Bergvesenet

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Rapportarkivet

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Kommer fra ..arkiv	Ekstern rapport nr	Oversendt fra	Fortrolig pga	Fortrolig fra dato:
Elkem Skorovas AS		Elkem Skorovas AS		

Tittel

Diverse notater,artikler som beskriver Skorovas Gruber

Forfatter	Dato	År	Bedrift (Oppdragsgiver og/eller oppdragstaker)
		1959	Elkem Skorovas AS

Kommune	Fylke	Bergdistrikt	1: 50 000 kartblad	1: 250 000 kartblad
Namsskogan	Nord-Trøndelag		18242	Grong

Fagområde	Dokument type	Forekomster (forekomst, gruvefelt, undersøkelsesfelt)
Økonomisk		Skorovas Gruber

Råstoffgruppe	Råstofftype
Malm/metall	Cu,Zn,Py

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

En rekke utskrifter av foredrag/artikler om Skorovas.
Disse beskriver bedriften, dels omvisninger, dels fra oppredningsverket.
Er fra tide 1957-60 ? og ikke spesifiserte forfattere.

Kort redegjørelse for Skorovasforekomstens geologi.

Skorovasmalmen ligger, i likhet med de øvrige Grong-forekomster og Løkken-malmen, i den såkalte grønnskiferformasjonen, av ordovicisk alder. I Skorovas-området består grønnskiferformasjonen dels av relativt massiv basaltisk lava, dels av mere skifrige pyroklastiske lag, tuffer og agglomerater, avsatt i et havområde, muligens sammen med rasktxxxxxxxxxxxx nederodert og sammenskylt basaltmateriale. Alle disse lag er efter sin dannelse vært utsatt for omvandlinger i forbinnelse med den kaledonske fjellkjedefoldning, og det er nu ikke alltid lett å bli sikker på opprinnelsen av de enkelte lag. Grønnskiferformasjonen i Grongfeltet er videre, som det sees av Foslies geologiske kart (Trones), sterkt gjennomsatt av dypbergarter, av gabbroid, og granittisk (Tronhjemittisk) karakter. En profil tvers over dalen ved Skorovatn viser således, regnet fra nord: Skorovasklumpens store gabbrofelt, nedover mot dalen grønnskifre, ved bebyggelsen i Kleiva av utpreget sedimentær opprinnelse, i stigningen på sydsiden først grønnskifer, sterkt xj gjennomvevet av trondhjemittganger, over bebyggelsen og oppover mot gruva grønnskifre, dels av basaltisk art, dels av mere eller mindre pyroklaster hvorav noe av surere karakter, så selve gruveområdet med omvandlet grønnxxxxxxskifre, og malmlinser, overleiret av mere normale grønnsteiner og grønnskifre.

Det har nylig vært hevdet at Skorovasmalmen er intimt knyttet til sure, pyroklastiske lag. Det er nok så at noen slike lag forekommer, mest i nivå med heisebanen, men bergarten som omgir malmen er helt overveiende en eller annen variant av grønnskifer, og ofte sees basaltstrukturer som blærer og liknende.

Lagstillingen er i det hele nokså flat, i malmområdet heller den svakt mot øst, oppover mot toppen av fjellet blir det noe brattere, i overensstemmelse med dette sees et stadig sterkere fall mot øst sydover i forekomsten. Noen steder i malmen kan foldninger iakttas, og malmen viser, ved glidespeil og små forkastninger, at den har deltatt i tektoniske bevegelser. Noen skarpt gjennomsettende linjer sees godt på flyfotografiene over Skorovasområdet, de representerer bevegelsessoner, muligens forkastninger. En av disse skjærer over malmen i dens østlige utkiling, men vi har ennu ikke funnet bevis for noen betydelig spranghøyde. Det ser i det hele tatt ikke ut til at tektoniske bevegelser har spilt noen avgjørende rolle i utformingen av malmforekomsten.

Malmens mineralselskap er enkelt: svovelkis, kopperkis og sinkblende, litt magnetitt i enkelte lag, blyglans er en sjeldenhet. Kopperkisen viser ikke noen regelmessig fordeling i forekomsten, mens derimot sinkblenden er anriket i heng, feltheng og feltligg

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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.

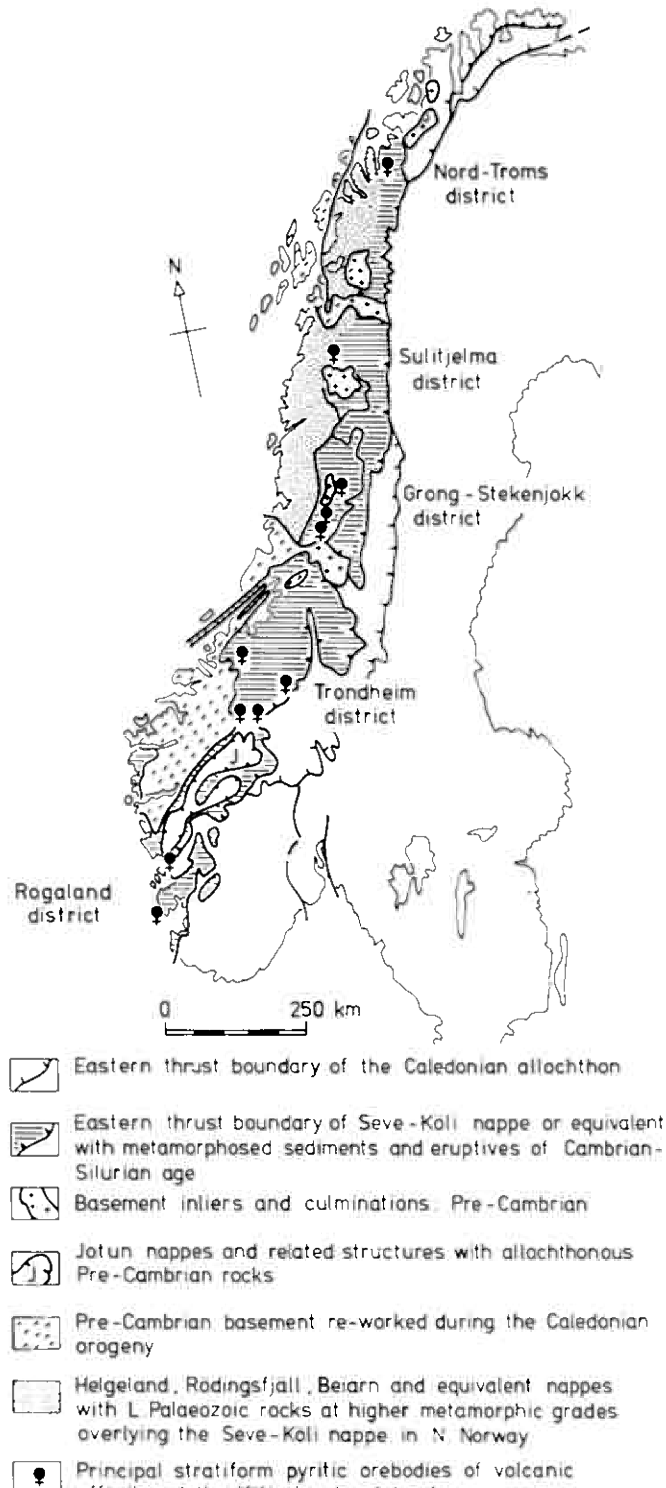


Fig. 1 Synoptic geological map of Scandinavian Caledonides showing main districts of stratiform volcanogenic ores at Köli structural level

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]

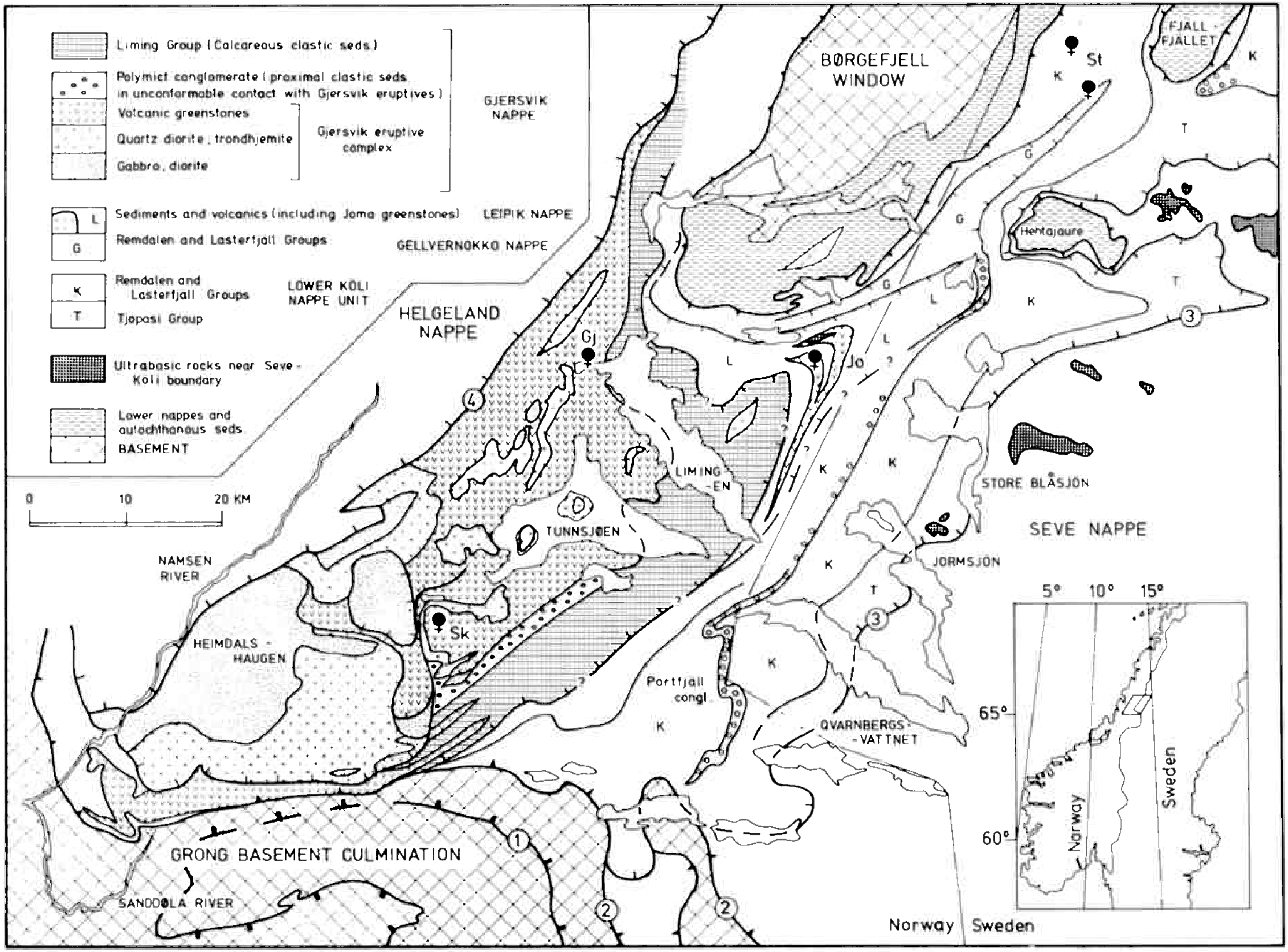


Fig. 2 Map showing location of main ore deposits in Grong–Stekenjokk district (Sk, Skorovas, Gj, Gjersvik, Jo, Joma and St. Stekenjokk) and main structural and stratigraphic units that can be distinguished within Köli Nappe. (1) Thrust at base of Olden basement nappe; (2) thrust at base of Seve–Köli 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 conglomeràtic, 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,

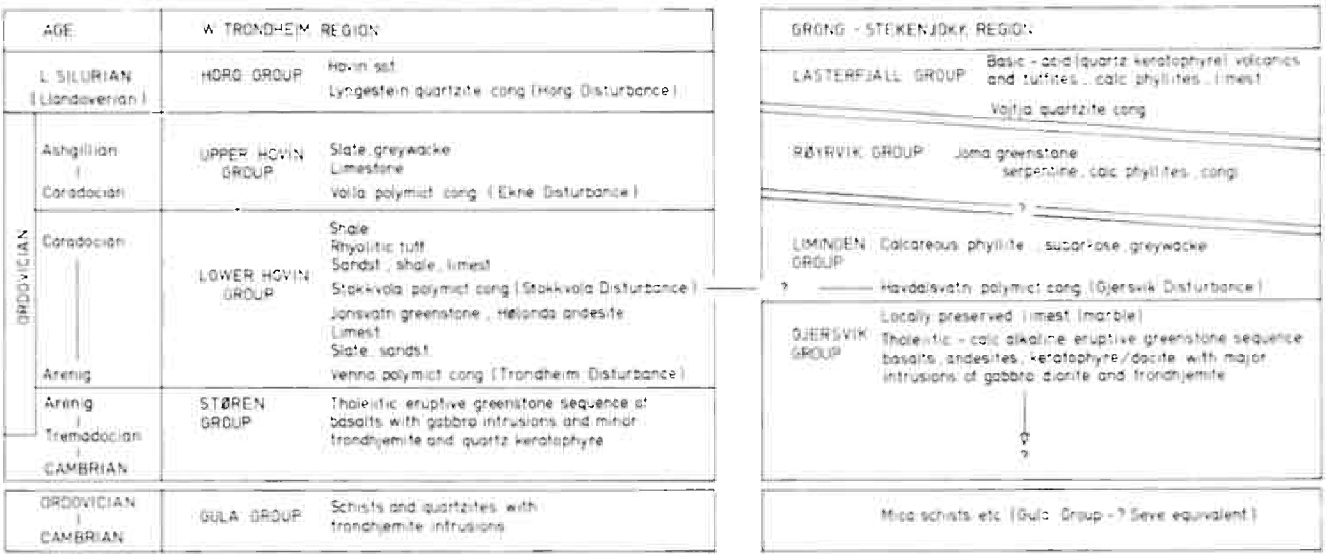


Fig.3 Inferred stratigraphic correlation between Lower Palaeozoic sequences to south and north of Grong Culmination. Correlation is approximate and based on information from Vogt,[72] Zachrisson,[82] Oftedahl [45] and Roberts.[53] Tectonic disjunction within the two areas is shown schematically by oblique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

