Bergvesenet

Postboks 3021, 7002 Trondheim

Rapportarkivet

Bergvesenet rapport nr	Intern Journal nr	Internt arkiv nr	Rapport lokalisering	Gradering
BV 3958			Trondheim	
Kommer fra ..arkiv	Ekstern rapport nr	Oversendt fra	Fortrolig pga	Fortrolig fra dato:

Tittel

Geological setting of the Skorovas orebody within the allochthonous volcanic stratigraphy of the Gjersvik Nappe, Central Norway.

Forfatter	Dato	Bedrift
Halls, C., Reinsbakken, A., Ferriday, I., Haugen, A., Rankin, A.	19	

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

Fagområde	Dokument type	Forekomster
Geologi		
Råstofftype	**Emneord**	
Malm/metall		

Sammendrag

GEOLOCICAL SETTING OF THE SKOROVAS OREBODY WITHIN THE ALLOCHTHONOUS VOLCANIC STRATIGRAPHY OF THE GJERSVIK NAPPE, CENTRAL NORWAY

C. Halls
Division of Mining Geology, Royal School of Mines, London, England.

A. Reinsbakken
Geologisk Institutt, Norges Tekniske Høgskole, Trondheim, Norway.

I. Ferriday
Division of Mining Geology, Royal School of Mines, London, England.

A. Haugen
Grong Gruber A/S, Joma, Norway

A. Rankin
Division of Mining Geology, Royal School of Mines, London, England.

ABSTRACT

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 L. Ordovician age defined by S. Foslie (1922-1943) and C. Oftedahl (1956) as the Gjersvik Nappe. The rocks of this Nappe are contained as a depressed segment of the larger Köli Nappe (Kulling 1966) and defined to the N. and S. 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 which 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 seafloor 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 L. 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 spilitised aphanitic equivalents (keratophyres). The heterogeneous pattern of deformation is resolved in terms of two main stages of folding complicated by componental sliding movements.

Mineralisation 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. Mineralisation of this type is at present only known in sub-economic quantities (S. Foslie and M. Johnson Høst 1932).

The Skorovas orebody, in common with other widely dispersed volcanic exhalites in the Gjersvik Nappe (C. Oftedahl 1958), 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 million 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 occurring 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 oxidising 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.

(1) INTRODUCTION

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 S.W. Norway to Nord Troms. The divisions of this complex metallogenic belt have been described by Vokes [73,75] and figure 1 shows the relationship of the principal districts to the thrust front of the Caledonian allochthon. The culminations of the underlying Pre Cambrian 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 S. Trøndelag (Trondheim district) [49,50,52], N. 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 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 N. Troms.

It is clear that the separate districts which 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 grunen 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.
It is generally recognised 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 eruptive at the margins of the Caledonian orogen in Ordovician times.[15,16,47,75] The genetic process relating the ores and host rocks has been masked by the effects of metamorphic recrystallisation and polyphase deformation which affected both ores[73,74] and host rocks during the process of allochthonous tectonic emplacement which was a consequence of collision of the Scandinavian and Laurentian cratons during Middle Silurian times[10,24]. The palaeo-environmental 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 then an understanding of the volcanostratigraphy and structure in an area extending from 1-10 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.

II) 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 Strand [14] and Oftedahl. More recent regional studies by Zachrisson in the adjacent Swedish areas of Jamtland and Vasterbotten 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 the map (figure 2) which shows the main second order tectonic divisions which have been recognised 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 recognised. 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 then finally the Lower Köli Nappe unit within which are situated the Stekenjokk Orebodies (St) (The Stekenjokk malm and the Levimalm).[82]

The broad classification into the second order tectonic units shown in figure 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 figure 2 the Upper tectonic contact with the Helgeland Nappe[23] is clearly defined. The plutonic and supracrustal stratigraphy is revealed in the passage from S.W. to N.E. 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 S.W. are succeeded 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 which is intermittently preserved at the uppermost level of the volcanic greenstone sequence. The marble is best preserved in the terrain N. of the Limingen Lake but a limited thickness is found to the N.N.E. of Skorovas mine in the terrain to the S. of Tunnsjøen. The volcanics with the overlying marble are followed by a spectacular polymict conglomerate, the typical aspect of which is shown in the photograph, figure 12A,B. The final part of the sequence is made up by the clastic sediments of the Limingen group composed by a variety of schistose conglomeratic, sub-arkosic and phyllitic rocks, the majority of which are distinctly calcare ous.

Oftedahl[41], in his discussion of the nappe units of the Grongfelt, has defined a thrust boundary of intermediate significance which 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 a strong similarity to the rocks of the Støren Group [72] in the Trondheim region. The Støren group, locally, conformably overlies schists of the Röros series containing Dictyonema Flabelliforme [62]. The maximum age of the Støren Group is thus determined as U. Cambrian - L. Ordovician (Tremadocian). and by analogy it is likely that the Gjersvik complex is of L. Ordovician age (Tremadocian - Arenigian).

The polymict conglomerate which overlies the Gjersvik greenstones evidently marked a significant episode of uplift and erosion in L. Ordovician times and may be correlated with the basal conglomerates of the Lower Hovin Group in the Trondheim region, notably the Venna[72], Lille Fundsjø and Steinkjer Conglomerates. The widespread occurrence of conglomerates at this stratigraphic level led Holtedahl[26] to propose a tectonic event of regional significance which he termed the Trondheim Disturbance. A graptolite fauna from the Bogo shale which lies above the conglomerates in the Lower Hovin Group is interpreted by Skevington[57] to lie within the Didymograptus hirundo zone. Thus the Trondheim Disturbance is believed to be of late - Arenig to early - Llanvirn age[3,11,50]. It should be noted that other tectonic events are recorded by conglomerates at stratigraphically higher levels in the M. Ordovician - L. Silurian sequence of the Trondheim region. Vogt[72] has identified an Ekne and a Horg Disturbance and there are evidently further refinements as discussed by Roberts[53].

The Table, figure 3, shows the inferred general stratigraphic correlation between the Lower Palaeozoic sequences in the Grong and Trondheim regions. Zachrisson 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 Lasterfjall Group (figure 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 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.

III) TECTONIC STYLE WITHIN THE SKOROVAS AREA OF THE 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 the geological map, figure 4, lies close to the Eastern boundary of one of the main plutonic massifs of the Gjersvik nappe. From the regional map, figure 2, it is clear that the massifs have distinctly tectonic boundaries of low to intermediate angle (figure 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 tectonised 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 which 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 characterises 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 spilitised 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 the section, figure 5, and imposing the early schistosity mentioned above. It was during this stage that the main thrust and slide horizons separating 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 emphasised that such planes of high tectonic strain also exist in several lesser orders within the volcanic sequence. These surfaces, as 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 generation. The least competent rocks within the volcanic sequence are the pillowed basaltic lavas and pillow breccias. These rocks, under the influence of intense local strain, suffer a complete penetrative reorganisation 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 W. Africa (G. Pouit - pers. comm.). 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 (figure 7A). 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 the geological section (figure 5).

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 (figures 2 and 4A). 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 lead 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 the photograph (figure 7B) shows part of the well-developed belt of second stage folding in the volcanic sequence at the S.E. 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 W. to N.W. 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 E. to N.E. direction from the flanks of a basement dome in the vicinity of the Grong culmination.

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 displacements of the order of metres but along the S.E. 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 metres (figures 4A & 5). The trend of these fractures is predominantly in a N.N.E. to N.E. direction and their formation postdates 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.

IV) THE PLUTONIC MEMBERS OF THE GJERSVIK ERUPTIVE SEQUENCE IN THE 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 tectonised 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 (figure 4A). The plutonic rocks of this belt have been subjected to the penetrative deformation which 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 of various facies were distinguished and at the opposite end of the compositional scale trondhjemite, tectonised 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 N. of the Grøndalsfjell massif and to the W. 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 recognised.

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

(a) The Grøndalsfjell massif: The starkly exposed rocks composing 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 x 200 metres, contained in a matrix of metamorphosed gabbro and hornblende diorite. The cumulus layering of the gabbro bodies is subvertical in attitude with a predominantly E. - W. trend. This must be accepted as evidence of significant post-cululus 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 crystallisation from a tholeiitic magma[25,67].

The nature of the xenolithic relationship is shown in the photograph, figure 8A, 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 cross-cutting joints producing a distinctive weathered surface as seen in figure 8B. The alteration leads to the uralitisation and chloritisation of the augite and hypersthene, the serpentinisation 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 saussuritised plagioclase of intermediate composition and accessory Fe - Ti oxides. The iron oxides are frequently altered to sphene and the hornblende is generally partly chloritised.

One of the most striking features of the hornblende diorite is the occurrence of coarse patches and pegmatoidal veins, 0.5 - 3 metres 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 rythmic banding paralled to their contacts. This can be interpreted as a result of episodic deuteric crystallisation 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 E. 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.

There are at least two generations of impersistent basic dykes which 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 N.E. trend with steep dips to the N.W. 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 N.E. trend and dip steeply to the N.W. The dykes are commonly 1-2 metres thick and can be followed for distances of 1-2 kilometres before pinching out. Close to the margins of the plutonic mass, and also within it, these dykes show well developed tectonic foliation and locally mylonitic facies demonstrating that the N.E. trending fracture system has been the focus of significant post-intrusion tectonic strain. The granodiorite dykes are composed dominantly of sodic plagioclase (roughly of oligoclase composition), quartz and accessory microcline, biotite, hornblende and sphene. The ferromagnesian minerals are generally partly chloritised 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 (figure 4).

In addition to the main gabbro-diorite body of the Grøndalsfjell massif delineated by Foslie on the map of the Trones rectangle, a significant mass of "fine grained gabbro" is also shown lying directly to the N. 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, figures 4A, 4B. Investigation has shown that Skorovasklumpen and the narrow belt of similar character which can be followed along the E. 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 bondary (figure 4A) and can be mapped over a distance of 4 kilometres. Original volcanic structuresl notably pillow forms and vesicles, are preserved within xenolithic masses and testify to the volcanic origin of the host rocks. Similar textural evidence of volcanic origin has been found within the basic sequence composing 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 which is readily made in the field.

The amphibolitic lavas locally display distinct penetrative tectonic lineation of the amphiboles and this lineation can be observed in the amphibolitised 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].

