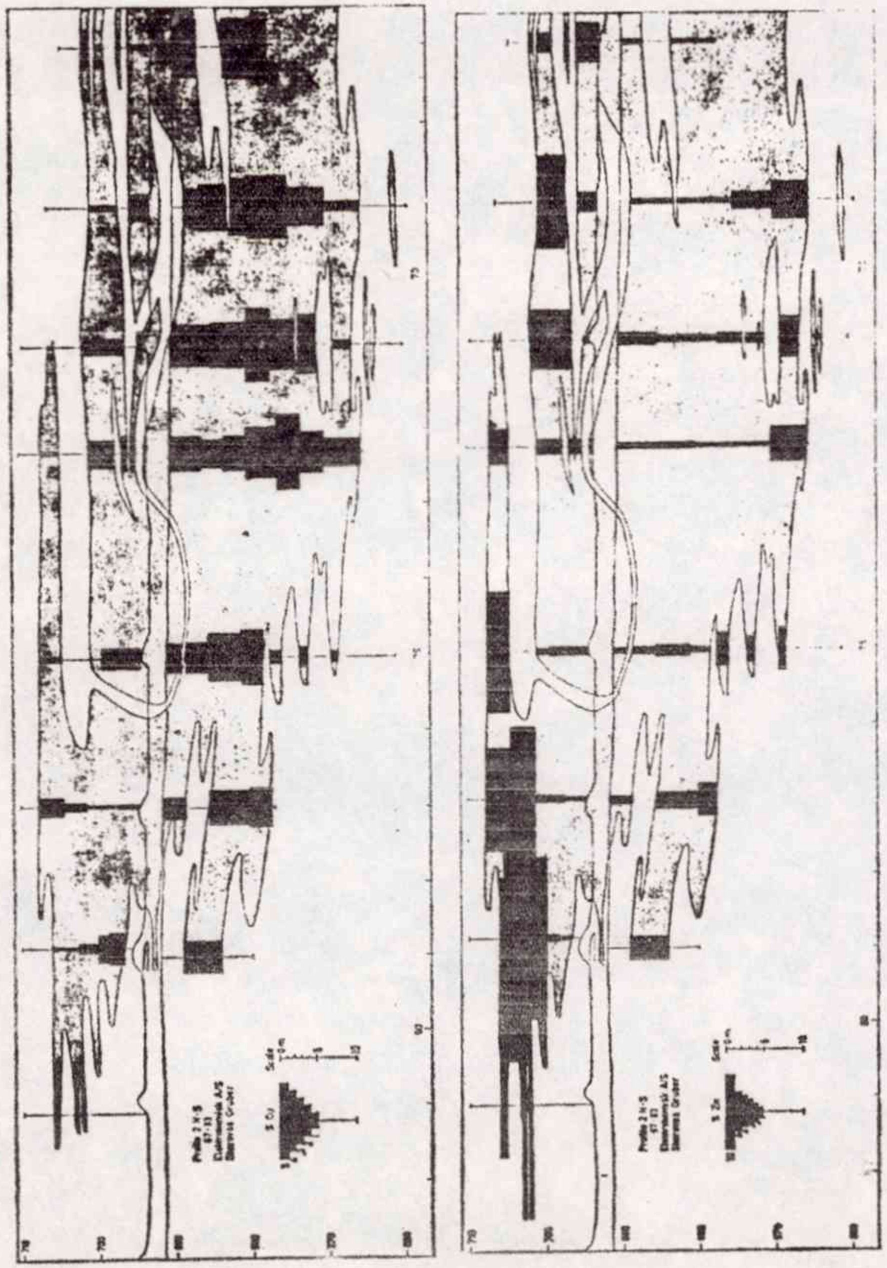

Fig. 19. N–S vertical section through the Skorovass ore-body showing distribution of Cu (upper figure) and Zn (lower figure) values.

galena. Notably absent is pyrrhotite. Pyrite is clearly the oldest sulphide, being replaced or intersected by most of the other ones. The gangue consists of chlorite, quartz and calcite. Veins of coarse quartz, calcite and chalcopyrite, sometimes also sphalerite, but rarely, if ever, pyrite, intersect the massive ore in places.

Wall rock alteration is distinct, although irregular, and includes chloritization, sericitization, silicification, carbonatization and talc formation. Mostly the contact between ore and schist is very sharp, but not infrequently an impregnated contact zone is present.

In the central part of the ore body, the sulphur content is high, and may exceed 50 per cent over considerable thicknesses. Consequently, the content of Cu and Zn is very low in this part, as it is also in the northern part which consists of coarse impregnation ore. Towards the southern end of the deposit, however, the amount of both metals increases greatly, exhibiting a typical zonal distribution, with copper enriched in the central, and zinc in the marginal, parts of the ore body (fig. 18).

S. Foslie (1939) who made the first detailed investigation of the deposit, considered it to be epigenetic, (hydrothermal metasomatic) whereas Chr. Oftedahl (1958) recently suggested a syngenetic origin (volcanic-exhalative). The genetic question is not definitely settled, but the present author (loc.cit.) is in favor of an epigenetic origin, although he finds it premature to state whether it is formed by replacement by magmatic emanations, or by remobilization of syngenetic deposits during the subsequent orogenesis.

The visit to the mine will include crosscuts showing various types of ore and contact relationships. Outcrops of massive and disseminated ore, as well as the surrounding schists will be studied.

References:

Foslie, S., 1939. Skorovass kisfelt i Grong. Norsk Geol. Tidsskr. 19.

Gjelsvik, T., 1960. The Skorovass Pyrite Deposit, Grong area, Norway. XXI International Congress.

Oftedahl, Chr., 1958. Oversikt over Grongfeltets skjerp og malmforekomster. Norges Geol. Unders. 202.

Geological setting of the Skorovas orebody within the allochthonous volcanic stratigraphy of the Gjersvik Nappe, central Norway*

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553.067: 553.277: 553.661.21(484.3)

Synopsis

The Skorovas orebody is one of the chief stratiform base-metal deposits within the allochthonous greenstone belt of the Central Norwegian Caledonides. It is contained in the volcanic level of a complex eruptive association of Lower to Middle Ordovician age defined as the Gjersvik Nappe. The rocks of this nappe are contained as a depressed segment of the larger Köli Nappe and defined to the north and south, respectively, by the Börgefjell and Grong–Olden basement culminations. The principal components of this nappe are a plutonic infrastructure of composite gabbroic intrusions within which has been emplaced a series of dioritic to granodioritic (trondhjemitic) bodies that form the roots of a consanguineous submarine polygenic volcanic sequence. The eruptive rocks are overlain unconformably by a sequence of polymict conglomerates and calcareous flysch sediments, the composition of which suggests immediate derivation by erosion from the underlying igneous complex.

Pre-tectonic segregations, veins and vesicle fillings of epidote, albite, chlorite, carbonate and quartz related to primary volcanic flow structures in the lava pile provide evidence of pervasive in-situ sea-floor metamorphism, and this interpretation is verified by the abundance of nearly monomineralic epidote clasts in the derived conglomerates.

The relationship of the eruptive and sedimentary suites is interpreted in terms of the evolution of an ensimatic island arc, of Lower to Middle Ordovician age, which underwent uplift and erosion prior to emplacement on the Fennoscandian basement during the climactic stages of collision tectonism of the Caledonian Orogeny in Silurian times.

The entire igneous and sedimentary assemblage has been affected by the tectonic stages of allochthonous emplacement, but the gross differences in competence between the component lithologies has resulted in a particularly heterogeneous style of deformation in which folding, componental sliding, fracturing and penetrative metamorphic refabrication have been governed largely by the geometry of the most competent lithologies, notably gabbro, diorite and granodiorite (trondhjemite) intrusives and, within the extrusive sequence, compact dacitic flows and their spilitized aphanitic equivalents (keratophyres). The heterogeneous pattern of deformation is resolved in terms of two main stages of folding complicated by componental sliding movements.

Mineralization occurs at two levels in the eruptive sequence. The layered gabbros and lensoid metagabbros of the plutonic infrastructure contain small cumulus bodies of nickel-, copper- and platinum-bearing pyrrhotite–pyrite–magnetite ore of magmatic derivation. Mineralization of this type is at present only known in sub-economic quantities.

The Skorovas orebody, in common with other widely dispersed volcanic exhalites in the Gjersvik Nappe, occurs within the volcanic sequence at a level marked by episodes of explosive dacitic volcanism and associated fumarolic activity. The Skorovas orebody consists of approximately 10 000 000 tons of massive and disseminated predominantly pyritic ore with an approximate average grade of 1.3% Zn and 1.0% Cu, together with trace amounts of Pb, As and Ag. The complex lensoid geometry of the orebody is resolved in terms of the disjunction of a single stratiform unit by tight isoclinal folding and componental movements, probably involving both translation and rotation.

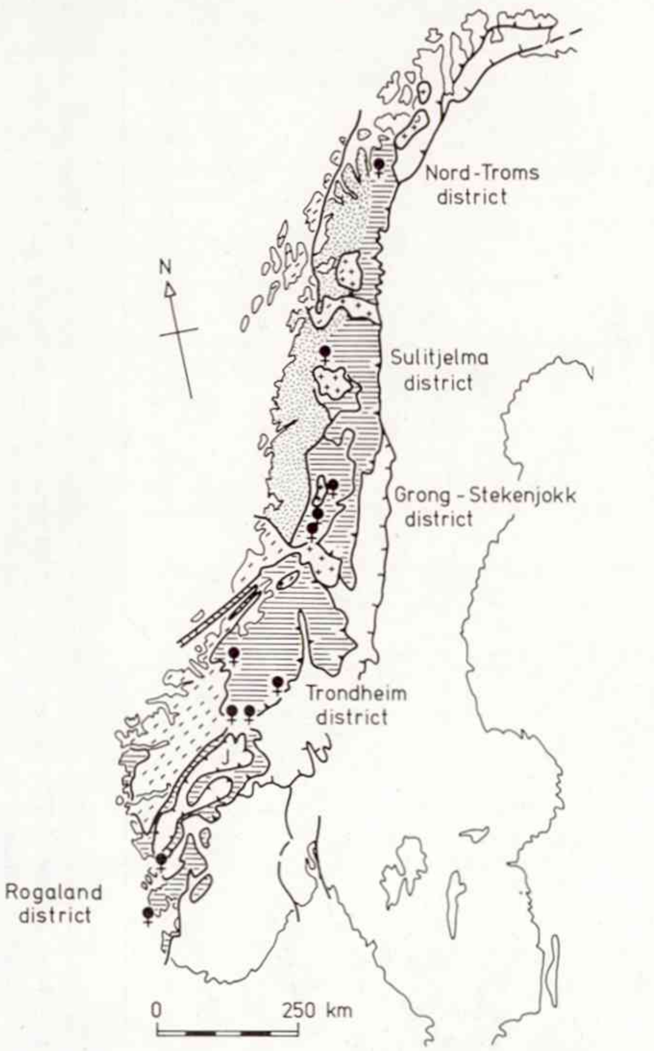
Enrichment of sphalerite, chalcopyrite and, locally, galena within the magnetite–pyrite ores at the stratigraphic top and margins of the ore lenses is interpreted as a primary feature. The banded magnetite–pyrite ores are commonly associated with magnetitic cherts or jaspers and are thus transitional in aspect to the thin, iron- and silica-rich, base-metal-depleted, exhalative sedimentary horizons that occur extensively within the extrusive sequence of the Gjersvik Nappe. These are interpreted as the products of settling of colloidal iron and silica hydrosols following explosive dispersal into an oxidizing submarine environment. They are valuable time-stratigraphic markers and indicators of way-up in complicated structures and are a potentially valuable tool in exploration for massive sulphide bodies formed in limited reducing environments.

The belt of metamorphosed Lower Palaeozoic rocks, chiefly of Ordovician age, within which the important stratiform pyritic copper- and zinc-bearing orebodies of the Scandinavian Caledonides are located extends over 1500 km from Rogaland in southwestern Norway to Nord Troms. The divisions of this complex metallogenic belt have been described by Vokes [73] and Vokes and Gale,[75] and Fig. 1 shows the relationship of the principal districts to the thrust front of the Caledonian allochthon. The culminations of the underlying Precambrian basement, together with the effects of erosion, have produced the segmentation of the allochthon on which the division into separate districts is broadly based. Structural and stratigraphic correlations along the length of the belt are made difficult by the structural complexity of the allochthon, the sparsity of fossil remains and the penetrative effects of tectonic deformation and regional metamorphism. Sufficiently detailed studies have been made, however, in the regions of South Trøndelag (Trondheim district),[49,50,52] North Trøndelag (Grong–Gjersvik district)[40] and the geographically adjacent areas of Jämtland and Västerbotten in Sweden [81,82,83] to show that the stratiform ores of Skorovas, Joma, Stekenjokk, Løkken and Röros lie within the Köli Nappe, which is the upper

*UNESCO–IUGS International Geological Correlation Programme, project no. 60: Correlation of Caledonian stratabound sulphides. Norwegian–British contribution no. 1.

structural unit of the Seve–Köli Nappe complex first defined by Törnebohm.[68] The broad correlation within the Köli structural level can reasonably be carried into the Sulitjelma district of Nordland,[39,80] and in all probability this correlation can be extended into the ore district of Nord Troms.

It is clear that the separate districts that comprise the Ordovician province of stratiform pyritic ores lie at a broadly comparable structural level in the Caledonian allochthon of the Scandinavian peninsula, but there are significant differences in the stratigraphy and metamorphic grade of the host rocks from district to district. In general, the Ordovician host rocks comprise a varied assemblage of supracrustal volcanic and sedimentary rocks with closely associated plutonic masses of ultrabasic, basic and acid composition. The conspicuous quantity of basaltic to andesitic volcanics in the supracrustal sequences, taken together with their deformed and metamorphosed condition, ranging in grade from lower greenschist to almandine amphibolite facies, has led to the familiar use of the terms greenschist and greenstone in descriptions of the stratigraphy of various districts.[61] Goldschmidt[22] early lent authority to this usage by defining the 'Stamm der grünen Laven und Intrusivgesteine' as an important constituent rock kindred of the south and central parts of the Caledonian allochthon at the structural level now under discussion.



Eastern thrust boundary of the Caledonian allochthon

Eastern thrust boundary of Seve-Köli nappe or equivalent with metamorphosed sediments and eruptives of Cambrian-Silurian age

Basement inliers and culminations: Pre-Cambrian

Jotun nappes and related structures with allochthonous Pre-Cambrian rocks

Pre-Cambrian basement re-worked during the Caledonian orogeny

Helgeland, Rödingsfjäll, Beiarn and equivalent nappes with L. Palaeozoic rocks at higher metamorphic grades overlying the Seve-Köli nappe in N. Norway

Principal stratiform pyritic orebodies of volcanic affinity at the Köli structural level

Fig. 1 Synoptic geological map of Scandinavian Caledonides showing main districts of stratiform volcanogenic ores at Köli structural level

It is generally recognized that the stratiform pyritic orebodies have a close genetic relationship to the volcanic rocks with which they are associated[73] and that this relationship originated with the formation of tholeiitic and calc-alkaline eruptives at the margins of the Caledonian orogen in Ordovician times.[15,16,47,75] The genetic process that relates the ores and host rocks has been masked by the effects of metamorphic recrystallization and polyphase deformation, which affected both ores[73,74] and host rocks during the process of allochthonous tectonic emplacement consequent upon collision of the Scandinavian and Laurentian cratons during Middle Silurian times.[10,24] The palaeoenvironmental interpretation of the rock assemblages contained in the structural elements of the Köli nappe is clearly of the greatest importance in interpreting the genesis of the associated ores; in a region of the tectonic complexity displayed by the Caledonian allochthon, however, it is clear that the primary geological framework must be established by a study of the field relationships at a level of regional detail such that the ore deposits can be considered at the scale of the geological phenomenon responsible for their formation. If a volcanogenic origin is postulated, an understanding of the volcano-stratigraphy and structure in an area that extends from 1 to 10 km outside the orebody itself must be sought. This has been the basis on which the present study of the environment of the Skorovas deposit was undertaken.

Regional structural and stratigraphic setting

Existing knowledge of the major structural and stratigraphic units of the Grongfelt originated with the regional geological mapping undertaken by Statsgeolog Steinar Foslie[12,14] during the period 1922–27, the details of which were amplified and interpreted by T. Strand[14] and C. Oftedahl. More recent regional studies by Zachrisson[81] in the adjacent Swedish area of Jämtland and Västerbotten have given an idea of the succession of structural units within the Köli Nappe sequence between the Grong and Stekenjokk areas. A compilation from these sources is made in Fig. 2, which shows the main second-order tectonic divisions that have been recognized within the Köli level of the Seve–Köli nappe. Combining the terminologies of Foslie,[12] Oftedahl[41] and Zachrisson,[81] there are four divisions to be recognized. The first and uppermost of these is the Gjersvik Nappe, within which lie the Skorovas (Sk) and Gjersvik (Gj) orebodies. Below this lies the Leipik Nappe, within which, by extending the structural interpretation of Zachrisson, the Joma orebody (Jo) must lie. Below this lies the Gelvernokko Nappe and, finally, the Lower Köli Nappe unit, within which are situated the Stekenjokk orebodies (St) (the Stekenjokk malm and the Levimalm).[82]

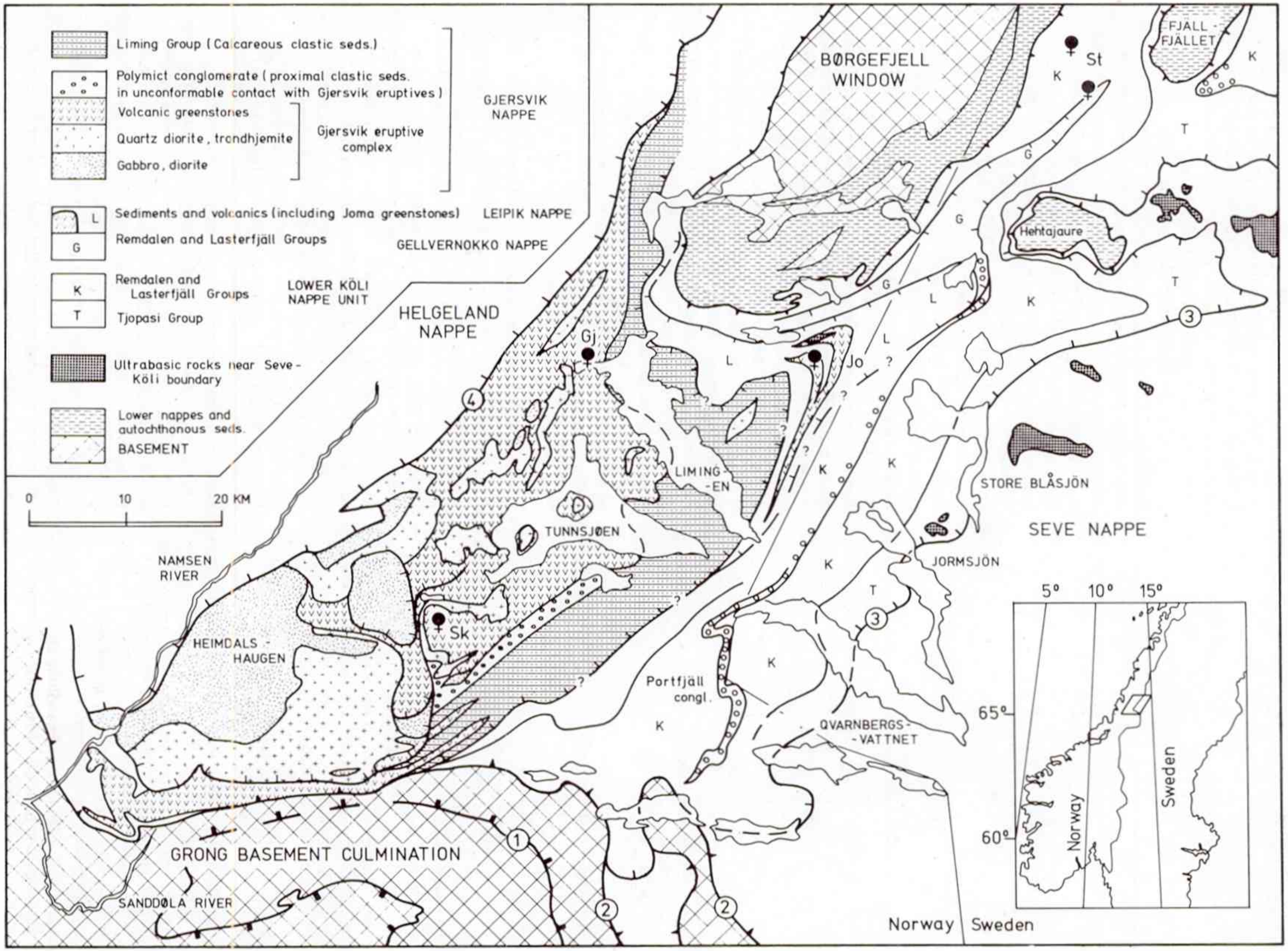


Fig. 2 Map showing location of main ore deposits in Grong–Stekenjokk district (Sk, Skorovas, Gj, Gjersvik, Jo, Joma and St. Stekenjokk) and main structural and stratigraphic units that can be distinguished within Köli Nappe. (1) Thrust at base of Olden basement nappe; (2) thrust at base of Seve–Köli Nappe; (3) thrust separating Seve and Köli sequences within Seve–Köli Nappe Complex; (4) thrust separating Gjersvik Nappe at top of Köli Nappe sequence from high-grade metamorphic rocks of Helgeland Nappe Complex. Boundaries based on geological information from Foslie, Oftedahl, Zachrisson, Gee and Gustavson

The broad classification into the second-order tectonic units shown in Fig. 2 provides a useful basis for descriptions of the regional geology, but the exact status of the second-order thrust boundaries is difficult to establish because these are taken, for the most part, to follow stratigraphic boundaries.[41,81] For the purpose of the present discussion, however, the precise location of the second-order structures and their relative tectonic status is less important than the plutonic and stratigraphic relationships preserved within the Gjersvik Nappe itself. In Fig. 2 the upper tectonic contact with the Helgeland Nappe [23] is clearly defined. The plutonic and supracrustal stratigraphy is revealed in the passage from southwest to northwest across the area of the map covering the Gjersvik Nappe. Without precise knowledge of the relative ages and finer lithological divisions of the various units the following sequence is conspicuous. Large masses of gabbro and granodiorite (trondhjemite) in the southwest are succeeded spatially to the northeast by the Gjersvik volcanic greenstone sequence with the contained orebodies at Skorovas and Gjersvik. A period of relative quiescence is indicated by the presence of a marble bed intermittently preserved at the uppermost level of the volcanic greenstone sequence. The marble is best preserved in the terrain north of the Limingen Lake, but a limited thickness is found to the NNE of Skorovas mine in the terrain to the south of Tunnsjøen. The volcanics with the overlying marble are followed by a spectacular polymict conglomerate, the typical aspect of which is shown in Fig. 12. The final part of the sequence is made up by the clastic sediments of the Limingen group, composed by a variety of schistose conglomeratic, sub-arkosic and phyllitic rocks, the majority of which are distinctly calcareous.

Oftedahl,[41] in his discussion of the nappe units of the Grongfelt, defined a thrust boundary of intermediate significance that separates the polymict conglomerate and the Limingen sequence of calcareous and conglomeratic metasediments, so that the Gjersvik Nappe, in its original definition, does not include the Limingen Group. It seems reasonable, however, to extend the compass of the Gjersvik Nappe to include the sediments of this group, which seem to be laterally related, in part, to the basal polymict conglomerate and to have derived most of their clastic components from the Gjersvik plutonics, greenstones and overlying limestones.

The rocks of the Gjersvik Nappe have, so far, yielded no fossil remains to give a basis for precise dating and correlation with stratigraphies in adjacent segments of the Seve–Köli Nappe. The volcanic and plutonic units of the Gjersvik eruptive complex do, however, bear certain similarities to the rocks of the Støren Group [72] in the Trondheim region. The Støren Group, locally, overlies schists of the Gula Group containing *Dictyonema flabelliforme.*[62] The contact between the two groups is, however, markedly tectonic [16] and, thus, the graptolite fossil evidence can only be used to suggest a possible maximum age of Upper Cambrian–Lower Ordovician (Tremadocian) for the Støren Group, and it is conceivable that the tholeiitic eruptive activity recorded in the Støren sequence [16] could have been initiated yet earlier in Cambrian time.

It has generally been proposed that the Gjersvik Group is of equivalent age to the Støren Group [45] and, by implication, that the two groups represent similar stages in the morphological and magmatic evolution of the Caledonian orogenic margin in central Scandinavia. Stratigraphic and geochemical evidence suggests, however, that the eruptive sequence of the Gjersvik Nappe is more evolved in terms of calc-alkaline character [16,47] – a matter that is given further consideration in a later section of this paper. Gale and Roberts have therefore suggested that the Gjersvik eruptives are of younger age than those of the Støren Group,[16] and a partial correlation, at least, with the andesitic greenstones of the Lower Hovin Group (Forbordfjell, Hølonda and equivalent greenstones)[53,72] seems reasonable. The age of the youngest Gjersvik eruptives therefore probably lies within the Arenig–Caradocian range, whereas the graptolitic fauna of the Bogo shale within the Lower Hovin Group, which overlies the Støren Group in the Trondheim region, is interpreted as belonging within the *Didymograptus hirundo* zone.[57] The Støren Group thus has a defined minimum age in the range Arenig to early Llanvirnian.

A further aspect of the stratigraphic correlation between the Lower and Middle Ordovician sequences in the Trondheim and Grong districts concerns the tectonic and stratigraphic status of various polymict conglomerate horizons that occur at intervals within the Lower and Upper Hovin Groups and, notably, that which overlies the Gjersvik eruptive sequence.