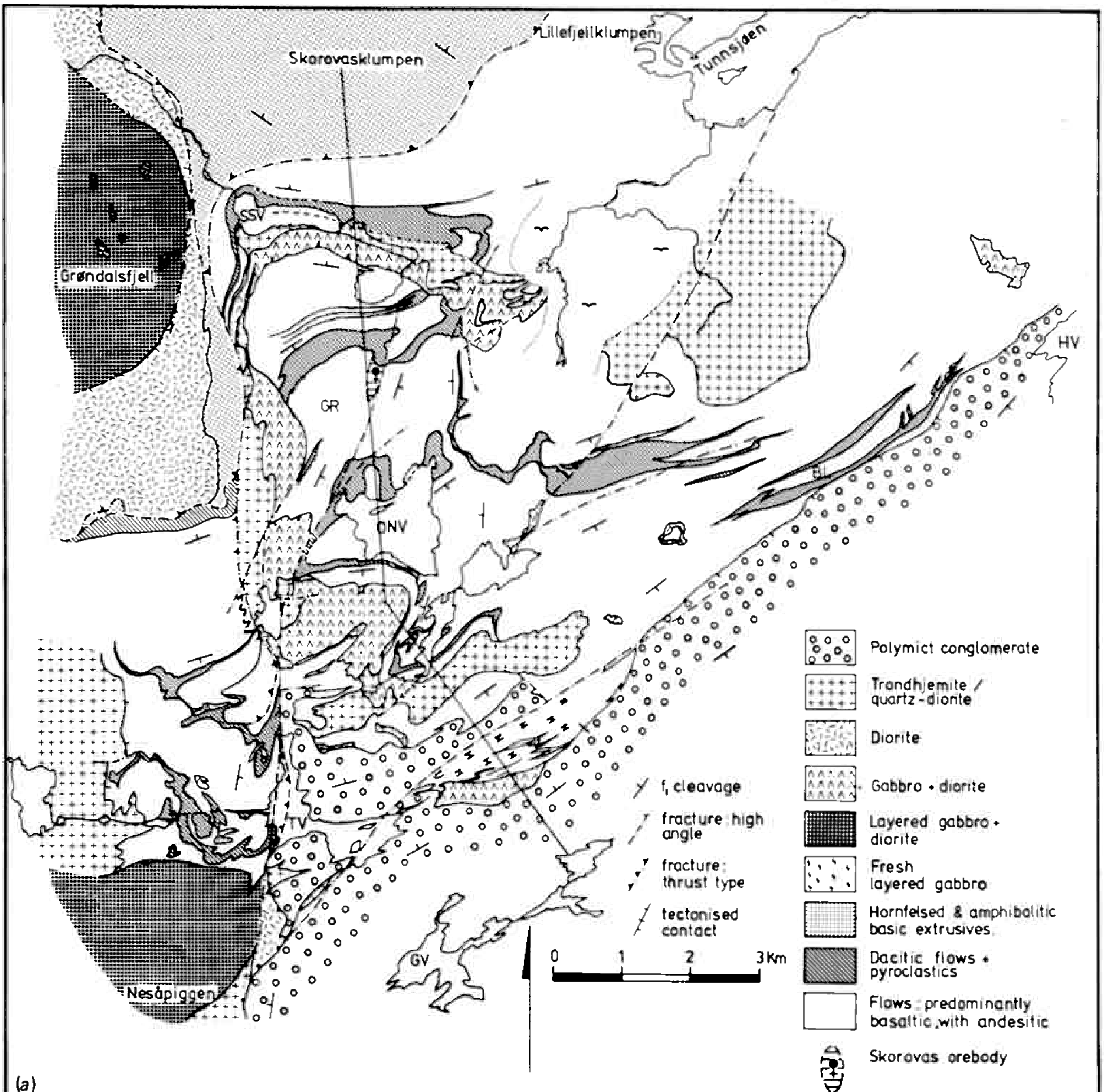


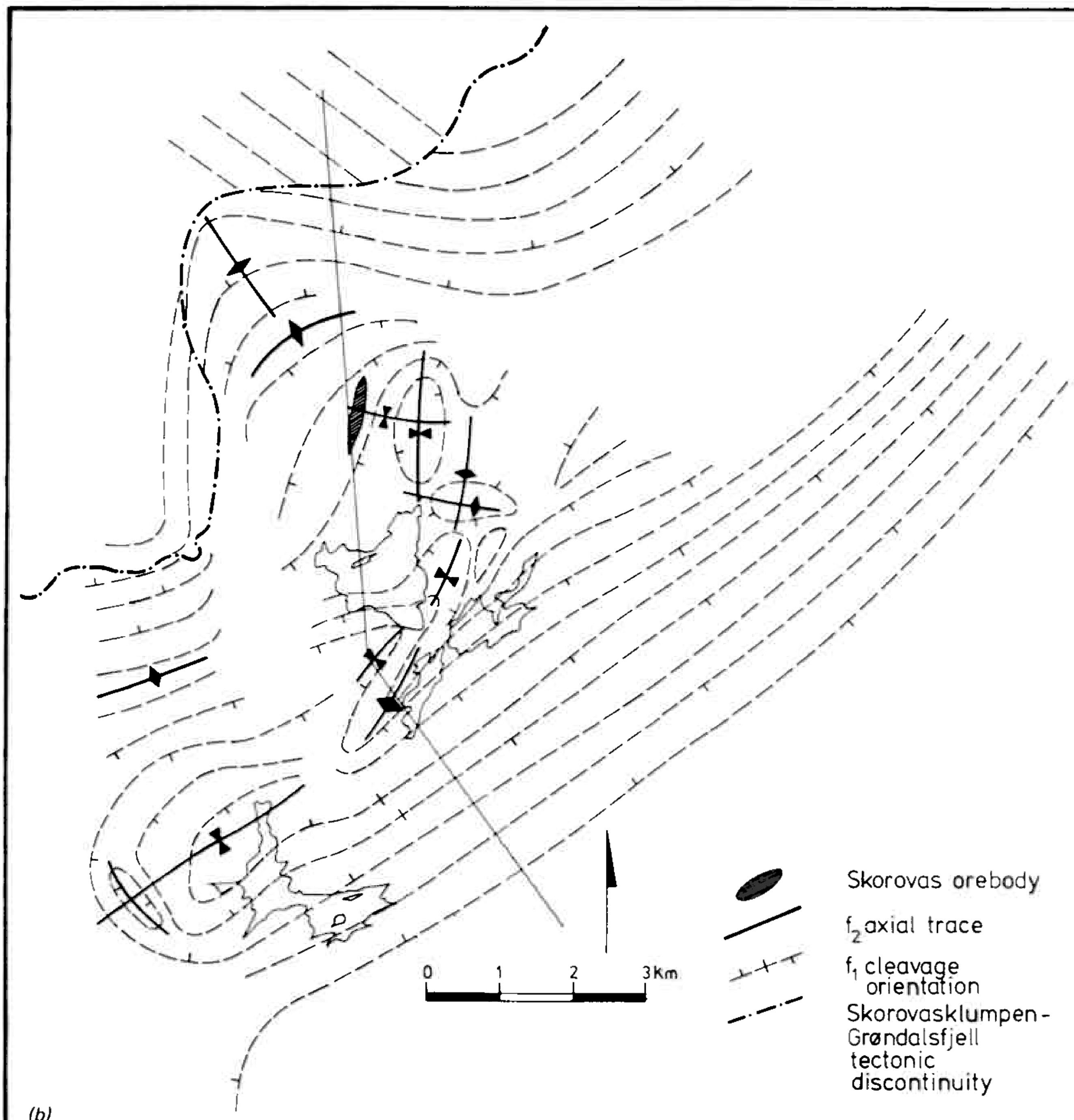
Fig. 4 Simplified geological map (*a*) of Skorovas area with line of section (Fig. 5) indicated (SSV, Store Skorovatn; GR. Grubefjellet; ONV, Øverste Nesåvatnet; TV, Tredjevatnet; BI, Blåhammeren; HV, Havdalsvatnet) and synoptic map (*b*) (see page 134) of principal structural trends

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



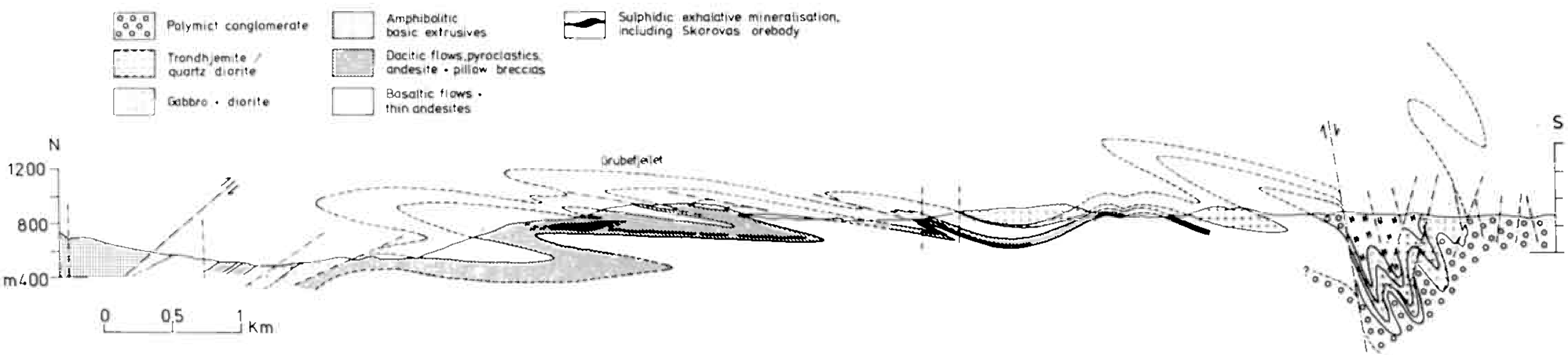


Fig. 5 Simplified geological section through Skorovas area

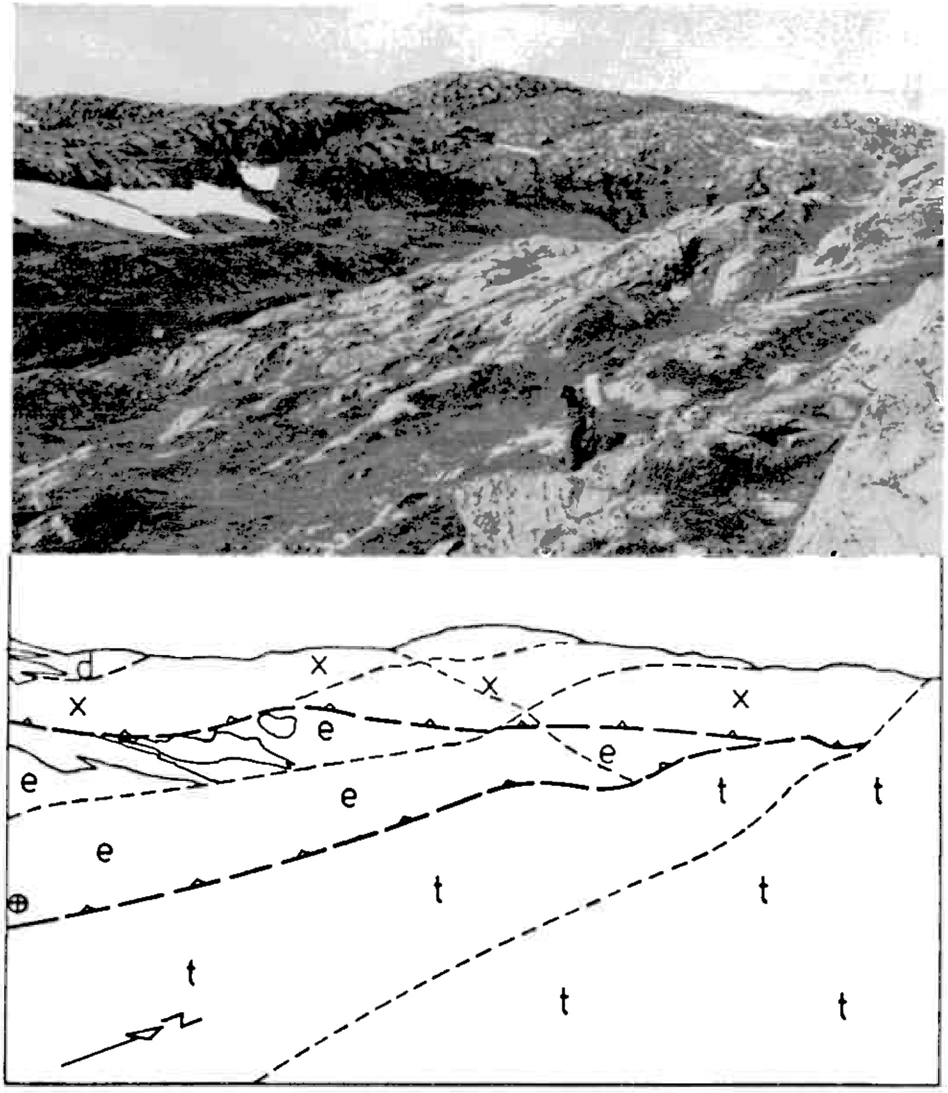


Fig. 6 Panoramic view of southeast margin of Grøndalsfjell massif seen from point of vantage on trondhjemite intrusive of Skorovas intrusive arc. Major thrust horizon separates diorite and gabbro (d) together with hornfelsed envelope (x) from structurally underlying schistose extrusives (e). A further 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

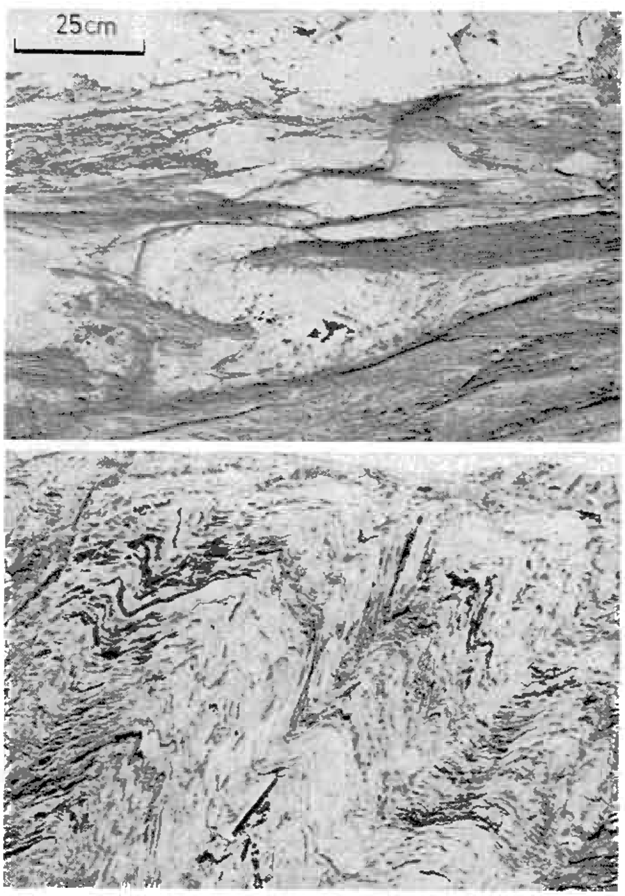


Fig. 7 Typical dislocated isoclinal style seen in minor folds of first generation in chert bands to south of Nesåklumpen (*a*) (top) and (*b*) localized post-schistosity folding and incipient crenulation cleavage of second generation formed in zone of high strain in schistose greenstones adjacent to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

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

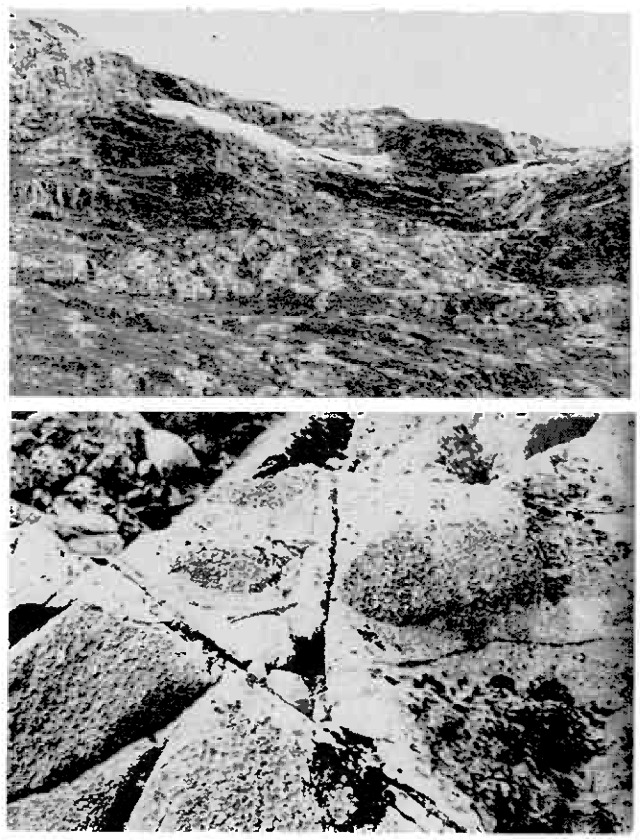


Fig. 8 Northeast face of Grøndalsfjell massif displaying occurrence of rafts of unaltered layered gabbro (dark) within dioritic matrix (*a*) (top) (rafts are of the order of 60–100 m x 200 m) and (*b*) field appearance of hydrated, uralitized envelope that borders large xenolithic masses of fresh layered 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

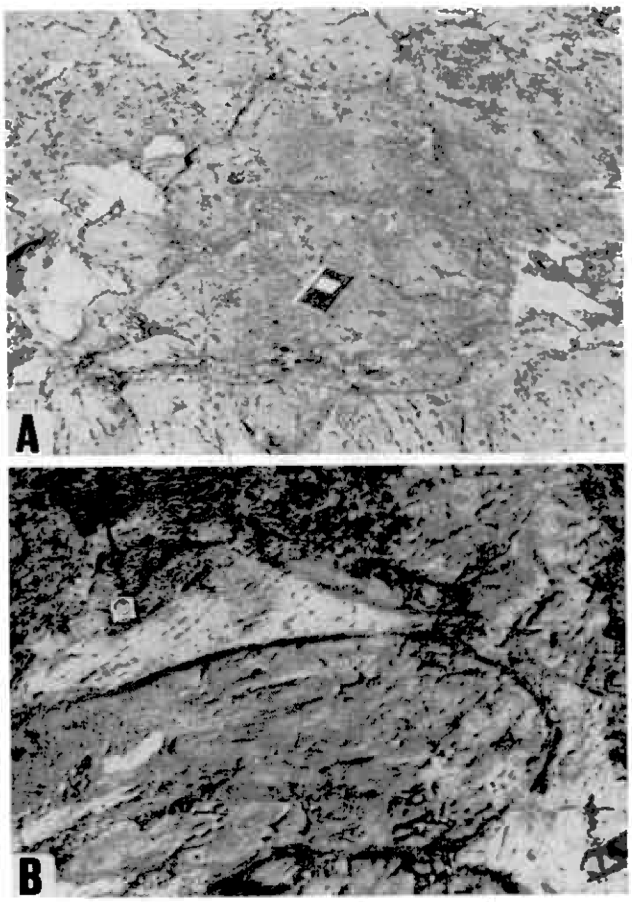


Fig. 10 *A*, Deformed basaltic pillow lavas observed on northern slopes of Grubefjell below orebody. Cuspate bodies of grey chert that occupy interstices between pillows are conspicuous. In cases of extreme deformation survival of these chert bodies within chloritic schist provides a useful guide to 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