(b) The rocks of the arcuate intrusive belt:

The intrusive arc differs from the plutonic massif of Grøndalsfjell in three distinctive ways:

(I) No unmetamorphosed gabbroic bodies have been found in which a plagioclase-pyroxene-olivine assemblage is preserved.

(II) 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.
(III) 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 S. of Tunnsjøen. (see map, figure 4A)

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 figure 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. 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.

V) THE VOLCANIC ROCKS OF THE GJERSVIK ERUPTIVE SEQUENCE IN THE 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 recognised 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 which 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 andesites with lesser amounts of andesitic and keratophyric rocks. This fact is apparent from the relative outcrop of acid and basic rocks shown on the map, figure 4A, 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 figures 10A and 10B. The 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. This is shown in the section, figure 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 2-10 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 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 - figure 13). 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 cross cutting 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. Acti nolite 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 conspicuosly 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 sph eroidal 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 the photographs, figures 11A and 11B.

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 re-organisation 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 which took place in the earliest event prior to the deformation of the rocks can be 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] has recognised 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 $>10^4 : 1$ are 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 analyses in the table (figure 13).

The recognition of the pervasive pre-deformation in-situ sea -floor metamorphism of the Gjersvik basalts also helps to resolve the controversy which surrounds the tectonic status of the Trondheim disturbance.[11, 51, 65] The polymict conglomerate which 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 (Figure 12A). It can also be demonstrated on a regional scale by mapping the level of unconformity through the isoclinal folds of the first deformation. This is shown in the geological section, figure 5.

The conglomerate is composed of boulders directly derived from the plutonic and volcanic sequence which 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 (figure 12B) which have evidently been derived by erosion of the metamorphosed basalts.

Final and conclusive evidence is thus provided for the L. Ordovician metamorphic event pre-dating the Trondheim disturbance which was discussed by Sturt et al.[65] and Dewey et al [11]. 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 predominantly vertical as opposed to lateral and must have been related to an early stage of tectonic evolution within the belt of L. Ordovician eruptives of which the Gjersvik Complex was a part.

Magmatic activity in the belt continued after the erosional event. The evidence for this is provided by quartz -feldspar porphyry dykes which 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 which can be traced laterally over considerable distances as shown on the map, figure 4A. 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".

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 N. of Store Skorovatn. This is shown in the map, figure 4A and the geological section, figure 5.

The orebody itself evidently lies within the vicinity of one eruptive focus which will be called the Grubefjell Centre. The other centres which are tentatively distinguished lie to W. and S.W. of Tredjevatnet (the Tredjevatnet Centre), to the E. of Överste Nesåvatn (the Nesåvatn Centre), and further East in the terrain near Blåhammeren. (the Blåhammeren Centre). The main belts of acid rocks shown on the map, figure 4A, serve to identify these centres. It is difficult to judge whether these 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 agglomoratic facies are visible in the acid horizons in the immediate vicinity of the mine as shown in figures 14A and B. Distal pyroclastic facies include fine tuff bands with associated exhalite sediments as shown in figure 15A. 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 which occurs at the Eastern end of the Northern limb of the intrusive 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 connections between the plutonic and volcanic levels during climatic episodes of acid eruptive activity.

Chemistries of the acid extrusive rocks from the Skorovas ore level are distinctly soda-rich as shown by analyses 1 and 2 in the table, figure 13. 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 the Table, figure 13, it is clear that the Skorovas volcanic rocks are a spilitic suite.

The question is immediately raised as to the relationship which 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 in section IV of this paper 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 saussuritisation, have original compositions in the range labradorite, in gabbro, to oligoclase, in trondhjemite.

Goldschmidt has given analyses of the type trondhjemites from the Trondheim district and from localities in W. Norway which 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 is thus of the order 3:1. Partial analyses of 3 trondhjemitic rocks from the Skorovas intrusive arc made by Scott[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 as can be seen from the analysis in table 13.

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 is one which 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] amongst others and it is clear, after the review of the problem given by Vallance,[69,70] that the case for post-eruptive metasomatic alteration of alkali contents by circulating sea water is a strong one. Taken in conjunction with the textural evidence which has been 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 seafloor metamorphism of the volcanic rocks during L. Ordovician times. This metasomatic alteration by circulation of heated seawater changed the chemistry of the rocks, notably enhancing the Na_2O content and concealing the natural magmatic consanguineity of the volcanic and plutonic rocks.

THE MAGMATIC AFFINITY OF THE 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, recognised the possibility of using certain elements, notably Y, Zr, Nb & 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 figure 13b 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 recognise 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 spilitised equivalents). In the case of mature calc- alkaline arcs the relationship is of a distinctly different order, notably ANDESITE >>BASALT. The field evidence when 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 Ordovician age formed within an ensimatic setting peripheral to 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;[10,29] the tectonic transport involved in the process of emplacement is estimated to have been at least 200-250 km.[16,17,63,64]

VI THE SKOROVAS OREBODY AND PERIPHERAL EXHALATIVE MINERALISATION.

The description of the volcanic host rocks which has been given above confirms the association between the Skorovas orebody and an eruptive sequence originating in an immature ensimatic island arc of early Ordovician age. It is appropriate to consider the morphology and mineralogy of the ore deposit and the peripheral exhalite mineralisation of the Skorovas region in terms of the exhalative volcanic hydrothermal origin which was 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 spilitised 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 between ore and keratophyric extrusive rocks is intimate as shown by the map figure 4A, the section, figure 5, and the section figure 17.

The Skorovas orebody, at the present state of development is estimated to comprise between 8 and 9 million tons of massive sulphide ore including 1.5 million tons of essentially pyritic ore with minimal base metal content. From the initiation of production in 1952 until 1975-76 approximately 4.7 million 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 million 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 mineralised 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 dominately 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 2wt.% and Cu ≤ 1 %.

THE STRUCTURAL STYLE OF THE OREBODY.

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

The orebody can be described as an en-echelon array of closely spaced groups of massive sulphide lensed, the distribution of which has created an elongate ore zone with a length of approximately 600 m. lying in a N. to N. N. E. orientation and with a width of the order of 200 m. A representative cross section of the orebody is shown in figure 17.
The lenticular bodies have their principal planes oriented 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 shown by figure 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 wall rocks. This evidence, together with the irregular geometry of the ore body 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 L. 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 wall rocks during the flattening and isoclinal folding of the first stage 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, due to 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 the section, figure 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 summarised as follows:

(i) 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.

(ii) 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, figure 16.

(iii) 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 N 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, figure 4B, have steeply dipping axial planes and an axial trend of approximately NNW orientation concordant with the pattern of the adjacent structural basin, on the flanks of which the orebody lies.

MINERALOGY AND STRATIGRAPHY WITHIN THE OREBODY

The bulk composition of the Skorovas orebody reflects a mineralogy of comparative simplicity. Pyrite together with 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 which have been recorded in analysis of the orebody. Values as follows may be considered as representative averages: Co 100 ppm, Ni 20 ppm, As 300 ppm, Ag 10 ppm, Au 0.1 ppm. Cadmium is notably enriched in sphalerite-rich facies of the ore, reaching values of several hundred ppm while 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 microns 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 which has been summarised in this paper and by other authors[20,21,41] has confined the choice of genetic models for the orebody to the following alternatives.

(i) Syngenetic deposition of the stratiform ore body(s) under submarine conditions as a result of emmission of metal rich fluids in the vicinity of an acid eruptive centre.

(ii) 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 recognise 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 notes 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 as shown schematically in figure 17. In the northern part of the orebody the composition is essentially pyritic with minimal base metal content. The analytical data proves 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 recognise facies of the ore which 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 figure 18c. 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 as shown by figures 18B and D. Figures 18A and 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

(Sentence continues on p 35)

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 chloritised 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 recognisable 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 the table, figure 19. The typical foliated texture of this ore is shown in figure 18D 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, neither 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 the table figure 19, 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 the table figure 19.

It appears also that a distinct primary lateral variation may also have been present 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 haematitic 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 ore body 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 ore bodies 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 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 oxidising 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 seawater[54]. It is upon the presence or absence of the conditions outlined that the distinction between the hydrothermally intensive and the hydrothermally extensive exhalite phenomena in the Skorovas area is based.

PERIPHERAL EXHALATIVE MINERALISATION

The magnetitic cherts and jasper which are found at the stratigraphic top of the Skorovas orebody signify the restoration of chemically normal oxidising conditions in the vicinity of the orebody. These ferruginous siliceous horizons represent a continuum between the intensive and extensive facies of mineralisation, as shown schematically in figure 20. 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 (1922)[7,8] in his studies of the Leksdal type of sedimentary sulphide deposit in the Trondheim district. Oftedahl[42] emphasised 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 as follows

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

(ii) 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 as shown in Figure 21 and also, generally speaking, in a lateral sense.

(iii) The sulphide facies are characteristically impoverished in base metals other than iron and manganese as shown by analysis 6 in the table Figure 19.

The explanation of 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 oxidising seawater will have occurred. The base metals will have been subjected to infinite dilution in the course of such a process, leaving oxidised 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 extending 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 volcano stratigraphy.

The sulphide-magnetite mineralogy of the reducate facies is to be ascribed to post depositional bacterial reduction of iron, deposited in the oxidised condition. A typical facies of this type is shown in Figure 15B.

The simple stratigraphy shown in the ideal section, Figure 21, can be regarded as the product of a single dispersal event. Some exhalites however give evidence of episodic explosive and fumarolic activity resulting in a complex cyclic stratigraphy in which tuff bands are intercalated with iron-enriched chert bands showing a complex mineralogy including stilpnomelane, iron-rich amphiboles and chlorites together with a spinel, commonly of magnetite composition as shown in Figure 15A.

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 Skorovas area by Ferriday, Halls and Hembre.

VII CONCLUSIONS

It was recognised 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 taking 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 which 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 taking 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 Figure 4A) 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 but may be regarded as indicative of the exploration potential of the larger gabbro massifs of the Gjersvik complex, notably Heimdalshaugen. The whole range of phenomena which have been described can therefore be said to typify the ore-forming environment within an ensimatic pericratonic island arc and only the porphyry style of subvolcanic mineralisation appears to be absent. This may, however, reflect the immature character of the arc.