The widespread occurrence of conglomerates (Venna,

AGE	W TRONDHEIM REGION	
L SILURIAN (Llandoverian)	HORG GROUP	Hovin sst. Lyngestein quartzite cong (Horg Disturbance)
ORDOVICIAN: Ashgillian – Caradocian	UPPER HOVIN GROUP	Slate, greywacke Limestone Volla polymict cong. (Ekne Disturbance)
ORDOVICIAN: Caradocian – Arenig	LOWER HOVIN GROUP	Shale Rhyolitic tuff Sandst., shale, limest. Stokkvola polymict cong (Stokkvola Disturbance) Jonsvatn greenstone, Hølonda andesite Limest. Slate, sandst. Venna polymict cong (Trondheim Disturbance)
Arenig – Tremadocian – CAMBRIAN	STØREN GROUP	Tholeiitic eruptive greenstone sequence of basalts with gabbro intrusions and minor trondhjemite and quartz keratophyre
ORDOVICIAN – CAMBRIAN	GULA GROUP	Schists and quartzites with trondhjemite intrusions

GRONG - STEKENJOKK REGION	
LASTERFJALL GROUP	Basic - acid (quartz keratophyre) volcanics and tuffites, calc phyllites, limest Vojtja quartzite cong
RØYRVIK GROUP	Joma greenstone serpentine, calc phyllites, congl
?	
LIMINGEN GROUP	Calcareous phyllite, subarkose, greywacke ? — Havdalsvatn polymict cong (Gjersvik Disturbance)
GJERSVIK GROUP	Locally preserved limest (marble) Tholeiitic - calc alkaline eruptive greenstone sequence basalts, andesites, keratophyre/dacite with major intrusions of gabbro diorite and trondhjemite ?
	Mica schists etc (Gula Group - ? Seve equivalent)

Fig.3 Inferred stratigraphic correlation between Lower Palaeozoic sequences to south and north of Grong Culmination. Correlation is approximate and based on information from Vogt,[72] Zachrisson,[82] Oftedahl [45] and Roberts.[53] Tectonic disjunction within the two areas is shown schematically by oblique parallel lines

Lille Fundsjø and Steinkjer conglomerates)[53] at the base of the Lower Hovin Group, overlying the Støren Group, led Holtedahl [26] to propose a tectonic event of regional significance that he termed the Trondheim Disturbance. Further comparative studies of stratigraphy in the Trondheim region led to the recognition of similar polymict conglomerates at higher stratigraphic levels. Vogt [72] identified an Ekne (Caradocian) Disturbance and also movements in the Lower Silurian which produced the basal quartzite conglomerate of the Horg Group (Lyngestein Conglomerate), which identified a Horg Disturbance. Further work by Roberts [53] has suggested additional refinements to the chronology of uplift and erosion in the Trondheim District during the mid-Ordovician, a separate event in Mid-Lower Hovin times being marked at the level of the Stokkvola conglomerate.[53] Tectonic evolution in the Trondheim region in Lower to Middle Ordovician time was evidently punctuated by episodes of vertical uplift and erosion, the Trondheim Disturbance being but the first of these. The polymict conglomerate, which overlies the Gjersvik eruptives at the base of the Limingen sedimentary series, evidently records a disturbance of the Trondheim type, which, to avoid confusion, will be named the Gjersvik Disturbance. This disturbance is probably most closely related in age to the Stokkvola event.[53]

Fig. 3 shows the inferred general stratigraphic correlation between the Lower Palaeozoic sequences in the Grong and Trondheim regions. Zachrisson [82] has cited the faunal evidence in support of a (Lower ?) Silurian age for the Stekenjokk orebodies, which lie within the lower part of the sequence of basic to acid volcanic rocks composing the upper part of the Lasterfjäll Group (Fig. 2); this means that the rocks composing the Gjersvik, Leipik and Gelvernokko nappes and the upper parts of the Lower Köli Nappe have a probable age range from Lower Ordovician to Lower Silurian, matching the age range of the Trondheim Supergroup as defined by Gale and Roberts.[16] The Skorovas and Gjersvik ore deposits lie within the Gjersvik Group of volcanic greenstones and must be approximately Lower to Middle Ordovician in age. It is, however, interesting that in the Stekenjokk area, accepting the fossil evidence of Zachrisson, conditions suitable for the formation of stratiform pyritic ores also existed in Lower–Middle Silurian times.

Tectonic style within Skorovas area of Gjersvik Nappe

The programme of field mapping in the Skorovas area, with which the present writers have been actively involved since 1971, was designed to re-examine the major structural and lithological boundaries within the plutonic to volcanic sequence of the Gjersvik Group and to extend, as far as possible, the geological interpretations of Foslie and Oftedahl as they affect the Skorovas area. Mapping in the scale range of 1:2000 to 1:10 000 has also enabled the first serious attempt to delineate the principal lithologies within the volcanic sequence, which were uniformly designated as greenstones by Foslie [12] on the 1:100 000 scale map of the Trones quadrangle. The Skorovas area, as shown in Fig. 4, lies close to the eastern boundary of one of the main plutonic massifs of the Gjersvik Nappe. From Fig. 2 it is clear that the massifs have distinctly tectonic boundaries of low to intermediate angle (Fig. 6). The plutonic rocks within these boundaries frequently preserve their original igneous fabrics, little modified by the penetrative effects of tectonic deformation. The volcanic rocks and minor intrusives outside them, in contrast, generally show intense penetrative tectonic fabrics. The plutonic massifs all have tectonized envelopes and the intrusion of the complete range of basic to acid plutonic rocks evidently took place prior to the main tectonic event, which led to the emplacement of the Gjersvik Nappe within the allochthon and which was also responsible for the generation of major isoclinal folds and the early axial plane schistosity that is generally well developed within rocks of the volcanic sequence.

Because of gross differences in competence between the various rock types, notably between the plutonic masses and the supracrustal volcanic cover, this particularly heterogeneous style of deformation characterizes the intermediate level of the Gjersvik Nappe, the pattern being controlled, on the largest scale, by the form of the major gabbro, diorite and granodiorite bodies. Within the volcanic sequence itself, high-level doleritic dykes and sills, together with compact dacitic flows and their spilitized aphanitic equivalents, exert a more local influence.

In common with adjacent parts of the allochthon,[81,82] the history of regional deformation can be resolved in terms of two major stages, the first of which produced the principal Caledonian 'grain' of the terrain, creating isoclinal folds of the style illustrated in Fig. 5, and imposing the early schistosity mentioned above. It was during this stage that the main thrust and slide horizons that separate the plutonic and volcanic levels of the Gjersvik eruptive sequence were established. The plutonic bodies evidently behaved as massive tectonic wedges, piercing and, in part, overriding the superjacent volcanics to create the present pattern.

It should be emphasized that such planes of high tectonic strain also exist in several lesser orders within the volcanic sequence. These surfaces, as was noted above, are similarly formed at lithological boundaries, showing marked contrasts in competency, and can partly be explained in terms of componental movements along the thinned and extended limbs of isoclinal folds of the early basaltic lavas and pillow breccias. These rocks, under the influence of intense local strain, suffer a complete penetrative reorganization of their mineralogy to form chlorite–albite–epidote schists devoid of any earlier volcanic fabric. In the field the existence of these surfaces and the flattening produced in the adjacent units creates a peculiarly lenticulated style of deformation through which the early isoclinal fold pattern must be traced. The 'lenticulate style' appears to be a characteristic feature of highly deformed volcanostratigraphy and associated plutonics in other regions, notably in the Mauretanides of West Africa (G. Pouit, personal communication). Minor fold structures of the early generation are not conspicuously evident within the volcanostratigraphy and are best observed in the finely stratified tuff bands and associated cherts and iron-rich chlorite schists of the exhalite facies (Fig. 7(*a*)). They can also be mapped over several tens of metres by following coherent chert horizons, acid tuff bands and dykes, and thence into the larger isoclines of the type illustrated in Fig. 5.

The configuration of these larger isoclines, taken together with the stratigraphic and structural evidence provided by the mapping of the surface of unconformity separating the eruptive sequence and the conglomerate series, demonstrates, at the present level of erosion, that the volcanic sequence in the Skorovas district lies inverted within the lower limb of a major southeast-facing fold, the identity of which can be broadly equated with the Gjersvik Nappe.

The second stage of deformation, superimposed on the grain of the early isoclines and schistosity, has created an open system of broad folds, which have resulted in an irregular pattern of dome and basin structures, the major axes of which evidently bear a relationship to the contacts of the plutonic massifs lying to the west and north (Figs. 2 and 4(*a*)). The formation of the open dome and basin structures is accompanied by further movements along the low-angle planes generated during the first stage of deformation. These movements led to the creation of minor folds and a second-stage crenulation cleavage, which is typically local and specifically associated with these horizons of high strain. The scale of the phenomenon is variable and Fig. 7(*b*)) shows part of the well-developed belt of second-stage folding in the volcanic sequence at the southwestern margin of the Grøndalsfjell massif. The vergence of the axial planes of these and other similar late folds implies that the principal tectonic stress responsible for this deformation was imposed from a west to northwest direction.

The deformation history can be interpreted in the following way. (1) Creation of the nappe, isoclinal folds and the early schistose fabric, together with the several orders of internal thrust horizons, was a consequence of the stresses imposed during the main stage of emplacement of the allochthon during Mid-Silurian times. (2) The second generation of tectonic structures is considered to have been imposed upon the first as a consequence of equilibration between the depressed Scandinavian basement and the imposed load of the allochthon. The depression of the granitic basement into a field of higher temperature and pressure can have given rise to plasticity of the basement, enabling local isostatic adjustments to take place by the initiation of a system of domes and basins in the basement. The second fold phase in the Skorovas region is interpreted as a consequence of forces imposed on the volcanic sequence by the massive plutonic bodies as they slid under the influence of gravity in an east to northeast direction from the flanks of a basement dome in the vicinity of the Grong culmination.

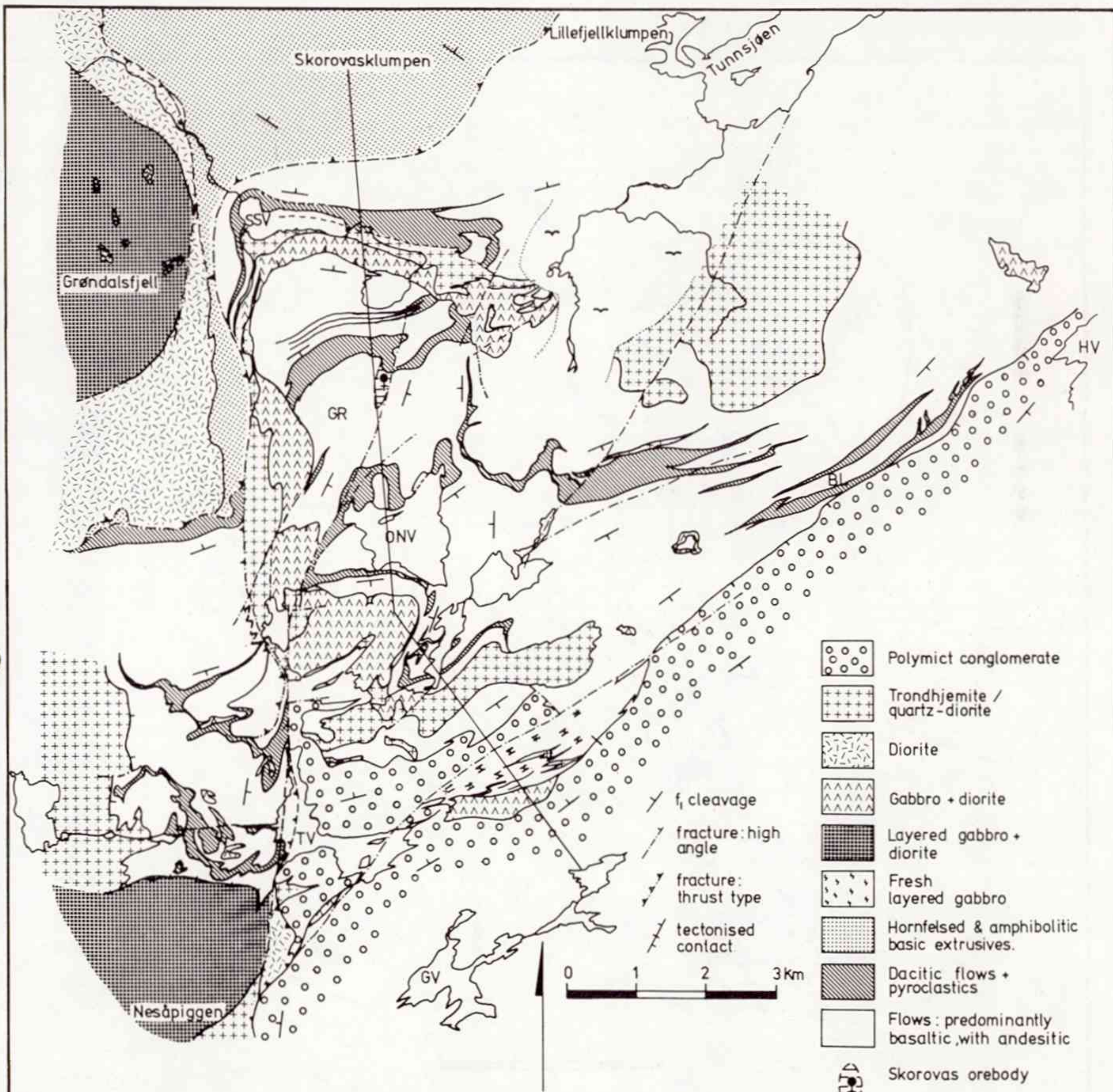


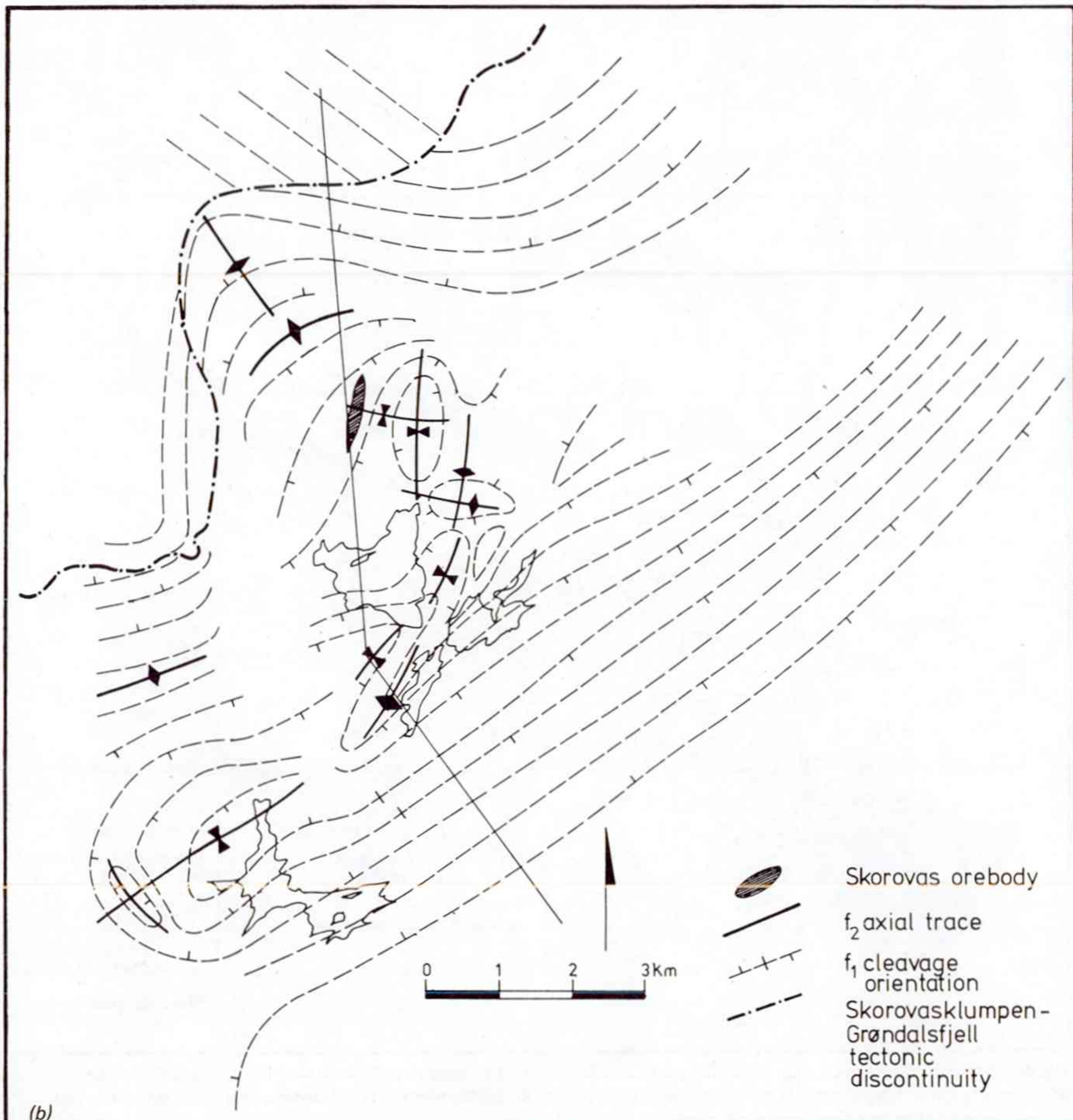
Fig. 4 Simplified geological map (*a*) of Skorovas area with line of section (Fig. 5) indicated (SSV, Store Skorovatn; GR. Grubefjellet; ONV, Øverste Nesåvatnet; TV, Tredjevatnet; BI, Blåhammeren; HV, Havdalsvatnet) and synoptic map (*b*) (see page 134) of principal structural trends

In addition to the fold and low- to intermediate-angle thrust structures created during the first two periods of folding, the topography and geology of the Skorovas area has been strongly influenced by the formation of a complex system of high-angle faults and fractures. For the most part these have suffered small displacement of the order of metres, but along the southwest contact of the Gjersvik eruptive complex with the polymict conglomerate oblique slip normal faulting has resulted in a vertical displacement of the order of 500 m (Figs. 4(*a*) and 5). The trend of these fractures is predominantly in a NNE to northeast direction and their formation post-dates the main periods of folding in the area. The late fracture patterns in the Skorovas area remain a problem for future investigation. In all probability they can be attributed to the final stages of Caledonian tectonism, but the influence of later events, such as basement reactivation during Mesozoic rifting, cannot be discounted.

Plutonic members of Gjersvik eruptive sequence in Skorovas area

On the 1:100 000 scale map of the Trones quadrangle compiled from the work of Foslie [12] the plutonic rocks of the Skorovas area occur in two groups. The first group comprises the tectonically bounded massifs of Grøndalsfjell and Nesåpiggen, which, though they have strongly tectonized envelopes, preserve much of their original igneous fabric in the interior. The second group occurs as an arcuate belt lying within the volcanic succession to the north, west and south of the Skorovas ore deposit (Fig. 4(*a*)). The plutonic rocks of this belt have been subjected to the penetrative deformation that affected the enclosing volcanic rocks and have responded tectonically as part of the volcanic level during deformation.

The plutonic rocks of the Skorovas area were divided by Foslie into two principal compositional groupings, as shown in the map of the Trones quadrangle.[12] Gabbros



(*b*)

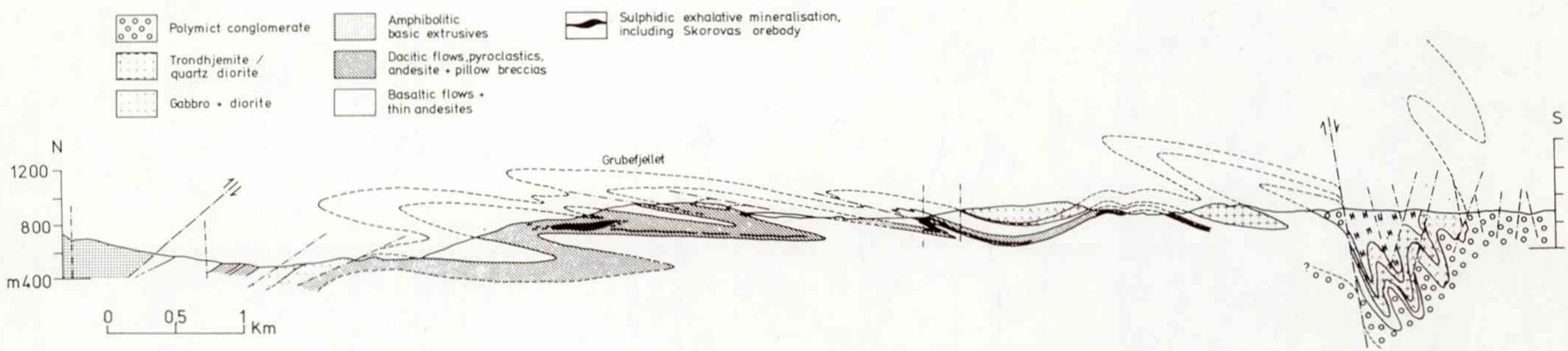


Fig. 5 Simplified geological section through Skorovas area

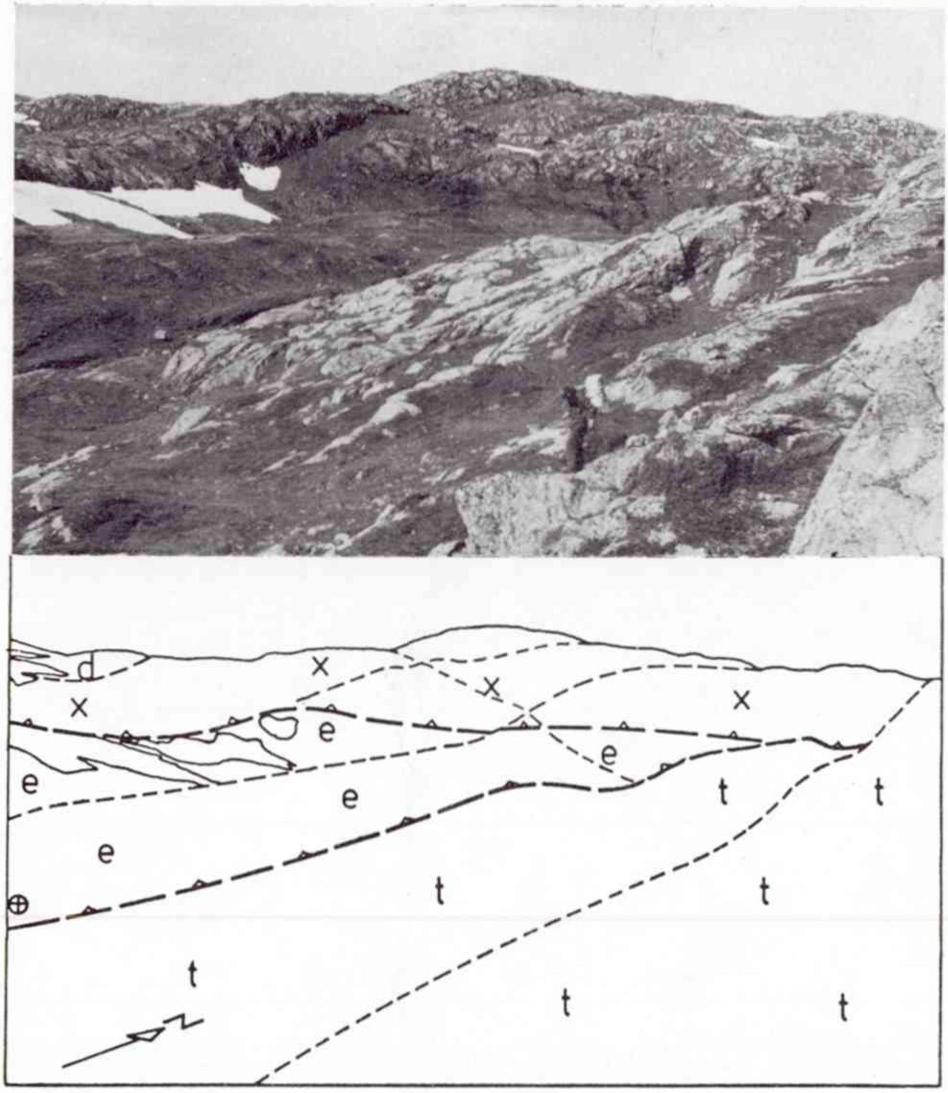


Fig. 6 Panoramic view of southeast margin of Grøndalsfjell massif seen from point of vantage on trondhjemite intrusive of Skorovas intrusive arc. Major thrust horizon separates diorite and gabbro (d) together with hornfelsed envelope (x) from structurally underlying schistose extrusives (e). A further thrust separates extrusives from trondhjemite (t) in foreground. Location of photograph (Fig. 7 (*b*)) shown by crossed circle at far left of vista

of various facies were distinguished and at the opposite end of the compositional scale trondhjemite, tectonized granite and granitic dykes and sills were also shown. There is no reference on the map to the occurrence of intermediate dioritic rocks in the immediate area of Skorovas, although Foslie was undoubtedly aware of their existence because diorites are mapped as a thin border zone to the north of the Grøndalsfjell massif and to the west of Heimdalshaugen. The detailed mapping carried out by the present writers has shown that dioritic rocks of intermediate composition form an important component in the plutonic sequence and that a definite relative chronology of intrusion can be recognized.

It has already been noted that the plutonic sequences in the Grøndalsfjell and Nesåpiggen massifs and the plutonic bodies that compose the arcuate intrusive belt (Fig. 4) are tectonically separated, and it is convenient to discuss their plutonic histories separately.

Grøndalsfjell massif

The starkly exposed rocks that compose the Grøndalsfjell massif provide spectacular evidence of their relative ages. The earliest intrusives are fresh layered olivine gabbros, which occur as large xenolithic masses or rafts with maximum dimensions of the order of 70 m x 200 m, contained in a matrix of metamorphosed gabbro and hornblende diorite. The cumulus layering of the gabbro bodies is sub-vertical in attitude with a predominantly east–west trend. This must be accepted as evidence of significant post-cumulus displacement.

The composition of the layered gabbro varies from troctolite to hypersthene gabbro and in all facies hypersthene occurs, either as a reaction rim around olivine or as independent ophitic grains. The mineralogy of the gabbro is thus compatible with crystallization from a tholeiitic magma.[25,67]

The nature of the xenolithic relationship is shown in Fig. 8(*a*), and it is clear that the hornblende diorite is a major component of the Grøndalsfjell massif. The peripheral contacts of the fresh layered gabbro with the diorite display a distinctive pattern of retrograde alteration, which partly follows the primary igneous layering and partly exploits crosscutting joints to produce a distinctive weathered surface (Fig. 8(*b*)). The alteration leads to the uralitization and chloritization of the augite and hypersthene, the serpentinization of the olivine and saussuritic degradation of the calcic plagioclase to produce albite, epidote, clinozoisite and calcite. In the troctolitic facies of the gabbro the growth of considerable quantities of chlorite within the plagioclase accompanies this breakdown. The alteration is ascribed to the contribution of water from the dioritic magma, which led to a retrograde subsolidus hydration in the pre-existing mass of layered gabbro.