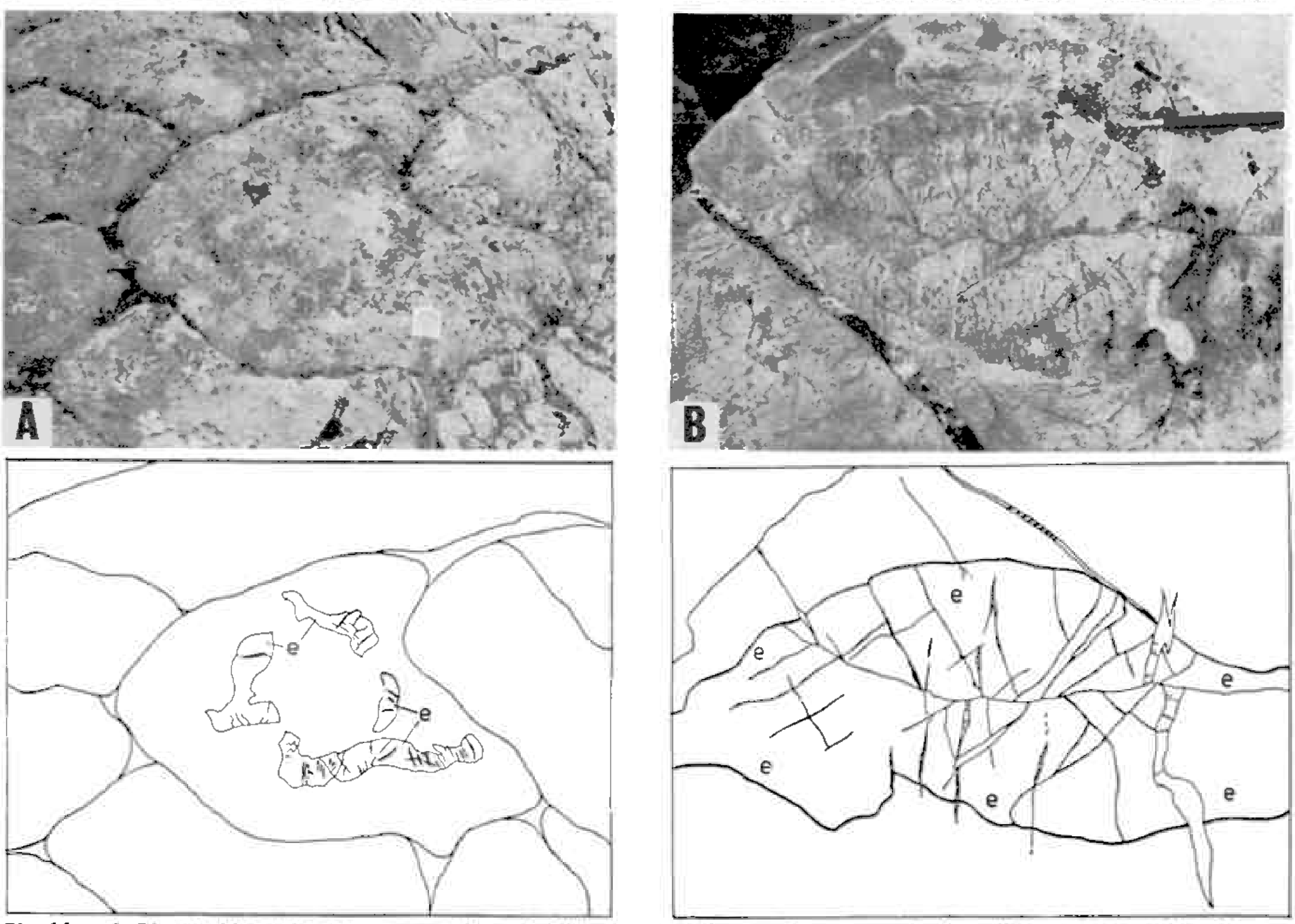


Fig. 11 *A*, Pillowed basaltic lavas from northwest of Havdalsvatn showing development of pre-deformational metamorphic segregrations of epidote-rich materials (e) parallel to pillow margins. During tectonic flattening epidote layer has responded by developing a system of brittle fractures. *B*, Lenticular 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'.

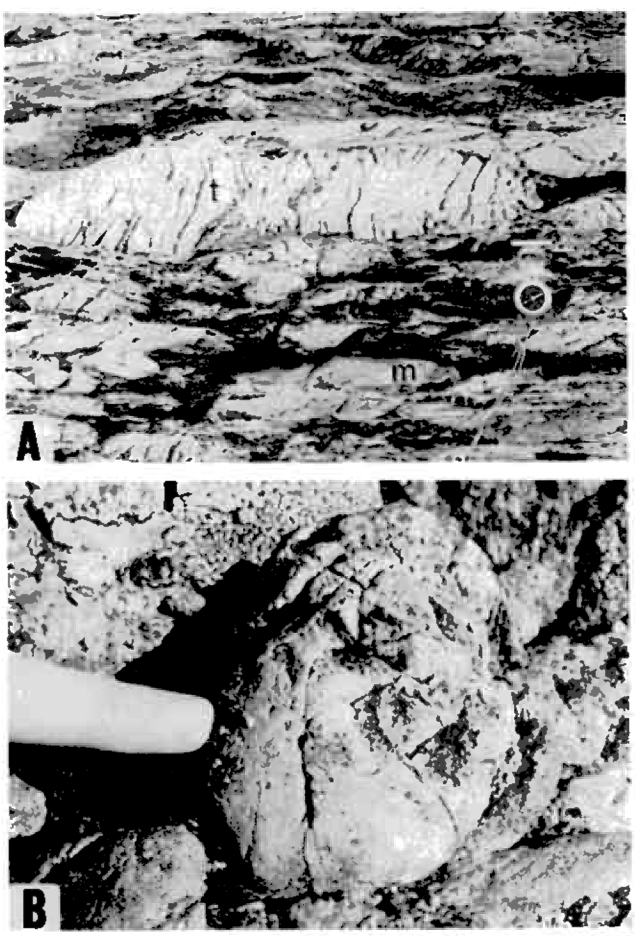


Fig. 12 *A*, Typical appearance of polymict conglomerates as seen to northwest of Havdalsvatnet. Flattened boulder of trondhjemite (t) displays tectonic fracture pattern characteristic of its brittle behaviour. Associated boulder of marble (m) has deformed in a ductile fashion. *B*, Large pebbles of 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 deformation 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.

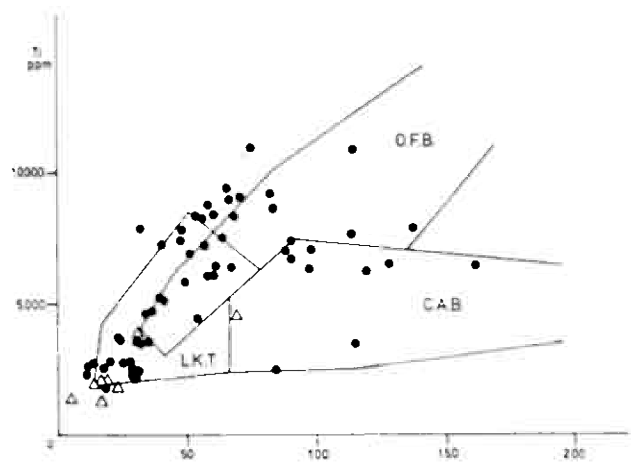


Fig. 13 Plot of Ti versus Zr contents for Skorovas basic extrusives (circles) and basic intrusives (triangles) showing abundance of low potash (island arc) tholeiites (LKT). Distinct trend towards field of calc-alkaline basalts (CAB) and grouping towards ocean-floor basalt (OFB) also shown

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.

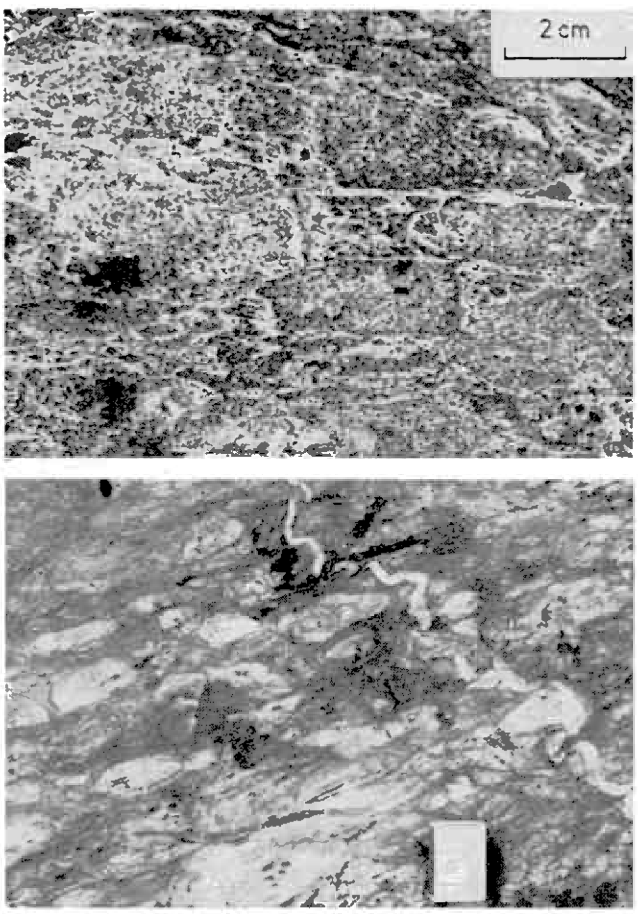


Fig. 14 Blocky pyroclastic texture (*a*) (top) seen in keratophyric flow unit on Grubefjell about 1200 m west of Skorovas orebody. Pyroclastic fragments are slightly flattened and siliceous matrix stands out as a reticular pattern. Flow is part of major acid horizon with which orebody is associated. (*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).

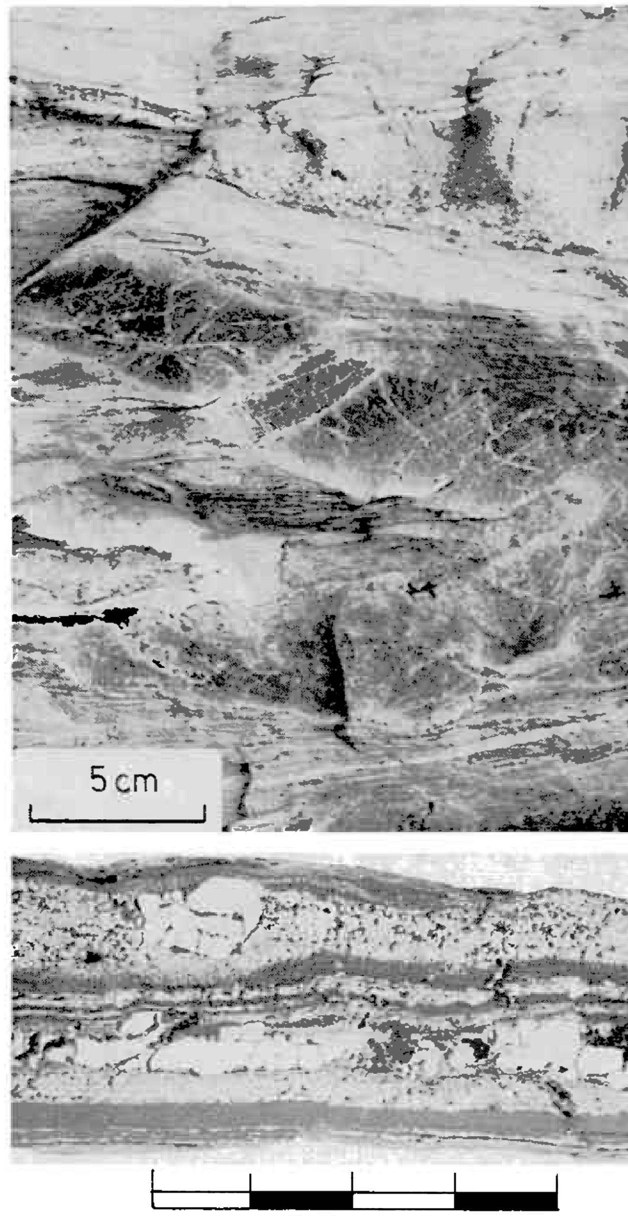


Fig. 15 Exhalite horizon (*a*) (top) 2 km east of Øverste Nesåvatn. Stratigraphic sequence is complex and made up of graded lapilli tuffs overlain by pink to brown coloured banded cherty sediments incorporating magnetite, hematite, stilpnomelane and iron-rich amphiboles. Purple chert band shows isoclinal 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 porphyroblasts 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 ≫ 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 ≫ 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

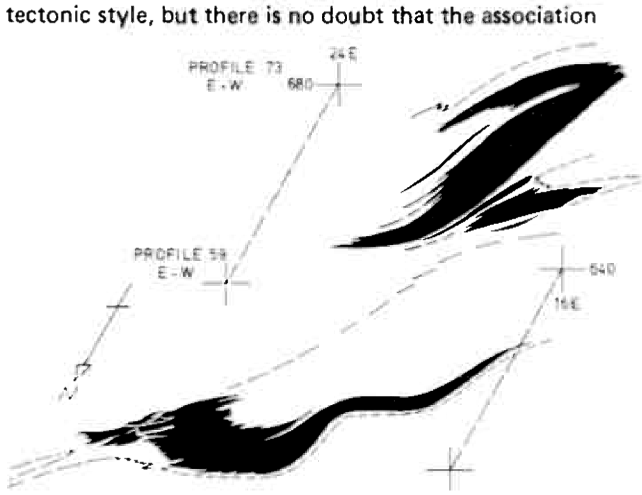


Fig. 16 Two sections of east orebody at profiles 59 and 73 east–west situated 140 m apart along morphological axis of orebody. Progressive development of a first-phase isoclinal fold is illustrated together with complex digitated style of isoclinal closures. Open style of second fold phase shown by undulation 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 ≫ Pb. Zinc content is of the order of 2 wt % and Cu ⩽ 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

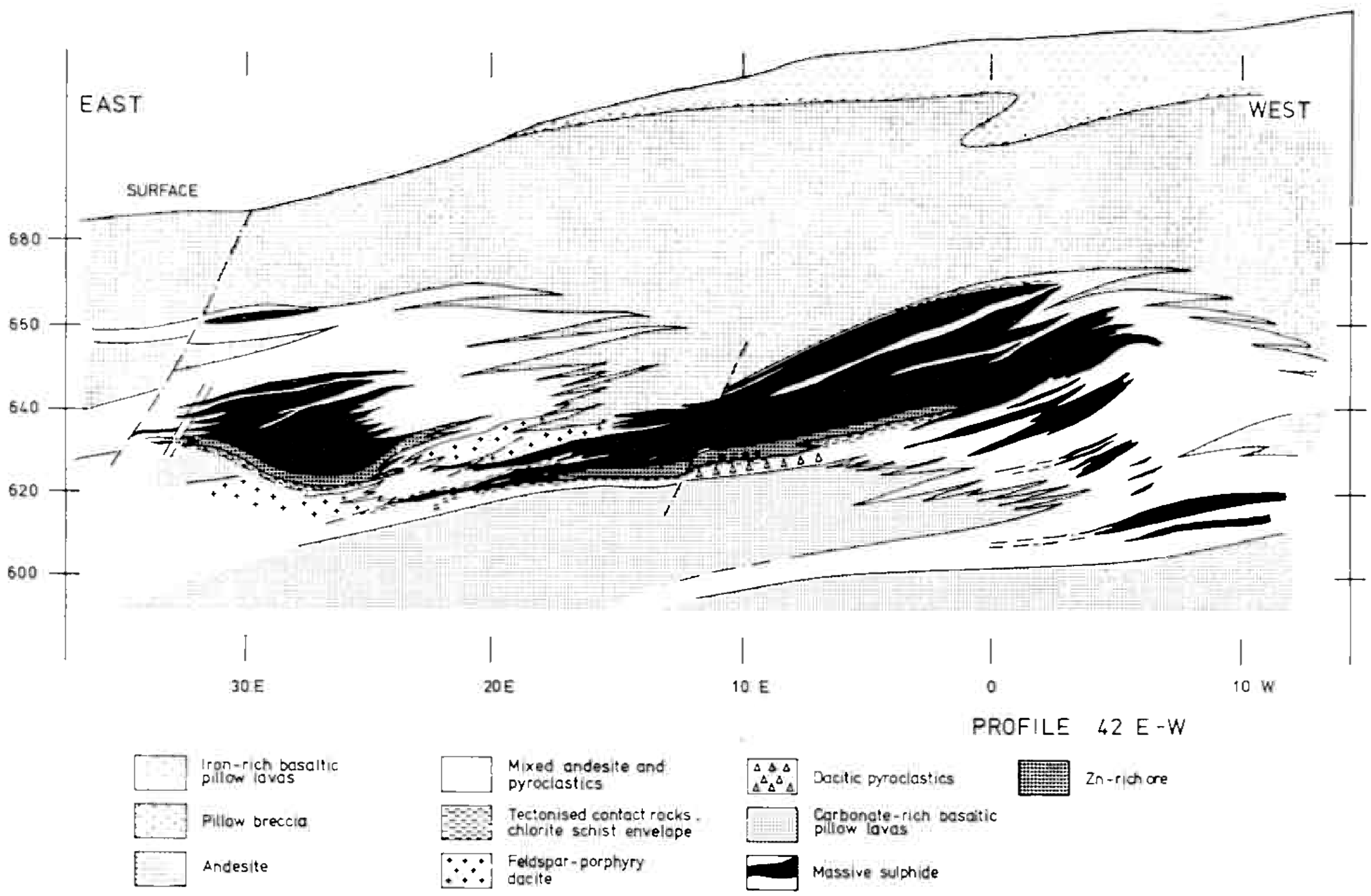


Fig. 17 Representative section through east and west orebodies at profile 42 east–west showing principal lithological divisions of host rocks and position of zinc-rich facies along footwall of principal eastern and western lenses. According to structural interpretation zinc-rich level is stratigraphic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