The study has also placed the Trondheim disturbance in its proper geological context as an episode of uplift associated with the later stages of evolution of a pericratonic island arc system in L. 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 which 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 which could have been located, in L. Ordovician times, on separate geographically and tectonically isolated margins of the orogenic system.[3]

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Eastern thrust boundary of the Caledonian allochthon.

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

Basement inliers and culminations: Pre-Cambrian.

Jotun nappes and related structures with allochthonous Pre-Cambrian rocks.

Pre-Cambrian basement re-worked during the Caledonian orogeny.

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

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

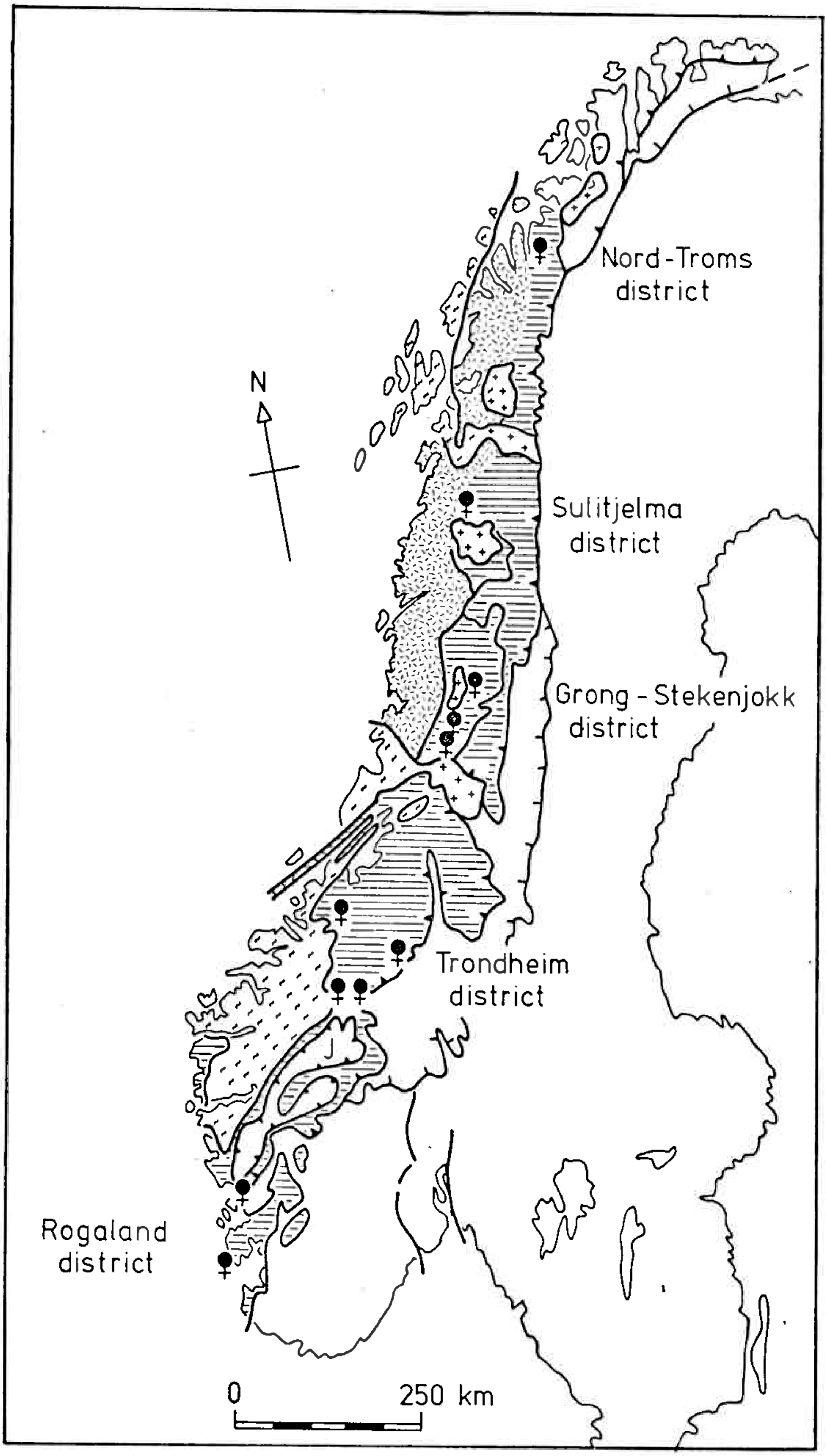

Nord-Troms
district
N
Sulitjelma
district
Grong - Stekenjokk
district
Trondheim
district
Rogaland
district
0
250 km

FIGURE 1

FIGURE 2 MAP SHOWING THE LOCATION OF THE MAIN ORE DEPOSITS IN THE GRONG ÷ STEKENJOKK DISTRICT (SK-SKOROVAS, Gj-GJERSVIK, Jo -JOMA AND St-STEKENJOKK) AND THE MAIN STRUCTURAL AND STRATIGRAPHIC UNITS WHICH CAN BE DISTINGUISHED WITHIN THE KÖLI NAPPE.

1) THRUST AT BASE OF THE OLDEN BASEMENT NAPPE
2) THRUST AT BASE OF THE SEVE-KÖLI NAPPE
3) THRUST SEPARATING THE SEVE AND KÖLI SEQUENCES WITHIN THE SEVE KÖLI NAPPE COMPLEX
4) THRUST SEPARATING THE GJERSVIK NAPPE AT THE TOP OF THE KÖLI NAPPE SEQUENCE FROM THE HIGH GRADE METAMORPHIC ROCKS OF THE HELGELAND NAPPE COMPLEX

(Boundaries based on geological information from FOSLIE, OFTEDAHL, ZACHRISSON, GEE AND GUSTAVSON).

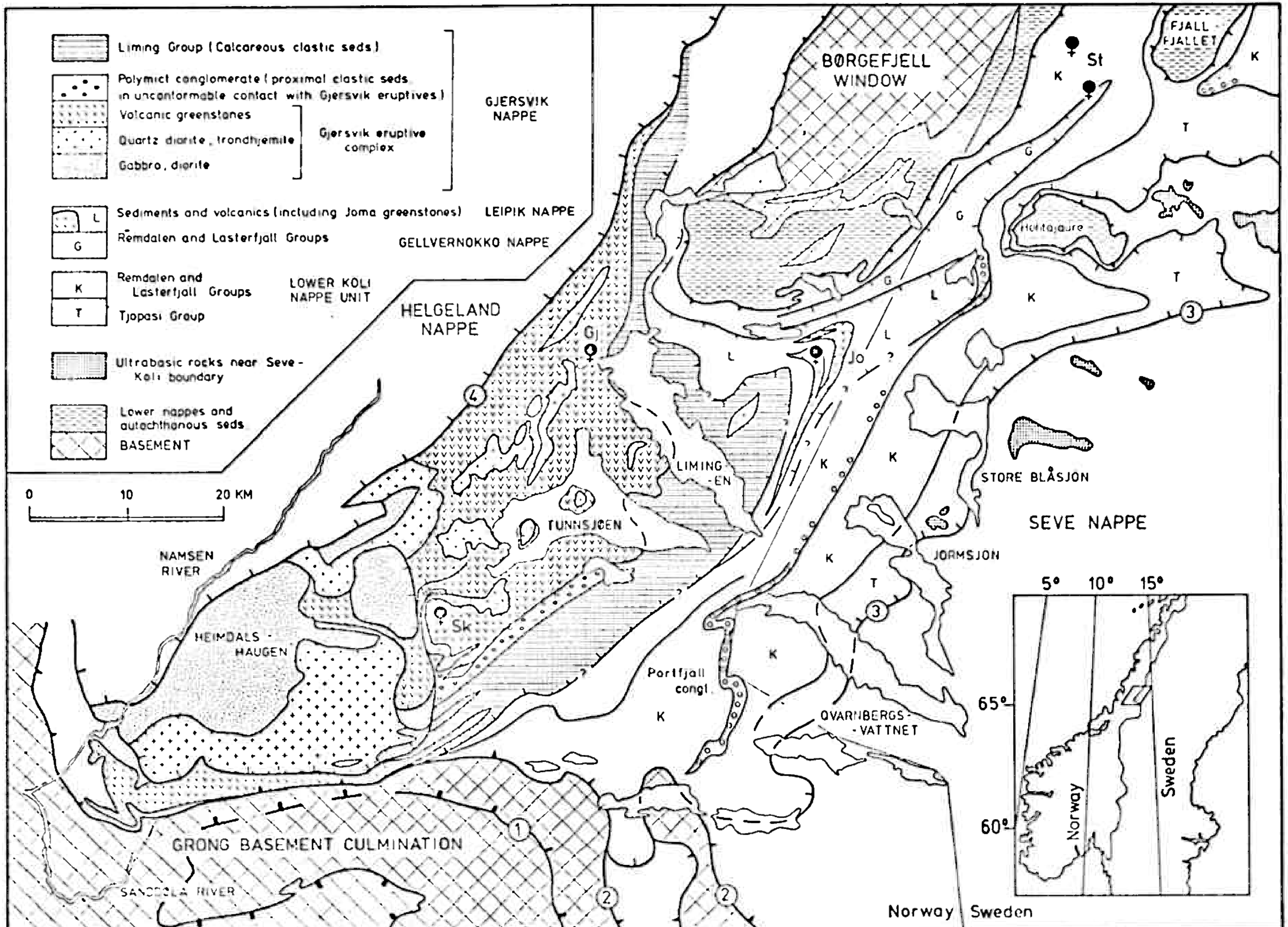

Liming Group (Calcareous clastic seds)
Polymict conglomerate (proximal clastic seds in unconformable contact with Gjersvik eruptives)
Volcanic greenstones
Quartz diorite, trondhjemite
Gabbro, diorite
Gjersvik eruptive complex
GJERSVIK NAPPE
Sediments and volcanics (including Joma greenstones)
LEIPIK NAPPE
Remdalen and Lasterfjall Groups
GELLVERNOKKO NAPPE
Remdalen and Lasterfjall Groups
Tjopasi Group
LOWER KOLI NAPPE UNIT
Ultrabasic rocks near Seve-Koli boundary
Lower nappes and autochthonous seds
BASEMENT
0
10
20 KM
HELGELAND NAPPE
NAMSEN RIVER
HEIMDALSHAUGEN
TUNNSJØEN
LIMING-EN
BØRGEFJELL WINDOW
STORE BLÅSJON
SEVE NAPPE
JORMSJON
Portfjall congl.
QVARNBERGS-VATTNET
GRONG BASEMENT CULMINATION
SANDOLA RIVER
Norway
Sweden
5°
10°
15°
65°
60°

FIGURE 2

FIGURE 3

Inferred stratigraphic correlation between the Lower Palaeozoic sequences to the South and North of the Grong Culmination. The correlation is approximate and based on information from Vogt 1945, Zachrisson 1971, Oftedahl 1974 and Roberts 1975. Tectonic disjunction within the two areas is shown schematically by oblique parallel lines.

