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STIPENDIET I 3 I 0 ARNE REINSBAKKEN M^cSc

THE GEOLOGY OF THE SKOROVAS MINE

BY ARNE REINSBAKKEN

April 18, 1977

GEOLOGISK INSTITUTT
NORGES TEKNISKE HØGSKOLE
TRONDHEIM, NORGE

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A. ACKNOWLEDGEMENTS

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Scholarship period Sept. 1974 - March 1977. 2½ yrs.

GEOLOGY OF THE SKOROVAS MINE

TERMINAL REPORT TO NTNF - INDUSTRY SCHOLARSHIP

BY ARNE REINSBAKKEN.

B. INTRODUCTION

The final report to NTNF-INDUSTRI-STIPEND-KOMITÈ is meant to be a status report for all work that has been carried out by the author concerning the SKOROVAS deposit and its immediate surroundings within the Grongfelt of Central Norway during the period Sept. 1974 to March 1977. The author would like to emphasize here that the data collected during this project is intended to form the basis for a more detailed study concerning the genesis and deformation of the SKOROVAS Orebody which the author intends to submit towards a Doctorate Degree, and therefore the research here is in the preliminary stages and some of the conclusions given here may well be revised as more data is obtained. The author realizes that a much more systematic sampling and analyses of the SKOROVAS Orebody and its volcanic host rocks is needed before the information can be more meaningful, however, taken as a preliminary study, much of the information and conclusions given here have some very interesting implications.

1. General Purpose of the Scholarship

As stated in the NTNF-INDUSTRI-STIPENDIET brochure, the scholarship should focus towards the candidates schooling and should give much time to his own studies during this period. As the author had previously been involved in academic research at the University level, much of the authors time was spent tackling the problems concerned with the detailed geological mapping of the SKOROVAS Orebody and the classification and description of the various volcanic units and ore-facies, to illustrate their intimate relationships to each other and to facilitate a volcanostratigraphy that would project to the surface exposures and, through further detailed surface mapping, would help in correlating to the more regional geological investigations carried out by Dr. C. Halls and students from Imperial College, London.

Eventually it was hoped that a genetic model could be established for the original depositional environment (paleogeography) which, in conjunction with the unravling of the superimposed structural deformation through its tectonic style, would be of enormous help in understanding the environment surrounding such a deposit as Skorovas and would therefore be helpful in the understanding of similar mineralization within the Grong area and similar Caledonian volcanic

Greenstone terrains, a useful exploration tool for future investigations. The author believes that it is through the intricate disection of such a complex deposit as Skorovas that one is to fully understand the nature of ore occurrence within the area as a whole and is of invaluable help in reconstructing the original environment of deposition. The Skorovas mine, with its myriad of cross cutting adits, shafts and drillholes, and its almost total surface rock exposure presents a golden opportunity for such detailed investigations.

2. Brief Outline of the Project

The NTNF-INDUSTRI-STIPENDIET covered a two and one half (2½) years period from Sept. 1. 1974 to March 1. 1977.
In the beginning the author was given ample opportunity to become aquanted with the Caledonian greenstone belts and their associated massive pyritic deposits through a detailed literature study of some 15 known deposits in Norway, as part of an information gathering effort towards a coding scheme for massive sulphide deposits devised by Prof. F.M. Vokes and berging. R. Sinding-Larsen. This literature study was accompanied by personal visits to several of the key mines within Norway (Tverrfjellet, Løkken, Joma, Skorovas, Bleikvassli and Sulitjelma) and to the Stekenjokk mine in Sweden. While working at the Geologisk Institutt, NTH, the author accompanied two separate student excursion groups visiting economic deposits in both Finland and Northern Sweden which has helped greatly in widening the authors understanding of the overall massive sulphide environments.

The author has also had the distinction of being involved in an International Geological Correlation Project (IGCP) - Correlation of Caledonian Stratabound Sulphides (CCSS) excursion to the Remdalsfjäll - Stekenjokk Area, Sweden and the Røros district, Norway (August 1975), where special emphasis was given to the volcanic-sedimentary stratigraphy and the environments surrounding the massive sulphide deposits found there. The author also attended several international conventions and symposiums where lectures and discussions were followed concerning volcanic greenstone geochemistry, platetectonics and the depositional environment surrounding massive sulphide deposits. The "Geologiska Vintermötet" was attended at Göteborg on Jan. 3.-5. 1976. At the symposium on "Ore Deposits associated to the deposition of Volcanic Rocks" in London, England on Jan. 8.-10. 1976, the author had the distinction of being co-author to a paper submitted concerning the geological setting of the SKOROVAS orebody.

Prior to the beginning of this SKOROVAS project, the author has had several summers experience in detailed geological mapping and structural interpretation in areas surrounding mineralization similar to that of Skorovas. This, together with the numerous excursions into the areas surrounding SKOROVAS, which has been regionally mapped by Dr. C. Halls, Ian Farriday and students from Imperial College, London, the author has gained an understanding of the complexities of the geology at SKOROVAS.