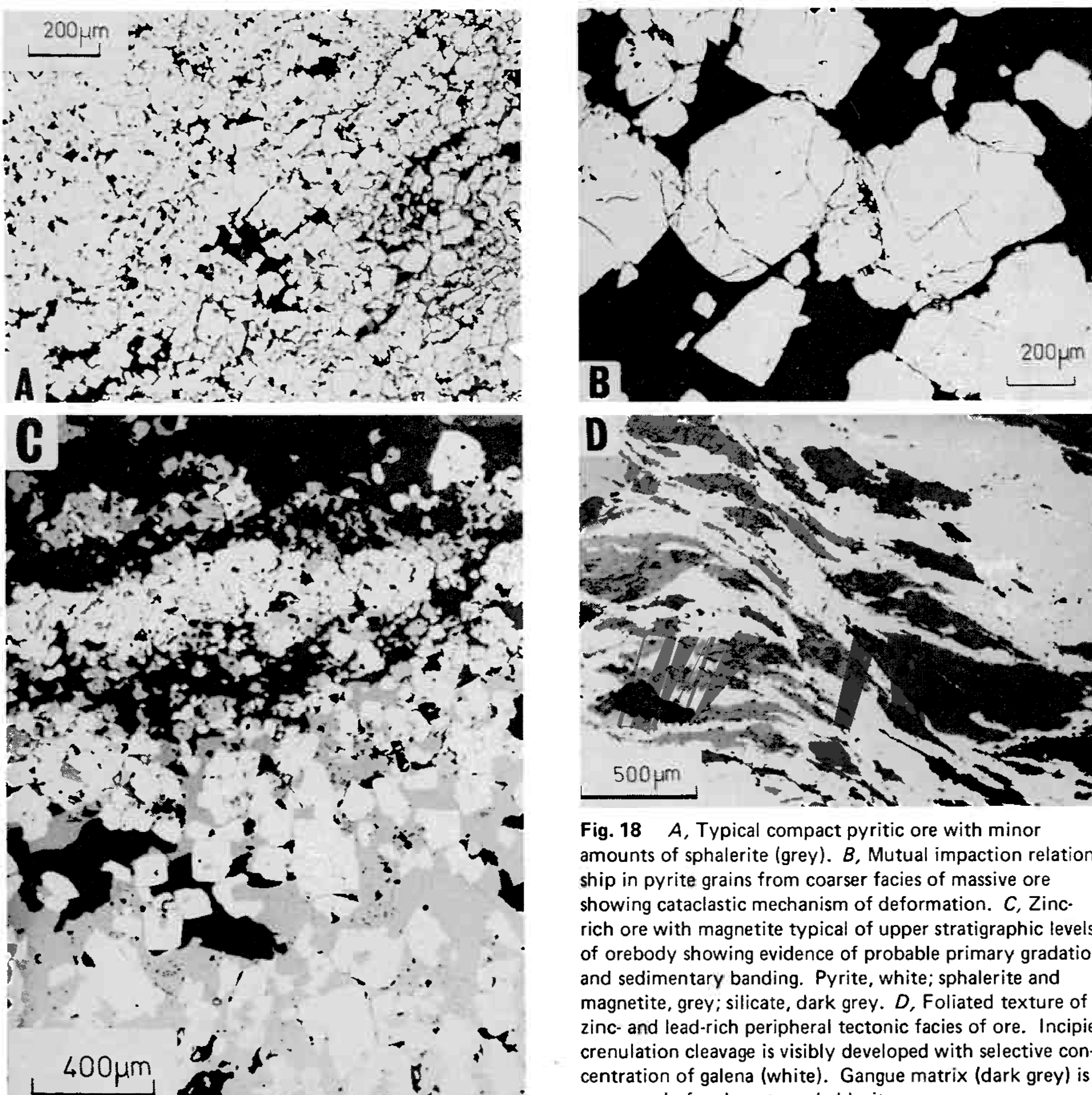


Fig. 18 *A,* Typical compact pyritic ore with minor amounts of sphalerite (grey). *B,* Mutual impaction relationship in pyrite grains from coarser facies of massive ore showing cataclastic mechanism of deformation. *C,* Zinc-rich ore with magnetite typical of upper stratigraphic levels of orebody showing 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 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.

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).

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

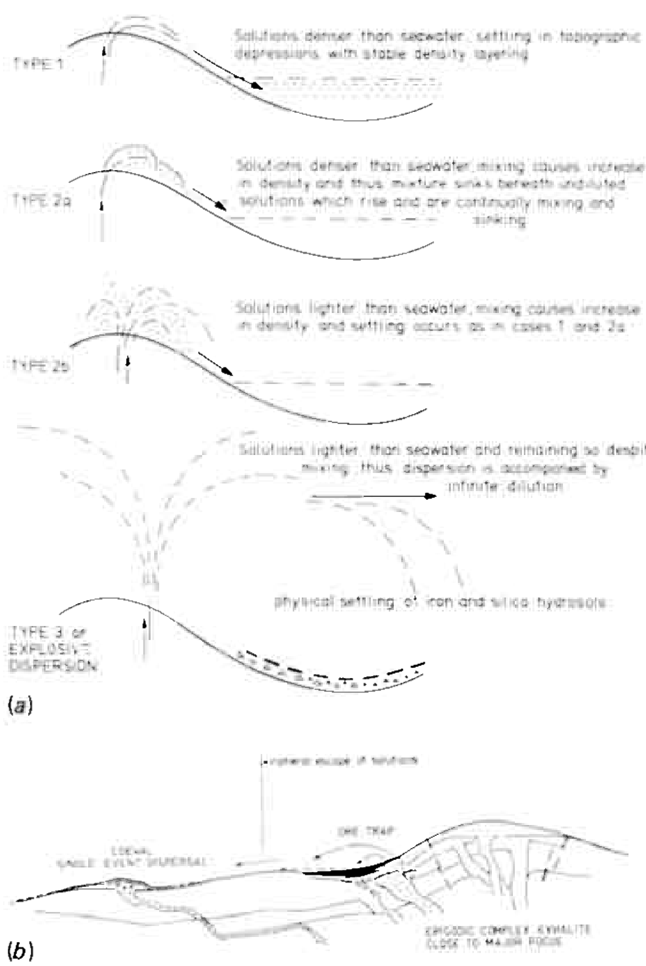


Fig. 19 Scheme of interaction of hydrothermal brines with sea water (*a*) (top) (after Sato [54]) and schematic eruptive and hydrothermal events in Skorovas volcanic centre during climactic dacitic episode (*b*)

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*)).

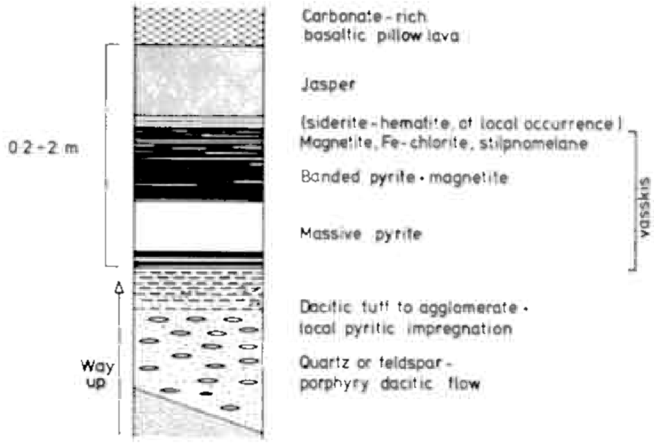


Fig. 20 Ideal section showing products of single event dispersal in extensive exhalite as observed in vicinity of Blåhammeren centre

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]

Acknowledgment

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Sanddøla, Oslo 1958
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Unggulius fra A. B.

Kan du lese det igjennem, mens du er her?

SKOROVAS GRUBER A/S

Skorovas Gruber is a pyrites mine belonging to the Norwegian industrial company Elektrokemisk A/S. It is situated in a mountainous area on the 65th latitude some 115 miles south of the Arctic circle and close to the Swedish border. The average altitude of the deposit is 2.ooo feet over the sea level in an area where the last scattered groups of pine and birch vanishes, to be replaced by heather and moss and other unostentatious representatives of the arctic flora. Due to the near vincinity of the North Atlantic, the weather is frequently rough and the snowfall during the winter season is occasionally very heavy.

The Skorovas deposit was purchased by Elektrokemisk A/S in 1913. Two other deposits in the same area, Joma and Gjersvik, had previously been acquired by Elektrokemisk in co-operation with a French group of investors, and constituted as a separate company under the name of A/S Grong Gruber. This company was taken over by the Norwegian Government in 1918, while the Skorovas deposit remained ~~in the~~ position of Elektrokemisk. ~~The Joma and~~ Gjersvik deposits are not yet brought into operation, but ~~preparatory work is now going on in the Gjersvik deposit and~~ the Government plans to ~~open the mine for full operation~~ within a couple of years.

Due to difficult market conditions, transport difficulties and the outbreak of World War II, the exploitation of the Skorovas deposit had to wait for years. In 195o, after some preliminary work, Elektrokemisk decided to put the mine into operation, this being the result of an approach from O.E.E.C. who predicted a ~~permanent~~ shortage of sulphur on the ~~world~~ market.

The first ~~shipload of pyrites from Skorovas was exported~~ early in 1953, and since then the mine has been worked continously with an annual ~~output~~ up to 15o.ooo ~~long~~ tons.

Because of the new competitive situation on the sulphur market, Skorovas Gruber has reduced its output to a considerable degree, the export in 1959 amounted to 107.000 tons

The Skorovas deposit has the form of an elongated lens, comparable to a hand with the palm facing upwards, 5oo m long and 3oo m wide, and with a thickness of nearly 4o m on an average. Over and around the main deposit, several smaller deposits are found. The quantity of pyrites is calculated to an amount of 7,3 million long tons. The ore is partly cupreous (47% S and o,8-1,4% Cu) and partly low-cupreous (47% S and o,1-o,6% Cu). The ore is worked with the most modern outfit. Longhole drilling and the slicing method is used. The output per man/shift is about 1o,5 tons.

Due to the extraordinary richness of the ore, the consentrator is comparatively simple. A good part of the ore is ready for sale after crushing down to 8 mm. The rest is treated in a Heavy-Media plant, and the finefraction is separated by jig- and table washing. Plans are now being prepared for an extention of the mill with an additional plant for bulk flotation of the poorer impregnations. As the ores in the whole Skorovas and Grong area are characterized by their fine grain, selective flotation is very difficult to perform.

The most spectacular feature of the Skorovas Gruber is the airial ropeway which brings the pyrites from the mine to the company's own harbour installations at Kongsmo in the Folden-fjord, a narrow seaway leading deep inland from the Atlantic Ocean. Ropeways may have been built with more imposing lengths than this 45 km transport line, but it seems unlikely that there is a ropeways which has to endure more difficult operational conditions. From an altitude of 467 m at the pit head, it ascends to a maximum altitude of 66o m, passing several valleys and mountains at varying heights until it reaches the fjord. The ropeway is divided in 3 sections with a total of 17o galvanized steel masts. It carries 6oo carriages, each with a capacity of 75o kg. The speed is 2,8 m per sec. and the distance between the mine and the harbour is covered in 4½ hours. Heavy snow falls and the rapid changes in humidity and temperatures with severe icing conditions caused serious difficulties during the first couple of winters, and a series of adjustments had to be made. The system is now working satisfactorily, and the transport is carried out without delay.

IX
VIII
In the Kongsmo harbour there is storing accomodation for about 40.000 tons pyrites, and loads of up to 5.000 tons on a single keel may be delivered. The loading capacity is 250 - 300 tons per running hour.

The main markets for the output is Sweden and West-Germany. Smaller amounts are exported to eastern markets.

In the lonely little valley around the Skorovas deposit a pleasant mining camp village has taken shape. The houses are all modern and very comfortably equipped. There are hostels for bachelors, employees and labourers. The social life is excellently served with a new community house and comprising a modern theatre, a restaurant, a gymnasium and rooms for meetings and games. a A modern well equipped school has been built for the children, of the people employed. The children now attending amount to 110. There is an interimistic church, being used while plans for a permanent church are prepared. The county physician has his residence in the village, and a ward and a nurse, provided by the mine, is at his disposal. The children are under permanent dental control, and this service will presently be extended to the grown-ups. The whole population of Skorovas is at the time being about 500.

....

X

Elektrokemisk A/S, the owner of Skorovas Gruber, was founded in 1904, in order to create new industries based on Norwegian hydroelectric power and raw materials and Norwegian patents. This was actually brought about by the development of a method for the fixation of nitrogen from air which had been discovered by the physicist, Professor Kristian Birkeland in cooperation with the industrial pioneer, Mr. Sam Eyde. Financed by and under the leadership of the new company, this method was developed on an industrial scale, and the foundation was thus laid for the powerful Norwegian nitrogen industry which was further expanded by Norsk Hydro-Elektrisk Kvælstofaktieselskab.

Since its foundation, Elektrokemisk A/S has pursued its original goal. It has laid the foundation for new and independent activities - expanding industrially in various directions. Elektrokemisk A/S has carved a name for itself throughout the smelting and aluminium industry of the world by introducing the famous Söderberg electrode and Elkem smelting furnaces - well known and adopted in all countries where industrial programmes embrace ~~reduction~~ smelting of ores by means of electric power.

Today Elektrokemisk's activities can be divided into the following groups:

Further development of electric smelting equipment and processes within its Research and Development Department.

Consultant work, design, sales of furnace equipment and complete plants through its Engineering Division.

Production of ferro alloys and electrode paste at its plant Fiskaa Verk.

Production of pyrites at its mine, the Skorovas Gruber.

Production of insulation materials at its factory, the Steinullfabrikken.

Production of raw aluminium at its plant, the Mosjöen Aluminium A/S in cooperation with the Swiss firm Aluminium-Industrie-Aktien-Gesellschaft (AIAG).

Elektrokemisk A/S
Skorovas Gruber
Skorovas Mines

Skorovas Gruber is situated in the mountains on the east side of the upper Namdal valley, 64° N. lat. about 2000 feet (600 meters) above sea level and close to the Norwegian/Swedish boarder in Namsskogan community - Nord-Trøndelag fylke. The mine is 168 miles (270 km) north of Trondheim, other distances are: To the nearest city, Namsos, 68 miles (110 km) to the nearest airport, Værnes, 150 miles (240 km) and to the nearest railway station, Lassomoen, 15 miles (24 km).

The entrance to the mine is from a hillside, 2050 feet (624 meters) above sea level. The mill and the ~~other~~ plant facilities are situated on the hillside on terraces below the mine entrance. The mine village is buildt in a small valley close to the plant, fairly protected by some pine- and birchtrees in the upper limit of the forest, about 1650 feet (500 meters) above sea level.

The first geological description of the Skorovas ore deposit, was made in 1873 by statsgeolog Hauan from the Norges Geologiske Undersøkelser.