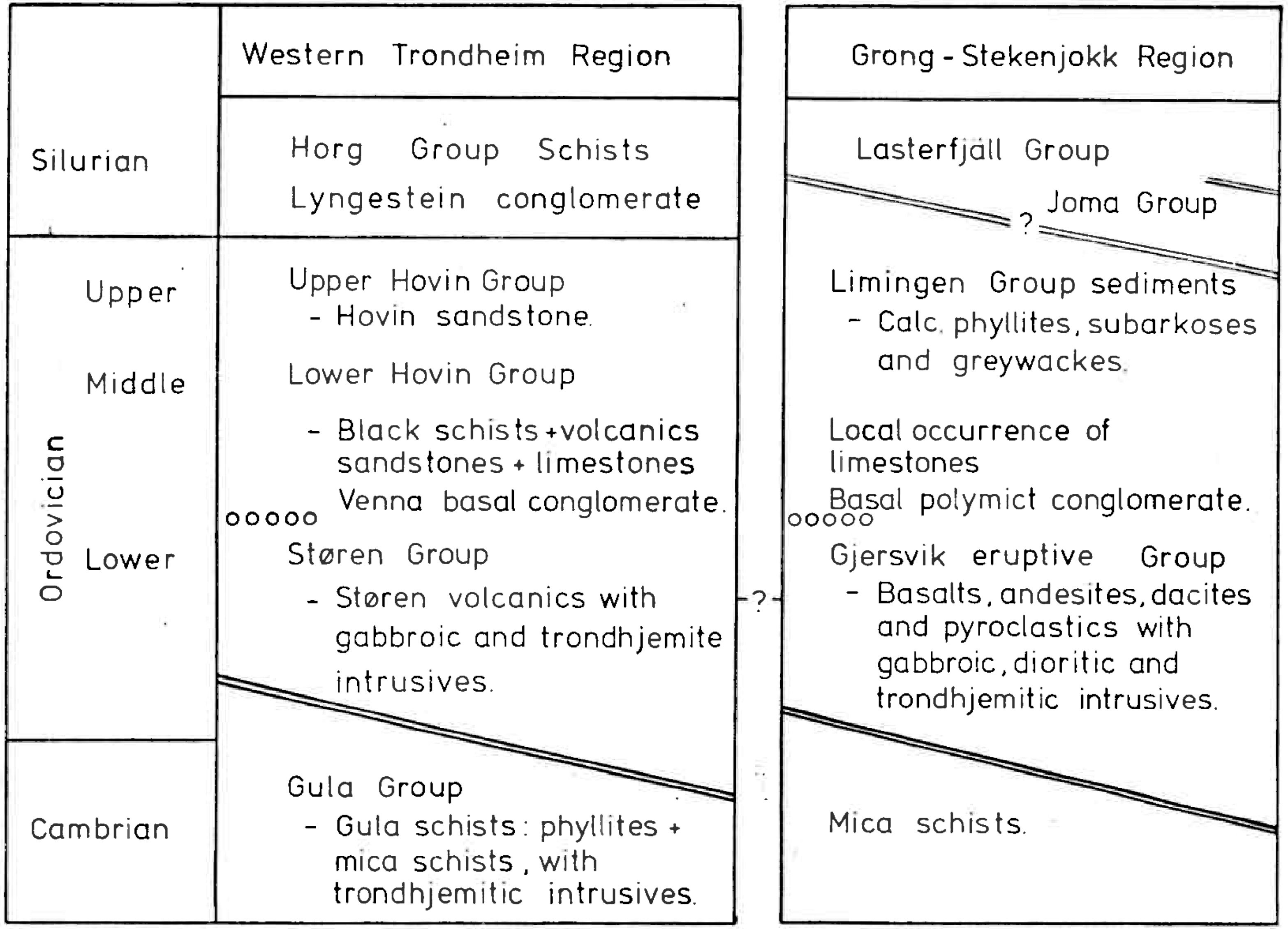

Western Trondheim Region
Grong - Stekenjokk Region
Silurian
Horg Group Schists
Lyngestein conglomerate
Lasterfjäll Group
? Joma Group
Ordovician
Upper
Middle
Lower
Upper Hovin Group
- Hovin sandstone.
Lower Hovin Group
- Black schists + volcanics
sandstones + limestones
Venna basal conglomerate.
Støren Group
- Støren volcanics with
gabbroic and trondhjemite
intrusives.
Limingen Group sediments
- Calc. phyllites, subarkoses
and greywackes.
Local occurrence of
limestones
Basal polymict conglomerate.
Gjersvik eruptive Group
- Basalts, andesites, dacites
and pyroclastics with
gabbroic, dioritic and
trondhjemitic intrusives.
-?-
Cambrian
Gula Group
- Gula schists: phyllites +
mica schists, with
trondhjemitic intrusives.
Mica schists.

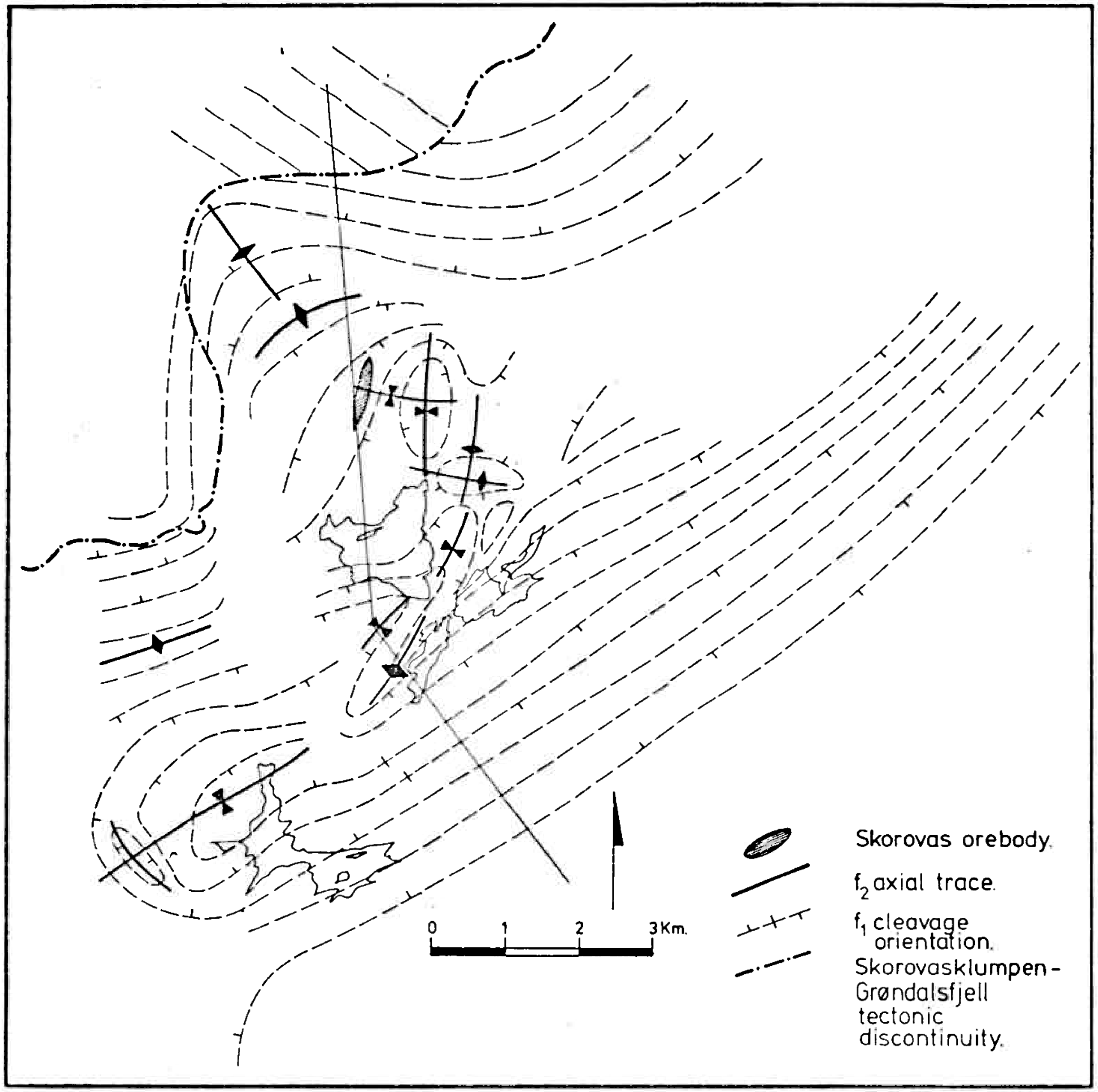
FIG 3

FIGURE 4A

Simplified geological map of the Skorovas Area with line of section (fig. 5) indicated. SSV: Store Skorovatn, Gr : Grubefjellet, ONV: Øverste Nesavatnet, TV: Tredjevatnet., Bl : Blåhammeren, HV: Havdalsvatnet

FIGURE 4B

Synoptic map of the principal structural trends.



0
1
2
3 Km.
Skorovas orebody.
f2 axial trace.
f1 cleavage orientation.
Skorovasklumpen-Grøndalsfjell tectonic discontinuity.

FIGURE 5

Simplified geological section through the Skorovas area.