The various facies of altered gabbro may extend for a considerable distance beyond the boundaries of the fresh layered rocks, and the distinction between altered gabbro and hornblende diorite is made in the field on the basis of the persistence of fluxion banding and layered structure within the surrounding aureole of hydration. The hornblende diorite is characteristically composed of subhedral dark green grains of hornblende together with saussuritized plagioclase of intermediate composition and accessory Fe–Ti oxides. The iron oxides are frequently altered to sphene and the hornblende is generally partly chloritized.

One of the most striking features of the hornblende diorite is the occurrence of coarse patches and pegmatoidal veins, 0.5–3 m wide, consisting of euhedral hornblendes, commonly up to 10 cm in length, set in a matrix of andesine feldspar together with accessory amounts of magnetite and pyrite. The pegmatoid veins show rhythmic banding parallel to their contacts. This can be interpreted as a result of episodic deuteric crystallization from hydrous fluids circulating within the largely consolidated dioritic body. These rocks can be justifiably described as appinites, and their presence implies that the level of exposure seen in the eastern margin of the Grøndalsfjell massif corresponds to the upper portion of a differentiated dioritic body.[25,78]

At the margins of the hornblende diorite, close to the contact of the plutonic mass with the enclosing greenstones, a quartz-diorite facies occurs locally.

At least two generations of impersistent basic dykes cut both the gabbro and the diorite with its appinitic facies. The dykes are thin, usually less than 20 cm in width, and have a northeastery trend with steep dips to the northwest. They are composed of fine-grained hornblende and plagioclase, together with minor iron oxides, and are locally porphyritic with plagioclase crystals up to 7 mm long.

The final eruptive event within the Grøndalsfjell complex was the emplacement of a swarm of leucocratic porphyritic granodiorite dykes, which show a predominantly northeasterly trend and dip steeply to the northwest. The dykes are commonly 1–2 m thick and can be followed for distances of 1–2 km before they pinch out. Close to the margins of the plutonic mass, and also within it, these dykes show well-developed tectonic foliation and, locally, mylonitic facies, which demonstrates that the northeast-trending fracture system has been the focus of significant post-intrusion tectonic strain. The granodiorite dykes are composed dominantly of sodic plagioclase (roughly of

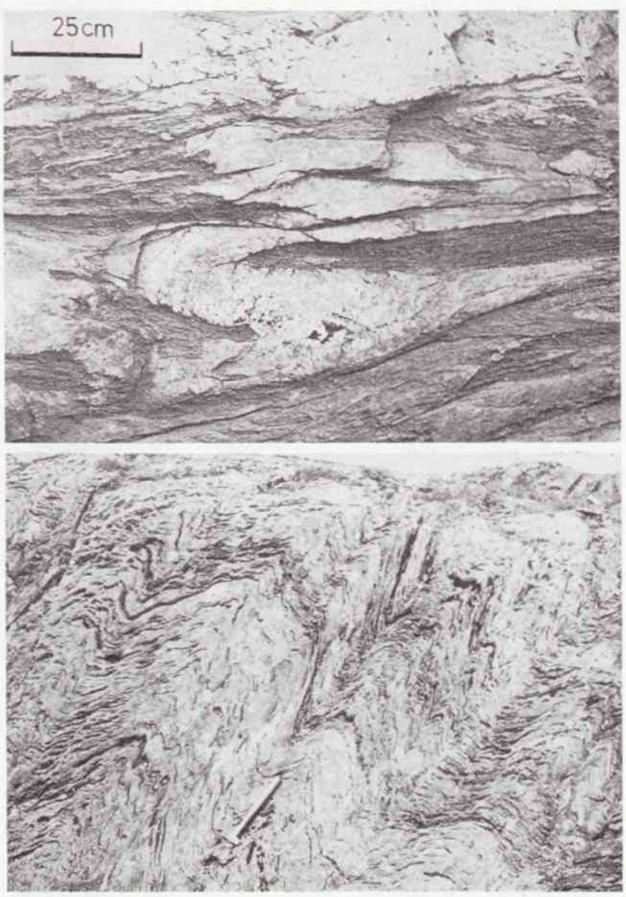


Fig. 7 Typical dislocated isoclinal style seen in minor folds of first generation in chert bands to south of Nesåklumpen (*a*) (top) and (*b*) localized post-schistosity folding and incipient crenulation cleavage of second generation formed in zone of high strain in schistose greenstones adjacent to tectonic boundary of Grøndalsfjell massif. Location of photograph is shown in caption to Fig. 6

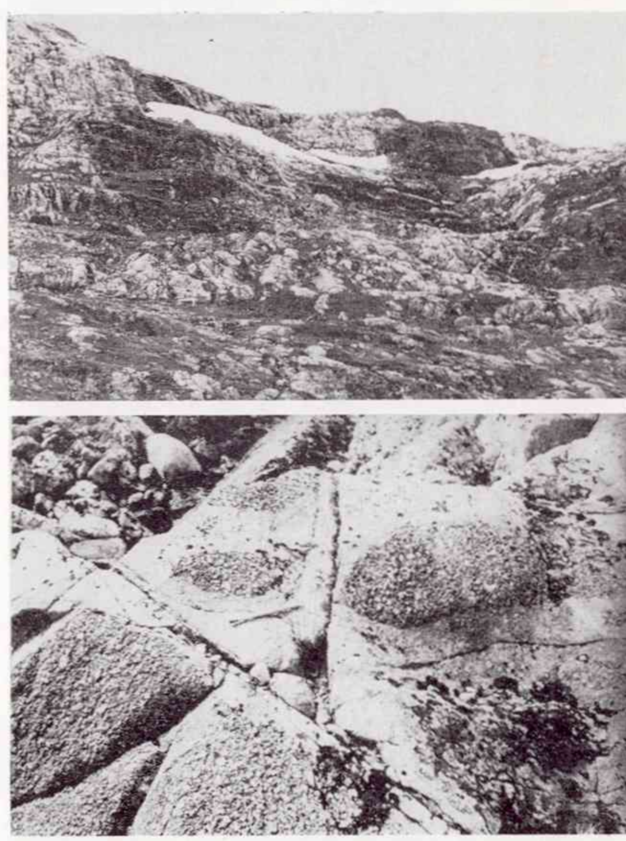


Fig. 8 Northeast face of Grøndalsfjell massif displaying occurrence of rafts of unaltered layered gabbro (dark) within dioritic matrix (*a*) (top) (rafts are of the order of 60–100 m x 200 m) and (*b*) field appearance of hydrated, uralitized envelope that borders large xenolithic masses of fresh layered gabbro on Grøndalsfjell (Fig. 8(*a*). Troctolitic gabbro shows strong differential weathering of pyroxene, feldspar and olivine, producing pitted surface. Uralitized assemblage weathers uniformly by comparison

oligoclase composition), quartz and accessory microcline, biotite, hornblende and sphene. The ferromagnesian minerals are generally partly chloritized and the feldspars have been variably altered to fine micaceous aggregates (sericite or paragonite). Because of the modal composition of these dykes, which is dominantly oligoclase together with quartz and with only accessory amounts of potash feldspar, the rocks may properly be described as trondhjemite in the sense of the definition applied by Goldschmidt in 1916.[22]

This summary of the igneous relationships preserved within the plutonic massif of Grøndalsfjell shows clearly that a considerable volume of dioritic magma was emplaced, probably at an intermediate to high crustal level, evidently by invading a pre-existing mass of layered gabbro, which is the oldest and presumably the deepest representative of the plutonic assemblage in the Skorovas area. It may be added that magmatism must also have been bimodal – that is to say that the magmas were supplied from two genetically different sources, the first tholeiitic and the second calc-alkaline. A range of similar igneous relationships occurs in the Nesåpiggen massif to the south (Fig. 4).

In addition to the main gabbro-diorite body of the Grøndalsfjell massif delineated by Foslie on the map of the Trones quadrangle, a significant mass of 'fine-grained gabbro' is also shown lying directly to the north of Skorovatn. This forms the imposing topographic feature of Skorovasklumpen in the basal slope of which lies the extension of the main thrust surface, which is interpreted as separating the tectonically 'massive' plutonic level from the highly deformed volcanic level. This feature is shown on the geological map of the Skorovas area and in the accompanying structural synthesis (Fig. 4). Investigation has shown that Skorovasklumpen and the narrow belt of similar character that can be followed along the eastern margin of the Grøndalsfjell massif are composed predominantly of metamorphosed basic volcanic rocks, together with interbands of acid (dacitic-keratophyric) composition and a proportion of high-level basic intrusive material. The basic rocks of the belt adjacent to the Grøndalsfjell massif are partly incorporated in a xenolithic screen of considerable complexity. The original igneous contact of the diorite with the volcanic country rocks is preserved intact within the main tectonic boundary (Fig. 4(*a*)) and can be mapped over a distance of 4 km. Original volcanic structures, notably pillow forms and vesicles, are preserved within xenolithic masses and testify to the volcanic origin of the country rocks. Similar textural evidence of volcanic origin has been found within the basic sequence that composes Skorovasklumpen.

The reason for the classification of the rocks of Skorovasklumpen as fine-grained gabbros by Foslie [12] and other workers lies in their amphibolitic metamorphic grade, which has produced a mineralogy dominated by hornblende and intermediate to calcic plagioclase. The presence of epidote as a constituent mineral throughout a significant part of the amphibolitic sequence implies that these higher-grade rocks span the epidote amphibolite facies to enter the field of amphibolite facies. Since there is no association with pelitic rocks, a precise description of the prograde regional metamorphism of the basic rocks of the Skorovas area depends chiefly upon a determination of the progressive changes in the composition of the hornblende and plagioclase, which must await further detailed work. Broadly, however, the mineral assemblages accord with the sequences regarded by Miyashiro [31,32,36] as typical for the regional metamorphism of mafic rocks at low to intermediate pressure.

One of the conspicuous features of the mineralogy of the amphibolite facies rocks of Skorovasklumpen is that pyrrhotite replaces pyrite as the accessory iron sulphide – an observation that is readily made in the field. The amphibolitic lavas locally display distinct pentrative tectonic lineation of the amphiboles, and this lineation can be observed in the amphibolitized volcanic xenoliths in the diorite. Amphibolite grade metamorphism evidently took place under the influence of early tectonic stresses with which the emplacement of the gabbro-diorite massif was partly synchronous. The establishment of a precise chronology for these events will depend upon the evidence provided by future detailed petrographic work. It is probable, however, that the contact aureole of the Grøndalsfjell massif and the amphibolitic rocks of Skorovasklumpen compose a continuum within the field of low to intermediate pressure in which regional and contact metamorphism converge.[34]

Rocks of the arcuate intrusive belt

The intrusive arc differs from the plutonic massif of Grøndalsfjell in three distinctive ways: (1) no unmetamorphosed gabbroic bodies have been found in which a plagioclase–pyroxene–olivine assemblage is preserved; (2) penetrative deformation has produced distinctly tectonic fabrics throughout most of the arc and mineral assemblages are reduced, for the most part, to those stable within the greenschist facies; and (3) quartz-rich dioritic to granodioritic rocks compose a large part of the complex and the eastern extremity of the arc joins a large granodiorite mass to the south of Tunnsjøen (see Fig. 4(*a*)).

Apart from these significant differences, which can probably be explained in terms of the higher level of emplacement of the arc complex within the volcanic sequence, the relative chronology of intrusive episodes in the arc is the same as that observed in the Grøndalsfjell massif. The most basic rocks are the oldest and the successively younger intrusions become increasingly silicic.

The degree of deformation within the plutonic arc is often extreme; but, locally, the original geometry of intrusion is preserved as shown in Fig. 9. The range of compositions present in the rocks of the arc is very wide and includes hornblende gabbro, diorite and granodiorite (trondhjemite). The definition of the petrographic character of each generation is complicated by the incorporation of xenoliths of earlier basic volcanic and plutonic rocks as well as by extreme deformation, local silicification and reduction of the primary minerals to greenschist assemblages.

Fig. 9 Trondhjemitic net veining in mafic diorite and hornblende gabbro on southwest Grubefjell

It is sufficient for the purposes of the present discussion to confirm the presence of gabbro, diorite and trondhjemitic granodiorite as components of the arc and to suggest that these are, in part, equivalent to the plutonic complex observed in the Grøndalsfjell massif. Prior to the major stages of Caledonian deformation leading to the allochthonous emplacement of the Gjersvik Nappe, it is assumed that the rocks of the intrusive arc and those of Grøndalsfjell were part of the same complex plutonic continuum.

Volcanic rocks of Gjersvik eruptive sequence in Skorovas area and their metamorphic condition

The volcanic rocks of the Gjersvik eruptive complex are of geological and economic interest for they are the host rocks of the Skorovas deposit. The volcanic succession has suffered extremely from the effects of deformation and low-grade metamorphism under conditions of the greenschist facies. These modifications, together with the primary complexity of the volcanostratigraphy, have been obstacles to the systematic mapping of the greenstones.

It has long been recognized that the Gjersvik greenstones are composed of a sequence of basic to acid rocks, including basalts, andesites and keratophyres of distinctly spilitic affinity.[21,41] Because of the confinement of systematic geological studies to the immediate vicinity of the Skorovas mine itself, previous summaries of the volcanic stratigraphy have been limited. During the present study an attempt has been made to document the range of primary volcanic structures that can be observed at the macroscopic scale within the acid and basic members of the stratigraphy and to examine their geometry with respect to metamorphism and deformation.

It is difficult to assess the relative volumes of basic and acid rocks within the volcanic sequence, but it can be said with confidence on the basis of regional mapping that, in the general area of Skorovas, the dominant volcanic rock types are basalts and basaltic andesities with lesser amounts of andesitic and keratophyric rocks. This fact is apparent from the relative outcrop of acid and basic rocks shown in Fig. 4(*a*), although this can only be treated as an approximate guide. Because of the deformed and dislocated condition of the sequence and the present level of erosion, the maximum thickness of volcanics is difficult to assess. A reasonable estimate based on constructed geological sections, taking into account the effects of tectonic flattening and extension, can be given as 3–4 km.

The sedimentary component within the pile is limited to very thin, but stratigraphically persistent, iron- and silica-enriched beds produced as a result of chemical dispersion during volcanic activity. Banded calcareous greenschists, which have been considered by previous writers to be of sedimentary origin, can be explained as tectonic facies originating from metamorphosed and flattened basic flow units.

The primary mineralogy of all the rocks in the volcanic succession has been degraded to assemblages of the greenschist facies. Textural evidence shows that the creation of the greenschist facies assemblages took place during two episodes, the first of which was prior to the first stage of penetrative tectonic deformation. The evidence confirming this metamorphic chronology is best preserved within the basic members of the sequence.

Basaltic and andesitic lavas

The state of deformation of the basaltic rocks varies according to their position with relation to the early isoclinal folding, the numerous lower-order thrust horizons and adjacent competent flow units or intrusives. It is possible, however, in the vicinity of Skorovas, to observe pillowed sequences in which the original geometries are nearly preserved, as shown in Fig. 10. The dimensions of pillows are variable, but diameters within the range 0.5–2 m are typical. In addition to pillowed basaltic flow units, there is a significant volume of deformed meta-hyaloclastite pillow breccia associated with the basaltic unit, which structurally overlies the orebody (see Fig. 17). The pillow breccia lithology is locally transitional to tuffaceous and agglomeratic basic pyroclastic facies and can be traced within a radius of 3 km around the orebody.

The abundance of amygdales, ranging in size from 2 to 10 mm and, exceptionally, reaching sizes of 5 cm, indicates that the lavas were erupted at relatively shallow depths, probably of the order of 100–500 m.[29,37] The primary mineralogy has been completely replaced or pseudomorphed by assemblages composed of chlorite, albite, epidote, actinolite, calcite and sphene. Stilpnomelane, regarded by Miyashiro [36] as atypical of low- to medium-pressure

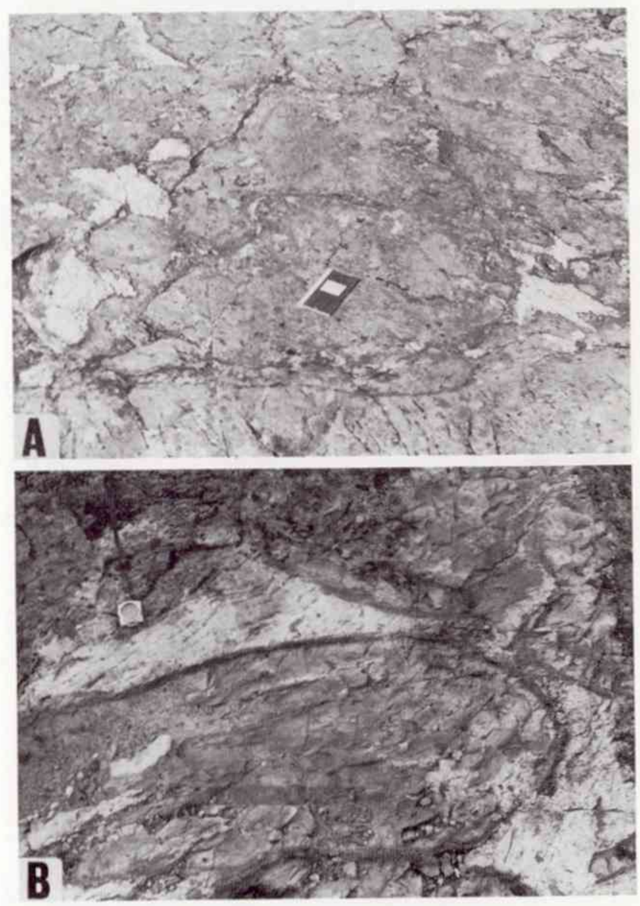


Fig. 10 *A,* Deformed basaltic pillow lavas observed on northern slopes of Grubefjell below orebody. Cuspate bodies of grey chert that occupy interstices between pillows are conspicuous. In cases of extreme deformation survival of these chert bodies within chloritic schist provides a useful guide to original volcanic structure of rocks.
B, Basaltic pillows from flow exposed on southwest shore of Tredjevatnet. Eruption of pillowed basalts followed deposition of a dispersed exhalite horizon in vicinity of Tredjevatnet centre. Layer of ferruginous silica gel, disturbed during eruption of the basalts, formed a jasper matrix for the pillows. Chloritized chilled margin of pillows is conspicuous. Significant amounts of pyrite are also found in association with jasper pillow matrix, the pillow lavas lying stratigraphically but a few metres from horizon of massive pyrite

regional metamorphic assemblages, is a conspicuous component of the basaltic andesites in the mine area. This can probably be explained in terms of the iron enrichment shown by these rocks (analysis 3, Table 1). Stilpnomelane, in common with the other greenschist minerals, occurs dispersed throughout the body of the rock and also as monomineralic fillings in amygdales and in crosscutting veinlets. The dominant mineralogy of the amygdales within the pillowed basalts varies widely. Combinations of two of the common greenschist mineral species are usual, involving quartz, epidote, calcite, chlorite, albite and pyrite. Actinolite is not usually found in amygdales. Within certain parts of the Skorovas area the dimensions of the amygdales and their mineralogy have been useful in discriminating between individual flow units, although amygdale mineralogy certainly cannot be applied as a universally reliable criterion of stratigraphy.

Within the more massive andesitic and basaltic rocks, original flow textures are preserved by the orientation of the altered plagioclase microlites. Augite phenocrysts are pseudomorphed by actinolite and chlorite and the accessory iron–titanium oxides are largely replaced by sphene. The basalts are not conspicuously porphyritic and igneous textures are frequently concealed in the meshwork of fine actinolite, chlorite, epidote–clinozoisite and albite into which the rocks have been transformed.

The effects of greenschist metamorphism are not only apparent at the micro scale but are also demonstrated by the gross redistribution of the rock components, which has produced massive bands and lenticular knots and spheroidal bodies, the mineralogy of which is predominantly epidote with lesser amounts of albite, quartz, etc. These bodies with dimensions of the order of tens of centimetres are arranged parallel to the surfaces of the pillow structures or as discontinuous layers parallel to flow surfaces within massive basalts and basaltic andesites. The typical form of these bodies is shown in Fig. 11.

The epidote-rich segregations are evidently pre-tectonic. During the first period of penetrative deformation the chloritic mass of the pillowed basalts has tended to develop a good schistose fabric and the geometry of the pillows, as a whole, has become flattened to varying degrees. The epidote layers have behaved as competent bodies and have deformed by brittle fracturing; in extreme cases the epidote bodies are preserved as cataclastically reduced streaks and boudins within the highly flattened pillows. The textural evidence clearly demonstrates that an important episode of greenschist metamorphism was responsible for pervasive alteration and gross reorganization of the mineralogy of the basic rocks prior to the tectonic event responsible for the early penetrative schistosity in the Skorovas region.

Deformation of the volcanic pile also took place under conditions of the lower greenschist facies and the mineralogy established during the primary metamorphic episode was not changed, but tectonic facies were produced as a result of further redistribution and segregation of the various mineral species.

The metamorphic alteration that took place in the earliest event prior to the deformation of the rocks can be

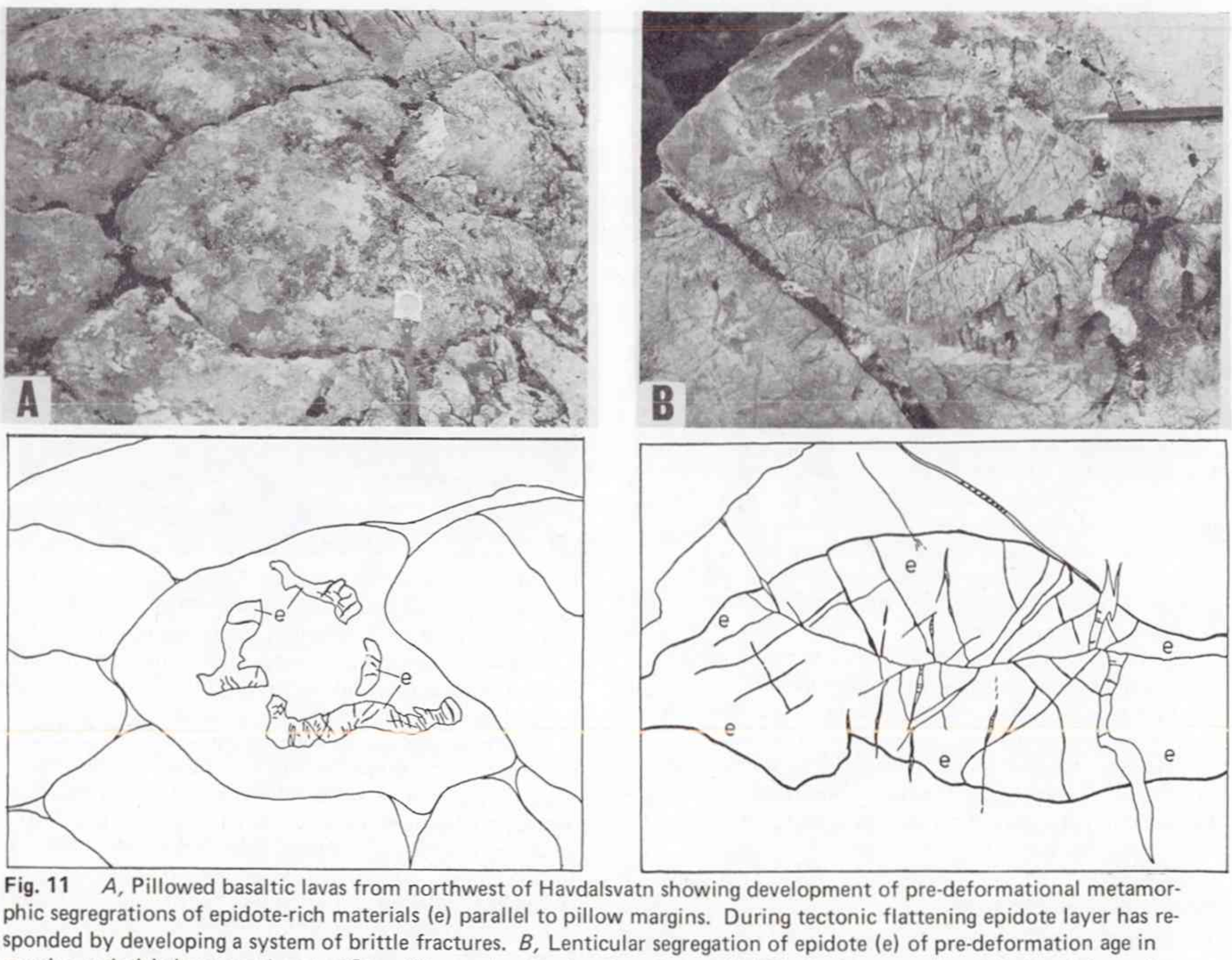


Fig. 11 *A,* Pillowed basaltic lavas from northwest of Havdalsvatn showing development of pre-deformational metamorphic segregrations of epidote-rich materials (e) parallel to pillow margins. During tectonic flattening epidote layer has responded by developing a system of brittle fractures. *B,* Lenticular segregation of epidote (e) of pre-deformation age in massive andesitic lavas southeast of Store Skorovatn. Conjugate pattern of brittle fractures produced during deformation of competent lenses is explicitly developed, as in generation of dilatant fractures filled with quartz, chlorite and carbonate

Table 1 Whole-rock analyses of Skorovas volcanics. Analyses (1–9) with average values of ocean-floor basalt (10; Cann[4]) and island arc tholeiite (11, Pearce and Cann[46]) for comparison. 1, Porphyritic quartz keratophyre, Grubefjell; 2, quartz keratophyre, Grubefjell; 3, andesite with stilpnomelane, Grubefjell; 4, andesite, Grubefjell; 5, andesitic clasts in agglomerate, Grubefjell; 6, pillowed basalt, Grubefjell; 7, pillowed basalt, Grubefjell; 8, basalt, 6 km southwest of Grubefjell; 9, basalt, northeast Øverste Nesåvatn

%	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
SiO_2	72.23	70.39	53.07	59.34	56.12	50.15	49.30	48.99	50.13	49.61	52.86
Al_2O_3	11.82	12.27	14.13	15.40	12.20	13.70	13.81	16.55	14.76	16.01	16.80
TiO_2	0.80	0.27	0.77	1.06	0.96	1.54	1.89	1.30	1.24	1.43	0.83
Fe_2O_3	2.14	3.37	6.48	3.49	3.31	3.31	+	+	+	+	+
FeO	1.28	0.44	6.62	6.01	6.44	7.78	14.70*	13.97*	14.95*	+	+
MnO	0.03	0.01	0.19	0.23	0.11	0.16	0.21	0.17	0.15	0.18	+
MgO	0.36	0.45	4.40	2.68	4.70	4.70	5.49	5.74	6.00	7.84	6.06
CaO	1.27	0.24	4.66	2.38	4.44	4.89	4.92	5.33	3.50	11.32	10.52
Na_2O	7.50	8.00	5.21	7.50	6.25	8.81	6.47	6.88	7.30	2.76	2.08
K_2O	0.07	0.02	0.51	0.19	0.02	0.52	0.43	0.66	0.55	0.22	0.44
P_2O_5	0.24	0.03	0.10	0.18	0.12	0.17	0.11	0.06	0.03	0.14	+
Loss on ignition	1.06	2.24	1.90	2.24	3.57	2.81					
Total Fe as Fe_2O_3	3.56	3.86	13.83	10.17	10.46	11.95	+	+	+	12.63	11.45
Total	98.90	99.49	98.04	100.70	98.24	98.54	99.54	99.64	98.24		

* Total Fe as FeO.
\+ Value not obtained by analytical method used.

ascribed to contemporaneous alteration of the volcanic rocks *in situ* as a result of the thermally driven circulation of sea water in the upper layers of the lava pile close to the site of eruption on the Ordovician sea-floor. Considerable evidence has accumulated in recent years to show that *in-situ* alteration of the mineralogy of submarine basalts to produce assemblages of greenschist and lower amphibolite facies is a phenomenon of wide occurrence within the upper layers of the sea-floor.[33,35] Humphris [27] recognized that the metamorphic assemblages in recent submarine basalts from the Mid-Atlantic Ridge can be divided into chlorite-dominated and epidote-dominated types. It is suspected that this division reflects a process of metamorphic segregation similar to that seen in the basalts of the Gjersvik sequence.