Elektrokemisk A/S bought the mining rights to all major ore deposits in the Grong area in 1912 - 1913. Near the end of World War I all these rights were sold to the Norwegian Goverment except the rights of the Skorova deposit.

The upper Namdal valley got its main highway, the R 6 , with connection to the southern Norway about 1923, and about 13 years later Elektrokemisk A/S finished the 12 miles(20 km) road connection from this highway up to Skorovas. The national railway up through the Namdal valley opened in 1940.

After explorations since 1911 the development of the Skorovas-orebodey started late in the 1930-years. After a short stop at the beginning of World War II, the development work was continued during the war. The unstable markets after the war, caused the work to be discontinued for some years, but from the late 1940-years the development was again intensified and the mine and plants were ready for regular production in November 1952.

The access to the orebody is through a 4000 feet horizontal adit from the hillside, and the major part of the orebody is above this level. The ore below this main level is released by two internal inclined shafts.

The mining is based on open transvers stoping in up to 85 feet (26 meters) wide stopes, leaving 9 meters (30 feet) pillars between the stopes. The 2½" diameter drill holes up to 115 feet (35 meters) long, are drilled by heavy equipment from safe working places. Through the year 33000 feet are drilled which loaded with about 26000 lbs explosives breakes about 160.000 metric tonn of ore. 45 men work underground with an average production of 18,5 tonn crude ore per man and shift. The normal production per year is about 200.000 tonn crude ore from underground, which equals about 160.000 tonn concentrate. The ore is slushed from draw-points under the stopes to 10 tonn ore-cars and hauled by electric battery motors and dumped into the coarse ore bins.

All the crude ore is crushed to minus 2". The coarser part of this crushed ore is treated in a sink and float prosess where a mixture of finely grained ferrosilicon and water is made to a pulp, with a spesifick gravity of 3,2. In this suspension the heavier ore sinks to the bottom of the vessel and the lighter waist rock "floats" off. The finer part of the crushed ore is treated by jigs-,tables and in a floatition section.

The concentrate from the mill is dumped into 4 large bins in the mountain and from this bins loaded directly into ropeway buckets. The tramway has a capacity of 50 tonn per hour and transports the ore 27 miles (45 km) cross the country to the nearest fjord. The tramway is divided in 3 sections, each 9 miles (15 km) and with 3 angle stations. The longest free span between supporting constructions is nearly 3300 feet (1000 meters).

The highest point on the tramway is 2160 feet above sea level. At all times 300 buckets each with a 750 kg (3/4 tons) payload are on their way t. the coast, and 300 empty buckets on their way back to the mine.
In total 8000 ball- and rollerbearings are moving when the tramway is running.

After some initial difficulties in the first years the regularity of the tramway is brought up to 75%, all stops included (storm, maintenance and breakdowns) in spite of a rather unhospitable landscape and long stormy winters. It may be worth mentioning that the anemometers at the most critical places will show wind velocities of herrycane strength (62 knots) not unfrequently. The tramway is in full speed up to strung gale force (40 knots).

The shipping port on Kongsmoen is situated at the end of the 50 miles(80 km) long and narrow Follafjorden. The storage bins have a capacity of 40.000 tonn, thereof 25.000 tonn protected against freezing (in the wintertime) in bins mined out into the rock. Net loading capacity is 300 tonn per hour. After having widened some narrows in the fjord, ships up to 11.000 tonn are loaded at the port.

The total production is exported, at present mainly to West-Germany and Sweeden.

The Skorovas village has 137 family homes, an appartmenthouse with 40 single-room for unmarried workers, a similar house for the unmarried staff-people and also a guest-house.

Besides the community public school with 85 pupils, the company runs a privat junior high school with about 35 students.

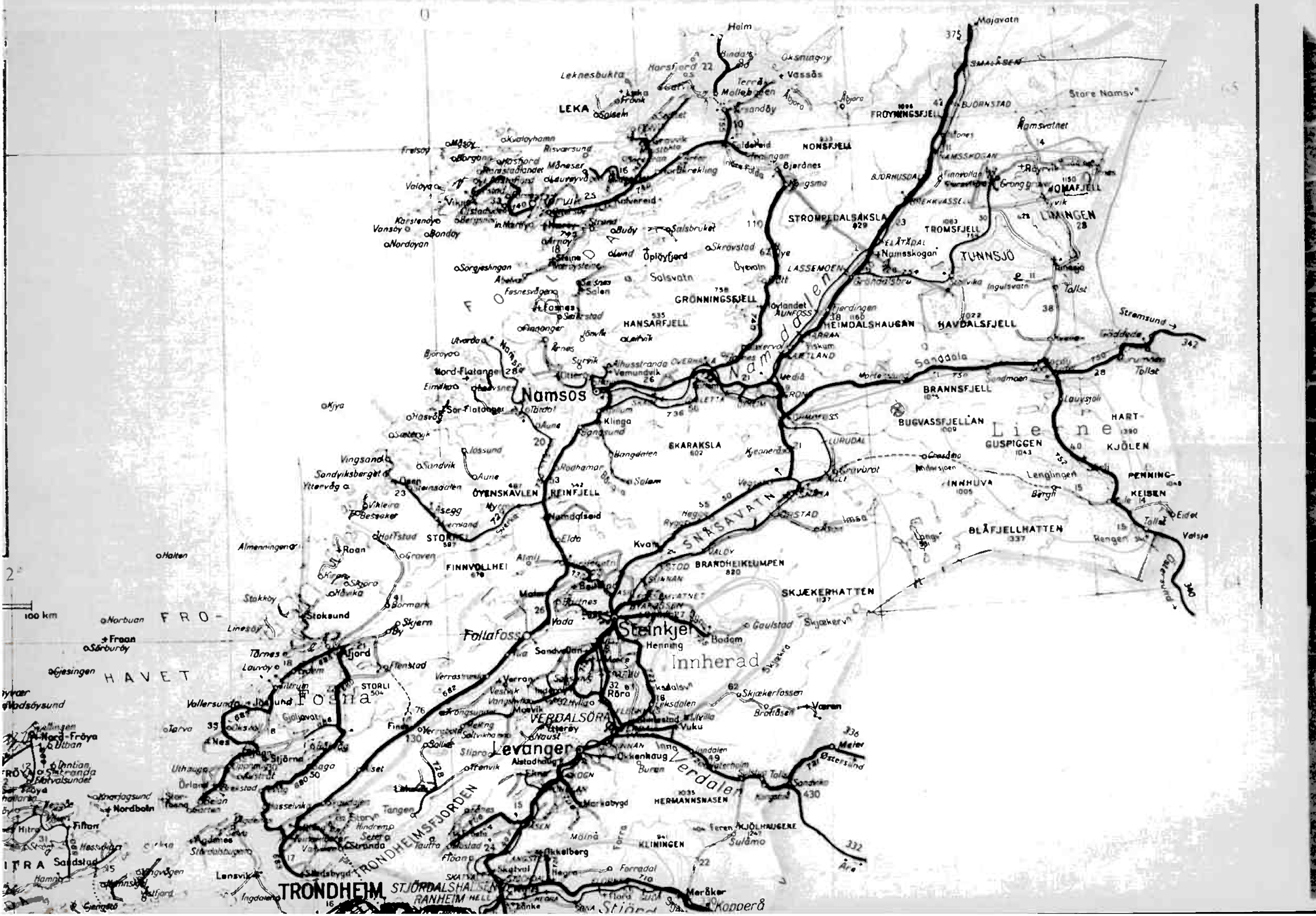
The company has also buildt a community house with set-up for theatre and movie performences, club-rooms for the different local activity-groups, restaurant, library, atlethick-hall, dentist-clinic, lady hairdresser, etc.

Resently a new heated indoor swimming pool is finished.

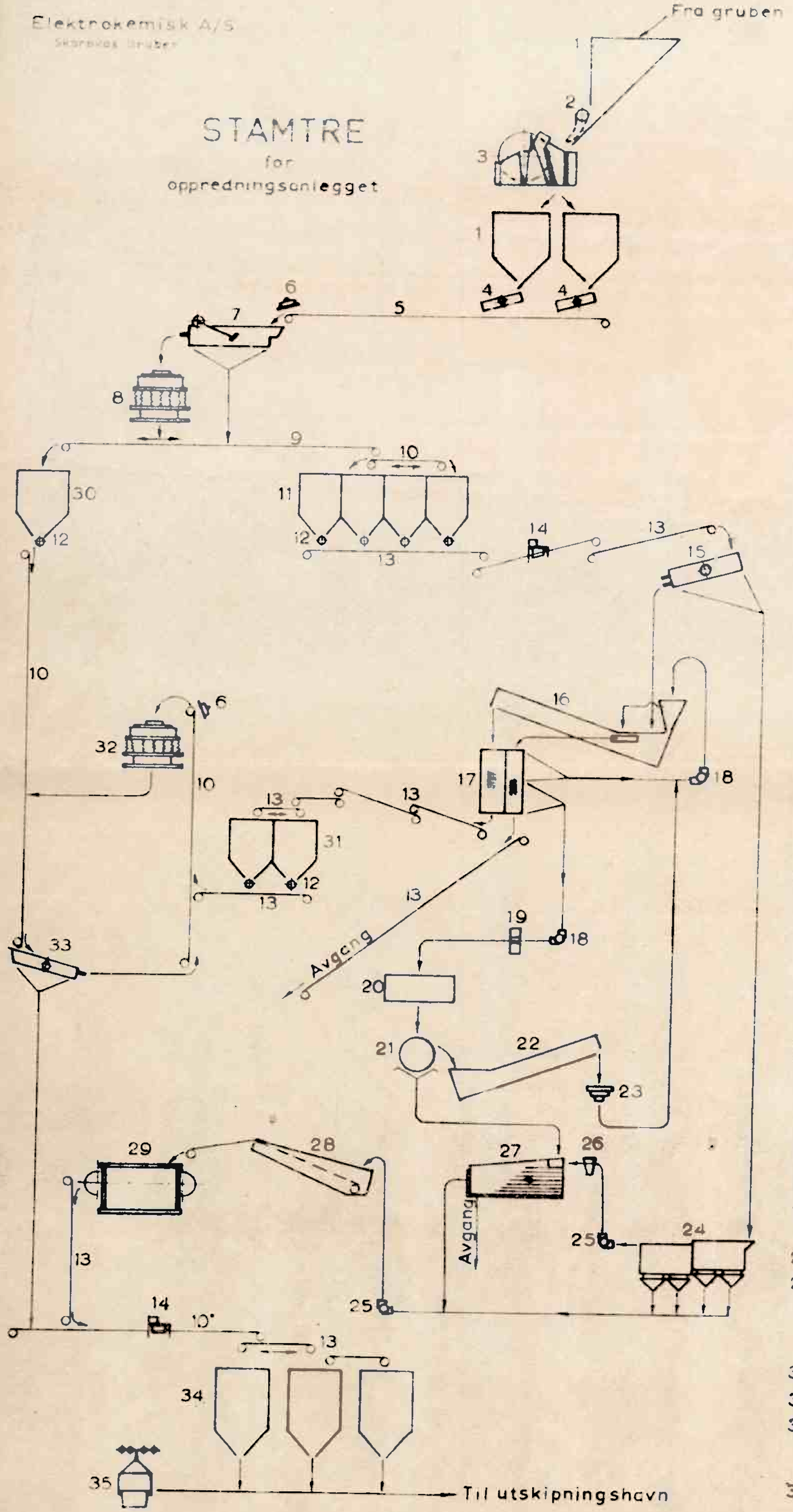
In 1965 was buildt a small church

The health-service district-doctor is living and has his office in Skorovas, and two ambulances are located at the mine. The neares hospital is in Namsos.

Skorovas Gruber employs in total ca. 210 people, labours and staff. About 185 of these are living in the mine village. With their families and together with people employed by the cooperative store, school, postoffice etc., the total population is a little more than 550 people.



Helm
Leknesbukta
LEKA
Vassås
Majavatn
SMALÅSEN
BJØRNSTAD
FRØYNINGSFJELL
Store Namsv.
Namsvatnet
NONSFJELL
Bjørnes
Røyrvik
NAMSSKOGAN
LIMINGEN
TUNNSJØ
TROMSFJELL
STRØMPEDALSAKSLA
Namsskogan
LASSEMOEN
Salsvatn
Salsbruket
Skorstad
GRØNNINGSFJELL
HANSARFJELL
HEIMDALSHAUGAN
KAVDALSFJELL
Tollst
Strømsund
Nord-Flatanger
Namsos
Namdalen
Sanddøla
Vemundvik
BRANNSFJELL
Skaraksla
BUGVASSFJELLAN
GUSPIGGEN
Lierne
HART-KJØLEN
PENNING-KEISEN
Vingsand
Sandviksberget
Ytterdal
ØYENSKAVLEN
REINFJELL
Namdalseid
Elda
Snåsavatn
Kvam
STORKEL
FINNVOLLHEI
BRANDHEIKLUMPEN
BLÅFJELLHATTEN
Stokkøy
Stoksund
Roan
Halten
Norbuan
Froan
Sørburøy
Gjesingen
FRO-
HAVET
Fosna
Follafoss
Steinkjer
Bodom
Gaulstad
Skjækerv.
SKJÆKERHATTEN
Innherad
Henning
Sandvollan
Røra
Verdalsøra
Vuku
Levanger
Verdalen
Vaeren
Skjækerfossen
HERMANNSNASEN
Meler
Østersund
Vollersund
Jøssund
Nes
Stjørna
Ørland
Brekstad
Agdenes
Nord-Frøya
Frøya
Hitra
HITRA
Sandstad
Nordbøln
Fillan
TRONDHEIMSFJORDEN
Stjørdalshalsen
Ranheim
Meråker
Kopperå
Åre
TRONDHEIM
Lensvik
Ingdalen
Klæbu
KJØLHAUGENE
KLININGEN
Ekkelberg
Forradal
Hegra
100 km



FLOW - SHEET

1 2x2 Ore Bins à ca. 800 tons

2 2 Rossfeeders 6 Chains, Motor 5 PH.

3 Jaw Crusher Blake 11,900 x 1200 mm. 250 t/h. Motor 122 PH.

4 2 Vibrating Feeders 800 x 1200 mm. Motor 3,2 PH.

5 Belt Conveyor 26", Speed 1 m/sek.

6 Lifting Magnets for Tramp Iron.

7 Plate Screen 1½" x 1½" Holes, Motor 7,5 HP, 300 Strokes/min.

8 4.1/4' Standard Symon Conecrusher, Motor 122 HP, Air Ventilator. 5 m_3/min.

9 Belt Conveyor 22", Speed 1 m/sek.

10 Belt Conveyors 20", Speed 1 m/sek.

11 Ore Bin, 4-rooms, 450 tons.

12 Roller Feeder 1/2 HP, 10 RPM.

13 Belt Conveyors 16", Speed 1 m/sek.

14 2 Adequate Weighers, 150 t/h and 120 t/h.

15 Allis-Chalmers 4'x10' Double Deck Ripl-Flo, Vibrating Screen 12x12 mm. and 6x6 mm. Meshes, Motor 6 PH.

16 Akins Separator, 36", Conc. 50 t/h 5-10 RPM, Motor 5 HP.

17 Allis-Chalmers 4'x16' Double Deck, Low-Head-Vibrating Screen 8x8 mm. and 1x12 mm. Stainl. Steel Motor 20 HP, Vibr. Mechanism 5.

18 2 Wilfley Pumps 2½" 650 l/m. and 750 l/min.

19 Dings Magnetizing Block 12"

20 Dorr Thickener, 3 m.Ø x 1,8 m. Motor 1,5 HP, Valve Linatex 3".

21 2 Magnetic Separators, Sydvaranger Drum Type 600 Ø x 475 mm. 1/2 HP, 40 RPM.

22 Akins Densifier, 24", Motor 3 HP ca. 3 RPM.

23 Demagnetizing Coil, 6".

24 2 Dorrco Pan American Placer Jig 2x36"x36" ca. 120 Strokes/min. Motor 1½ HP.

25 2 Rubber Lined Vacseal Pumps 2".

26 3 Deister Cone Baffle Classifiers.

27 3 Deister Plat-O Ore Concentrating Tables 290 Strokes/min. 2 HP.

28 Dewatering Machine.

29 Nordengren Vacuum Pan Filter Kap. 10 t/h. Speed 44-300 cm/min. Sadivar Geared Motor Variator 4,75 HP.

30 Pure Ore Bin 250 tons.

31 Concentrated Ore Bin 500 tons.

32 4' Short Head Symon Conecrusher Motor 122 HP, Air-ventilator 5 m^3/min.

33 2 Wisbech Vibrating Screens à 3 m^2 Motor 4 HP, Meshes 8x8 mm.

34 3 Bins à 5000 tons for the Ropeway.