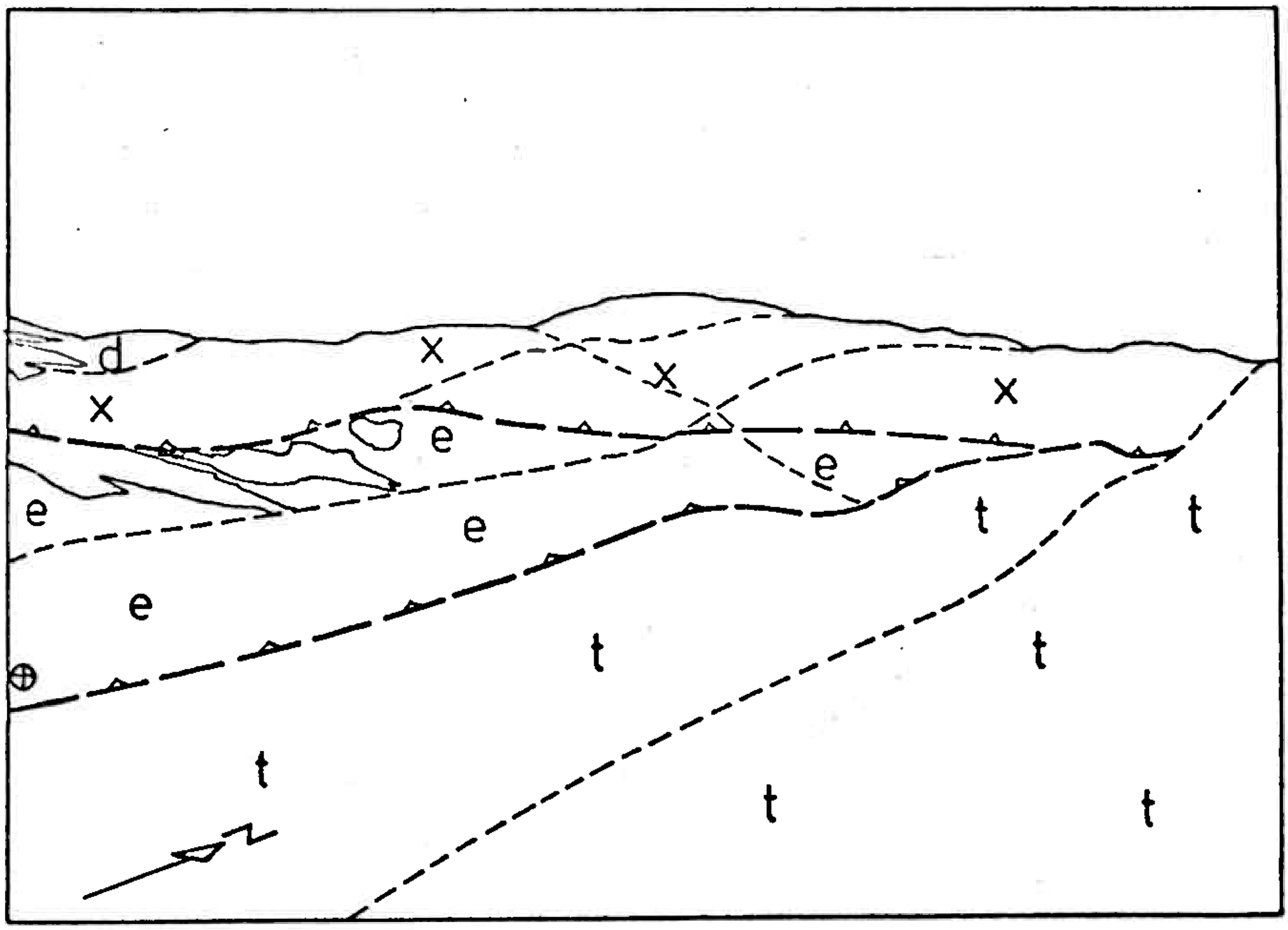

d
x
x
x
x
e
e
e
e
e
t
t
t
t
t
t
t

FIGURE 6

Panoramic view of the South East margin of the Grøndalsfjell massif seen from a point of vantage on the trondhjemite intrusive of the Skorovas intrusive arc. The major thrust horizon separates diorite and gabbro (d) together with the hornfelsed envelope (x) from structurally underlying schistose extrusives (e). A further thrust separates the extrusives from the trondhjemite (t) in the foreground. The location of the photograph, figure 7, is shown by the crossed circle at the far left of the vista.

FIGURE 7A.

Typical dislocated isoclinal style seen in minor folds of the first generation in chert bands to the S. of Nesåklumpen.

FIGURE 7B.

Localised post schistosity folding and incipient crenulation cleav age of the second generation formed in the zone of high strain in schistose greenstones adjacent to the tectonic boundary of the Grøndalsfjell massif. The location of this photograph is shown on the key to the photograph figure 6.

FIGURE 8A

The north-east face of the Grøndalsfjell massif, displaying well the occurrence of rafts of unaltered layered gabbro (dark) within a dioritic matrix. Rafts are of the order of 60 to 100 m. x 200 m.

FIGURE 8B

The field appearance of the hydrated, uralitised envelope which borders the large xenolithic masses of fresh layered gabbro on Grøndalsfjell (figure 8A). The troctolitic gabbro shows strong differential weathering of the pyroxene, feldspar and olivine, producing the pitted surface. The uralitised assemblage weathers uniform ly by comparison.

FIGURE 9

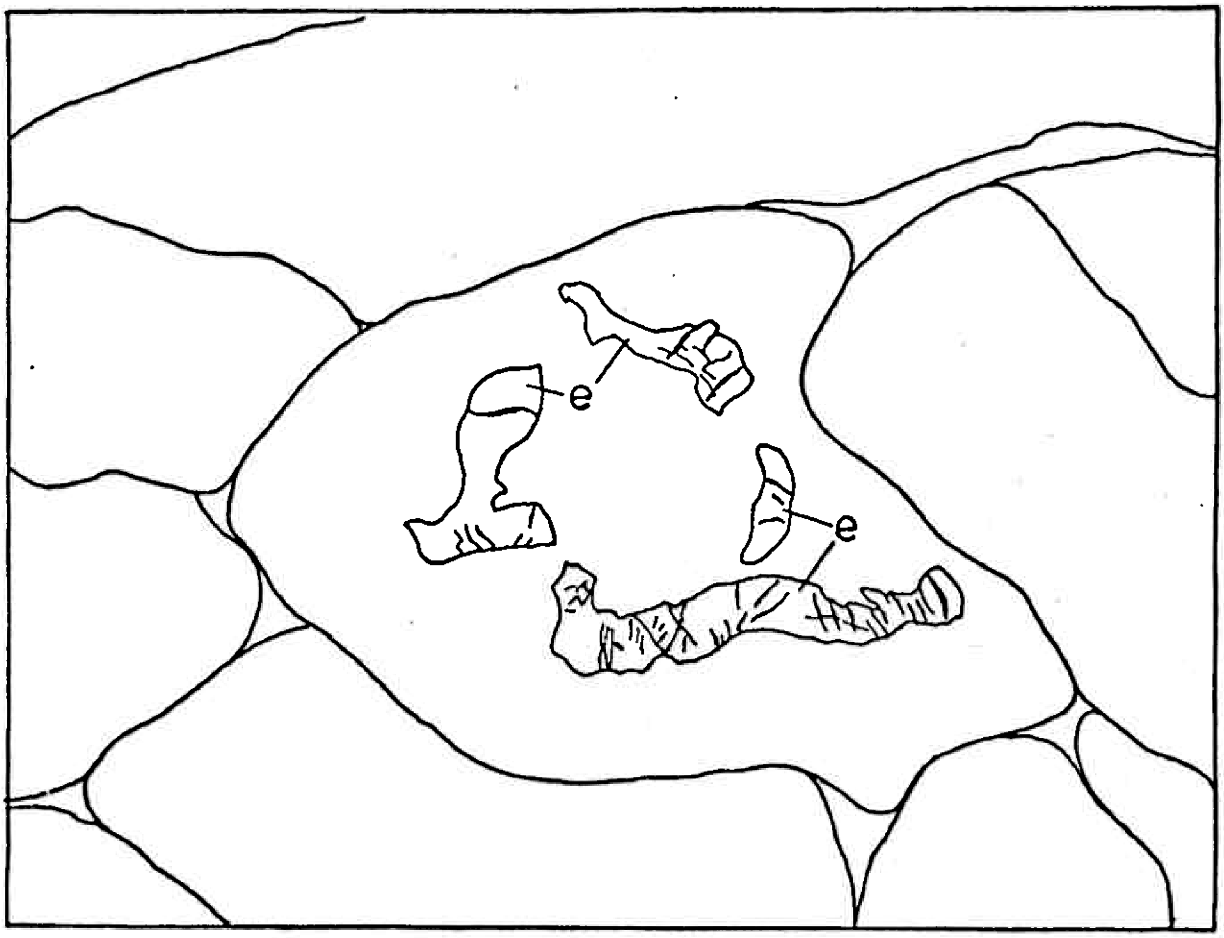
Trondhjemitic net veining in mafic diorite and hornblende gabbro on South-west Grubefjell.

FIGURE 10A

Deformed basaltic pillow lavas observed on the northern slopes of Grubefjell below the orebody. The cuspate bodies of grey chert which occupy the interstices between the pillows are conspicuous. In cases of extreme deformation, the survival of these chert bodies within the chloritic schist provides a useful guide to the original volcanic structure of the rocks.

FIGURE 10B.