The *in-situ* hydrothermal alteration processes evidently involve the convective circulation of large volumes of sea water relative to the altered rock. Water : rock ratios of the order of $> 10^4$:1 were calculated by Spooner and Fyfe [59] and the alteration process is believed to extend to a depth of at least 2 km within the lava pile.[59,60]

The *in-situ* sea-floor metamorphism of the Gjersvik volcanic sequence was evidently an important event and, as well as causing gross mineralogical changes by chemical redistribution within the scale of individual flow units, bulk changes in the chemical composition of the lavas also occurred, leading to the conspicuously spilitic chemistries shown by the analysis in Table 1.

The recognition of the pervasive pre-deformation *in-situ* sea-floor metamorphism of the Gjersvik basalts also helps to resolve the controversy that surrounds the tectonic status of disturbances of the Trondheim type.[11,51,55] The polymict conglomerate that unconformably overlies the volcanic sequence was formed prior to deformation and allochthonous transport of the Gjersvik Nappe. This is easily demonstrated on a local scale by the pervasive schistose fabric of the matrix and the distinctive stretching of the competent clasts parallel to the axes of the early isoclinal folds (Fig. 12(*A*)). It can also be demonstrated on a regional scale by mapping the level of unconformity through the isoclinal folds of the first deformation (see Fig. 5).

The conglomerate is composed of boulders directly derived from the plutonic and volcanic sequence that underlies it. Locally, the composition is dominated by marble clasts with associated pebbles of jasper, and in other places the clast population is dominated by boulders of phaneritic granodiorite (trondhjemite), diorite, meta-gabbro and various of the resistant volcanic rocks. Pebbles of keratophyre are common, but of greatest interest are the pebbles of the metamorphic epidote assemblage (Fig. 12(*B*)), which have evidently been derived by erosion of the metamorphosed basalts.

Final and conclusive evidence is thus provided for a Lower–Middle Ordovician metamorphic event pre-dating the Gjersvik Disturbance. The metamorphism was produced by the thermal and hydrothermal effects associated with the contemporaneous eruptive activity embodied in the Gjersvik Nappe. The tectonic movements involved in the formation of the polymict conglomerate were predominately vertical as opposed to lateral and must have been related to an early stage of tectonic evolution within the belt of Lower–Middle Ordovician eruptives of which the Gjersvik Complex was a part.

The status of a possible metamorphic event pre-dating the Trondheim Disturbance has been discussed elsewhere.[11,65] Further investigation will probably reveal the ubiquity of sea-floor-hydrothermal metamorphic assemblages as clastic constituents of the polymict conglomerates of the Venna and equivalent horizons. It may be regarded as axiomatic that such assemblages should be incorporated into the conglomeratic rocks produced by episodic uplift of the Ordovician sea-floor and that the history of metamorphism would be as extended as the history of submarine volcanism.

Magmatic activitv in the belt continued after the erosional event. The evidence for this is provided by quartz–feldspar porphyry dykes that cut both the eruptive complex, the unconformity and the overlying conglomerates prior to the first phase of deformation. These dykes are similar in composition to other granodioritic rocks within the eruptive complex and are regarded as the latest product of calc-alkaline magmatism within the Skorovas area.

Acid to intermediate flows and pyroclastics

There are, within the Skorovas region, a range of acid lavas, tuffs and agglomerates, which are locally abundant and form horizons that can be traced laterally over considerable distances (see Fig. 4(*a*)). These rocks are of critical interest because they are closely associated with both the Skorovas orebody itself and with a variety of iron- and silica-rich sediments, which, following the conceptual terminology of Carstens [6,7,8] and Oftedahl,[42] are appropriately described as 'exhalites'.

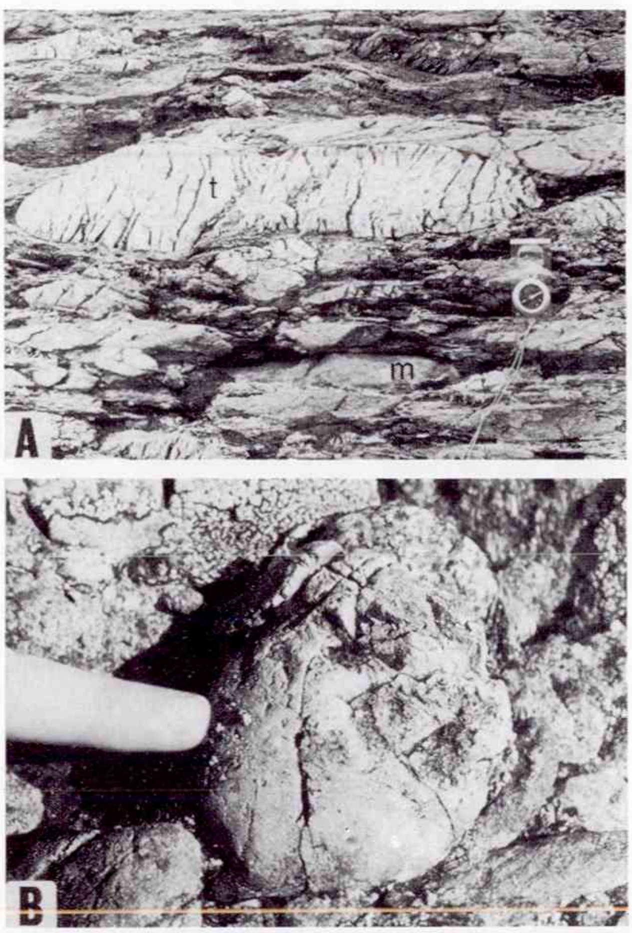


Fig. 12 *A,* Typical appearance of polymict conglomerates as seen to northwest of Havdalsvatnet. Flattened boulder of trondhjemite (t) displays tectonic fracture pattern characteristic of its brittle behaviour. Associated boulder of marble (m) has deformed in a ductile fashion. *B,* Large pebbles of pre-deformational epidote-rich metamorphic segregations derived by erosion from underlying lavas are a common constituent of greenstone-bearing facies of polymict conglomerate. Example photographed close to unconformity on southern shore of Tredjevatnet

Because of the deformation of the volcanic sequence and the inherent lateral variability of the volcanostratigraphy it is not possible to describe a unique and widely applicable type succession. The distribution of the various facies of acid rocks within specific parts of the Skorovas area suggests that a minimum of four centres of acid pyroclastic eruption were active. Their products are preserved, as far as it is possible to tell, at an approximately similar level in the volcanic sequence. In the vicinity of the Skorovas orebody there is stratigraphic evidence of at least two pyroclastic levels, the lowest of which is exposed in the basal slope of Skorovasklumpen to the north of Store Skorovatn (this is shown in Figs. 4(*a*) and 5).

The orebody itself evidently lies within the vicinity of one eruptive focus, which will be called the Grubefjell Centre. The other centres, tentatively distinguished, lie west and southwest of Tredjevatnet (the Tredjevatnet Centre), to the east of Överste Nesåvatn (the Nesåvatn Centre), and further east in the terrain near Blåhammeren (the Blåhammeren Centre). The main belts of acid rocks shown in Fig. 4(*a*) serve to identify these centres. It is difficult to judge whether the centres represent independent volcanic structures or lateral eruptions on the flanks of a single polygenetic edifice.

The acid volcanic horizons show a range of well-preserved pyroclastic fabrics to which Oftedahl [41,42] drew specific attention. Various agglomeratic facies are visible in the acid horizons in the immediate vicinity of the mine (see Fig. 14). Distal pyroclastic facies include fine tuff bands with associated exhalite sediments (Fig. 15(*a*)). Such horizons are spread over large areas and are thus valuable stratigraphic markers.

Pyroclastic facies can frequently be traced laterally into compact porphyritic and aphanitic bands of keratophyric aspect – presumably, flows or highly modified tuffs. In the vicinity of the Blåhammeren Centre porphyritic flows are physically continuous with porphyry dykes from which the eruptions appear to have originated. The dykes, in turn, can be traced towards the large mass of trondhjemite that occurs at the eastern end of the northern limb of the intrustive arc. The disjunction caused by déformation at the margins of the intrusive masses and within the volcanic sequence, however, denies a conclusive statement concerning the connexions between the plutonic and volcanic levels during climatic episodes of acid eruptive activity.

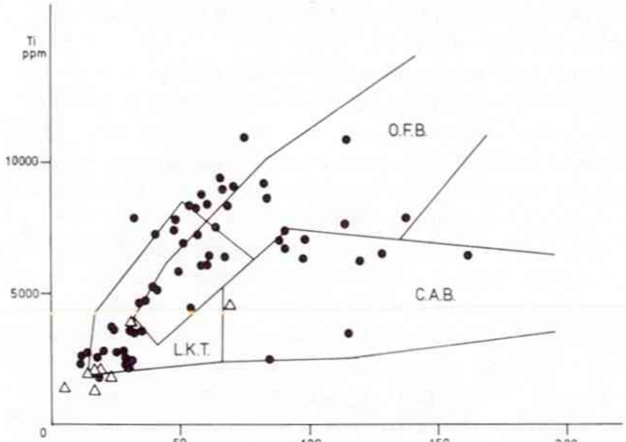


Fig. 13 Plot of Ti versus Zr contents for Skorovas basic extrusives (circles) and basic intrusives (triangles) showing abundance of low potash (island arc) tholeiites (LKT). Distinct trend towards field of calc-alkaline basalts (CAB) and grouping towards ocean-floor basalt (OFB) also shown

Chemistries of the acid extrusive rocks from the Skorovas ore level are distinctly soda-rich (see analyses 1 and 2 in Table 1). Petrographically, the rocks display a modal composition dominated by albite and quartz, occurring both as phenocrysts and as the constituents in the aphanitic groundmass, which is a mosaic of albitic plagioclase microlites and quartz. Whatever mafic silicates may have been present are now represented by dispersed chlorite. Pyrite is usually present as an accessory. The rocks are properly described as quartz keratophyres [25,76] and, taking into consideration the analyses from the basaltic and intermediate rocks shown in Table 1, it is clear that the Skorovas volcanic rocks are a spilitic suite.

The question is immediately raised as to the relationship that such a volcanic suite might have to the plutonic rocks at various structural levels in the immediate vicinity of Skorovas. The brief account of the plutonic rocks given above demonstrates the wide variation in the condition of metamorphism and deformation displayed by these rocks; there is no suggestion, however, that the compositions are abnormally sodic and the feldspars, though degraded by saussuritization, have original compositions in the range labradorite, in gabbro, to oligoclase, in trondhjemite.

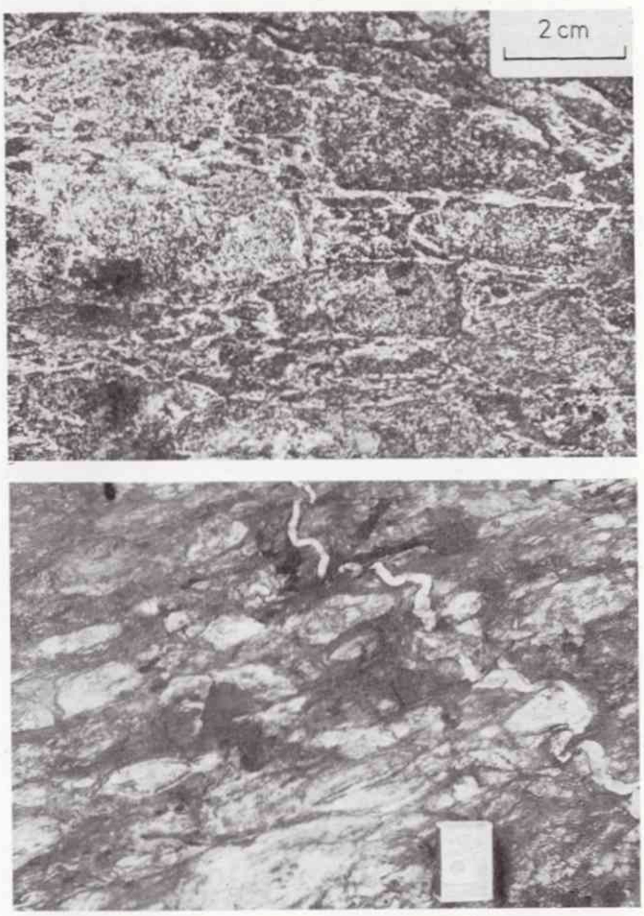


Fig. 14 Blocky pyroclastic texture (*a*) (top) seen in keratophyric flow unit on Grubefjell about 1200 m west of Skorovas orebody. Pyroclastic fragments are slightly flattened and siliceous matrix stands out as a reticular pattern. Flow is part of major acid horizon with which orebody is associated. (*b*) Agglomeratic facies of keratophyric horizon shown in (*a*). Locality is in immediate vicinity of ore horizon above mine entrance on northeast Grubefjell. Acid fragments are partly silicified and tectonically flattened. A competent quartz vein with orientation close to principal stress responsible for flattening during first stage of penetrative deformation has responded by buckle folding

Goldschmidt has given analyses of the type trondhjemites from the Trondheim district and from localities in western Norway that show total Na_2O values in the range 4.3–6.0 wt % and K_2O values in the range 1–2.5 wt %. This gives a typical $Na_2O:K_2O$ ratio for trondhjemite of the order of 3:1. Partial analyses of three trondhjemitic rocks from the Skorovas intrusive arc [56] show that the Na_2O contents fall in the range 2–4.5 wt % and K_2O values fall in the range 1–2.5 wt %. $Na_2O:K_2O$ ratios are of the order 1:1.5–3:1. This range is clearly of the right order for trondhjemitic to granodioritic rocks with SiO_2 contents of about 70 wt %. The $Na_2O:K_2O$ ratios of the spilitic rocks are one to two orders of magnitude greater than those seen in the regionally associated plutonics (see Table 1).

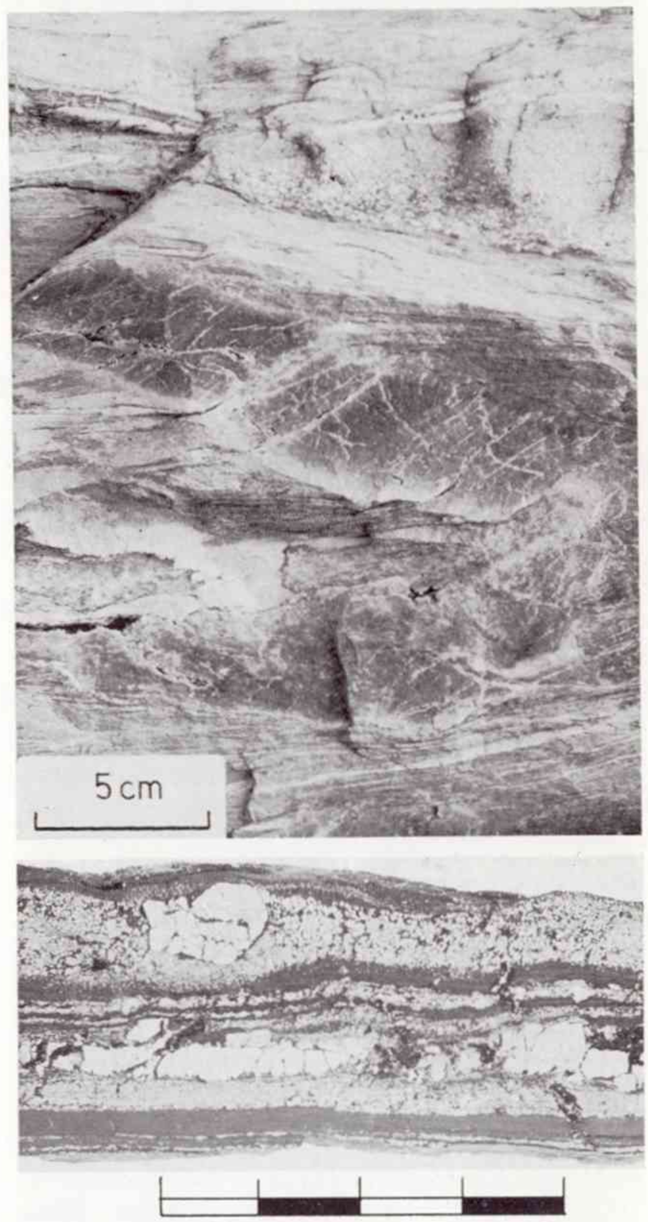


Fig. 15 Exhalite horizon (*a*) (top) 2 km east of Øverste Nesåvatn. Stratigraphic sequence is complex and made up of graded lapilli tuffs overlain by pink to brown coloured banded cherty sediments incorporating magnetite, hematite, stilpnomelane and iron-rich amphiboles. Purple chert band shows isoclinal fold style of earliest deformation with conspicuous refraction of early cleavage. (*b*) Banded pyrite–magnetite sediment typical of reduced facies of iron-rich exhalites (vasskis). Large pyrite porphyrobasts have suffered cataclasis and dislocation to varying degrees. Specimen from 1.5 km north of Blåhammeren. Scale in cm

A comprehensive programme of whole-rock analysis is being undertaken at the present time to establish the major differences in chemistry between the plutonic and the volcanic sequences, but it is clear that the most significant chemical difference does lie in the conspicuous enrichment in sodium, which has evidently occurred in the whole range of the volcanic suite.

The chemical discrepancy displayed by the volcanic and plutonic suites of the Skorovas area has been the root of a lengthy controversy concerning the affinities of spilitic rocks in general. The problem has been discussed by Wells,[76,77] Sundius [66] and Vallance,[69,70] among others, and it is clear, after the review of the problem by Vallance,[69,70] that the case for post-eruptive metasomatic alteration of alkali contents by circulating sea water is strong. Taken in conjunction with the textural evidence described above, there seems little reason to doubt that the spilitic character of the Skorovas volcanic sequence is the result of metasomatism, which accompanied the sea-floor metamorphism of the volcanic rocks during Lower Ordovician times. This metasomatic alteration by circulation of heated sea water changed the chemistry of the rocks, notably enhancing the Na_2O content and concealing the natural magmatic consanguineity of the volcanic and plutonic rocks.

Magmatic affinity of Skorovas eruptives and their tectonic significance

The relative mobility of the major elements in basic and acid rocks during metamorphic alteration poses obvious problems with regard to the determination of the magmatic affinity of eruptive sequences and the confirmation of consanguineity within them. Cann,[4] in 1970, recognized the possibility of using certain elements, notably Y, Zr, Nb and Ti, which were unaffected by severe secondary alteration processes, as indicators of the magmatic affinity of ocean-floor basalts. Pearce and Cann [46] subsequently extended this concept for use in determining the tectonic setting of basic volcanic rocks by empirically defining the ranges of variation of the stable trace elements in suites of basaltic rocks collected from various defined oceanic and island arc environments.

Sixty-nine basaltic rocks from various parts of the Skorovas district have been analysed for stable trace elements. In Fig. 13 the values for Ti are plotted against those for Zr with reference to the fields of various basaltic magma types as defined by Pearce and Cann.[46] In addition, the Ti/Zr values for eight associated gabbroic to dioritic rocks from the intrusive arc are superimposed. These rocks were chosen for their even phaneritic texture and lack of conspicuous layering. The plot shows that the basaltic rocks of the Skorovas district concentrate in the field of island arc tholeiites with a notable trend towards the field of calc-alkali basalts. It is also possible to recognize a grouping of values towards the field of ocean-floor tholeiites. The coincidence of the analysed values in the plutonic rocks with the field of island arc tholeiites is regarded as a confirmation of consanguineity in the groups of basic plutonic and volcanic rocks falling in this field.

Study of the trace elements suggests that the eruptive sequence in the Skorovas area originated in a tectonic setting in which basaltic rocks typical of an immature island arc were being generated.[19,28] Moreover, a knowledge of the field relationships in terms of the chronology and relative volumes of the eruptive rocks at the plutonic and volcanic levels confirms this view. Little quantitative information is available concerning the relative volumes of the various eruptive products in mature calc-alkaline arcs and in immature tholeiitic arcs. Baker [2] has given some comparative estimates based on observations of the South Sandwich Island volcanic sequence, and these are judged to be in the same order of proportion as those observed in the Skorovas area, notably basalt $\gg$ andesite $>$ dacite and rhyolite (or their spilitized equivalents). In the case of mature calc-alkaline arcs the relationship is of a distinctly different order – andesite $\gg$ basalt. The field evidence, taken in conjunction with the supporting information from chemical analysis and petrographic examination, forces the conclusion that the eruptives of the Skorovas area are, in fact, the constituents of an immature island arc of Lower to Middle Ordovician age formed within an ensimatic setting peripheral to the Laurentian or the Scandinavian craton. The eruptive sequence, its magmatic evolution terminated, was emplaced as the structural and stratigraphic core of the Gjersvik Nappe during the climactic stages of the Caledonian orogeny in mid-Silurian times. The tectonic decapitation of the island arc is believed to have originated with the collision between the Scandinavian craton–arc margin and a Laurentian counterpart;[10,24] the tectonic transport involved in the process of emplacement is estimated to have been at least 200–250 km.[16,17,63,64]

Skorovas orebody and peripheral exhalative mineralization

The description of the volcanic host rocks given above confirms the association between the Skorovas orebody and an eruptive sequence originating in an immature ensimatic island arc of Lower to Middle Ordovician age. It is appropriate to consider the morphology and mineralogy of the ore deposit and the peripheral exhalite mineralization of the Skorovas region in terms of the exhalative volcanic hydrothermal origin proposed for it by Oftedahl.[41,42]

The orebody is situated within a part of the volcanic sequence displaying distinctly calc-alkaline character. Apart from the keratophyric pyroclastic and flow units, at the level of which the orebody is located, the sequence includes a thickness of basaltic andesites and rocks in the range of silica contents appropriate to andesite and dacite, now represented by spilitized equivalents. The precise stratigraphic location of the orebody with respect to the acid horizons is difficult to establish owing to the disjunctive tectonic style, but there is no doubt that the association

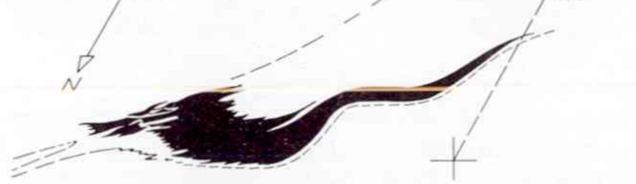


Fig. 16 Two sections of east orebody at profiles 59 and 73 east–west situated 140 m apart along morphological axis of orebody. Progressive development of a first-phase isoclinal fold is illustrated together with complex digitated style of isoclinal closures. Open style of second fold phase shown by undulation of lower contact of ore on profile 59 east–west

between ore and keratophyric extrusive rocks is intimate (see Figs. 4(*a*), 5 and 17).

The Skorovas orebody, at the present state of development, is estimated to comprise between 8 000 000 and 9 000 000 tons of massive sulphide ore, including 1 500 000 tons of essentially pyritic ore with minimal base-metal content. From the initiation of production in 1952 until 1975–76 approximately 4 700 000 tons of ore were milled to produce pyrite fines with an average grade of 1.2% Cu, 1.8% Zn and 45% S. This concentrate was marketed primarily for its high sulphur content. Following the decline in the market for sulphur-rich concentrates, a new beneficiation plant has been constructed for the production of Cu and Zn concentrates. Present ore reserves are calculated as approximately 2 000 000 tons with an average grade of 1.15% Cu and 2.29% Zn. It is a difficult problem to assess the average grade of the mineralized body as a whole since this clearly depends upon the geological-economic criteria chosen to define it. It is, nevertheless, possible to state that the mineralogy is dominantly pyritic and that the sulphur content of massive ore is of the average order of 35 wt % with $Zn > Cu \gg Pb$. Zinc content is of the order of 2 wt % and $Cu \leqslant 1$ %.