35 Ropeway-Wagon, 750 kg. Pyrite, Ropeway 45 Km., Kap. 50 t/h.

1)

You have all got a Flow-sheet of the dressing but you know - in a noisy plant it is very dificulty to explain things and answer your questions.

Therefor I shall give a short describtion now and you may rather afterwards - when we have taken you through the washing plant - ask us your questions.

We have allready noted some facts on the Flow-sheet and I can tell you, that the same number which you find on the Flow-sheet - you also will find fastened to every machine.

(1) The ore from the mine is tipped in one of two ore bins - each with a capacity of about 800 tons.

(3) The ore passes a Jaw-crusher, type Blake 11, with an opening of 900 x 1200 mm (that is: about 40" by 48 inches). With a size of the crossed ore of 4-5 inches - the capacity is about 250 t/h.

(1) From two other bins the ore is carried by a

(5) belt conveyor (more than 300 m. long) to the dressing plant. This conveyor-belt is 26 inches wide, and has a speed of 1 m/sek.

(6) An electro magnet is placed over the belt. A hammer or sledge at a weight of 10 kg (about 20 pounds) should be lifted at a distance of 35 cm. (i.e. about 14") [When you are passing here you must be carefull with your watches]

2) (7) The ore passes a screen with holes of a size
(8) of 1½ inches and by a 4-and a quarter (4¼) feet Standard Symon conecrusher the ore are crossed to about 1½-2".

From the mine we get what we call „high grade ore" - or „pure ore" with 46-48 % sulphur - and a „washery grade ore" with 35-42 % sulphur which we have to treat in our dressing plant.

(9) The belt under the conecrusher is reversible.
(30) The „pure ore" goes to a bin with a capacity
(11) of 250 t - and the „washery ore" to a bin with 4-rooms and a capacity of 450 tons.

(V) The „pure ore" is in a closed circuit
(32) crossed down to marketable product by a 4' SH
(33) Symon conecrusher and 2 screens with 8 x 8 mm
(10) meshes - and on a conveyor belt, 20" wide, -
(14) with an automatic weigher, - transported to
(34) one of the 3 Robeway-bins, each with a capacity of 5.000 t.

(12) The „washery ore" is by roller-(or drum-) feeders
(13) with 10 RPM, fed by more 16" conveyor-belts to the dressing plant.

(15) From a screen: Allis-Chalmers, 4'x 10' Double Deck Ripl-Flo, vibrating screen the coarser size - over 6 mm, - which represents about 70-80 % of the washery ore -
V goes to the Sink and Float System.
(16) We use here an Akins Separator with a diameter on the screw of 36" and the capacity is about 50 t. concentrate per hour.

3)

As Heavy-Media we are using Ferrosilicon and the loss is about 250-300 gro (that is about 8-10 ounces) per ton concentrate. That represents a value of about 30 øre or 4 pence per ton.

(17) The screen after the Akin-Separator is an Allis-Chalmers 4' x 16' Double Deck, low Head Vibrating screen with an under-screen-cloth of stainless steel with 1 x 12 mm meshes.

As usual - the Ferrosilicon liquid from the
(18) first part of the sreen is pumped directly to the Heavy-Media-vessel again, and the specific gravity is about 3.20 to 3.30

From the second part of the screen, where the Concentrate and the waste are thoroughly washed, the
(18) diluted liquid of the Ferrosilicon is pumped
(19)-(20) through a magnetizing bloc to a Dorr-thickener
(21) The Ferrosilicon is recovered in 2 magnetic
(22) separators, dewatered in an Akins densifier and
(23) through a demagnetizing coil fed to the system again.
(17) From the screen - the concentrate is transported
(13) (31) by 16" conveyor-belts to ore bins of 500 tons capacity and is crossed in the same crushing-circuit as the „pure ore"

V The washery ore under 6 mm is treated in
(24) 2 Dorrco Pan American Placer Jigs. The concentrate is taken from the bottom cones and all the over-
(26) flow is by 3 Deister Cone Classifiers distributed
(27) to 3 Deister Plat-O-Concentrating Tables.

4 tables are necessary but one is for the present out of operation.

The concentrate from the jigs and the tables must be dewatered. The product passes a dewatering

(28) machine with a slow running belt - 10 cm/sek. -

The moisture amounts to about 13 - 15 % and on

(29) a following vacuum pan filter the moisture is lowered to 4 - 5 %.

(13) With other conveyor-belts the dried ore is

(10) transported to the weigher-belt over the three Rope-way bins.

Ich habe - ganz kurz gesagt - dass wegen des Geräusches der verschiedenen Maschinen, wird es sehr schwierig während des Rundganges in der Aufbereitungsanlage die Sachen zu besprechen. Auf dem Stammbaum sind aber mehrere Daten schon notiert und Sie können uns eure Fragen stellen, wenn wir nach dem Rundgange wieder hier zurückgekommen sind. Die Nummer - die Zahlen - auf dem Stammbaum werden Sie auch auf jeder Maschiene finden.

Ich darf Sie nur daran zu erinnern, dass wenn Sie die Hubmagnete (nr 6) über dem Transportbande nr 5 passieren - müssen Sie mit Ihren Uhren vorsichtig sein.

The Skorovass pyrite mine, Grong area.

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

For the XXI International Congress, T. Gjelsvik has prepared a paper on the Skorovass deposit (1), to which is referred to for details. Only a short abstract is given here.

The greenschist formation at Skorovass can be subdivided into 3 parts:

1, at the base, banded, limy greenschists of clearly sedimentary origin, containing blue quartzites with small "vasskis" bands. ~~(locality 1 and 2 , in the mine village).~~

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

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

A band of trondhjemite separates the two lowest formations 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.

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 dimention parallel to the strike, which is north-south. (See the longitudinal and transverse sections, fig)

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, crosscutting 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 appear 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 grainsize and proportions of the minerals, the ore is commonly banded, and again in conformity with the schistozity of the ~~greenstones.~~ 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 coarsegrained lowgrade type. The ore minerals are pyrite, chalcopyrite and sphale rite, with subordinate amounts of tennantite, magnetite, arsenopyrite and galena. Notably absent is pyrrhotite. Pyrite is clearly the oldes 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.

Wallrock 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 exeed 5o per cent over considerable thickness. Consequently, the content of Cu and Zn is very low in this part, even in the northern part which consists of coarse impregnation ore this holds. as this Towards the southern end of the deposit, however, the amount of both metals increases greatly, exhibiting an typical zonal distribution, with copper enriched in the central, and zinc in the marginal parts of the ore body (fig).

S.Foslie (2) who made the first detailed investigation of the deposit, considered it to be epigenetic, (hydrothermal metasomatic), whereas Chr.Oftedahl (3) recently suggested an syngenetic origin (subvolcanic-exhalative). The genetic question is not definitely settled, but the present author (loc cit) is in favor of an epigentic origin, although he finds it premature to state whether it is formed by replacement by magmatic emmanations, 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.

1. Gjelsvik, T. The Skorovass Pyrite Deposit, Grong area, Norway: XXI International Congress, 1960.
2. Foslie, S. Skorevass kisfelt i Grong: Norsk Geol. Tidsskr. 19 ,19
3. Oftedahl, Chr. Oversikt over Grong-feltets skjerp og malmforekomster: Norges Geol. Undersøk. ,202, 1958.

There are storing facilities for up to 5 different grades of fine pyrites or flotation concentrat. Three frostfree bins excavated in the hillside wil together store 25.000 tons, and a sheltered emergency store can take another 15.000 tons.

Depth at the wharf is 23' at extra low tidewater. Effective loading capacity, 235 metric tons an hour.

I

Skorovas Gruber ligger i et kupert fjellterreng på østsiden av Øvre Namdal som er senteret i Namsskogan kommune. Kommunens areal er ca 1400 km2 og med en befolkning på 2200 eller 1,6 person pr. km2 representerer den ett av landets tynnest befolkede strøk. Hoveddalen ligger omlag 150 m.o.h. mens de høyeste topper omkring Skorovas går opp i 1000 m.o.h. Der er..... etc.

II

"Grongfeltet" som er nevnt ovenfor er et område innen den kaledonske fjellkjede, som er karakterisert ved mektige dekker av grønnsten. Vedrørende kisens dannelse (genesis) kan man kun konstantere at man ikke har noen sikker antagelse, men der er fremsatt flere plausible teorier. Kisforekomstene i Grongfeltet ligger alle i Grønnstein, en basisk lava (-----) som antas å være rent ut under vann.

Skorovasforekomsten har sin hovedakse liggende N-S. Den nordlige del stikker frem i dagen oppe på snaufjellet, og da den her er formet som en 300 m bred plate, har det dannet seg et større rustfarget felt som er synlig på lang avstand. Mot syd deles kisplaten i flere parallelle linser, hvorav den mektigste fortsetter som en sigarformet kropp til ca -----m fra utgåendet. Mineralselskapet er svovelkis med mindre mengder kobberkis, zinkblende, kvarts og klorit. Mer sporadisk forekommer magnetitt, kalkmarmor, fahlertz og arsenkis. Magnetkis og blyglans er ikke funnet og edelmetallinnholdet er lavt.

III

Malmen brytes i skiver som er lagt tvers over forkomsten. Skivene er opptil 26 m brede og foreløbig settes igjen 9 m brede pillarer mellom de utbrudte rom. For brytningen brukes "langhull" - lengde opptil 35 m - som bores ut med tunge spesialmaskiner og skjøtestenger, fra lett tilgjengelige og sikre ("safe") borsteder. Årlig bores ca 10.000 m "langhull" som ladet med ca. 12.000 kg sprengstoff løsner ca 160.000 tonn malm.

IV

Man må selvfølgelig ta i betraktning at driftsforholdene ved utendørsanleggene i Skorovas ig i særdeleshet taubanen, er preget av det sterkt vekslende og tildels harde klima, og det kan nevnes at taubanens vindmålere som er plassert på særlig værharde punkter, ikke sjelden registrerer vind av orkans styrke.

V

Skal man her nevne hjelpeavdelingene?
Mek. og el. verksted - telefon.
Egen bygningsavdeling
Snøbrøyting etc.
Analyselab.

VI

Grubeanlegget med taubanen beskjeftiger ca 220 arbeidere og funksjonærer. Av disse er omlag 185 bosatt i Skorovas, og med sine familier samt noen få offentlige funksjonærer utgjør de en befolkning på ca. 600.

X It is however necessary to have in mind that the rapidly changing and ~~the~~ at times rather harsh climat, will influence on the operation of all outdoor equipment at Skorovas, and this relates especialy to the ropeway. It may thus be mentioned that the wind velocity meters which are positioned at the most exposed points along the ropeway, not seldom register winds of hurricane strength.

The oredeposit of Skorovas was before comensement of mining beleaved to consist of pyrites of a fairly uniform quality with about 1,5% copper in calco-pyrite and 1 to 1½% zinc in galema.

Our developmentworks have however shown that oregrades and contents of metals will vary considerably in the different parts of the mine.

Roughly the deposit can be described as a nearly horisontal rulershaped body laying north-south with a slight tilt to the east. At the northern end where ore outcrops we have a course low grade pyrit in quartz with little copper and zinc. Moving southward the ore gradually changes to solid pyrit split up by wedges of greenstone and with great and uneven variations in content of copper and zinc even in the same crossections. In the southern half of the deposit the ruler narrows and the shape of the orebody can more correctly be compared with a pencil or a cigar. Here we find a core of good grade pyrite, fairly high in copper and low in zinc, but around this core the pyrite is of lower grade with less copper and much richer in zinc. Common characteristics for all grades is the absence of lead bearing minerals and pyrrhotite. It may also be mentioned that the ore contains little silver, only traces of gold and cobalt and about 0,05% arsenic.

Present mill-facilities include a heavy media separation plant, jigs and washingtables, which machinery only can perform a mecanical selection of oreminerals and barren rock. In the long run this will clearly not be satisfactory, as we can not benefit of the different kinds of oregrades to the full extend. This as much as our customers have different demands as to metal contents, and also because we should be able to supply potential new customers with the product they are demanding, as far as our raw materials make this possible.

Present plans include building of a flotation plant in connection with our present mill installations. At the same time we will go to finer crushing before heavy media separation, and we will also instal further jigs working in millsircuits before flotation.

In the mine there is developed a system of longhole slicing by which we are able to break and load different oregrades selectively, and with close cooperation between mine and mill we aim to produce and market the following products:

Cupreferous fine pyrites with medium contents of copper and zinc
" " " " higher " " " " "
Noncupreferous" " " medium contents of zinc
Bulk flotation consentrate with copper and zinc
Flotation consentrate very low in copper and zinc

ELEKTROKEMISK A/S
Skorovas Gruber

The mine.

Geology: The ore occures in a Greenestone formation originally submarine spilit-lava-flows, with horizons of volcanic ash and tuffs. Our theory is that the ore has been deposited chefely along mentioned ash-tuff-horizons by lowtemperaturmetasomatic activity. Near the ore the greenestone is choritisised and chisty.

The orebody has a core of pure pyrit (48-50% S) with some copper in calcopyrite, but it is at the outscirts split up by wedges of barren rock and the ore grade is lower. At ~~toppingx top~~ also occures several smaler lenses and bottum of the main orebody and irreagular parties of low grade ore.

As the ~~main~~ orebody is flatlaying there is no definit "strike" or "fall". The ~~part~~ has a cigarshoped cross-section, thining out to the south and to the north widening to a plate that partly cropes out and partly changes to impoore low grade ore.

Mining.

The deposite is opened by a main addit dividing into two transportdrifts under the orebody. Most of the ore lies above these drifts and mining was started in the cigarshoped section and proceeded southwards.

We started continued mining with shrinkagestopes 30 feet (9 m) wide, going stright across the orebody and with 20 feet (6 m) pillars in between. Later width of stope were widened to 40 feet (12 m) and pillars 27 feet (8 m).

However, shrinkagestopes appeared to be less satisfacto as the pure pyrites in the middle section became mixed up with lower grades from the roof and with greenestone wedges in east and west stope ends.

A mining system had to be found whereby pure and impure ore could be broken and loaded independently, and some modification of longholeslising was desided upon.

From ~~small~~ shrinkagestopes we are now breaking slots 40 feet wide across the orebody, and these slots are widened by blasting slices 23 feet wide into the open slot. Both slots and slices are drilled and blasted in a sequens that anables us to load out different oregrades independantly.

From bells under slot and slices the ore is scraped through slusher drifts to bunkers delivering into granbytype cars in the transportdrifts.

Cars are moved by battery locomotives to the mine opening where the cars are emptied into bunkers, one for pure grade and one for washery grade ore.

Effects: Everage daily output is about 650 tons.
Mine workers (belowe gr.) 60 40
Maintenance etc. 12
O.p. mansh. u.g. about 11 tons
" " mine dep. " 9 "

O.P. drillershift in stopes incl. blasting 100 t. (25 m³)(880 quft.)
Scraperloading 150 t. per man and machineshift.
Loading into cars ca. 400 t per mansh.

Sulphur Prospects in Scandinavia - Corrections concerning Elektrokemisk A/S, Skorovas Gruber, Norway.

The October 1959-issue of "Sulphur" gives under the heading "Sulphur Prospects in Scandinavia" some information concerning the "Skorovas Mine" and its owner "Elektrokemisk A/S". These information are partly misleading and are in the following corrected and made more explicit.

Elektrokemisk A/S is not state-owned, but a private company concerned with series of industrial activities and developments. Founded by the industrial pioneer Mr. Sam Eyde in 1904 its intention was to create new industries based on Norwegian hydroelectric power, raw materials and own patents. This initial goal has since beem pursued, and the firm has laid the foundation for various new and independent industrial activities. Elektrokemisk A/S will be well known to the smelting- and aluminium industri of the world through the introduction of the renowned "Søderberg electrode" and its Elkem smelting furnaces.

Today Elektrokemisk' activities can be devided into the following groups:

Further development of electric smelting equipment and processes within its Research- and Development Department.

Consulting work, design, sales of furnace equipment and complete plants through its Engineering Division.

Production of ferro alloys and electrodepaste at its plant Fiskaa Verk.

Production of pyrites at its mine Skorovas Gruber.

Production of insulation materials at its factory, the Steinullfabrikken.

Production of raw aluminium at its plant, the Mosjøen Aluminium A/S in cooperation with the Swiss firm Aluminium-Industrie-Aktiengesellschaft (AIAG).

The Skorovas deposit was purchased by Elektrokemisk in 1913. Two other deposits in the same area, Joma and Gjersvik, had previously been aquired by Elektrokemisk in cooperation with a French group of investors, and constituted as a separate company under the name of A/S Grong Gruber. This company was taken over by the Norwegian State in 1918, while the Skorovas deposit remained under the ownership of Elektrokemisk. The Joma and Gjersvik deposits are not yet brought into operation, but the government now has plans to start operation at Gjersvik within a couple of years.