Basaltic pillows from a flow exposed on the S.W. shore of Tredjevatnet. The eruption of the pillowed basalts followed the deposition of a dispersed exhalite horizon in the vicinity of the Tredjevatnet centre. The layer of ferruginous silica gel, disturbed during the eruption of the basalts, has formed a jasper matrix for the pillows. The chloritised chilled margin of the pillows is conspicuous. Significant amounts of pyrite are also found in association with the jasper pillow matrix, the pillow lavas lying stratigraphically but a few metres from a horizon of massive pyrite.


e
e
e

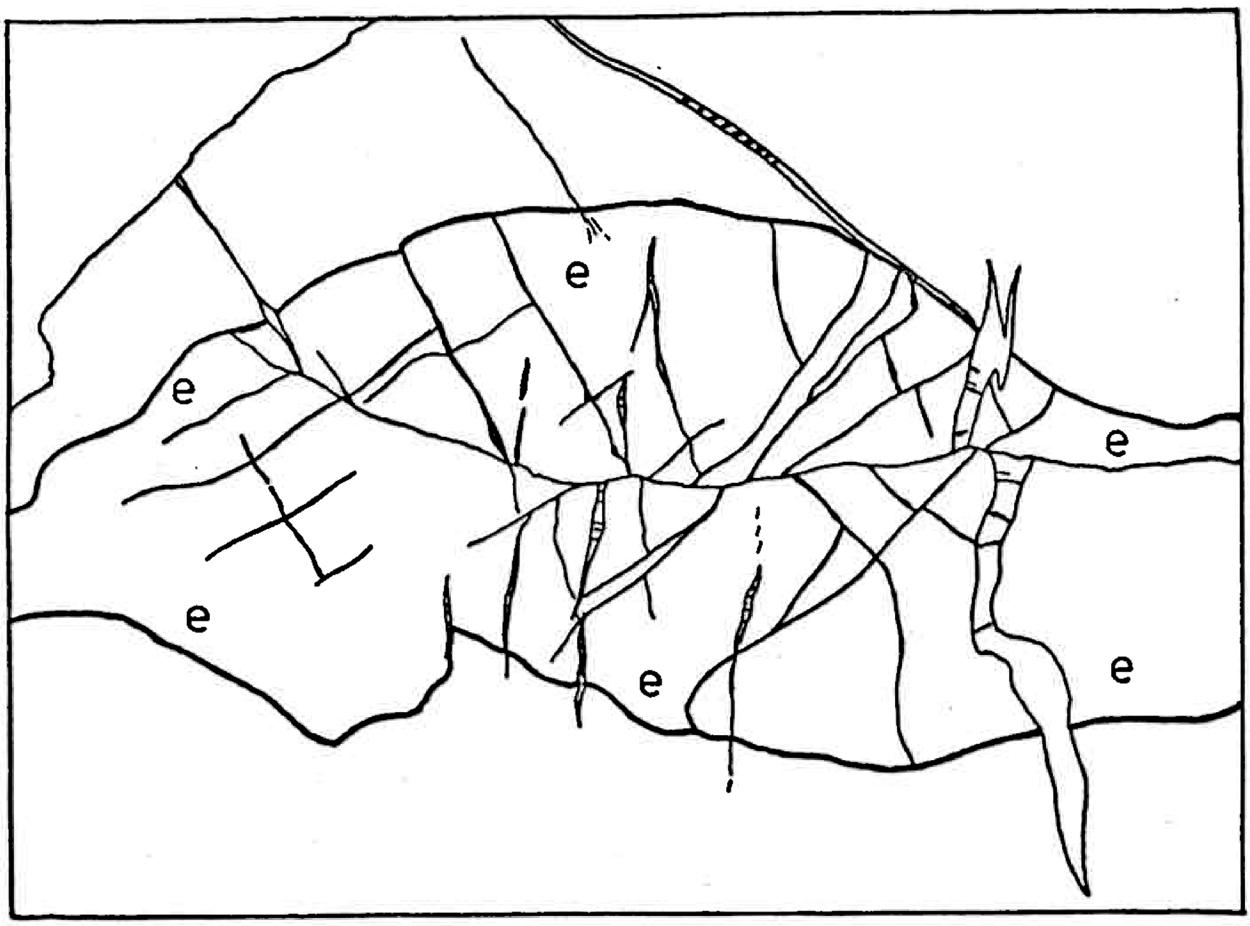

e
e
e
e
e
e

FIGURE 11A

Pillowed basaltic lavas from N.W. of Havdalsvatn showing the development of pre-deformational metamorphic segregrations of epidote-rich material (e), parallel to pillow margins. During tectonic flattening the epidote layer has responded by developing a system of brittle fractures.

FIGURE 11B.

Lenticular segregation of epidote (e) of pre-deformation age in massive andesitic lavas, southeast of Store Skorovatn. The conjugate pattern of brittle fractures produced during deformation of the competent lenses is explicitly developed as also is a generation of dilatant fractures filled with quartz, chlorite and carbonate.

FIGURE 12A

Typical appearance of the polymict conglomerates as seen to the N.W. of Havdalsvatnet. A flattened boulder of trondhjemite (t) displays a tectonic fracture pattern characteristic of its brittle behaviour. An associated boulder of marble (m) has deformed in a ductile fashion.

FIGURE 12B

Large pebbles of the pre-deformational epidote-rich metamorphic segregations derived by erosion from the underlying lavas are a common constituent of the greenstone-bearing facies of the polymict conglomerate. This example was photographed close to the unconformity on the southern shore of Tredjevatnet.

%	1	2	3	4	5	6	7	8	9	10	11
SiO_2	72,33	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	-
Ig. Loss	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	99,64	99,64	98,24		

FIG 13 A

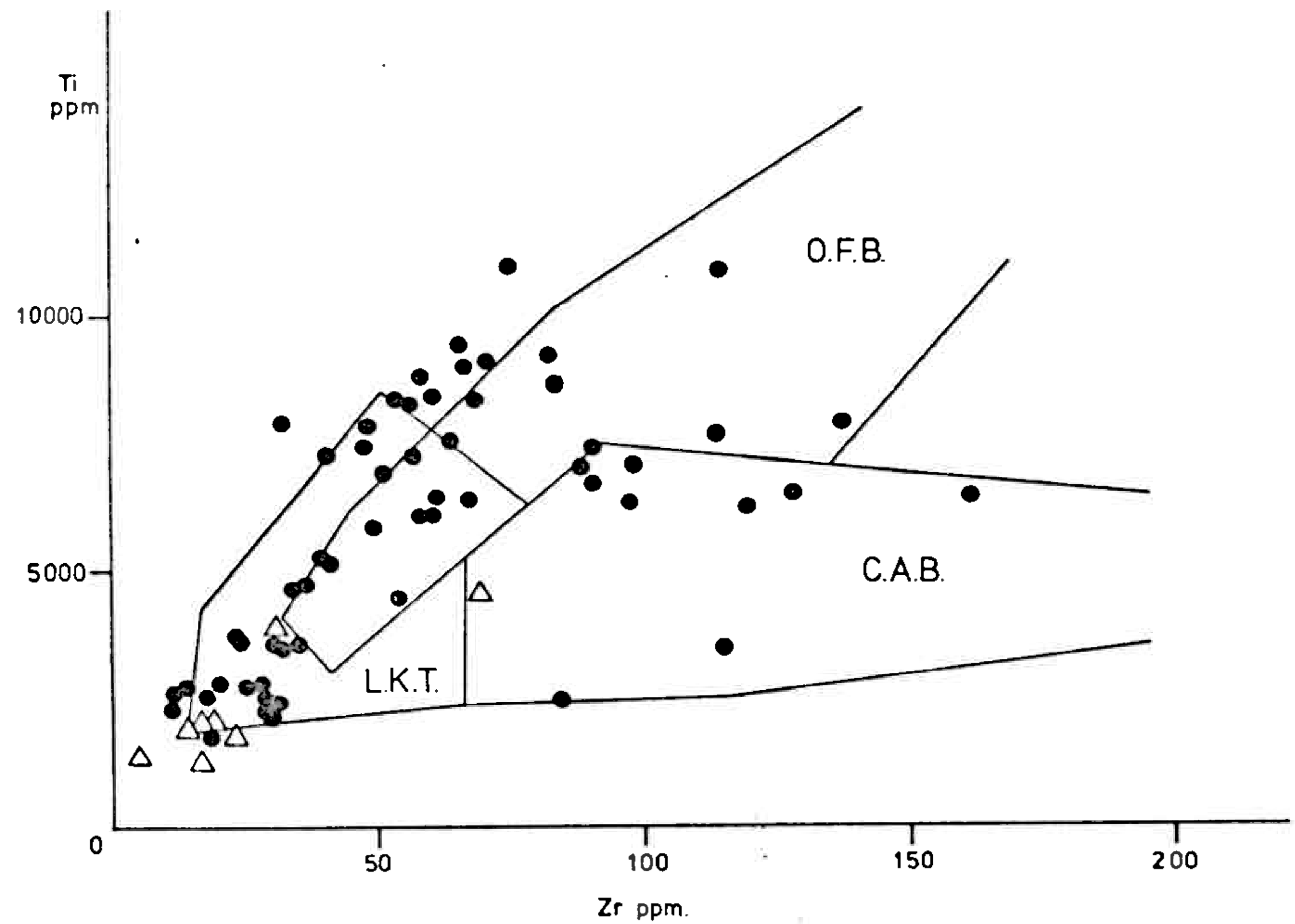


FIG 13 B

FIGURE 13A

Whole-rock analyses of Skorovas volcanics (1 - 9) with average values of ocean-floor basalt (10-from Cann, 1971) and island arc tholeiite (11-from Pearce, 1975) 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. south-west of Grubefjell, 9 : Basalt, north-east Øverste Nesåvatn.

- indicates value not obtained by analytical method used.

\+ indicates total Fe as FeO.

FIGURE 13B

Plot of Ti versus Zr contents for Skorovas basic extrusives (circles) and basic intrusives (triangles). The plot shows the abundance of low potash (island arc) tholeiites (LKT), with a strong tendency toward the development of calc-alkaline basalts (CAB). OFB : ocean floor basalt field.

FIGURE 14A

Blocky pyroclastic texture seen in a keratophyric flow unit on Grubefjell about 1200 m. W. of the Skorovas orebody. The pyroclastic fragments are slightly flattened and the siliceous matrix stands out as a reticular pattern. This flow is part of the major acid horizon with which the orebody is associated.