Structural style of orebody

The morphological complexity of the Skorovas orebody caused by tectonic disjunction of isoclinally folded lenses and the extreme tectonic deformation of the wallrock envelope has been a considerable obstacle to the clear formation of a genetic model.[20]

The orebody can be described as an *en-échelon* array of closely spaced groups of massive sulphide lenses, the distribution of which has created an elongate ore zone with a length of approximately 600 m lying in a north to NNE orientation and with a width of the order of 200 m. A representative cross-section of the orebody is shown in Fig. 17.

The lenticular bodies have their principal planes orientated parallel to the axial planes of first-phase isoclinal folds and the individual lenses are apparently, to a significant degree, the products of partial disjunction of fold limbs within that fold system. In detail, as is shown by Fig. 17, the ore zone shows a longitudinal division into an eastern and a western orebody. This division may reflect the shape of the orebody at the site of accumulation prior to deformation. The lateral extremities of the ore lens systems characteristically show multiple digitation and bifurcation and there are frequently zones of sulphidic impregnation reaching ore grade that lie between the digitations of massive ore. As Gjelsvik [20] noted, discordance is locally observed between the contacts of some of the larger massive lenses and the schistosity of the wallrocks. This evidence, together with the irregular geometry of the orebody as a whole, was used in support of an epigenetic mode for the formation of the deposit, although Gjelsvik conceded that early folding had probably been an influence in creating its present morphology and that emplacement took place immediately following the eruption of the volcanic sequence in Lower Ordovician times.

It is possible to explain the local discordance between early schistosity and the contacts of the massive lenses in terms of the contrast in the mechanical behaviour of the base-metal-poor pyritic lenses and the volcanic wallrocks during the flattening and isoclinal folding of the first stage

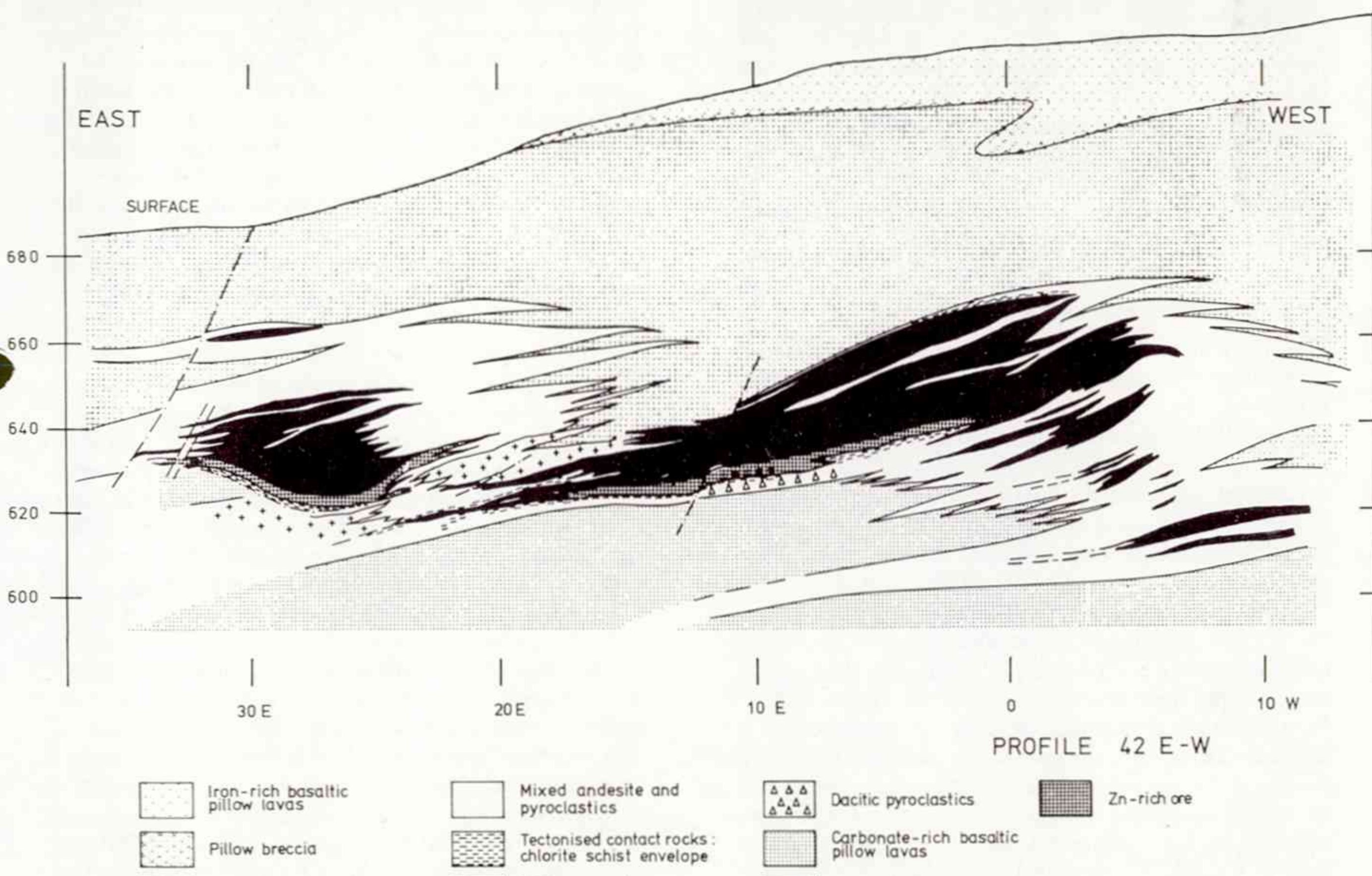


Fig. 17 Representative section through east and west orebodies at profile 42 east–west showing principal lithological divisions of host rocks and position of zinc-rich facies along footwall of principal eastern and western lenses. According to structural interpretation zinc-rich level is stratigraphic top of ore. Complex digitation of ore is well illustrated

of deformation. The disjunction created by componental movements at the ore contacts during this early phase must also have been magnified in response to the stresses imposed during the second period of folding.

The early deformation in the immediate contact zone of the orebody was sufficient, because of the contrast in competency, to create a schistose tectonic facies composed predominantly of chlorite, carbonate and, locally, talc. These components were derived by segregation from the altered basic host rocks – andesite, basaltic, andesite and basalt. The schistose tectonic envelope is shown locally in Fig. 17. The creation of this envelope facilitated the continuance of componental movements within the vicinity of the ore contacts during later deformation.

The history of structural deformation within the orebody can be summarized as follows:

(1) Early isoclinal folding, accompanied by creation of a schistose envelope with componental movements in the vicinity of the orebody contacts, led to a tectonically disjunct style.

(2) Periods of post-schistosity deformation produced folds of various scales. In the immediate contact zone small folds of up to several metres in wavelength occur sporadically in response to local variation in orebody geometry. The orebody as a whole, however, was folded on a broad open style, which is typical of later deformation in the Skorovas region. This is shown in the isometric projection (Fig. 16).

(3) The final episode of deformation was marked by high-angle fractures of low displacement with a general northerly trend.

The early isoclinal structures display axial alignment in a north to NNE direction with axial planes dipping at approximately 25° towards the east. This is reflected in the axial elongation of the orebody. The later open folds, part of the regional dome and basin system shown in the structural analysis (Fig. 4(*b*)), have steeply dipping axial planes and an axial trend of approximately NNW orientation concordant with the pattern of the adjacent structural basis, on the flanks of which the orebody lies.

Mineralogy and stratigraphy within orebody

The bulk composition of the Skorovas orebody reflects a mineralogy of comparative simplicity. Pyrite, sphalerite, magnetite and chalcopyrite are the dominant ore mineral species. Pyrrhotite is conspicuously absent. Galena occurs in much smaller amounts, and arsenopyrite and tennantite occur locally as accessory constituents. This mineralogy accounts for the average range of trace and minor metallic elements recorded in analyses of the orebody, the following values being considered as representative averages: Co, 100 ppm; Ni, 20 ppm; As, 300 ppm; Ag, 10 ppm; and Au, 0.1 ppm. Cadmium is notably enriched in sphalerite-rich facies of the ore, reaching values of several hundred ppm, and Mn reaches similar values in the pyritic facies. Most of the minor chemical variation can be accounted for by diadochic substitution within the common ore minerals. Arsenic and silver are notably contributed by arsenopyrite and tennantite, and grains of native gold have been observed as inclusions of 5 μm in size in arsenopyrite from peripheral parts of the ore. The principal gangue mineralogy of the ore consists of chlorite, quartz and calcite, together with lesser amounts of sericite and, locally, stilpnomelane.

The structural and stratigraphic evidence summarized here and by other authors [20,21,41] has confined the choice of genetic models for the orebody to the following alternatives: (1) syngenetic deposition of the stratiform orebodies under submarine conditions as a result of emission of metal-rich fluids in the vicinity of an acid eruptive centre or (2) epigenetic emplacement of the orebody by replacement of part of the volcanic sequence in the vicinity of the eruptive centre, this taking place during post-eruptive hydrothermal activity in early Ordovician times.

If the first alternative is to be given favour, it would be desirable to be able to recognize some evidence of stratigraphy within the orebody. Gjelsvik [20,21] conducted a systematic analytical study of the major base-metal contents of ore from 43 drill-holes on selected profiles spanning the length and breadth of the orebody. The results of this study showed that the contents of zinc and copper varied antipathetically, zinc showing a tendency towards enrichment in the peripheral zones of the orebody and copper tending to concentrate in enriched core regions. It was also noted that the overall content of copper and zinc showed an increase towards south of the orebody. In the southern part Gjelsvik noted that zinc, in particular, is enriched towards the hanging-wall and in the eastern and western extremities of the ore lenses. In the central zone it is enriched in the vicinity of the footwall contact (Fig. 17). In the northern part of the orebody the composition is essentially pyritic, with minimal base-metal content. The analytical data prove a systematic variation in base-metal content both laterally and vertically within the orebody, and this is confirmed by petrographic studies and field observation.

In the course of the present study it has been possible to recognize facies of the ore that are probably of chemical-sedimentary origin and those which are essentially tectonic. The pattern described by Gjelsvik [20,21] probably reflects the influence of both processes. The primary textural evidence for the operation of sedimentary processes in ore deposition is given by the graded banding of the pyritic ores in which rapid changes of modal composition and grain size occur from band to band. This type of texture is shown in the banded pyrite, sphalerite magnetite ore of Fig. 18(*C*). It is highly unlikely that such banding is of tectonic origin. Moreover, where tectonism has had a pervasive effect on the ore, the textures are of distinctly tectonic style (see Figs. 18(*B*) and 18(*D*). Figs. 18(*A*) and 18(*B*) show that the deformation of the pyritic lenses was marked by mutual impaction and cataclasis of the constituent grains. Any gross tectonic flattening or extension of the lenses must have been accomplished by relative movement between the individual grains accompanied by cataclastic degradation. This mechanism has been described as macroscopic ductility by Atkinson,[1] who has also shown that cataclasis is probably the only significant deformation mechanism available to pyrite, under dry conditions in the P–T range appropriate to the greenschist facies. It is unlikely that deformation took place under dry conditions,[48] but the range of textural evidence strongly suggests that, within the massive pyrite, cataclasis was the dominant deformation mechanism. Atkinson [1] also notes that the strength of polycrystalline pyrite is strongly and inversely dependent on porosity. Large volumes of the Skorovas orebody are composed by nearly monomineralic close-packed aggregates of pyrite with low porosity and, when lithified, these masses must have behaved in a highly competent manner relative to the adjacent chloritized lavas and pyroclastics. Under the influence of the tectonic stresses prevailing during the first period of deformation it seems reasonable to propose that the style of deformation within the orebody may have been controlled by the development of narrow zones of cataclastic flow within which much of the tectonic strain would have been accommodated. In this way, the formation of a disjunct lenticular arrangement of ore lenses could be explained as well as the rarity of well-preserved isoclinal structures.

Tectonic mineralogical facies of the orebody are undoubtedly recognizable in the base-metal-enriched lenses and extremities on the lateral periphery of the ore. Zinc values are enhanced by an order of magnitude and lead values by two orders of magnitude. This is shown by analysis 5 in Table 2. The typical foliated texture of this ore is shown in Fig. 18(*D*), which also displays the incipient development of a crenulation cleavage related to the second phase of deformation.

Tectonic mechanisms are not, however, the sole explanation of the peripheral enrichment of base-metal values; nor do they completely explain the separation between maximum zinc and copper values in the pyritic ores. There appears to be a definite stratigraphy in which cupriferous pyritic ores (analyses 1 and 2 in Table 2) are overlain by zinc-rich ores with laterally developed facies rich in banded magnetite and carbonate. Analyses for these ore types are shown as 3 and 4 in Table 2.

It appears also that a distinct primary lateral variation may also have been present to account for the generally depleted levels of copper and zinc in the northern part of the orebody. Final evidence of the operation of chemical-sedimentary processes in the formation of the orebody is provided by the occurrence of magnetitic and hematitic chert bands (jasper) in the foot- and hanging-walls of the orebody stratigraphically overlying the magnetite and zinc-rich facies.

Evidence of a primary stratigraphy within the orebody clearly exists despite considerable tectonic modification. It is also plain that the metal distribution can be interpreted in terms of a stratigraphic zonation, which resembles that found in orebodies of undisputed volcanic exhalative origin in such areas as the Miocene Green Tuff belt of Japan.[30]

The detailed palinspastic reconstruction of the lateral and vertical facies variation within the complex Skorovas orebody is the subject of a current study by Reinsbakken

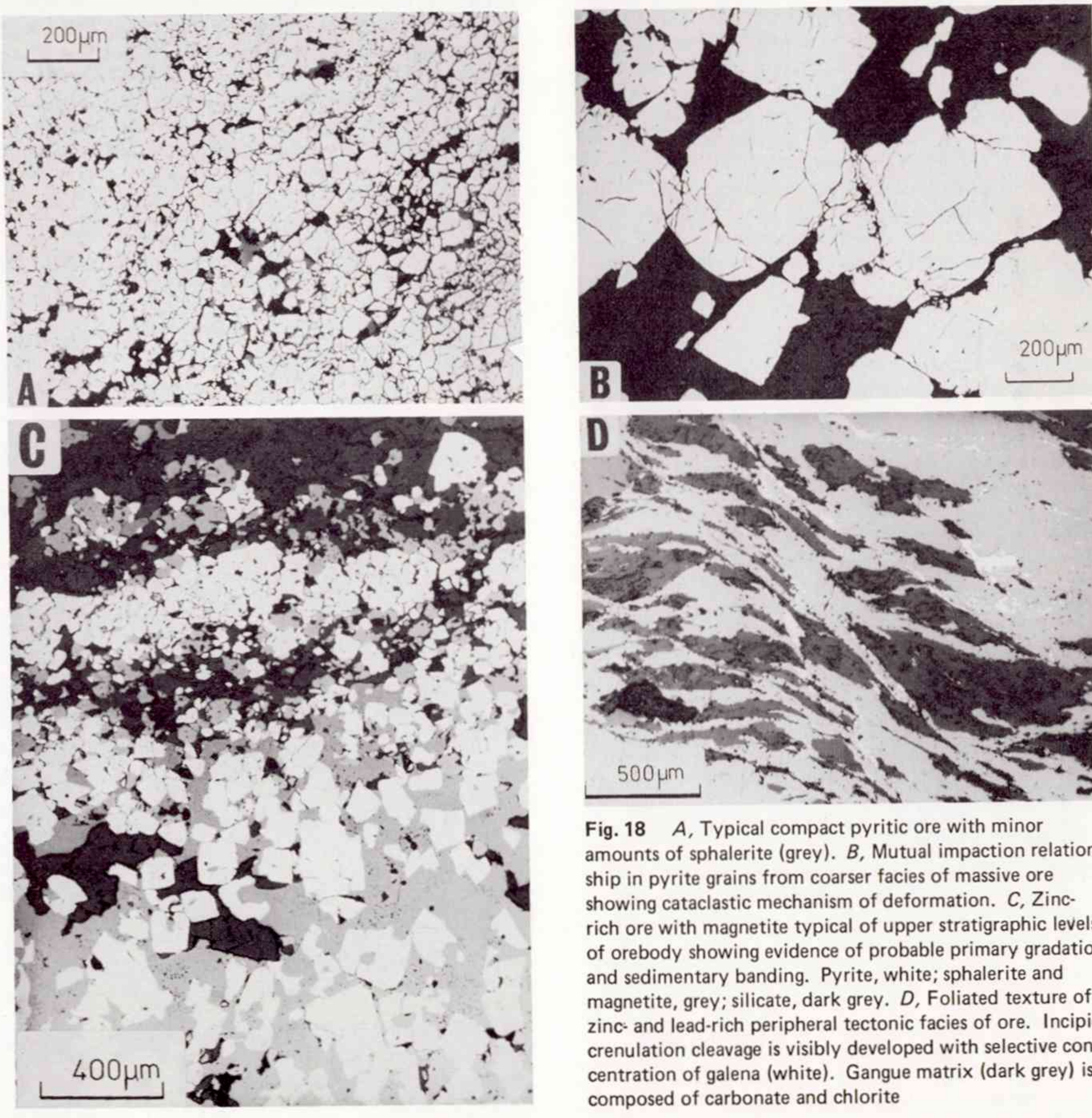


Fig. 18 *A,* Typical compact pyritic ore with minor amounts of sphalerite (grey). *B,* Mutual impaction relationship in pyrite grains from coarser facies of massive ore showing cataclastic mechanism of deformation. *C,* Zinc-rich ore with magnetite typical of upper stratigraphic levels of orebody showing evidence of probable primary gradation and sedimentary banding. Pyrite, white; sphalerite and magnetite, grey; silicate, dark grey. *D,* Foliated texture of zinc- and lead-rich peripheral tectonic facies of ore. Incipient crenulation cleavage is visibly developed with selective concentration of galena (white). Gangue matrix (dark grey) is composed of carbonate and chlorite

and will not be discussed further here. It may be said, however, that the zonal distribution of copper and zinc within the pyritic mass suggests that precipitation of the ore minerals could be explained in terms of an evolving chloride-complex model such as that used by Sato to explain

Table 2 Average metal values for Skorovas ore types and sulphide facies of an extensive exhalite

%	*1*	*2*	*3*	*4*	*5*	*6*	*7*
S	46.80	47.20	38.90	42.28	27.50		51.10
Cu	1.09	2.30	0.99	0.79	1.47	0.06	0.20
Zn	0.15	0.80	3.90	9.33	44.20	0.02	0.41
Pb	0.03	0.04	0.05	0.04	4.00	0.01	

1, Massive pyritic ore (27 samples); 2, copper-rich ore (14 samples); 3, banded magnetite-rich pyrite–sphalerite ore with carbonate (18 samples); 4, pyritic zinc-rich ore at stratigraphic top of orebody (13 samples); 5, Zn–Pb–Cu-rich peripheral ore – probably a tectonic facies (2 samples; 6 massive base-metal-depleted pyrite or 'vasskis', Havdalsvatn (1 sample); 7, relatively enriched pyritic ore, Skorovas (30 samples).

zonation within the Kuroko deposits.[55] The applicability of such a model depends on the existence of conditions such that the metal- and sulphur-enriched hydrothermal solutions are not rapidly and widely dispersed into the dominantly oxidizing conditions of the submarine environment. This requirement must be met by topographical barriers in the vicinity of the hydrothermal emanations or by density contrasts between the emanating brines and sea water.[54] It is upon the presence or absence of the conditions outlined that the distinction between the hydrothermally intensive and the hydrothermally extensive exhalite phenomena in the Skorovas area is based.

Peripheral exhalative mineralization

The magnetitic cherts and jasper found at the stratigraphic top of the Skorovas orebody signify the restoration of chemically normal oxidizing conditions in the vicinity of the orebody. These ferruginous siliceous horizons represent a continuum between the intensive and extensive facies of mineralization (see Fig. 19). The relative frequency of the association between acid pyroclastic horizons of various facies and banded magnetite–pyrite and chert in the Skorovas area, and within the Grongfelt as a whole, was one of the primary inspirations for the theory of exhalative-sedimentary ore genesis expounded by Oftedahl in 1958,[41,42] who carried forward the concepts formulated by C. W. Carstens [7,8] in his studies of the Leksdal type of sedimentary sulphide deposit in the Trondheim district. Oftedahl [42] emphasized the association between acid pyroclastic activity and the formation of the iron- and silica-enriched sediments. Understanding of the various exhalative facies has been carried forward in the course of the present study.

The main characteristics of the extensive peripheral exhalites are noted below.

(1) The exhalite horizons are relatively thin, 0.1–2 m in thickness, are laterally persistent within the volcanostratigraphy and can be traced over distances of the order of several kilometres.

(2) Internal variations of stratigraphy occur in detail. The sequence is always marked, however, by a change from a reducate sulphidic or magnetitic banded stratum to an oxidate ferruginous chert (jasper). These changes occur in a vertical sense (Fig. 20) and also, generally speaking, in a lateral sense.

(3) The sulphide facies are characteristically improverished in base metals other than iron and manganese (see analysis 6, Table 1).

These widespread bands can be explained by a mechanism of explosive volcanic dispersal during the climactic dacitic eruptions associated with the various volcanic centres. In the course of such a process rapid and complete mixing of the residual hydrous fraction of the dacitic magma with oxidizing sea water will have occurred. The base metals will have been subjected to infinite dilution in the course of such a process, leaving oxidized iron and silica hydrosols in suspension. The hydrosols will have suffered greater dispersion than the pyroclastic fragments and by subsequent settling will have produced a thin stratum of iron- and silica-rich sediment that extends well beyond the limits of the latter. It is for this reason that the extensive exhalite horizons are so named. They also constitute valuable time-stratigraphic markers within the intrinsically variable volcanostratigraphy.

The sulphide–magnetite mineralogy of the reducate facies is to be ascribed to post-depositional bacterial reduction of iron, deposited in the oxidized condition. A typical facies of this type is shown in Fig. 15(*b*).

The simple stratigraphy shown in the ideal section (Fig. 20) can be regarded as the product of a single dispersal event. Some exhalites, however, give evidence of episodic explosive and fumarolic activity that results in a complex cyclic stratigraphy in which tuff bands are intercalated

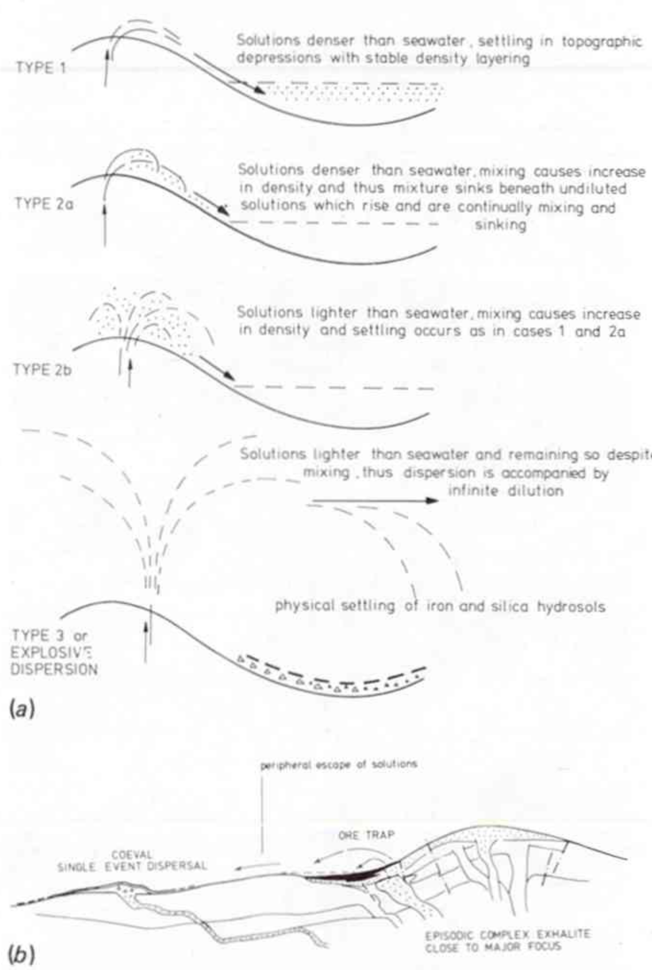


Fig. 19 Scheme of interaction of hydrothermal brines with sea water (*a*) (top) (after Sato [54]) and schematic eruptive and hydrothermal events in Skorovas volcanic centre during climactic dacitic episode (*b*)

with iron-enriched chert bands that show a complex mineralogy, including stilpnomelane, iron-rich amphiboles and chlorites, together with a spinel, commonly of magnetite composition (Fig. 15(*a*)).

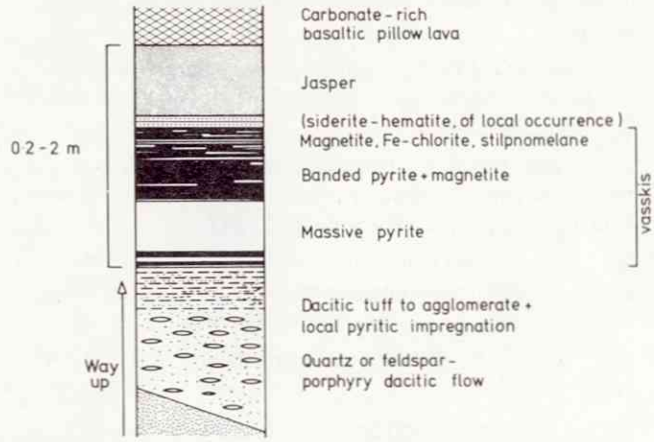


Fig. 20 Ideal section showing products of single event dispersal in extensive exhalite as observed in vicinity of Blåhammeren centre

As well as being valuable time-stratigraphic markers, the exhalites may be developed as a tool in identifying vent-proximal and vent-distal environments and have obvious value as a guide in exploration. An investigation of exhalites as an exploration tool is currently being carried out in the Skórovas area by Ferriday, Halls and Hembre.

Conclusions

It was recognized in the early stages of the present study in 1972 that the Skorovas area provided a unique window on the eruptive and ore-forming processes that take place within a Palaeozoic island arc environment. An attempt has been made in this paper to describe the major eruptive, hydrothermal metamorphic and tectonic processes that have acted to produce the present geology of the Skorovas area in the context of its position in the Gjersvik Nappe.