To avoid any misunderstanding we underline that Elektrokemisk A/S is a private company and that the Gjersvik and Joma mines belong to a state-owned company called A/S Joma Bergverk.

Due to difficult market conditions, transport difficulties and the outbreak of World War II the exploitation of the Skorovas deposit had to wait for years. In 1950, after some preliminary work, Elektrokemisk decided to put the mine into operation, this being the result of an approach from O.E.E.C. who predicted a serious shortage of sulphur on the European market.

The first shipment of Skorovas-pyrites took place early in 1953, and since then the mine has been worked continiously with an annual production up to 150.000 tons a year. As a result of the difficulties on the sulphur-market in the last years Skorovas Gruber now has reduced its output to a considerable degree - thus the export in 1959 amounted to 107.000 tons.

The mine is situated in a montainous area on the 65th latitude, some 200 miles north of Trondheim, and close to the Swedish border. The average altitude of the deposit is 2000 ft, well above the highest-growing birches.

The deposit can be described as a flatlying irregular orebody with the longer axis laying north-south. At the northern end where the ore outcrops there is a coarse impregnation of low grade pyrite in quartz with little copper an zinc. Moving southward the ore gradually changes to solid pyrite split up by wedges of greenstone and with great and uneven variations in content of copper and zinc. In the southern half of the deposit the orebødy narrows and the shape can be compared with a pencil or cigar. Here we find a core of good grade pyrite fairly high in copper and low in zinc, but arround this core the pyrite is low grade with less copper and much richer in zinc.

The mine, which is new and equipped with modern machinery is worked by a system of longhole slicing by which it is possible to break and load the different oregrades selectively. Output per manshift underground is 13,o tons.

Most of the ore is of very good quality and part of it is ready for sale after being crushed to minus 8 mm. The rest is at present treated in a Heavy-Media-plant supplemented with a jig and washingtables for the finer crushed fractions. Present plans include building of a flotation plant in connection with existing mill installations. With this combined plant it will be possible to beneficiate all oregrades to the full extent.

The most spectacular feature of the Skorovas Gruber is the airial ropeway which brings the pyrites from the mine to the company's own harbour installations at Kongsmo in the Foldenfjord, a narrow seaway leading deep inland from the Atlantic Ocean. Ropeways may have been built with more imposing lengths than this 45 km transport line, but few ropeways have to endure more difficult operational conditions, From an altitude of 502 m at the pit head, it ascends to a maximum altitude of 660 m, passing several valleys and mountains at varying heights until it reaches the fjord. Divied in 3 sections with a total of 170 galvanized steel masts, it carries 600 carriers, each with a capacity of 750 kg. The speed is 2,8 m per sec. which gives a capacity of 50 tons per hour.

In the Kongsmo harbour there is storing accomodation for about 40.000 tons pyrites, and loads up to 5.000 tons can be shipped. The loading capacity is 250-300 tons per running hour.

Lastly may be mentioned the mining camp, housing a population of about 500 in well-built houses. On the social side one can mention a wee equipped clup-house and a modern school. To make the community complete there only remains building a church which at present is on the drawing-board.

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The mine is situated in a montainous area on the 65th latitude, some 20 miles north of Trondheim, and close to the Swedish border. The average altitude of the deposit is 2000 ft, well above the highest-growing birches.

Roughly the deposit can be described as a nearly horisontal ~~culershaped~~ body laying north-south with a slight tilt to the east. At the northern end where ore outcrops ~~we have~~ a coarse of low grade pyrite in quartz with little copper and zinc. Moving southward the ore gradually changes to solid pyrite split up by wedges of greenstone and with great and uneven variations in content of copper and zinc. In the southern half of the deposit the ~~ruler~~ narrows and the shape ~~of the orebody~~ can ~~more correctly~~ be compared with a pencil or cigar. Here we find a core of good grade pyrites fairly high in copper and low in zinc, but arround this core the pyrites is low grade with less copper and much richer in zinc.

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Forord.

To av de store kisforekomster i Grongfeltet, Gjersvik og Joma, ble oppdaget i henholdsvis 1909 og 1911. Den tredje store forekomst, Skorovass, var kjent fra før, og den ble mutet i 1910. Dette førte til en veritabel skjerpefeber i distriktet. Skjerpeperioden resulterte i oppdagelsen av et stort antall små og mellomstore forekomster, men inntil nå er det ikke kjent noen flere forekomster enn de tre nevnte, som er så store at de ~~er~~ ansees for drivverdige.

Forord.

I 1910 ble den store Skorovass kisforekomst oppdaget, og like etter ble to andre store kisforekomster, Joma og Gjersvik, funnet. Dette førte til en veritabel skjerpefeber i distriktet, men inntil nu er det ikke kjent noen annen forekomst som er så stor at den er drivverdig. Skjerpeperioden resulterte imidlertid i oppdagelsen av et stort antall små og mellomstore forekomster.

Praktisk talt alle de funne forekomster lå innenfor det daværende Grong herred, og malmfeltet fikk derfor navnet Grongfeltet. Dette navnet har det bibeholdt, til tross for at det store Grong herred i 1923 ble oppdelt i herredene Grong, Harran, Namsskogan og Røyrvik. Således ligger nu Joma- og Gjersvikforekomstene i Røyrvik og Skorovassforekomsten i Namsskogan.

Den første utvikling av Grongfeltet er knyttet til "Det Norske Aktieselskab for Elektrokemisk Industri", nu Elektrokemisk A/S.

Allerede i 1910 besluttet Elektrokemisk å ta håndgivelse på Gjersvikfeltet. Sent i 1911 ble feltet erhvervet og undersøkelsen igangsatt, og selskapet fikk håndgivelse på Jomafeltet. For å få kapital til undersøkelsen av Joma- og Gjersvikforekomstene og de mange omliggende forekomster gikk Elektrokemisk sammen med et fransk syndikat, og 14/12 1912 ble A/S Grong Gruber stiftet, med for største delen fransk aksjekapital. Dette selskap innkjøpte i 1914 Jomafeltet. Elektrokemisk holdt imidlertid Skorovassfeltet utenfor Grong Gruber; dette felt ble innkjøpt i 1914.

Ved slutten av første verdenskrig fant regjeringen (ved statsminister Gunnar Knudsen) at staten burde sikre seg disse store kisforekomster av flere grunner, bl. a. at utenlandsk innflytelse ikke skulle få en dominerende innflytelse. Etter at staten hadde kjøpt opp aksjene i A/S Grong Gruber fra både det franske syndikat og Elektrokemisk A/S, vedtok Stortinget 31. mai 1918 den såkalte "Gronglov" forat eventuelle nye funn ikke skulle komme på fremmede hender:

Lov av 31. mai 1918 nr. 6:

"Om ertsforekomster inden en del av Nordre Trondhjems amt."

§ 1. Anmeldelse, muting eller erhvervelse paa anden maate av mutbare anvisninger eller gruber er ikke tilladt for andre

-und [illegible]staten inden et omraade av Nordre Trondhjems amt, begrenset mot nord av amtsgrensen mot Nordlands amt, mot øst av riksgrensen, mot syd av en ret linje fra grenserøs nr. 192 til Sandsjøens østlige vik, Kalviken og herfra av sjøerne Sandsjøen, Laksjøen, Skjelbredvand og Ottersjøen med mellemliggende levestykker og videre av Sanddøla til denne elvs utløp i Namsen og mot vest av Namsen og dennes bielv Storelven, til denne skjæres av amtsgrensen.

2. § 2. (endret ved lov av 30. juni 1932 nr. 6 og nålydende):

Kongen kan med Stortingets samtykke avslutte kontrakter om bergverksdrift inden det i § 1 nevnte område med norske kommuner eller norske statsborgere eller aktieselskaper og andre selskaper med begrenset ansvar, som har helt norsk styre med sete i Norge eller som har et styre, hvorav flertallet består av norske statsborgere og som har sete i Norge.

§ 3. (uendret)

Denne lov træder i kraft straks."

Norge hadde hermed fått et statsgravefelt. Da staten hadde fratatt privatpersoner skjerperetten og dermed også stoppet ~~ejendommene~~ deres interesse for videre funn og undersøkelser, kan man si at det ~~dermed~~ hviler en forpliktelse på staten til å foreta en grundig undersøkelse av dette lovende malmdistrikt. Ut fra dette synspunkt begynte Norges geologiske undersøkelse ved statsgeolog Steinar Foslie i 1922 med en grundig geologisk kartlegging av Grongfeltet. Denne kartlegging, som i det vesentlige var ferdig i 1931, omfattet også en befaring av alle registrerte skjerp og forekomster, samt avmerking av rustsoner og lignende som kunne være nye forekomster.

Foslie fortsatte senere den geologiske kartlegging av de sammenforliggende strøk Nordli og Sørli. Dette arbeide var ferdig i slutten av 1930-årene. Foslie rakk imidlertid ikke å bearbeide dette meget store materiale. Om geologien har han bare publisert beretninger fra feltarbeidet i 1922 og 1923. I "Norges svovelkisforekomster" har Foslie (1926) beskrevet de tre store forekomster Joma, Skorovass og Gjersvik (Foslie, 1923 og 1924) samt Finburfeltet. I spesielle arbeider er forekomstene Lillefjellklumpen (1932) og Joma (1949) blitt beskrevet.

Foslies manuskriptkart er nu under trykning og geologiske beskrivelser til kartene er under utarbeidelse. Det synes imidlertid rimelig å samle beskrivelsene av malmforekomstene i en egen oversikt, heller enn å la disse beskrivelser fremkomme i kartbladsbeskrivelsene under de respektive kartblad. I det foreliggende arbeide er det derfor gitt en oversikt over alle Foslies observasjoner over store og små forekomster. I tillegg hertil kommer forfatterens egne resultater fra befaringer i perioden 1952-56. Særlig Jomaforekomsten, den største av alle Grongfeltets forekomster, er blitt studert i adskillig detalj. De strukturelle geologiske synspunkter som derved ble oppnådd, har ledet til at forfatteren har foretatt en omvurdering av malmlegemets form. Skorovassforekomstens geologiske omgivelser er også blitt underkastet detaljstudium. Et par andre forekomster, Kirma, Borvassfeltet og Finnburgruven er blitt besøkt. Forøvrig er oversiktens anførsler resymé av Foslies feltobservasjoner når intet annet er spesielt nevnt.

På Foslies kart over Syd-Norges malmforekomster er 43 av Grongfeltets forekomster avmerket (Foslie, 1925). I den foreliggende oversikt er forekomstene nummerert fra 1 til 131, se pl. 1 bak i boken. De enkelte skjerp innen hva som kan være en enkelt malmsone har tildels fått egne nummer, idet dette kan lette oversikten over de kjente data. Beskrivelsen av de enkelte forekomster innledes med omtale av "de tre store", Joma, Skorovass og Gjersvik, deretter følger de mindre forekomster. Etter disse beskrivelser gis en malmgeologisk oversikt over Grongfeltet og en diskusjon av forekomstenes dannelsesmåte.

Nr. 2. Skorovass gruver.

Historie og tidligere beskrivelser.

Skorovassforekomsten er den eneste i Grongfeltet som det hittil er blitt drift på. Forekomsten ligger i nesten 700 meters høyde i en fjellkolle ("grubefjellet"), med topper på vel 800 m.

Allerede før 1873 var det skjerpet på den meget sterke rustsone i fjellet, og dette hadde fått den lokale benevnelse "Rauberget". I nevnte år ble strøket geologisk rekognosert av cand. min. K.H. Hauan. I sin dagbok til professor Kjerulf beretter Hauan at han kort sønnenfor et skjerp fant en større, naturlig fjellhule hvor en svovelkisvegg på et par favners høyde er blottet. Denne kis hadde unngått skjerpernes oppmerksomhet. "At kismassen er ganske betydelig, synes utvilsomt", skriver Hauan. Forekomstenn er nevnt av Kjerulf (1875, s.69) i en tabell over Nordtrøndelags gruver og skjerp under navnet "Rauberget v. ved Tunsjø".

Bergmester N.O.Hagen foretok 4/9 1904 en befaring av forekomsten sammen med kirkesanger Lindseth. I Hagens rapport over "den saakaldte Skorevands kisforekomst" beskrives seks arbeidspunkter med maksimal kismektighet på 4,5 m.

Forekomsten ble så anmeldt da skjerpeperioden begynte, og Hauans "malmvegg", den senere Gamlegruva, ble mutet 16/10 1910. Elektrokemisk opprettet kontrakt om erhvervelse i 1912 og innkjøpte feltet i 1914. I perioden 1913-1916 ble forekomsten undersøkt med to stoller og 20 borhull. Den første beskrivelse er publisert av J.H.L. Vogt (1915, s. 37-56). Senere er forekomsten omtalt av A. Bugge (1922) og H.H. Smith (1922).

Skorovassforekomsten og de mindre forekomster i et omkringliggende område ble beholdt av Elektrokemisk A/S da staten i 1918 kjøpte opp resten av Grongforekomstene.

En oversikt over de inntil da kjente fakta ble gitt av Foslie (1926, s. 86-90) i hans arbeid over de norske svovelkisforekomster.

I 1935 ble den nyere undersøkelse påbegynt, og Foslies rapport av 1938 danner grunnlaget for forberedelsen til driften. Den viktigste anleggsperiode tok til i 1950, og i 1952 ble driften påbegynt. Årlig brytes ca. 180 000 tonn råmalm, hvorav fremstilles 150 000 tonn eksportkis. Den rikeste kisvare knuses; resten vaskes ved et "heavy medium" anlegg, hvor gråberg og fattig kis
3,1 med sps.v. under ~~3,3~~ fraskilles. Den nedknuste kis sendes med en 45 km lang taubane til Kongsmo for skipning.

Foslies antagelse, på grunnlag av 55 borhull og elektromagnetisk måling, var at kisen hadde grovt ~~[illegible]~~ form som lange flattliggende linser. Oppfaringen gjennom 4 år har vist at selvom dette bilde generelt er riktig, har de sterke tektoniske bevegelser på malmens grenseflater resultert i at den brytbare malm nærmest har form av en litt flat sigar, se fig. 8.

Fig. 7.

Det geologiske resultat av Foslies undersøkelser er publisert i et foredragsreferat (Foslie, 1939, s. 115-118). Hovedresultatet er at malmdannelsen er metasomatisk. De løsninger som har vandret inn i grønnsteinen og avsatt kisen, har samtidig omdannet den omgivende bergart til lysere rustskifre.

Geologiske forhold.

Malmen opptrer i et mektig grønnsteinskompleks. Dette har omkring malmen mest bra skifrighet med et østlig fall på 10-15°. Det synes ikke å være noen tydelig påviselig tektonisk grunn for forekomstens beliggenhet. Vest for gruvefeltet øker det gradvis med granittårer i grønnsteinen inntil vi får en granittsone med klumper og rester av grønnstein og gabbro. Denne granittsone bøyer omkring forekomsten (se fig.), og i veiskjæringen mellom Samvirkelaget og gruvekontoret sees forskjellige stadier av granittens assimilasjon av grønnstein og gabbro.

Tabell 1.

Sammensetningen av bergartene omkring malmen illustreres av tabell 1. Foruten den vanlige grønnstein (tabellens nr. 1), den klorittrike skifer (nr. 2) og mer ubestemmelig kalkrik skifer (nr. 3) opptrer i malmens umiddelbare nærhet en serie lyse, ofte rustne bergarter. Foslie (1939, s.115) sier om disse "rustskifre": "Bevarte kvartsfylte blærerum viser at disse opprinnelig har vært lavaer, eventuelt også endel tuffer." Bergartene er vakkert blottet langs gruvens heisbane. Etter forfatterens undersøkelser har vi her følgende forhold.

Langs det nederste av heisbanen sees markerte benker av grønnstein eller grønnskifer. Benkene representerer utvilsomt undersjøiske lavastrømmer, kanskje slik at hver større benk er en lavastrøm. Ved første tårn overleires grønnskiferen av et ca. 3 m tykt lag av agglomerat. Det viser lyse boller i en mørkere grunnmasse av blågrå skifer. Bollene er vanligst 5-10 cm store. Ved forskifringen er bollene utgnidd til langstrakte flate linser, de lengste opp i 40 cm lengde. Kjemisk analyse (se tabell av et bollerikt lag viser kvartskeratofyr-sammensetning. Avsetningen må følgelig bestå av vulkanske bomber av obsidian eller rhyolit, blandet med aske av varierende sammensetning.