FIGURE 14B

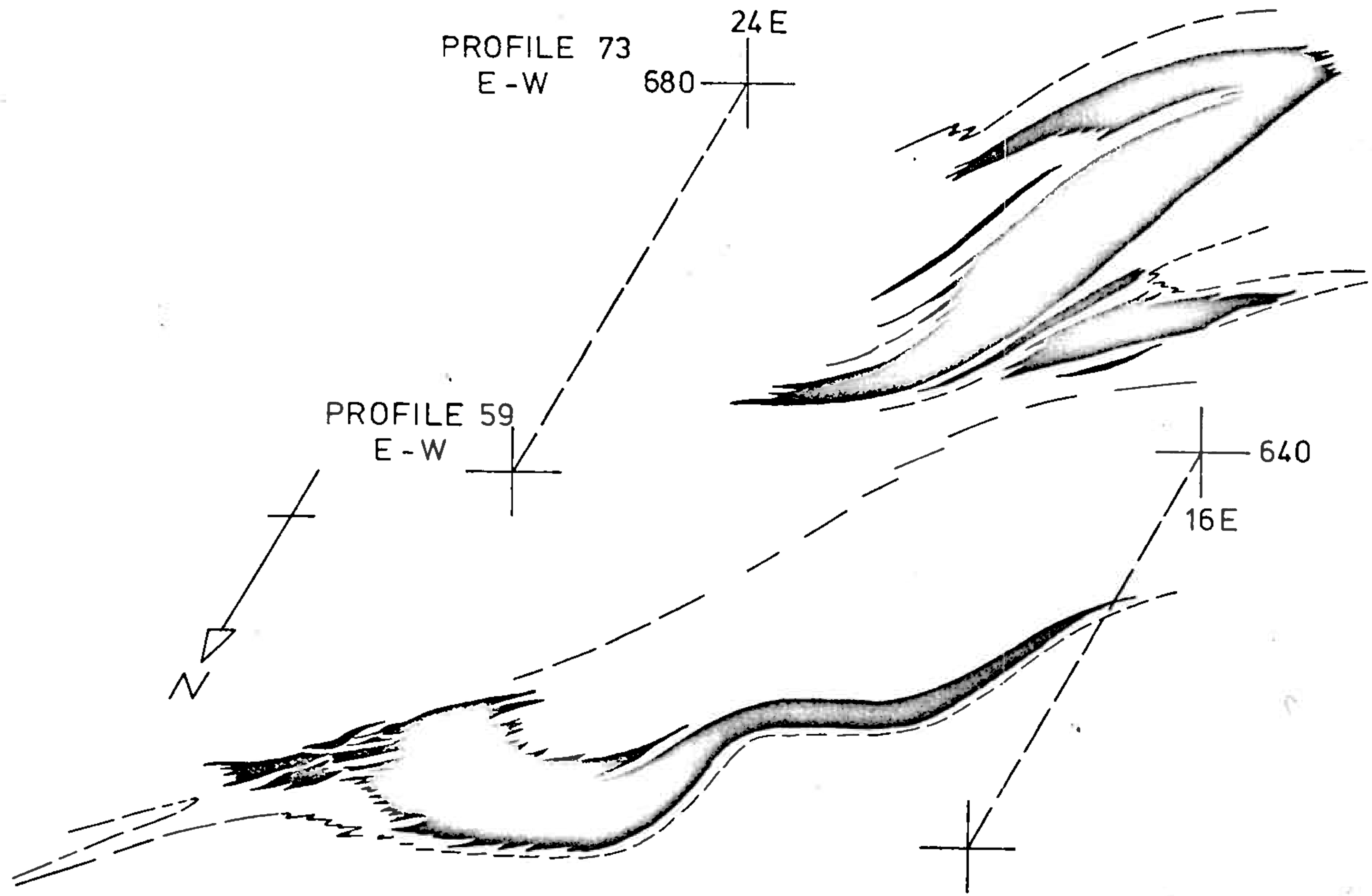
Agglomeratic facies of the keratophyric horizon shown in figure 14A. This locality is in the immediate vicinity of the ore horizon above the mine entrance on N.E. Grubefjell. The acid fragments are partly silicified and tectonically flattened. A competent quartz vein with an orientation close to the principal stress responsible for flattening during the first stage of penetrative deformation has responded by buckle folding.

FIGURE 15A

Exhalite horizon 2 km. east of Øverste Nesåvatn. The stratigraphic sequence is complex and is made up of graded lapilli tuffs overlain by pink to brown coloured banded cherty sediments incorporating magnetite, hematite, stilpnomelane and iron rich amphiboles. A purple chert band shows the isoclinal fold style of the earliest deformation with conspicuous refraction of the early cleavage.

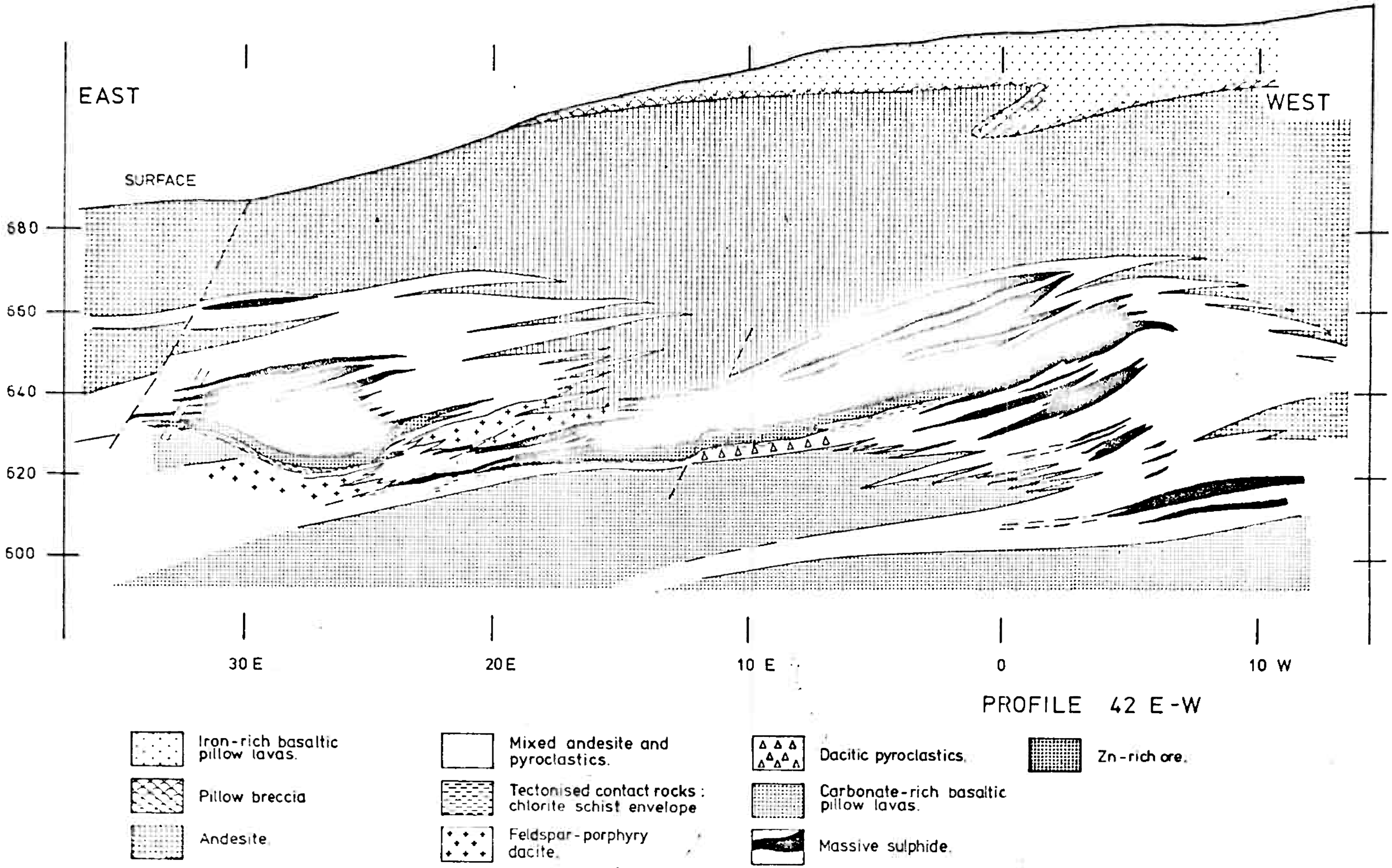
FIGURE 15B.

Banded pyrite-magnetite sediment typical of the reduced facies of the iron-rich exhalites (vasskis). The large pyrite porphyrobasts have suffered cataclasis and dislocation to varying degrees. Specimen from 1.5 km. N. of Blåhammeren. Scale in cm.



PROFILE 73
E - W
24 E
680
PROFILE 59
E - W
640
16 E
N

FIGURE 16 TWO SECTIONS OF THE E. OREBODY AT PROFILES 59 AND 73 E-W SITUATED 140 M. APART ALONG THE MORPHOLOGICAL AXIS OF THE OREBODY. THE PROGRESSIVE DEVELOPMENT OF A FIRST PHASE ISOCLINAL FOLD IS ILLUSTRATED TOGETHER WITH THE COMPLEX DIGITATED STYLE OF THE ISOCLINAL CLOSURES. THE OPEN STYLE OF THE SECOND FOLD PHASE IS SHOWN BY THE UNDULATION OF THE LOWER CONTACT OF THE ORE ON PROFILE 59 E-W.



EAST
WEST
SURFACE
680
660
640
620
600
30 E
20 E
10 E
0
10 W
PROFILE 42 E-W
Iron-rich basaltic pillow lavas.
Pillow breccia
Andesite.
Mixed andesite and pyroclastics.
Tectonised contact rocks : chlorite schist envelope
Feldspar-porphyry dacite.
Dacitic pyroclastics.
Carbonate-rich basaltic pillow lavas.
Massive sulphide.
Zn-rich ore.

FIGURE 17 REPRESENTATIVE SECTION THROUGH THE EAST AND WEST OREBODIES AT PROFILE 42 E-W. SHOWING THE PRINCIPAL LITHOLOGICAL DIVISIONS OF THE HOST ROCKS AND THE POSITION OF THE ZINC RICH FACIES ALONG THE FOOTWALL OF THE PRINCIPAL EASTERN AND WESTERN LENSES. ACCORDING TO THE STRUCTURAL INTERPRETATION THIS ZINC RICH LEVEL IS THE STRATIGRAPHIC TOP OF THE ORE. THE COMPLEX DIGITATION OF THE ORE IS WELL ILLUSTRATED.

FIGURE 18A

Typical compact pyritic ore with minor amounts of sphalerite (grey).

FIGURE 18B

Mutual impaction relationship in pyrite grains from a coarser facies of the massive ore showing the cataclastic mechanism of deformation.