Attention has been specifically directed to the hydrothermal processes that take place at the volcanic level, but it is important to record the occurrence of cumulus ores of magmatic origin within the plutonic complex. At Lillefjellklumpen, to the north of Skorovas (see Fig. 4(*a*)), a small platinum-bearing pyrrhotite–chalcopyrite–pentlandite lens has been found in association with a minor body of metagabbro. This occurrence was described by Foslie and Johnson-Høst in 1932.[13] The present study has shown that small cumulus bodies of chalcopyrite–pentlandite-bearing ore occur at a variety of sites in the layered gabbros of the deeper plutonic level. At the present time these bodies are of incidental economic interest only. The whole range of phenomena described can therefore be said to typify the ore-forming environment within an ensimatic pericratonic island arc, and only the porphyry style of sub-volcanic mineralization appears to be absent. This may, however, reflect the immature character of the arc.

The study has also placed the Gjersvik, Trondheim and related disturbances in their proper geological context as episodes of uplift associated with the stages of evolution of a pericratonic arc system in Lower to Middle Ordovician times. Vertical movements of this style can be said to be a characteristic feature of the evolution of arc systems,[71] and Murphy[38] has described fault-bounded back-arc basins of Tertiary age in Indonesia that contain up to 8-km thickness of clastic sediments, which were deposited under subaerial to shallow marine conditions. It is, perhaps, a debatable exercise to attempt to correlate the timing of such movements, which may be intrinsically of intra-arc origin, with tectonic events of differing style taking place in other provinces of the Caledonides that could have been located, in Lower Ordovician times, on separate geographically and tectonically isolated margins of the orogenic system.[3]

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References

1. Atkinson B. K. Experimental deformation of polycrystalline pyrite: effects of temperature, confining pressure, strain rate, and porosity. *Econ. Geol.*, **70**, 1975, 473–87.

2. Baker P. E. Volcanism at destructive plate margins. *J. Earth Sci.*, **8**, 1972, 183–95.

3. Berry W. B. N. Age of Bogo Shale and western Ireland graptolite faunas and their bearing on dating early Ordovician deformation and metamorphism in Norway and Britain. *Norsk geol. Tidsskr.*, **48**, 1968, 217–30.

4. Cann J. R. Rb, Sr, Y, Zr and Nb in some ocean floor basaltic rocks. *Earth Planet. Sci. Lett.*, **10**, 1970, 7–11.

5. Carmichael I. S. E. Turner F. J. and Verhoogen J. *Igneous petrology* (New York: McGraw-Hill, 1974), 739 p.

6. Carstens C. W. Oversigt over Trondhjemsfeltets bergbygning. *Kgl. norske Videnskabers Selsk. Skr.* no. 1, 1919, 152 p.

7. Carstens C. W. Der Unterordovicische Vulkanhorizont in dem Trondhjemgebiet. *Norsk geol. Tidsskr.*, **7**, 1922, 185–270.

8. Carstens C. W. Zur Frage der Genesis der norwegischen Kiesvorkommen. *Z. prakt. Geol.*, **40**, 1932, 97–9.

9. Carstens H. Jernmalmene i det vestlige Trondhjems-felt og forholdet til kisforekomstene. *Norsk geol. Tidsskr.*, **35**, 1955, 211–20.

10. Dewey J. F. Evolution of the Appalachian/Caledonian orogen. *Nature, Lond.*, **222**, 1969, 124–9.

11. Dewey J. F. Rickards R. B. and Skevington D. New light on the age of Dalradian deformation and metamorphism in western Ireland. *Norsk geol. Tidsskr.*, **50**, 1970, 19–44.

12. Foslie S. Geological maps prepared during 1922–1927 and published at 1:100 000 scale by Norges Geologiske Undersøkelse as follows:
Namsvatnet med en del av Frøyningsfjell, Oslo 1957
Tunnsjø, Oslo 1958
Sanddøla, Oslo 1958
Trones, Oslo 1958
Nordli, Oslo 1959

13. Foslie S. and Johnson-Høst M. Platina i sulfidisk nikkelmalm. *Norg. geol. Unders.* no. 137, 1932, 77 p.

14. Foslie S. and Strand T. Namsvatnet med en del av Frøyningsfjell. *Norg. geol. Unders.* no. 196, 1956, 82 p.

15. Gale G. H. and Roberts D. Palaeogeographical implications of greenstone petrochemistry in the Southern Norwegian Caledonides. *Nature, phys. Sci.*, **238**, 1972, 60–1.

16. Gale G. H. and Roberts D. Trace element geochemistry of Norwegian Lower Palaeozoic basic volcanics and its tectonic implications. *Earth Planet. Sci. Lett.*, **22**, 1974, 380–90.

17. Gee D. G. and Zachrisson E. Comments on stratigraphy, faunal provinces and structure of the metamorphic allochthon, central Scandinavian Caledonides. *Geol. För. Stockh. Förh.*, **96**, 1974, 61–6.

18. Gee D. G. A geotraverse through the Scandinavian Caledonides — Östersund to Trondheim. *Sver. geol. Unders. Arsb.* 69, no. 9, 1975, 66 p.

19. Gill J. B. Geochemistry of Viti Levu, Fiji, and its evolution as an island arc. *Contrib. Mineral. Petrol.*, **27**, 1970, 179–203.

20. Gjelsvik T. The Skorovass pyrite deposit, Grong area, Norway. In *Rep. 21st Int. geol. Congr. Part 16: Genetic problems of ores* (Copenhagen: Berlingske Bogtrykkeri, 1960), 54–66.

21. Gjelsvik T. Distribution of major elements in the wall rocks and the silicate fraction of the Skorovass pyrite deposit, Grong area, Norway. *Econ. Geol.*, **63**, 1968, 217–31.

22. Goldschmidt V. M. Übersicht der Eruptivgesteine im Kaledonischen Gebirge zwischen Stavanger und Trondhjem. *Kristiania Vidensk.-Selsk. Skr., Math.-Naturv. K1, 2,* 1916, 60–112. (Der Opdalit-Trondhjemit-Stamm)

23. Gustavson M. The low-grade rocks of the Skålvaer area, S. Helgeland, and their relationship to high-grade rocks of the Helgeland Nappe Complex. *Norg. geol. Unders.* no. 322, 1975, 13–33.

24. Harland W. B. and Gayer R. A. The Arctic Caledonides and earlier oceans. *Geol. Mag.*, **109**, 1972, 289–384.

25. Hatch F. H. Wells A. K. and Wells M. K. *Petrology of the igneous rocks, 13th edn* (London: Murby, 1972), 551 p.

26. Holtedahl O. Paleogeography and diastrophism in the Atlantic-Arctic region during Paleozoic time. *Am. J. Sci.*, **49**, 1920, 1–25.

27. Humphris S. E. The hydrothermal alteration of oceanic basalts by seawater. Ph.D. thesis, MIT and Woods Hole Oceanographic Institute, 1976, 247 p.

28. Jakeš P. and Gill J. Rare earth elements and the island arc tholeiitic series. *Earth Planet. Sci. Lett.*, **9**, 1970, 17–28.

29. Jones J. G. Pillow lava and pahoehoe. *J. Geol.*, **76**, 1968, 485–8.

30. Lambert I. B. and Sato T. The Kuroko and associated ore deposits of Japan: a review of their features and metallogenesis. *Econ. Geol.*, **69**, 1974, 1215–36.

31. Miyashiro A. Regional metamorphism of the Gosaisyo-Takanuki district in the central Abukuma Plateau. *J. Fac. Sci. Tokyo Univ., Sect. 2,* **11**, 1957–59, 219–72.

32. Miyashiro A. Metamorphism of mafic rocks. In *Basalts: the Poldevaart treatise on rocks of basaltic composition* Hess H. H. and Poldevaart A. eds (New York: Interscience, 1968), vol. 2, 799–834.

33. Miyashiro A. Shido F. and Ewing M. Metamorphism in the Mid-Atlantic Ridge near 24° and 30°N. *Phil. Trans. R. Soc.*, **A268**, 1971, 589–603.

34. Miyashiro A. Metamorphism and related magmatism in plate tectonics. *Am. J. Sci.*, **272**, 1972, 629–56.

35. Miyashiro A. Pressure and temperature conditions and tectonic significance of regional and ocean-floor metamorphism. *Tectonophys.*, **13**, 1972, 141–59.

36. Miyashiro A. *Metamorphism and metamorphic belts* (London: Allen and Unwin, 1973), 492 p.

37. Moore J. G. Petrology of deep-sea basalt near Hawaii. *Am. J. Sci.*, **263**, 1965, 40–52.

38. Murphy R. W. Tertiary basins of Southeast Asia. *Proc. S. E. Asia Pet. Explor. Soc.*, **2**, 1975, 1–36.

39. Nicholson R. and Rutland R. W. R. A section across the Norwegian Caledonides; Bodø to Sulitjelma. *Norg. geol. Unders.* no. 260, 1969, 86 p.

40. Oftedahl C. Om Grongkulminasjonen og Grongfeltets Skyvedekker. *Norg. geol. Unders.* no. 195, 1956, 57–64.

41. Oftedahl C. Oversikt over Grongfeltets skjerp og malmforekomster. *Norg. geol. Unders.* no. 202, 1958, 76 p.

42. Oftedahl C. A theory of exhalative-sedimentary ores. *Geol. För. Stockh. Förh.*, **80**, 1958, 1–19.

43. Oftedahl C. A manganiferous chert in the Caledonian greenstone of Trondheim. *Norske Vidensk. Selsk. Forh.*, **40**, 1967, 48–54.

44. Oftedahl C. Greenstone volcanoes in the central Norwegian Caledonides. *Geol. Rdsch.*, **57**, 1968, 920–30.

45. Oftedahl C. *Norges geologi* (Trondheim: Tapir, 1974), 169 p.

46. Pearce J. A. and Cann J. R. Tectonic setting of basic volcanic rocks determined using trace element analysis. *Earth Planet. Sci. Lett.*, **19**, 1973, 290–300.

47. Pearce J. A. and Gale G. H. Identification of ore-deposition environment from trace-element geochemistry of associated igneous host rocks. In *Volcanic processes in ore genesis* (London: Institution of Mining and Metallurgy and Geological Society, 1977), 14–24.

48. Price N. J. Laws of rock behavior in the earth crust. In *Rock mechanics – theory and practice.* Somerton W. H. ed. (New York: AIME, 1970), 3–23. *(Proc. 11th Symp. on Rock Mech.)*

49. Roberts D. Structural observations from the Kopperå-Riksgrense area and discussion of the tectonics of Stjødalen and the N. E. Trondheim region. *Norg. geol. Unders.* no. 245, 1967, 64–122.

50. Roberts D. Springer J. and Wolff F. C. Evolution of the Caledonides in the northern Trondheim region, Central Norway: a review. *Geol. Mag.*, **107**, 1970, 133–45.

51. Roberts D. Timing of Caledonian evorogenic activity in the Scandinavian Caledonides. *Nature, phys. Sci.*, **232**, 1971, 22–3.

52. Rui I. J. and Bakke I. Stratabound sulphide mineralization in the Kjøli area, Røros district, Norwegian Caledonides. *Norsk geol. Tidsskr.*, **55**, 1975, 51–75.

53. Roberts D. The Stokkvola conglomerate – a revised stratigraphical position. *Norsk geol. Tidsskr.*, **55**, 1975, 361–71.

54. Sato T. Behaviours of ore-forming solutions in sea-water. *Min. Geol. Japan*, **22**, no. 111, 1972, 31–42.

55. Sato T. A chloride complex model for Kuroko mineralization. *Geochem. J.*, **7**, 1973, 245–70.

56. Scott R. D. The Grubefjell volcanics. Thesis submitted in partial fulfilment of the requirements for the degree of B.Sc., Royal School of Mines, London, 1973, 129 p.

57. Skevington D. A note on the age of the Bogo Shale. *Norsk geol. Tidsskr.*, **43**, 1963, 257–60.

58. Skevington D. and Sturt B. A. Faunal evidence bearing on the age of late Cambrian-early Ordovician metamorphism in Britain and Norway. *Nature, Lond.*, **215**, 1967, 608–9.

59. Spooner E. T. C. and Fyfe W. S. Sub-sea-floor metamorphism, heat and mass transfer. *Contrib. Mineral. Petrol.*, **42**, 1973, 287–304.

60. Spooner E. T. C. *et al.* O^{18} enriched ophiolitic metabasic rocks from E. Liguria (Italy), Pindos (Greece), and Troodos (Cyprus). *Contrib. Mineral. Petrol.*, **47**, 1974, 41–62.

61. Strand T. The Pre-Devonian rocks and structures in the region of Caledonian deformation. In *Geology of Norway* Holtedahl O. ed. *Norg. geol. Unders.* no. 208, 1960, 170–284.

62. Strand T. Cambro-Silurian deposits outside the Oslo region. In *Geology of Norway* Holtedahl O. ed. *Norg. geol. Unders.* no. 208, 1960, 151–69.

63. Strand T. and Kulling O. *Scandinavian Caledonides* (New York: Wiley-Interscience, 1972), 302 p.

64. Strand T. The Scandinavian Caledonides: a review. *Am. J. Sci.*, **259**, 1961, 161–72.

65. Sturt B. A. Miller J. A. and Fitch F. J. The age of alkaline rocks from West Finnmark, northern Norway, and their bearing on the dating of the Caledonian orogeny. *Norsk geol. Tidsskr.*, **47**, 1967, 255–73.

66. Sundius N. On the spilitic rocks. *Geol. Mag.*, **67**, 1930, 1–17.

67. Tilley C. E. and Muir I. D. Tholeiite and tholeiitic series. *Geol. Mag.*, **104**, 1967, 337–43.

68. Törnebohm A. E. Grunddragen af det centrala Skandinaviens bergbyggnad. *Kgl. Sv. Vet. Akad. Handl.*, **28**, no. 5 1896, 212 p.

69. Vallance T. G. Concerning spilites. *Proc. Linn. Soc. N. S. W.*, **85**, 1960, 8–52.

70. Vallance T. G. Spilites again: some consequences of the degradation of basalts. *Proc. Linn. Soc. N. S. W.*, **94**, 1969, 8–51.

71. van Bemmelen R. W. *The geology of Indonesia* (The Hague: Mart. Nijhoff, 1949), 997 p.

72. Vogt T. The geology of part of the Hølonda-Horg district, a type area in the Trondheim region. *Norsk geol. Tidsskr.*, **25**, 1945, 449–528.

73. Vokes F. M. Regional metamorphism of the Palaeozoic geosynclinal sulphide ore deposits of Norway. *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **77**, 1968, B53–9.

74. Vokes F. M. A review of the metamorphism of sulphide deposits. *Earth Sci. Rev.*, **5**, 1969, 99–143.

75. Vokes F. M. and Gale G. H. Metallogeny relatable to global tectonics in southern Scandinavia. In *Metallogeny and plate tectonics* Strong D. F. ed. *Spec. Pap. geol. Ass. Can.* no. 14, 1976, 413–41.

76. Wells A. K. The nomenclature of the spilitic suite. Part I: the keratophyric rocks. *Geol. Mag.*, **59**, 1922. 346–54.

77. Wells A. K. The nomenclature of the spilitic suite. Part II: the problem of the spilites. *Geol. Mag.*, **60**, 1923, 62–74.

78. Wells A. K. and Bishop A. C. An appinitic facies associated with certain granites in Jersey, Channel Islands. *Q. Jl geol. Soc.*, **111**, 1955, 143–66.

79. Wilson J. T. Did the Atlantic close and then re-open? *Nature, Lond.*, **211**, 1966, 676–81.

80. Wilson M. R. The geological setting of the Sulitjelma ore bodies, Central Norwegian Caledonides. *Econ. Geol.*, **68**, 1973, 307–16.

81. Zachrisson E. Caledonian geology of northern Jämtland – southern Västerbotten: Köli stratigraphy and main tectonic outlines. *Sver. geol. Unders., Ser. C*, no. 644, *Arsb.* 64, no. 1 1969, 33 p.

82. Zachrisson E. The structural setting of the Stekenjokk ore bodies, Central Swedish Caledonides. *Econ. Geol.*, **66**, 1971, 641–52.

83. Zachrisson E. The westerly extension of Seve rocks within the Seve-Köli Nappe Complex in the Scandinavian Caledonides. *Geol. För. Stockh. Förh.*, **95**, 1973, 243–51.

The stratigraphic and mineralogical identity of exhalative sediments with relationship to the stratiform volcanogenic orebody at Skorovas, Norwegian Caledonides.

I. L. Ferriday*, C. Halls* and O.-S. Hembre.+

Kjerulf, in 1879 (1), suggesting a process in which "gaseous emanations" from seafloor vents were instrumental, was one of the first to propose an exhalative genesis for massive sulphide orebodies in the Trondheim region. Subsequently, several workers (2, 3, 4, 5, 6, 7, 8,) have supported this theory. In particular, H. Carstens and C. Oftedahl drew attention to the exhalative genesis not only of massive sulphide mineralisation but also of iron-formations and cherts in the Grong and Trondheim Regions. The exhalative theory is now overwhelmingly accepted for the genesis of the majority of massive sulphides in the Scandinavian Caledonides (9, 10, 11, 12, 13,).

The relationships between these deposits and the thin, iron-rich, relatively sulphide and base-metal depleted exhalative horizons, which occcur commonly in the same host successions have not, however, received detailed attention. Similarily the spatial relationships between volcano-stratigraphy and the various mineralogical types of exhalative mineralisation in the Caledonides have been little described. It was with the purpose of clarifying such relationships that detailed investigations of exhalative mineralisation in the Skorovas area, Grong Region, were begun by the authors in 1974.

The Skorovas orebody is situated at the volcanic level within the Gjersvik eruptive Group of Lower to Middle Ordovician age which comprises the core of the Gjersvik Nappe, a subordinate structural element of the Köli Nappe sequence in the Central Norwegian Caledonides. (Fig. 1), (10).

The excellent exposure provided by the present level of erosion in combination with the effects of polyphase deformation has facilitated the recognition of two related modes of exhalative hydrothermal mineralisation. The first, which may be defined as the "intensive" mode, is represented by the pyritic sulphide orebody of Skorovas itself, containing economic concentrations of zinc and copper (magnitude 10^7 tons, of 1% Cu, 1,5% Zn).

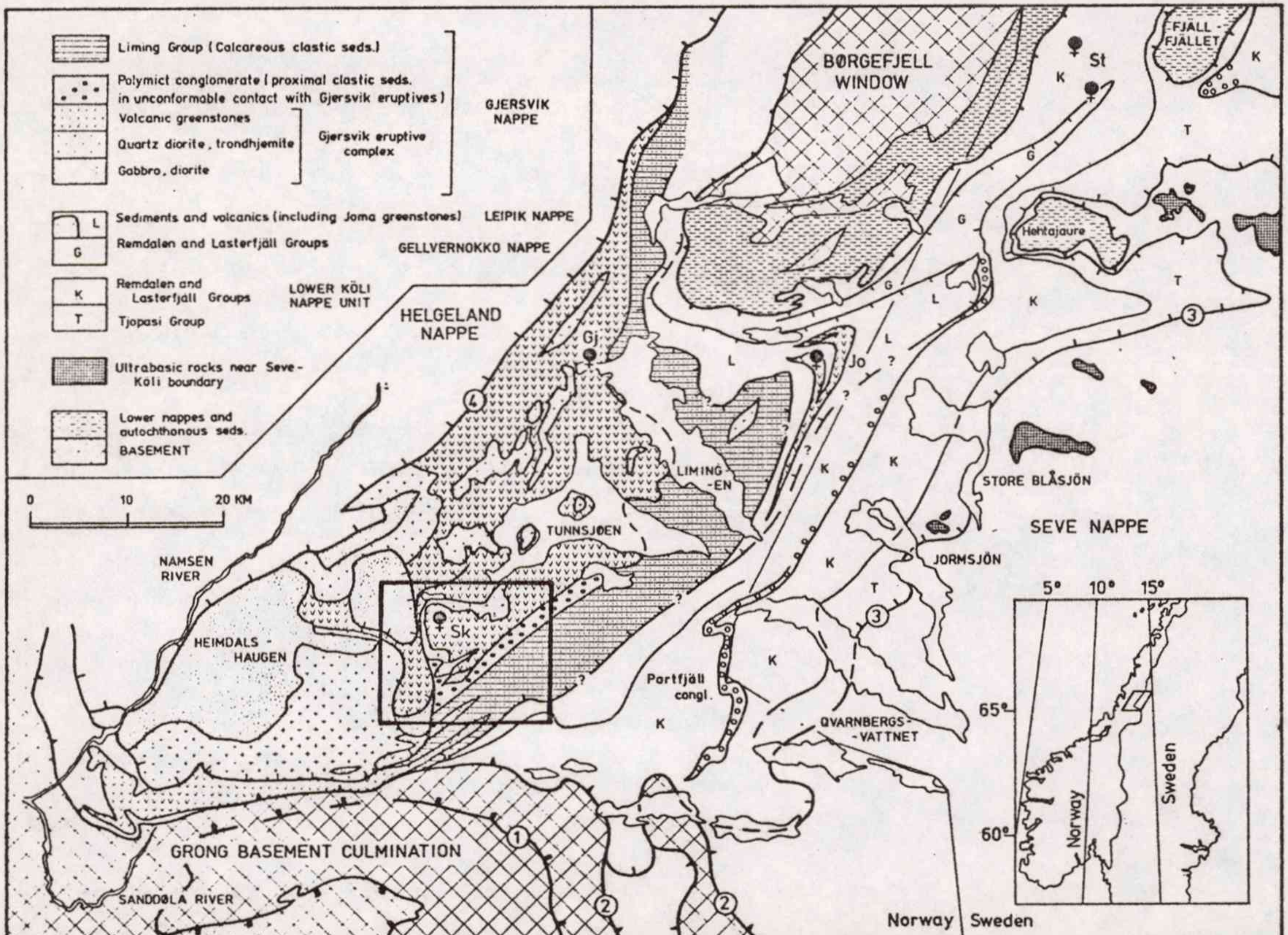


Fig. 1 Map showing location of main ore deposits in Grong–Stekenjokk district (Sk, Skorovas, Gj, Gjersvik, Jo, Joma and St. Stekenjokk) and main structural and stratigraphic units that can be distinguished within Köli Nappe. (1) Thrust at base of Olden basement nappe; (2) thrust at base of Seve–Köli Nappe; (3) thrust separating Seve and Köli sequences within Seve–Köli Nappe Complex; (4) thrust separating Gjersvik Nappe at top of Köli Nappa sequence from high-grade metamorphic rocks of Helgeland Nappe Complex. Boundaries based on geological information from Foslie, Oftedahl, Zachrisson, Gee and Gustavson

(From Halls et al, 1977)

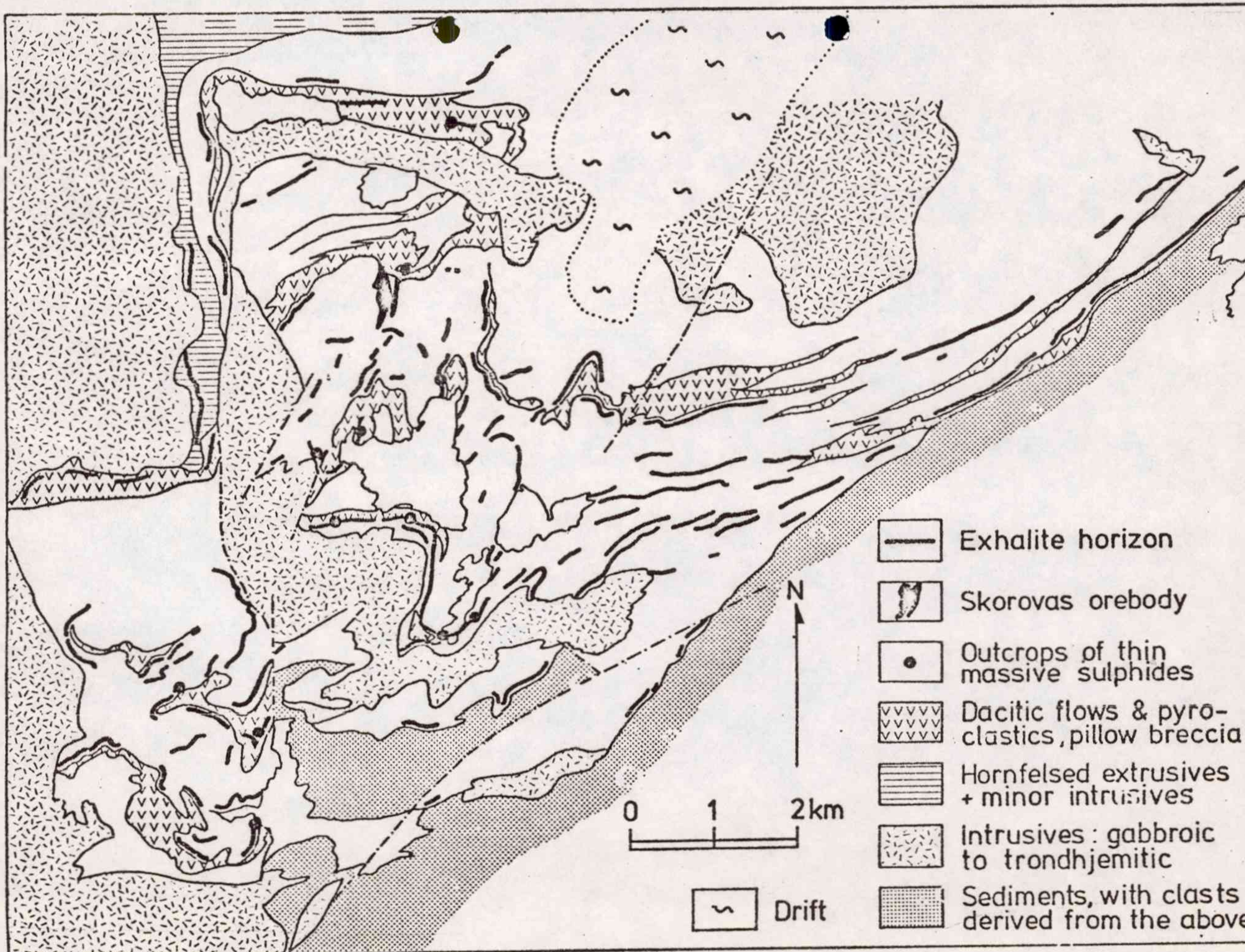

N
0 1 2km
Drift
Exhalite horizon
Skorovas orebody
Outcrops of thin massive sulphides
Dacitic flows & pyro-clastics, pillow breccia
Hornfelsed extrusives + minor intrusives
Intrusives: gabbroic to trondhjemitic
Sediments, with clasts derived from the above

Fig. 2.