Over agglomeratlaget følger en serie med oftest 4-6 m tykke lavastrømmer, og mellom hvert ligger det tynnere lyse lag av sur aske, dels agglomeratisk. Derover dominerer rustne lyse skifre, og disse kan følges fra heisbanens topp opp til malmen. Disse rustskifre må tolkes som sure asker, dannet ved eksplosiv vulkanvirksomhet på havbunnen. Blotningene over malmsonen tyder på at der også over malmen ligger en liten serie av lyse rustskifre. Det forhold at selve malmen ligger i de lyse rustskifre og videre at disse er rustne nettop fordi de inneholder svovelkis, synes å antyde at malmdannelsen kan være knyttet til disse skifre, altså til undersjøisk eksplosiv vulkanisme som har produsert sure tuffer.

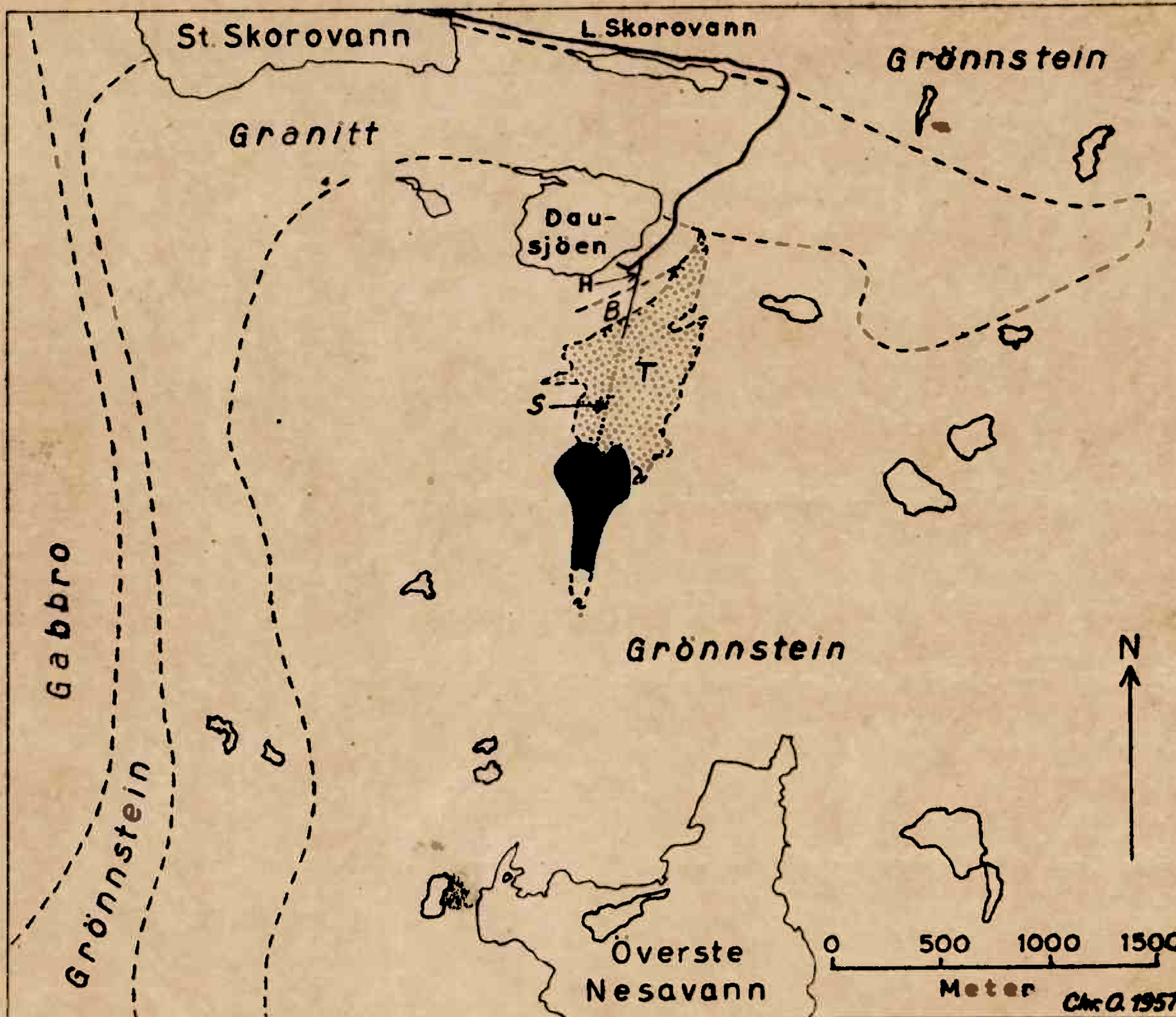
Malmen.

Fig. 8.

Som oftest er det en helt skarp grense mellom kis og grønnstein. Den siste har da alltid skifrighet parallelt grensen. Kisen kan ha en tilsvarende parallell skifrighet markert ved oppsprekning eller ved bånding av grovere svovelkis- eller kobberkiskorn i den finkornigere svovelkis. Kislegemet kan også, særlig i horisontal retning, gå over i grønnstein ved gradvis avtagende impregnasjon. ~~Som profilene (fig. 8) viser,~~ For øvrig har ikke grønnsteinen utpregede folder omkring malmlegemene, men smyger seg i bløte bølger rundt disse.

Grenseforholdene tyder etter forfatterens mening på at malmen var et fast legeme under den siste tektonisering og bare undergikk en delvis omkrystallisering. Hvorvidt selve malmdannelsen er syngenetisk eller epigenetisk (fra en tidligere tektonisk fase) lar seg ikke avgjøre her. Den siste tektonisering må ha medført en differensiell glidning tvers igjennom hele lagpakken. Det er ingen tegn til noen klare skyveplan, og det eneste som sees av forkastninger er de meget små og sene forkastninger hvis maksimale spranghøyde er 10 meter.

Malmen består mest av meget finkornig svovelkis med litt kobberkis, magnetkis og sinkblende. Mineralogisk er forekomsten interessant ved at det er en klar anrikning av kobberkis i forekomstens øverste linse ("Loftet"). Her finnes også sen og lavhydrotermal kobberkis og sinkblende i roser og på sprekker i malmen. En slik sinkblende er analysert (upublisert analyse, ved Foslie), og den har bare 2,5 mol.-% FeS. Dette svarer etter Kullerud (1953, s. 136) til en mulig dannelsestemperatur av under 138° C. Disse mineraler er således i alle fall lavhydrotermale, og de må være langt yngre enn dannelsen av selve malmlegemet.


St. Skorovann
L. Skorovann
Grönnstein
Granitt
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B
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Grönnstein
Grönnstein
N
Överste
Nesavann
0
500
1000
1500
Meter
Chr. O. 1957

1. Mine Ore Bins
2. Cone crusher 4 1/4'
3. Bin
4. Belt weigher
5. Wet screen, 5 mm
6. Heavy media plant with Akins separator
7. Draining and washing screen
8. Concentrate bin
9. Cone crusher 4'
10. Vibrating screen
11. Roll crusher
12. Jig
13. Consentrating tables
14. Dewatering spiral classifier
15. Vacuum filter
16. Mill feed bin
17. Constant weight feeder
18. Ball mill
19. Jig
20. Spiral classifier
21. Conditioner
22. Flotation cells
23. Thickener
24. Drum filter
25. Rotary Dryer
26. Concentrate bin
27. Bins delivering to aerial ropeway

Location: 64° 40' north latitude, elevation about 600 m (2000 ft) near the Norwegian-Swedish border in the municipality of Namsskogan, Nord-Trøndelag fylke (county).

Distance from Trondheim, 270 km (165 miles), from the nearest town, Namsos, 110 km (69 miles), from the nearest airport, Værnes, 240 km (150 miles), from the nearest railway station, Lassemoen, 23 km (14 miles).

Ore Deposit: First described in 1873. Acquired by Elektrokemisk A/S in 1913. Production started up 1952. Area of

Concession: ~~170~~ 165 sq.km. (64 sq. miles)

Capacity per year: 150.000 tons of fine pyrites

Transport: 45 km (28 miles) ropeway to shipping point, Kongsmoen.

Labor Force: Permanently employed at the mine: about 200.

Population: Population of the mining village about 600.

The plant of Skorovas Gruber is situated in rugged mountain terrain to the east of the upper reaches of the river Namsen in the municipality of Namsskogan. This municipality has an area of about 1400 sq.km and, with a population of 2200 or 1,6 persons per sq.km, represents one of the country's most sparsely populated areas. The attitude of the Namsen valley is here about 150 meters above sea level, while the highest peaks surroûnding Skorovas extend up to 1000 meters. Of the 1400 sq.km there are 384 sq.km of productive forest land, 36 sq.km of lakes and rivers and 4 sq.km of cultivated land, the remaining 1000 sq.km is moors and mountains.

The antrance to the mine (624 m above sea level) is located way up in the mountainside with the ore dressing plant, ropewaystation and workshops grouped on terraces at lower levels. The mining village lies fairly well protected in a small valley below the mine and is surrounded by scattered pine and birch trees. Due to the northerly latitude, the timber line is at about 500 m above sea level, and above this the only vegetation to be found is sparse heather and moss.

The first profissional description of the Skorovas deposit was made by a public servant, State geologist Hauan, who visited the place in 1873. Drill holes and other signs of blasting that geologist Hauan found, indicated that even at an earlier perioed curiosity had been shown as to what might lie hidden beneath the layer of rust which covers the mountain at this spot. Repeated investigations were made in the following years, but the endless distances wothout any kind of established communications and the large capital investments which would be required, made it unprofitable to begin regular operation at that time. Thus, the first samples of ore going to factories in Sweden and soth Norway, had to be transported eastward to Sweden over the nearby lake, Tunnsjøen, by boat in summer and by horse and sled in winter.

In 1912-13 Elektrokemisk acquired all the mining rights of any interest in the Grong area, including Skorovas. Around the end of the First World War the Norwegian Government took over the Joma and Gjersvik mining areas while Elektrokemisk retained rights to the Skorovas deposit.

Some preliminary work was done in the years between the Wars. In the middle of the 1920's the district was connected to the national highway network by a road along the river Namsen, the present Highway 50. In the 30's Elektrokemisk built, with government support, a 20 km road connecting

Skorovas with Highway 50. At the same time, the main railway from Trondheim was extended to the Grong area, and now this line - Nordlandsbanen - is completed northward as far as Bodø.

The opening of the Skorovas deposit was started at the end of 30's. After a short interruption at the outbreak of the war, the work was continued without entusiasm until the end of the war. A further delay occured, as market conditions were rather uncertain during the first post-war years, but in the year of 1950preparations started afresh, and in November 1952 normal production could begin.

The "Grong mining area" mentioned above is an area within the Caledonian mountain chain, characterized by thick coverts (mappets) of green-stone. As far as the genesis of the ore deposits is concerned, one can only state that there is no sure explanation but several plausible theories have been advanced. All ore deposits in the Grong area are connected with the green-stone, a basic lava which is assumed to have been extruded under water. The main axis of the Skorovas deposit lies in a north-south direction. The northern part outcreps above the timber line, and, as it forms a strip 300 m long, a rather large rustcolored area has developed which is visible from a long distance. Towards the south, the main ore body splits into several parallel leses, the largest of which exteds like a cigar-shaped body for about 600 m. The principal mineral is pyrites with lesser quantities of copper pyrite, zinc blende, quarts and chlorite. More sporadically are found magnetite, calcium carbonate and fahlertz. Magnetic pyrite and galena have not been found, and the content of arsenic and precious metals is low.

The mine is opened up by a main adit running 1200 meters into the mountain, and from this, most of the ore may be mined. The deepest laying part of the ore body is reached by two inclined shafts. Mining operations were started in the innermost part of the mine and are gradually retreating toward the outcrop.

The ore is removed in stopes across the width of the ore body. These stopes are up to 26 m wide, and pillars 9 m wide are left in between. Longhole slicing with holes - up to 35 m long - drilled with heavy machines and extension rods from "safe" positions, is the normal mining practice. The yearly average is roughly 10.000 m long-holes which, filled with about 12.000 kg of explosives, yield approximately 160.000 metric tons of ore.

The mine at Skorovas is now well mechanized. Daily effort per longhole-driller is 27 meters of "drill holes" including repairs and moving of equipment. Output per man shift "underground" (45 men) is 15 tons. Normally, 185.000 tons of crude ore are extracted per year, yielding 150.000 tons of fine pyrites.

The stopes are undermined by bell-openings leading the broken ore to slusherdrifts, where it is moved by scrapers to the adit and here filled into "Granby"-cars of 3,6 m^3 capacity. Battery-operated electric locomotives moves the cars in trains of five to the mineopening.

A small portion of the ore is pure enough to be exported after crushing only. The rest of the ore goes through an ore dressing plant, where the major portion is processed in a heavy media separation vessel. The ore is here fed to a pulp of ferrosilicium and water with specific gravity 3,3.

The pyrites sink and the unwanted tailings (barren rock) will float, and are skimmed off. The fines (- 5 mm) treated in jigs and on consentrating tables.

Difficult market conditions in recent years have led to very strict requirements on quality. The output from parts of the mine where leah ore occurs can therefore not be mixed with the higher grade pyrites, but must be refined by flotation in order to give a satisfactory sulphur content. The ore dressing will therefore be supplemented by a flotation unit which will be in operation from 1963. According to present plans, this plant will treat 40.000 tons of ore per year, working two shifts, and will thus produce 25.000 tons of concentrate with a sulphur content of 48-50 per cent.

From the ore dressing department the pyrites is delivered to three excavated bins in rock. Each bin has a capacity of about 5.000 metric tons and the pyrites are tapped from the bins directly into the ropeway buckets. The ropeway is 45 km in length and has a capasity of 50 tons per hour of operation. The ropeway has three traktion-sections, each of 15 km, and it has two moved intermedial stations. There are 170 pylons and 23 structures for anchoring and tightening of the carrying cable, all built of galvanized steel. The longest span is more than 1000 meters. Total drop is 467 meters and the highest point is 660 meters above sea level. Traction is supplied by three motors, two of 55 kW and one of 120 kW. The rolling stock consists of 600 buckets, each carrying a net load of 750 kg. When the ropeway is in operation, 3600 wheels and sheaves are rolling. The speed is 2,8 m per second, and a bucket makes a trip from Skorovas to Kongsmoen in 4½ hours. After the initial difficulties had been overcome and necessary improvements had been made, the operation of the ropeway has been quite regular. It is however, necessary to have in mind that the rapidly changing and at times rather harsh climat, will influence on the operation of all outdoorequipment at Skorovas, and this relates especially to the ropeway. It may thus be mentioned that the wind velocity meters which are positioned at the most exposed points along the ropeway, not seldom register winds of hurricane strength.

The shipping port of Kongsmoen lies at the inner end of the 80 km long and rather narrow Folla Fjord. There are storing facilities for up to 5 different grades of fine pyrites or flotation consentrate. Three frostfree bins excavated in the hillside will together store 25.000 tons, and a sheltered emergerncy store can take another 15.000 tons.

Depth at the wharf is 23' at extreme low tidewater. Effective loading capacity, 275 metric tons per hour.

Because of a narrow in the fjord, the harbour at present can not receive ships of more than 5.000 tons d.w. Extensive dredging work that will start in near future, as supposed to result in a chanal depp enough to alowe ships up to 8.000 tons d.w. to enter the harbour. At the same time the wharf will have to be extended so as to be able to receive vessels of up to 120 meters in length.

Skorovas fine pyrites have been sold in most of the European markets. In recent years deliveries have gone chiefly to Sweden and West Germany.

Samples in 1961 of the cupreous pyrites from Skorovas showed the following average:

Sulphur	46,8 %
Copper	1,2 %
Zinc	1,6 %
Iron	41,1 %
Arcenic	0,05 %.

Deliveries of pyrites with low copper content, usually are higher in sulphur, but contains only 0,5 - 0,6 % copper.

All buildings at Skorovas - apart from the elementary school and the teacher's residence - are owned by the company. A few houses were built during the Second World War but most of the buildings were erected during the expansion period from 1950 and onwards.

There are 74 dwelling houses, with together 130 flats, one hostel with 40 single rooms, sitting and dining-room and kitchen caters for single workers, unmaried office personal have their own mess, and there is als company guest house.

In addition to the public elementary school, with about 85 pupils, there is a private secondary school with about 30 pupils.

Furthermore, the company has built a community house with combined theater and cinema, meeting rooms, cafeteria, library, gymnasium, dental clinic, beaty shop and a few hobby rooms. The house covers an area of 800 sq.m. and has a volume of 8.000 cu.m.

The public physician for Namsskogan municipality lives and has an office in Skorovas. The local Red Cross operates two ambulances. The nearest hospital is at Namsos.

The mine, including the ropeway, employs about 220 persons. Of these, about 185 lives at Skorovas and, together with their families and with the few public servants and people working in the local shop, they add up to a population of about 600.