FIGURE 18C

Zinc-rich ore with magnetite typical of the upper stratigraphic levels of the orebody showing evidence of probable primary gradation and sedimentary banding. Pyrite-white, sphalerite and magnetite-grey, silicate-dark grey.

FIGURE 18D

Foliated texture of the zinc-and lead-rich peripheral tectonic facies of the ore. Incipient crenulation cleavage is visibly developed with selective concentration of galena (white). The gangue matrix (dark grey) is composed of carbonate and chlorite.

%	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	

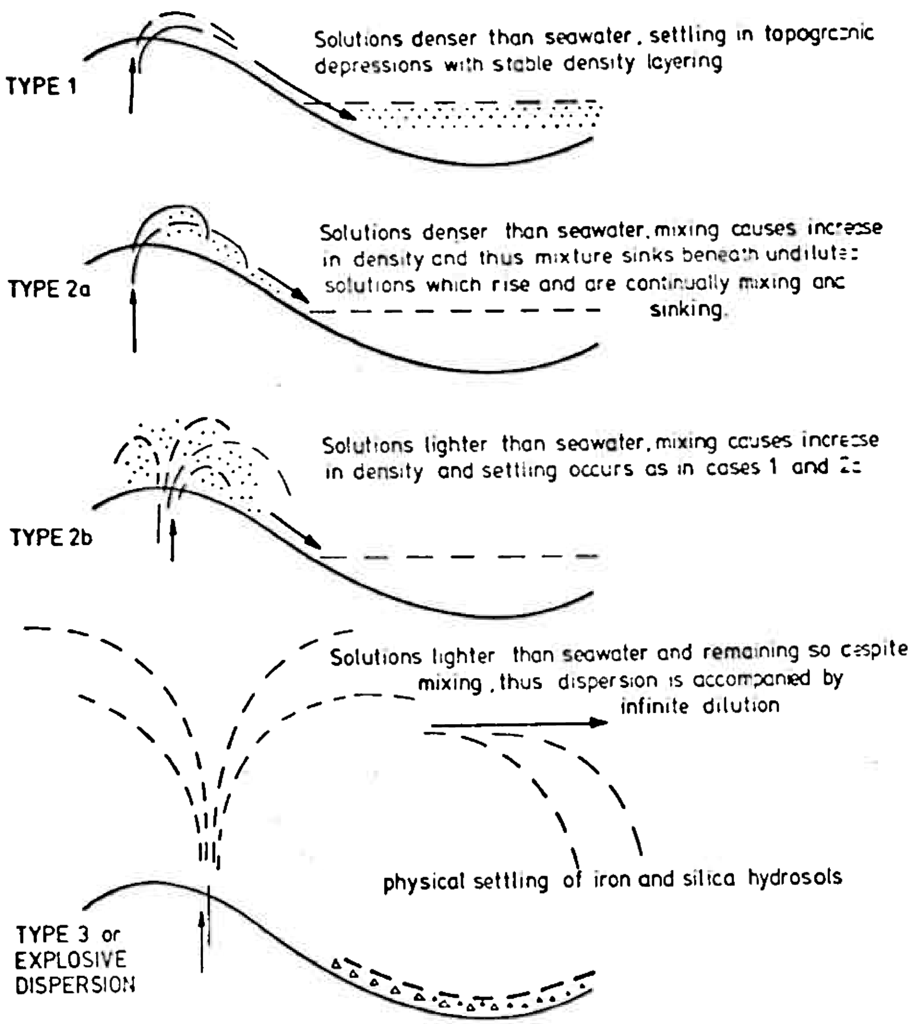
FIG 19

FIGURE 19

Table of average metal values for Skorovas ore types and sulphide facies of an extensive exhalite.

1. Massive pyritic ore (27 samples),
2. Copper-rich ore (14 samples),
3. Banded magnetite-rich pyritic sphalerite 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).

SCHEME OF INTERACTION OF HYDROTHERMAL BRINES WITH SEAWATER Modified from Sato 1972.



SCHEMATIC ERUPTIVE AND HYDROTHERMAL EVENTS IN THE SKOROVAS VOLCANIC CENTRE DURING THE CLIMACTIC DACITIC EPISODE

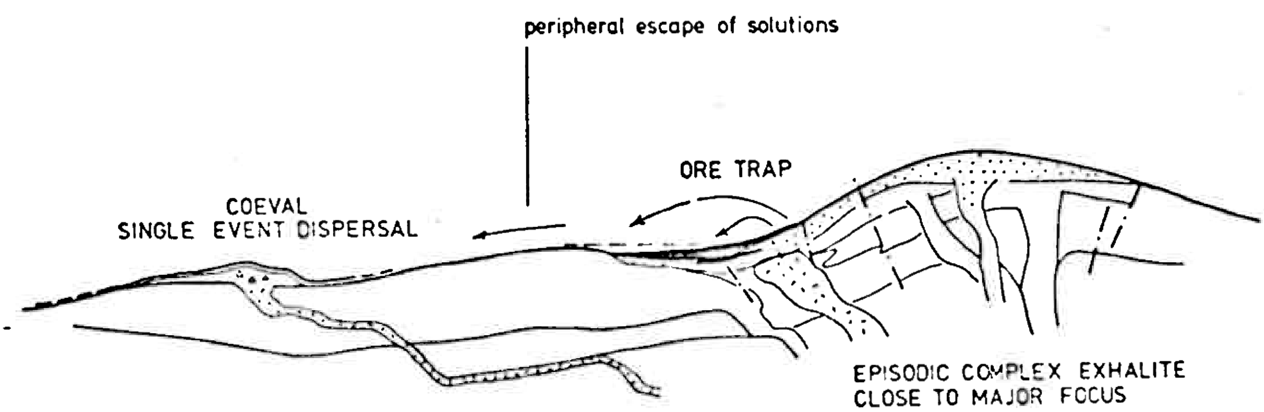


FIG 20

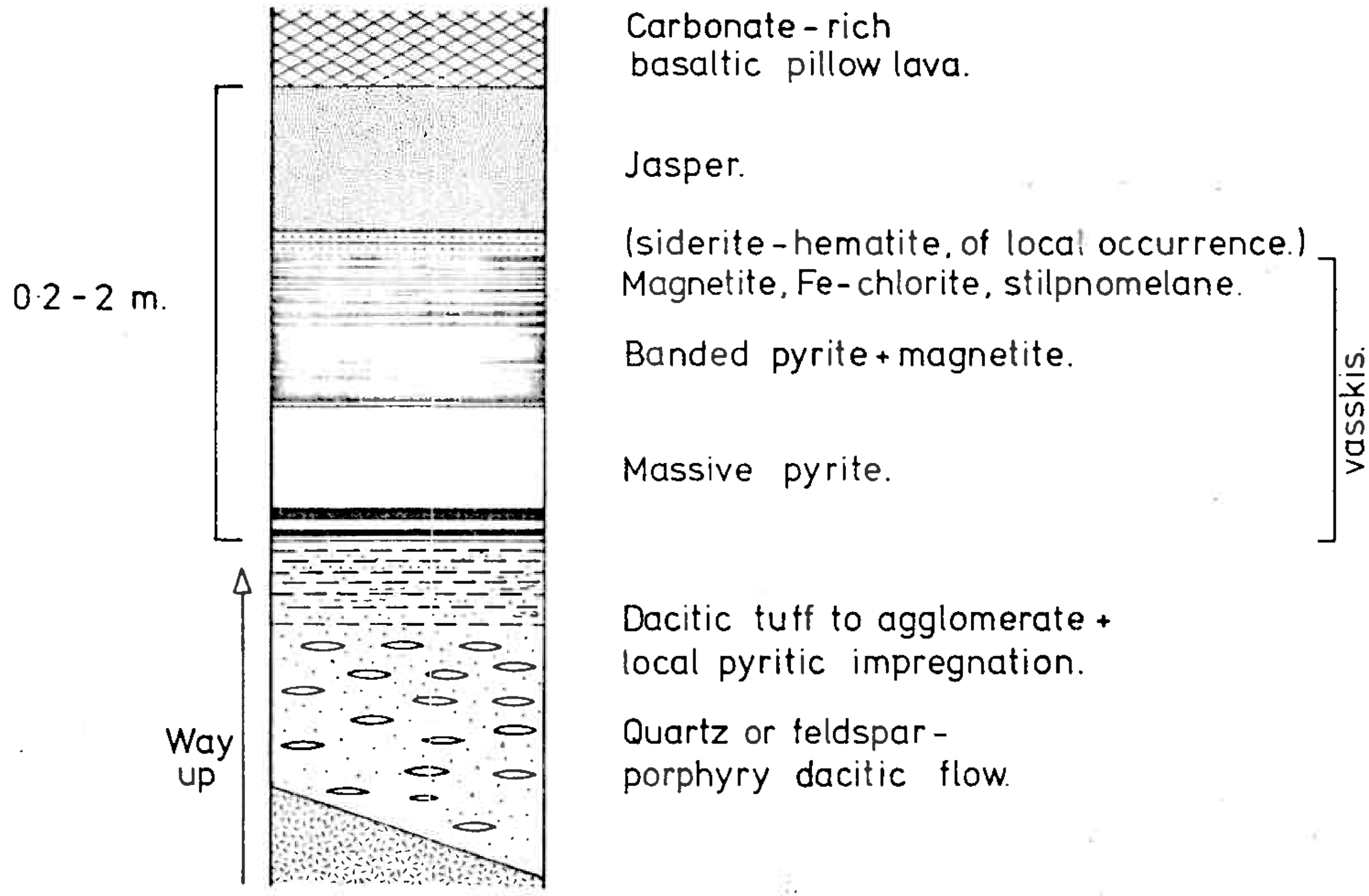

Carbonate - rich basaltic pillow lava.
Jasper.
(siderite - hematite, of local occurrence.)
Magnetite, Fe - chlorite, stilpnomelane.
Banded pyrite + magnetite.
Massive pyrite.
vasskis.
0·2 - 2 m.
Dacitic tuff to agglomerate + local pyritic impregnation.
Quartz or feldspar - porphyry dacitic flow.
Way up

FIG 16

FIGURE 21

Ideal section showing the products of single event dispersal in an extensive exhalite as observed in the vicinity of the Blahammeren centre.