The morphology and mineralogy of the orebody is interpreted as the result of direct deposition from metalliferous brines under reducing conditions in a submarine topographic trap in the vicinity of an eruptive centre. The second mode of mineralisation is represented by thin, laterally extensive chemical-sedimentary horizons which are interbanded within the sequence of basaltic to andesitic flows and acid pyroclastic units. Iron and manganese oxides, sulphides and silicates, together with quantities of ferruginous chert are the principal constituents of these horizons which are interpreted as the result of precipitation of Fe-Mn and silica hydrosols following wide dispersal of exhaled fluids into the oxidising marine environment.

The scale of dispersal involved in the formation of the "extensive" exhalite horizons is apparent from their distribution over an area of at least $150km^2$ around the Skorovas orebody with maximum traceable strike lengths of the order of 10km. (Fig. 2). The variations in the internal stratigraphies of the extensive exhalite horizons ranging from single beds of ferruginous chert to complex laminated sequences involving chert, silicates, sulphides and oxides, demonstrates that hydrothermal dispersal was in some cases the result of isolated single events and in others that an extended episodic process was involved.

The distinctive mineralogies and competent behaviour of the extensive exhalite horizons despite the prevailing conditions of strong deformation and greenschist metamorphism make them reliable time-stratigraphic markers in the inherently variable volcanostratigraphy of the Gjersvik Group. The mappable stratigraphic connection between the Skorovas orebody and certain extensive exhalite horizons demonstrates a genetic connection between the two modes of mineralisation and the potential value of the extensive horizons as a tool in exploration as well as in stratigraphic contról. In this paper a preliminary account is given of the morphology, mineralogy and stratigraphic relationships between extensive and intensive exhalite horizons in the Skorovas area.

The extensive exhalite horizons have been classified into five types according to characteristic mineralogies and textures, the following being in order of decreasing abundance within the area: a) Siliceous (hematite - magnetite cherts), b) Silicate (epidote or stilpnomelane + magnetite, pyrite, silicates. Laminated with thin cherts.), c) Oxide - carbonate (magnetite interbanded with quartz - carbonate), d) Oxide - sulphide

Distribution of exhalite types in the Skorovas area.

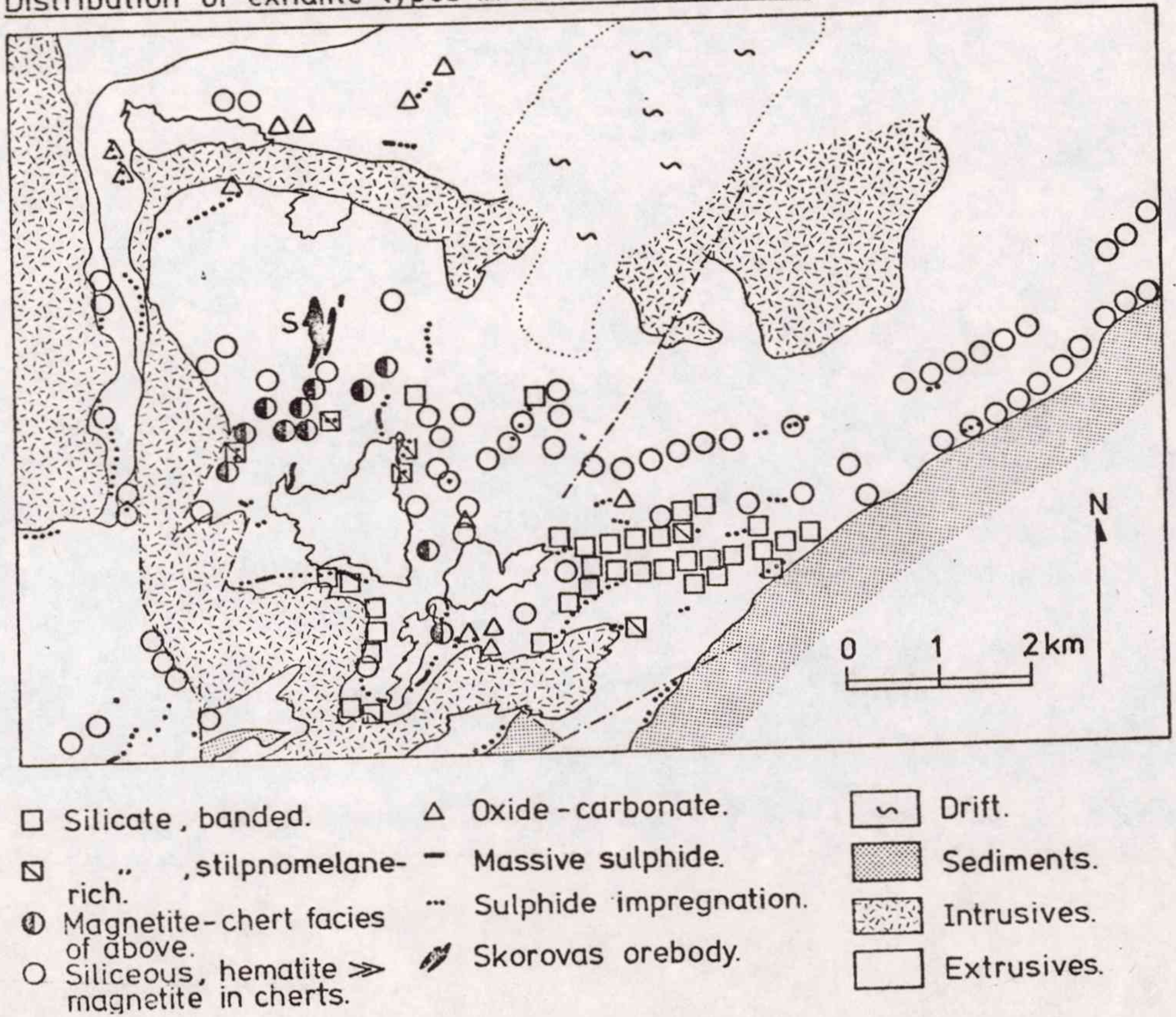


Fig. 3

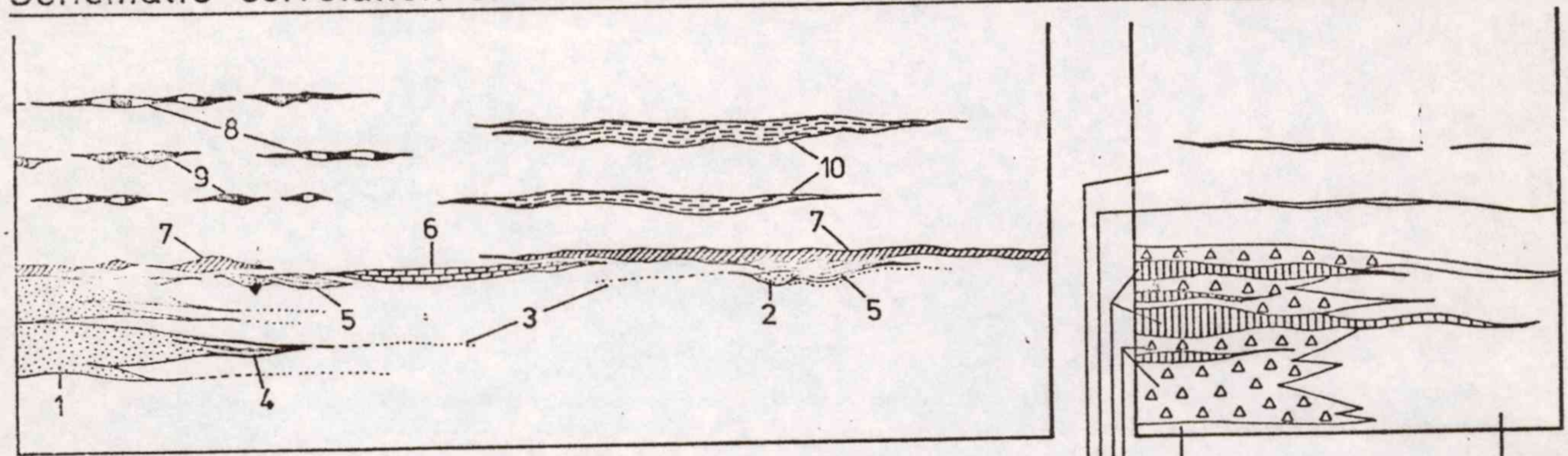
(magnetite $\geqslant$ pyrite. Banded porphyroblastic texture), e) Massive sulphide ($>$ 40% pyrite, + quartz $\pm$ carbonate, commonly sedimentary-banded).

An accurate assessment of the physico - chemical conditions under which exhalite horizons were deposited is hindered by post - depositional processes including diagenesis, regional metamorphism amd local thermal metamorphism, the effects of which have been to a varying degree superimposed on the primary mineralogy of the precipitate. However, in the Skorovas area, it is evident from field and petrographic evidence that the exhalite horizons have suffered a maximum of greenschist facies regional metamorphism, a grade no higher than that reached during seafloor metamorphism in diagenesis (10). Such evidence, including the preservation of delicate early diagenetic textures by hematite and magnetite crystallites in cherts, suggests that the observed mineralogies are not far removed from the diagenetic mineralogies, and that the processes of refabrication have to a large extent been isochemical.

It is evident that the distribution of the various exhalite types in the Skorovas area (Fig. 3) is controlled by changes in the nature of exhaled fluids during the eruptive history, and by the variation of physico - chemical conditions in the submarine environment, which appear to be governed chiefly by variations in relief of the sea - floor.

A model is proposed for the sequence of exhalative and eruptive events, summarized schematically in Fig. 4, whereby early iron - saturated, silica - rich chloride - bicarbonate fluids were expelled relatively rapidly and continously during the waning stages of the main phase of acid pyroclastic ejection. This resulted in the precipitation of large base metal - rich sulphide bodies in reducing traps in the vicinity of the main exhalative centre and of thinner base metal - poor sulphide bodies from diluted fluids in traps at a greater distance from the exhalative centre. The rarity of graphitic horizons in the Skorovas area suggests that the contribution made by sulphate - reducing bacteria towards the formation of the orebody was probably negligible, but may have been significant in the case of certain base metal - depleted sulphide lenses in which graphitic schist occurs in thicknesses of up to 10cm. underlying the sulphidic zones. Otherwise, the activity of organisms during quiescent periods in the extrusive history is suggested by the common occurrence of filamentous algal, Girvanella - like textures

Schematic correlation of exhalative and extrusive events, Skorovas area.



10 Banded silicate exhalites.

9 Proximal facies of above, stilpnomelane ± pyrite.

8 " " " , magnetite chert.

7 Hematite-rich siliceous exhalite.

6 Oxide-carbonate exhalite.

5 Oxide-sulphide exhalite.

4 " " : marginal facies of orebody.

3 Sulphide impregnation.

2 Distal, base metal-depleted massive sulphide.

1 Base metal-rich massive sulphide.

Lower lavas, epidote generally > carbonate, massive or pillowed.

Agglomerates + pillow breccias.

Acid flows + fine-grained tuffs.

Thin fine-grained tuffs.

Upper lavas, commonly carbonate-rich, massive or pillowed.

(Vertical scales greatly exaggerated)

Fig. 4

preserved in siliceous and silicate exhalites, and possibly by pyrite framboids in distal sulphidic exhalites although the origin of such structures is still in debate. The banded sulphide - oxide facies of the orebody and equivalent distal horizons are considered to have been formed at the margins of the vent - proximal traps and in small distal traps respectively, where supply of fluid from the exhalative centre, possibly including smaller satellite centres, was discontinuous and where physico - chemical conditions fluctuated though remaining generally reducing. The banded oxide - carbonate exhalites, commonly occurring peripheral to thin base metal - depleted sulphide lenses, are also considered to be the result of precipitation from diluted fluids, but within shallow basins where relatively unrestricted circulation of seawater resulted in greater dilution and fluctuating, marginally higher Eh and pH.

The termination of the early iron - saturated phase of exhalation was marked by the precipitaion of hematitic or ferric hydroxide - silica gels over extensive areas in oxidising conditions. These may have precipitated from relatively iron - depleted late stage fluids, or from an extremely diluted fraction of the early fluids which was formed as a result of turbulent dispersal from the exhalative centre. At short stratigraphic intervals above and below, and distal from the Skorovas orebody, the occurrence of numerous minor turbulent exhalative episodes involving silica - rich fluids gave rise to restricted horizons in which chert fills the interstices between pillow lavas. The extensive hematitic chert horizons occur at the stratigraphic top of the orebody and in close association with acid extrusives which are distal, but stratigraphically equivalent to the orebody and its host agglomerates and acid extrusives. Rarely, in situations peripheral to outlying massive sulphide horizons, such exhalites are underlain by manganese oxides in thicknesses of up to 5cm. The deposition of the siliceous gels was followed by a protracted period of quiescence in volcanic activity during which they underwent lithification. This is demonstrated by the local occurrence of angular chert fragments in stratigraphically overlying extrusives.

During the final stages of volcanic activity in the Skorovas area, fluids rich in dissolved silica, iron and clay forming components were emitted episodically during an extended period. In the vicinity of the main extrusive centre and stratigraphically above the orebody this resulted in the precipitation of thin discontinuous horizons composed of iron - silica gels or iron - rich clay mineral assemblages intercalated between individual lava flows. These are present as black or grey magnetite chert and stil - pnomelane/ stilpnomelane - pyrite horizons respectively. In the distal environment, their equivalents are the rhythmically banded silicate exhalites, containing epidote as the major silicate together with quartz, feldspar and subordinate sheet silicates, garnet, stilpnomelane and/or tremolite - hast - ingsite. The epidote - rich silicate bands of these exhalites are distinctively pink or maroon - brown in colour due to the inclusion of clusters of sub - micron sized crystals of hematite within the core zones of individual epidote grains. Rarely, a restricted development of such exhalites occurs peripheral to or in contact with the earlier siliceous exhalites. The banded silicate exhalites are interpreted as having been formed by rhythmic deposition of thin laminae composed of silica gel, hematite/ferric hydroxide or clay minerals in placid, relatively oxidising conditions. The separation of the various components making up the laminar couplets is attributed to an Eh/ pH - controlled mechanism operating during the precipitation process, or to the differing hydraulic equivalence and settling rates of the colloidal com - ponents within the flow regime of the exhaled solutions (14), or most likely to a combination of both these chemical and physical effects.

The supracrustal rocks of the Skorovas area are interpreted to have been formed in an ensimatic island arc of Lower Palaeozoic age (10). In order to explain the gross compositional differences and marked interlude between the silicate exhalites and other exhalite types including the Skoro - vas orebody, it is proposed that the principal sources of their components lay at different levels in the island arc structure. The components of the silicate exhalites are concluded to have been derived by leaching of Fe, Ca, Al and silica from the volcanic pile as a result of pervasive spilitization by convectively circulating fluids. Veinlets having the same distinctive min - eralogies as the silicate exhalites, including stilpnomelane and epidote with hematite inclusions, occur commonly within the extrusives, particularly in the vicinity of the orebody and the main extrusive centre. The components of the fluids which were expelled earlier to form the orebody and associated exhalite types are believed to have been concentrated in an iron - rich hyd - rous fraction at subvolcanic levels as a consequence of differentiation, while the contribution by leaching of the volcanic pile may have been minimal.

In conclusion, it has been demonstrated that detailed investigation, not only of exhalative massive sulphide orebodies but also of other exhalative sediments occurring in the same host successions, is a useful tool in exploration mapping and of importance to the expansion of existing knowledge of the role of volcanic and hydrothermal processes in metallogenesis. This is of particular relevance in environments of strong deformation, as exemplified by the Skorovas area, where investigations have provided a detailed model for the environment of the orebody and for the exhalative/eruptive history of a significant proportion of the Grong Region in the Scandinavian Caledonides.

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REFERENCES

1. Kjerulf, Th., 1879
Die Geologie des südlichen Norwegens: Kristiania 1879

2. Carstens, C.W., 1922
Der Unterordovische Vulkanhorizont in dem Trondhjemgebiet:
Norsk Geol. Tidsskr., 7, 185 - 270

3. Carstens, C.W., 1932
Zur Frage der Genesis der Norwegischen Kiesvorkommen:
Z. Prakt. Geol., 40, 97 - 99

4. Carstens, C.W., 1955
Jernmalmene i det vestlige Trondhjemsfelt og forholdet til kisforekomstene:
Norsk Geol. Tidsskr., 35, 211 - 220

5. Oftedahl, C., 1958
A thory of exhalative - sedimentary ores:
Geol. För. Stockh. Förh., 80, 1 - 19

6. Oftedahl, C., 1958
Note on gel structures in a pyrite bed, the Grong district:
Norg. Geol. Unders., no. 205, 107 - 110

7. Oftedahl, C., 1966
A manganiferous chert in the Caledonian greenstone of Trondheim:
Det Kongl. Norske Vidensk. Selsk. Forh., 40, no. 10, 48 - 54

8. Geis, H.-P., 1958
Die Genese der norwegischen Kieslagerstätten:
Erzmetall 11, 541 - 543

9. Sen, R. and Mukherjee, A.D., 1975
Volcanic exhalative type of pyritic sulphide mineralisation of Kvænangen window, Troms, Norway:
Neues Jahrb. Min., Abhdl. 125, 63 - 79

10. Halls, [illegible], Reinsbakken, A., Ferriday, I.L., Haugen, A. and Rankin, A., 1977
The geological setting of the Skorovas orebody within the allochthonous volcanic stratigraphy of the Gjersvik Nappe, Central Norway:
In Volcanic Processes in ore genesis (London: Inst. Min. Metall. and Geol. Soc.), 128 - 151

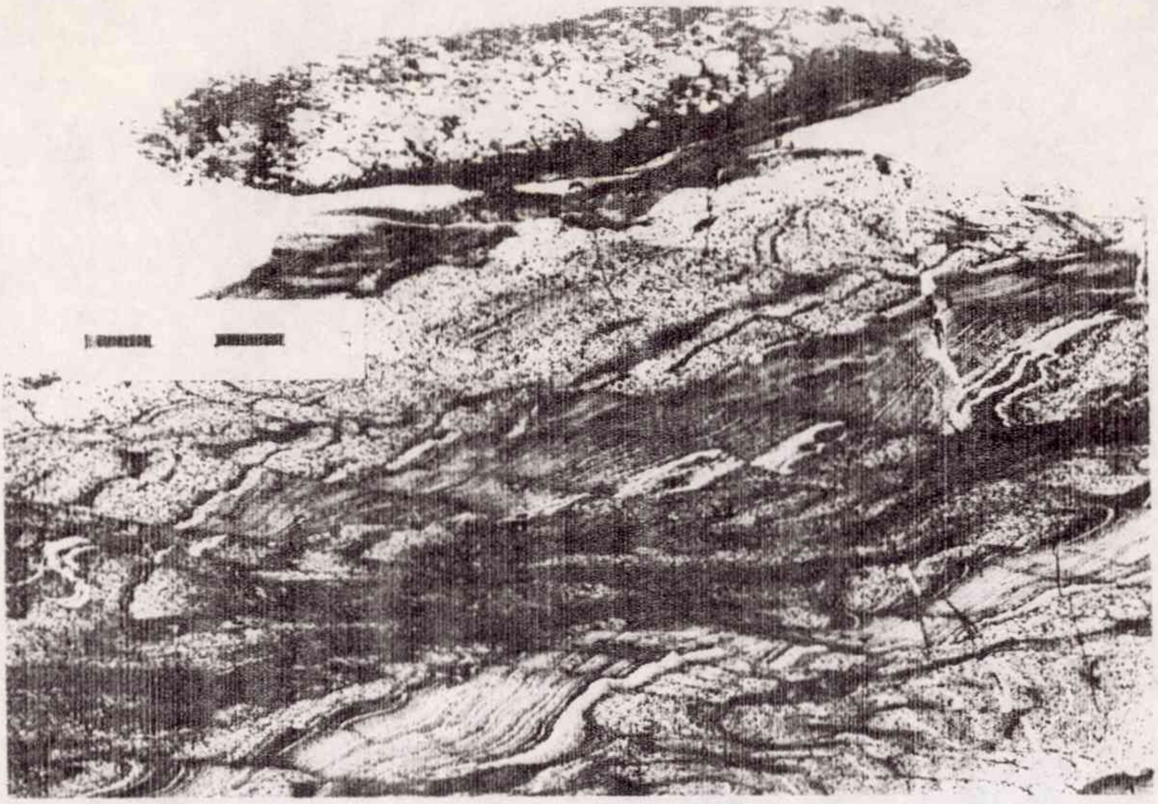
11. Rui, I., 1977
Massive sulfidmalmer knyttet til sedimentære og vulkanske bergarter i Rörosfeltet: in Symposium på Kaledonske malmforekomster, BVLI's Tekniske Virksomhet, Trondheim, 109 - 115

12. Gammeltvedt, G., 1977
Lökken - forekomsten, Sör Tröndelag:
in Symposium på Kaledonske malmforekomster, BVLI's Tekniske Virksomhet,
Trondheim, 57 - 61

13. Geis, H.-P., 1968
Geologi og petrografi på Nord Karmöy:
Norg. Geol. Unders., no. 247, 108 - 132

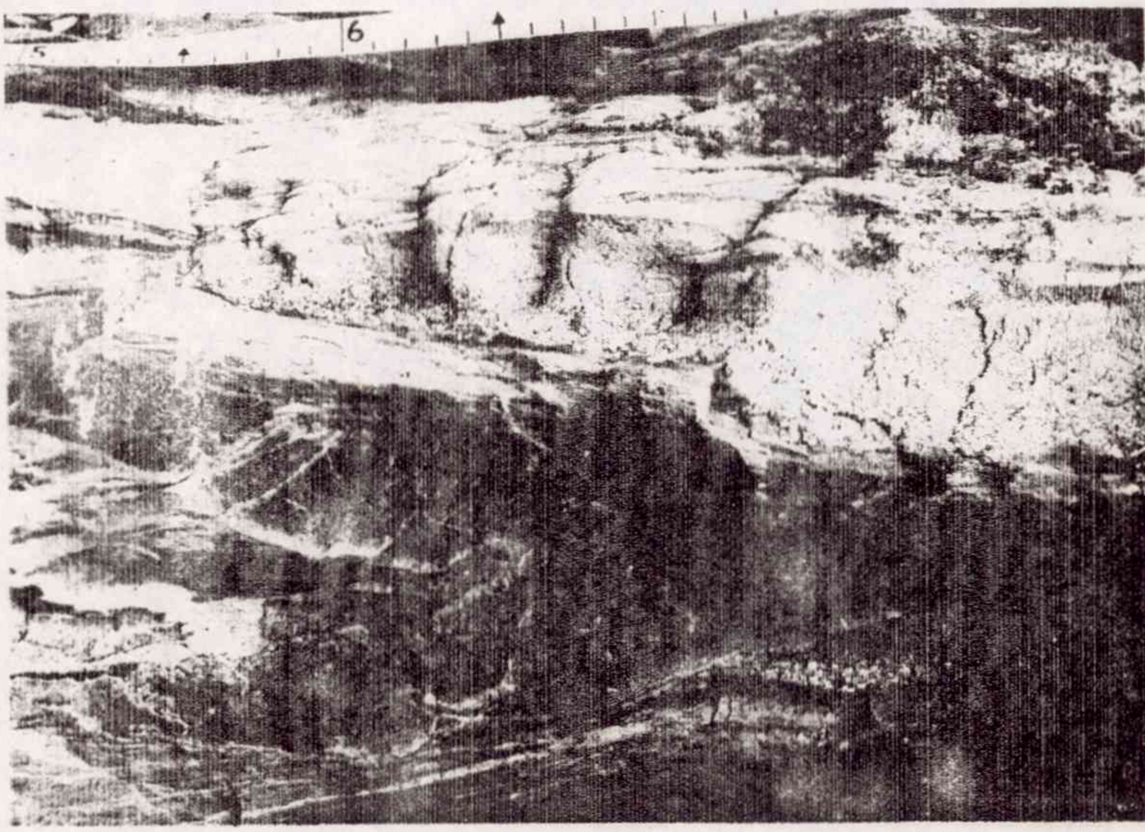
14. Turner, J.S. and Gustafson, L.B., 1978
The flow of hot saline solutions from vents in the sea floor - some impli -
cations for exhalative massive sulphide and other deposits:
Econ. Geol. 73, 1082 - 1100

A selection of field and microscopic textures of exhalative sediments from the Skorovas area, Grongfeltet.



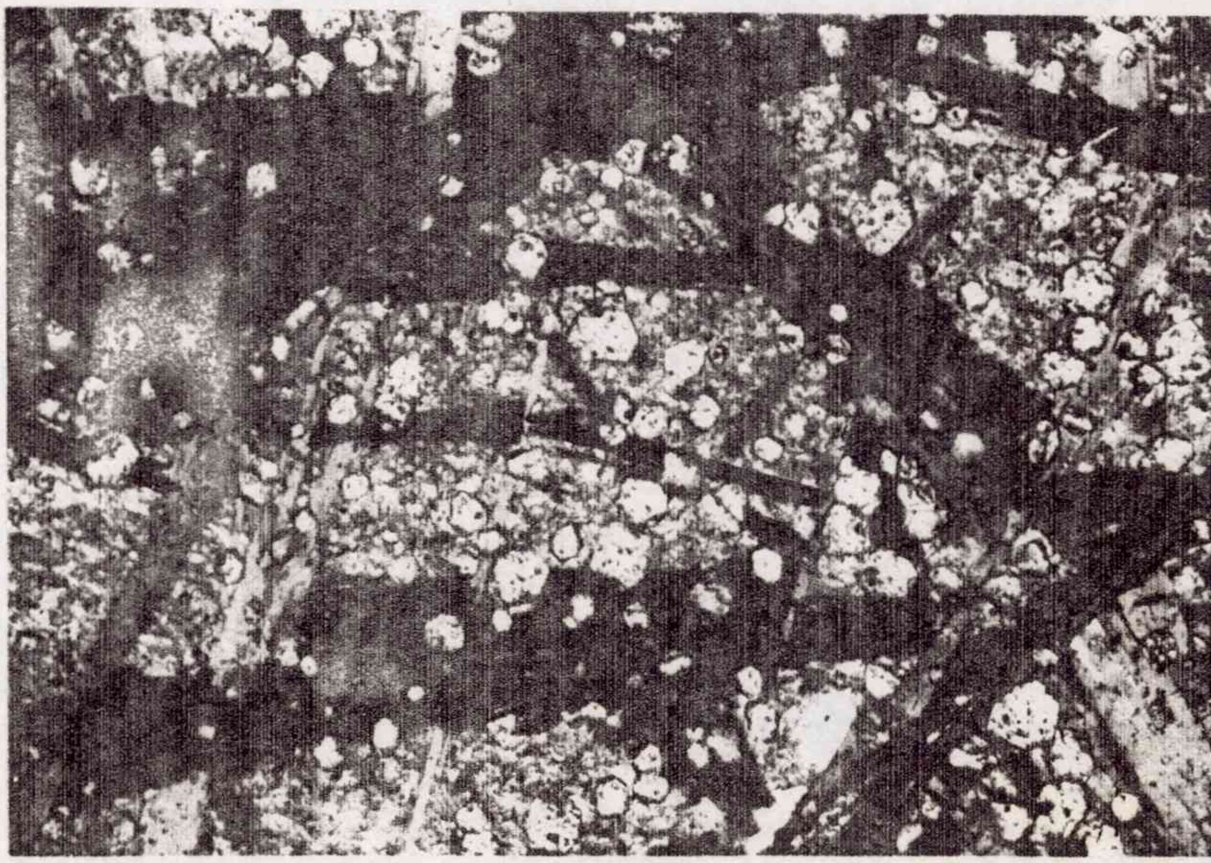
Above: Finely banded pink/brown silicate exhalite, black bands of magnetite; together with associated lapilli tuffs, E.Ø.Øverste Nesåvatnet. Scale in cms.

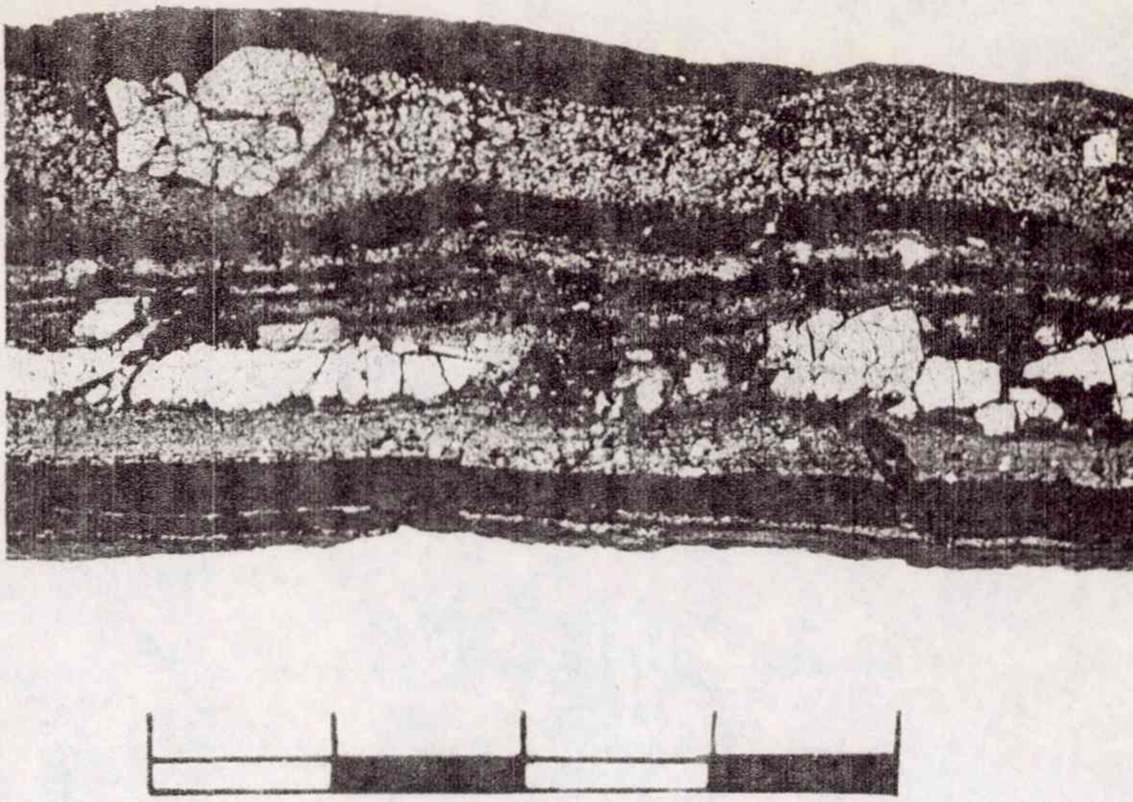
Below: Isoclinally folded chert band in silicate exhalite with graded tuffs. Location as above.



Above: Filamentous algal-like textures preerved by hematite crystallites in chert. From the Finnkrudåma area. x.

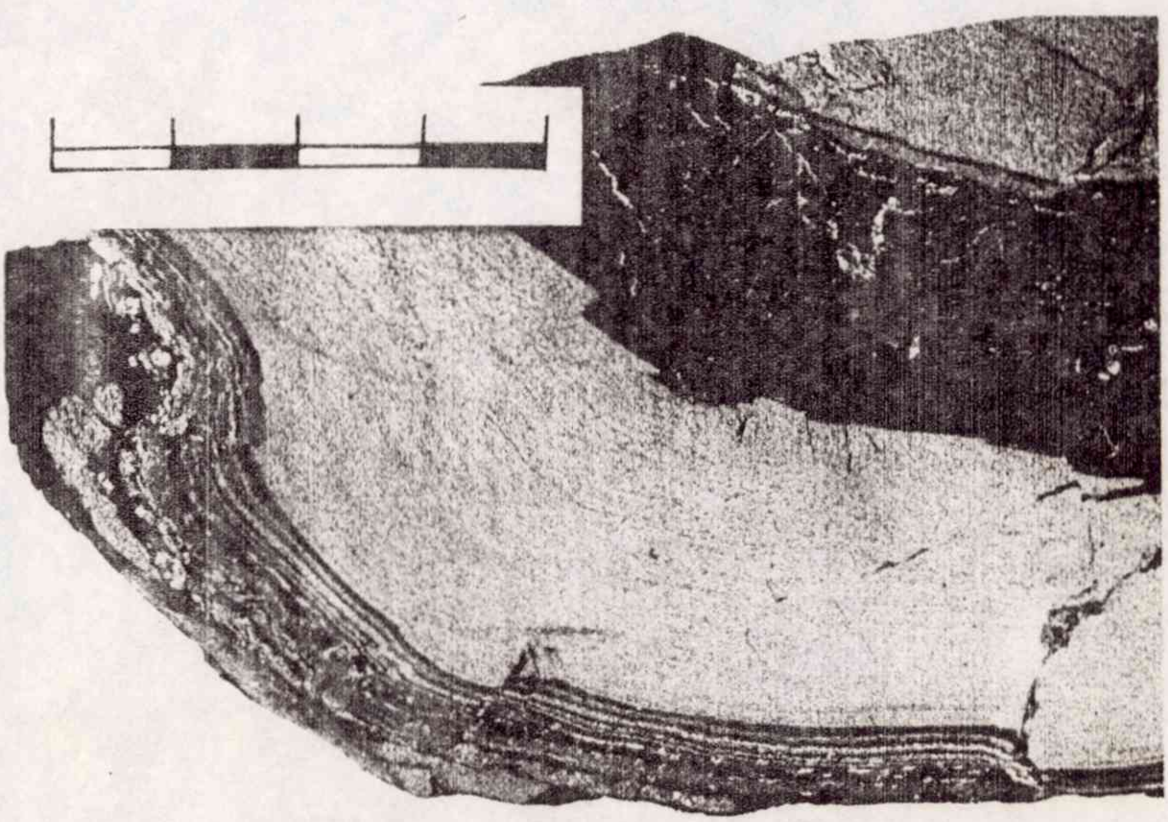
Below: Stilpnomelane (dark blades) and garnet euhedra in a chlorite-quartz-feldspar matrix. From a silicate exhalite in the Stamnestjønna area. x.

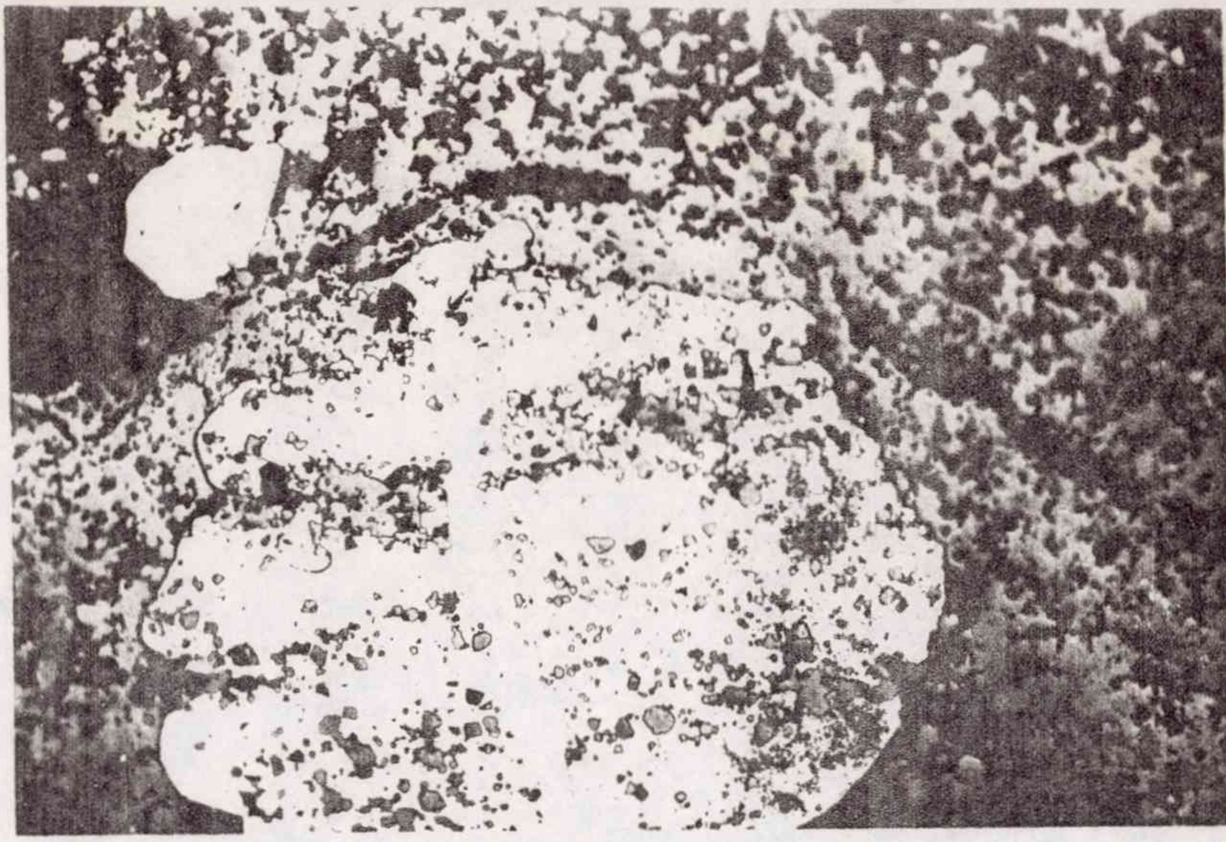




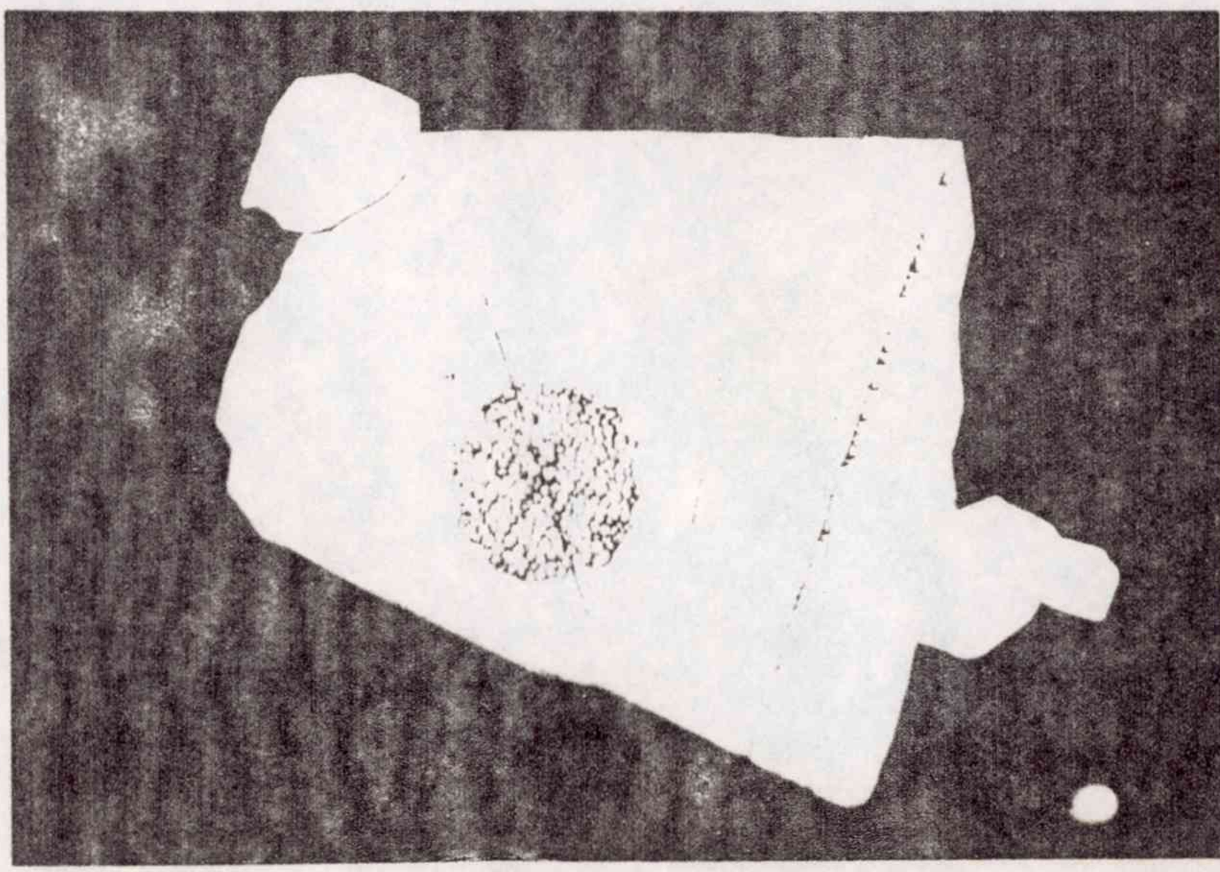
Above: Typical texture of oxide-sulphide exhalites, with tectonic cataclasis of large pyrite porphyroblasts, Blåhammer-Havdalen area. Scale in cms.

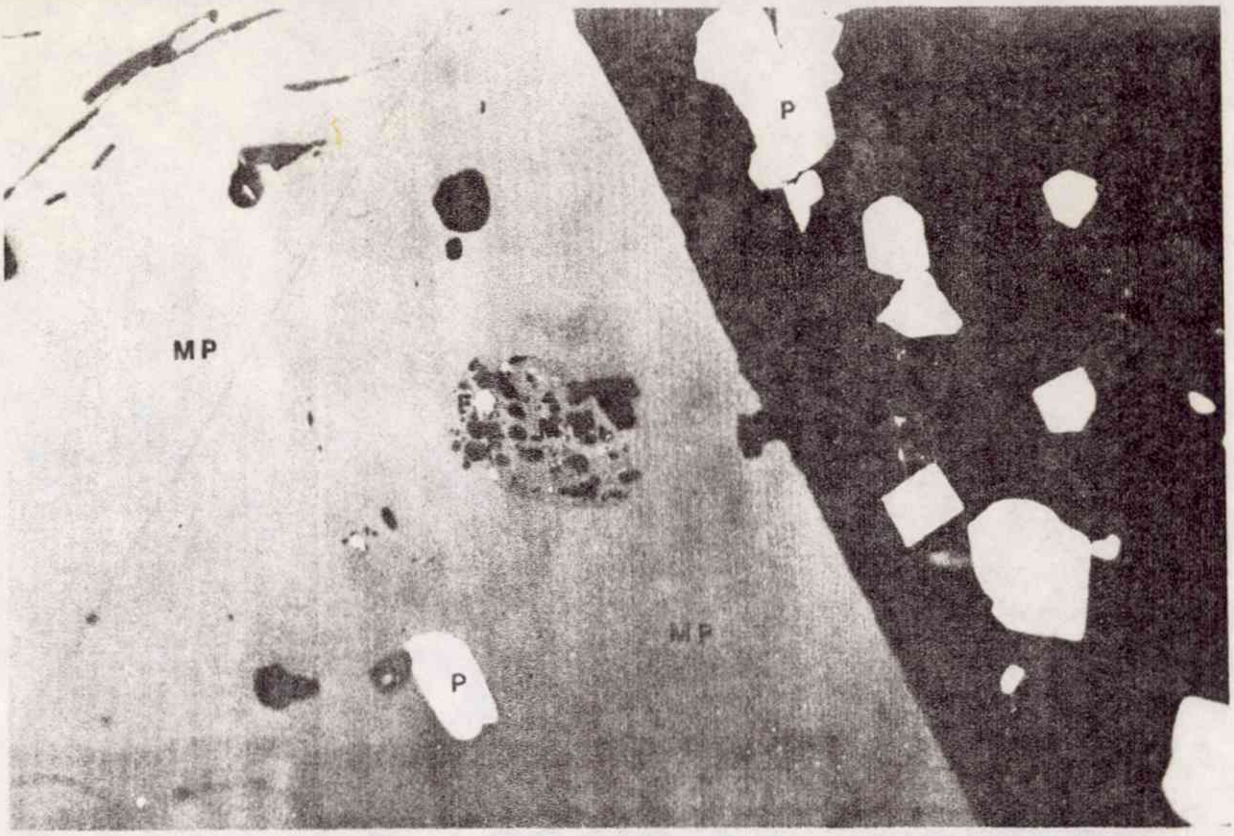
Below: Sedimentary banded, base metal-depleted massive sulphide, interbanded with silicate material composed primarily of Fe-rich chlorite, Nesåfoten, S.W. Tredjevatnet. Scale in cms.





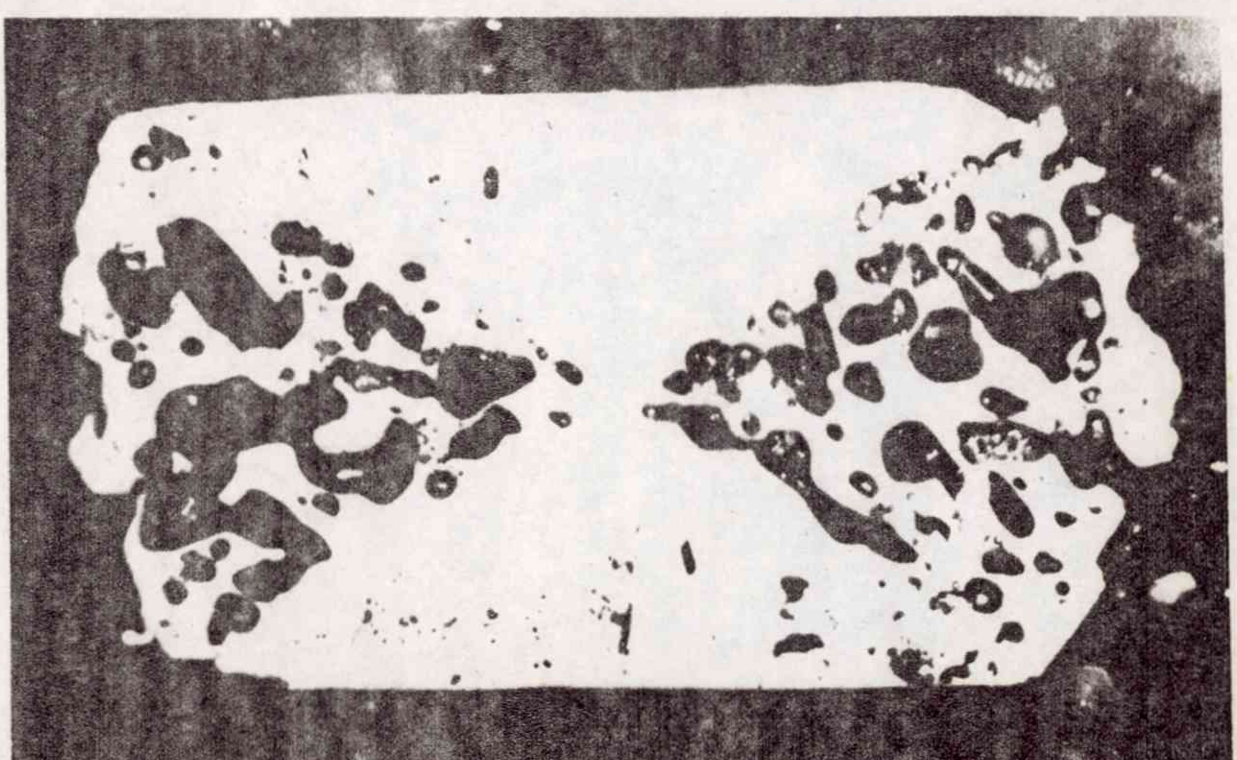
Above: Sedimentary banding in early magnetite flattened around a pyrite porphyroblast. The elongate inclusion-free zone in the porphyroblast may represent a veinlike influx of pyrite-bearing solution. 100x. From an oxide-sulphide exhalite in the Blåhammer-Havdalen area.
Below: Pyrite framboid preserved though overgrown by phase of porphyroblastic pyrite. 250x. Location as above.

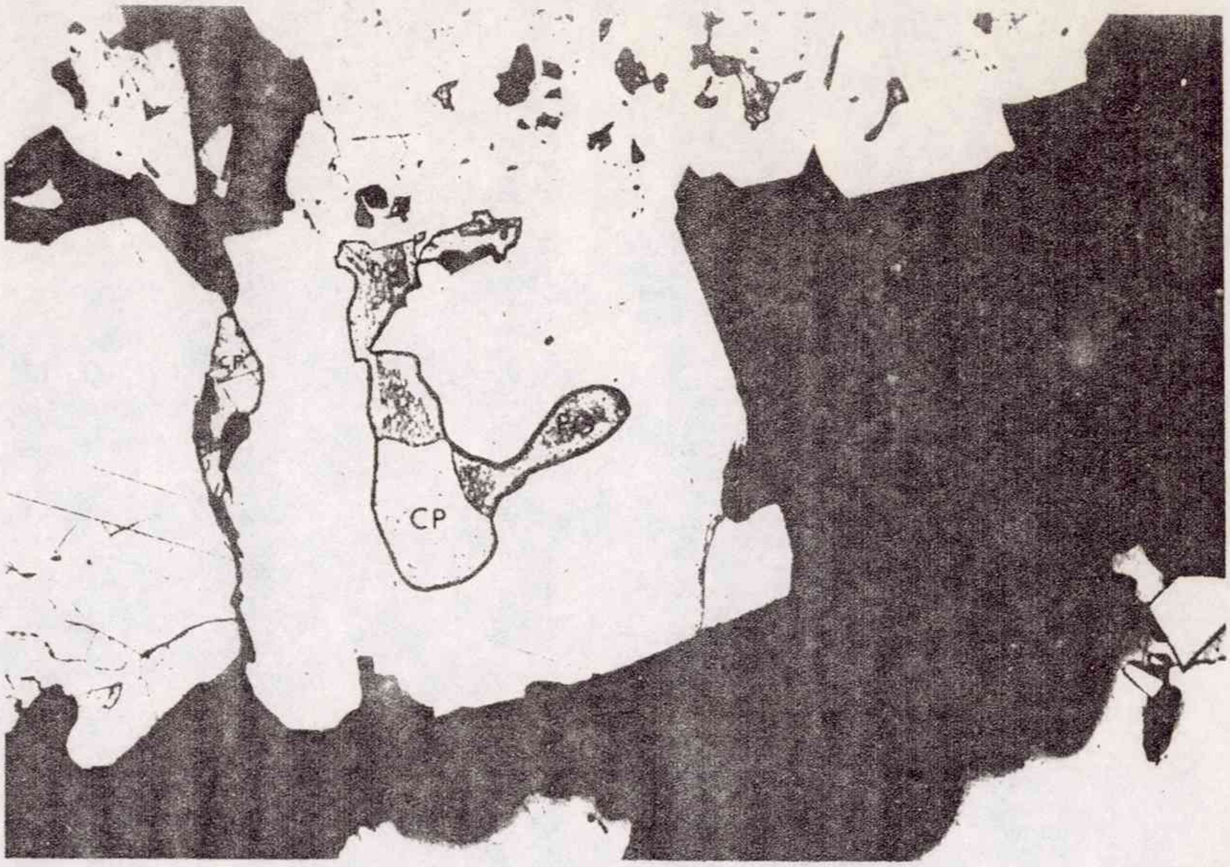




Above: Successive generations of magnetite and pyrite in an oxide-sulphide exhalite, demonstrating the complex early history of such chemical sediments. Framboidal pyrite(F) is overgrown by inclusion rich magnetite(M) while both these and a second porphyroblastic phase of pyrite(P) are included in a late mega-porphyroblastic phase of magnetite(MP). 150x. From Blåhammer-Havdalen.

Below: Early inclusion-rich magnetite with marked zonation of framboidal pyrite and silicate inclusions, probably due to early growth of twins (=⋈) followed by rapid interstitial growth. Silicate matrix. 250x. Location as above.





Above: Typical occurrence of chalcopyrite(CP) with pyrrhotite(PO) as rounded inclusions and filling fractures in pyrite porphyroblasts in oxide-sulphide exhalite. 100x. From Blåhammer-Havdalen area.

Below: Chalcopyrite(CP)-silicate intergrowth with pyrite(P) and magnetite(M). 100x. Location as above.