Previous detailed geological mapping (both surface and mine mapping) is lacking in the SKOROVAS area and the only maps that were available were some general geological interpretations on a 1:10.000 scale compiled by D. Husby and another by the undergraduate students from Imperial College, London (1972-73) on which is only made the simple distinction between greenstones, keratophyres and Trondhjemite and gabbro intrusives. Within the two earlier publications concerning the SKOROVAS deposit, T. Gjelsvik 1960 and 1968, and Chr. Oftedahl 1958, the only reference made to volcanic rocks comes in the form of generalities refering to the "SKOROVAS greenstone", spilitized greenstones, keratophyre agglomerate and submarine acid explosion breccias and tuffs.

Since no previous detailed descriptions of the volcano stratigraphy and associated volcanic structures have been attempted from the SKOROVAS area, the first step of this project was to systematically map several easily accessible and key localities within the mine, enabling identifiable volcanostratigraphic units to be projected northwards to the surface exposures for further surface mapping and correlations made with the regional geological mapping in the surrounding areas. The various volcanic units were thouroughly sampled and some 55 type sample of the various volcanic units represented were analysed by the author at the Geologisk Institutt, NTH, for total silicate and trace elements using both XRF and AAS. A detailed description of the analytical procedures used at the Geologisk Institutt, NTH, is given in Appendix II in this report. The total silicate analyses results have been of definite help in the establishment of the various volcanic divisions used in this report and in correlation between various facies of the same volcanic units and in the general understanding of the volcanic environment under which these rocks were formed.

As previously mentioned, the main direction of this investigation was to systematicly classify the volcanic rocks found at SKOROVAS according to an appropriate classification scheme such as Rhyo-Dacites, Dacites, Andesites and Basalts (Table 1, page 31) and to standardize the terminology of the structures and textures used in describing the various volcanic units. An effort has been made here to diverge from the usage of the much too general greenstone and keratophyre terminology.

Similar classifications were devised for the various massive and disseminated ore facies that were found at SKOROVAS, based on their morphological features and chemical compositions and supplemented by mineralogical and microtextural studies from polished and thin section studies (Table 6, pp. 51). The vast number of macro and microphotographs of the various volcanic units and the ore facies, along with a detailed description of each is found in Appendix III.

Three strategicly placed surface diamond drill holes that penetrate deeply into the volcano stratigraphy were described in detail, in an attempt to correlate the presently used volcanic classification scheme with the various units and terminology that the previous workers have used and to help coordinate the surface and mine mapping in the deeper parts of southern extremes of the orebody. The more recently described diamond drill holes (by A.H. and LBL) and the drill holes described by S. Foslie and T. Gjelsvik, that are found along the relevant E-W profiles, were carefully reread and an attempt was made to classify the volcanic units according to the volcanic classification scheme used in this report, in this way forming some standardization to the previous drill core reports. The results were transfered on to 1:500 scalecross-sectionsenabling the author the use of much unused data. It is hoped that all future diamond drill core logging and rock descriptions will fit into this proposed classification scheme to help standardize the geological terminology used at SKOROVAS.

3. Summary of Work Completed under this Project

(a) At SKOROVAS GRUBER

(1) All detailed geological mine mapping on a 1:200 scale has been transfered onto the available 1:200 E-W and N-S mine Profiles and set into a Geological Maps Folder which is intended as a collection for all future detailed mine mapping.

(2) All available geological data including previous drill hole descriptions by AH, LBL, S. Foslie and T. Gjelsvik has been transfered onto 1:500 scale mine profiles in an attempt to give a better overall perspectiveof both the East and the Main orebodies.

(3) A detailed description with accompanying 1:50 scale color coded cross section of three strategic surface diamond drill holes DBH 10.045; 10.040; 10.042.

(4) A detailed surface geological map, scale 1:2000 of the immediate SKOROVAS mine area.

(5) Several key E-W cross sections, scale 1:2000, through the mine area: Profiles ca. 80 S, 42 S and 22 S, and one N-S cross section through profile O N-S.

(6) A compilation of all geological data from this project as well as previous work onto a 1:10.000 map of the area surrounding the SKOROVAS mine, which is intended to be of help in correlating the geology from the SKOROVAS mine into the surround areas mapped by Dr. C. Halls and I. Farriday from the Imperial College, London.

(b) At the Geologisk institutt, NTH.

(1) The data collection and filling in of the coding program for 15 massive sulphide deposits from the Scandinavian Caledonides.

(2) The total and trace element silicate analysis of 55 volcanic rock samples, representative of the various volcanic divisions found at SKOROVAS.

(3) The Cu-Zn-Pb-Mn analysis of 15 samples of the massive

and impregnated ore types mapped at SKOROVAS - to correlate with analyses that have previously been performed at the SKOROVAS assay lab.

(4) The production of numerous macro and micro photographs taken of polished rock slabs, thin sections and polished sections to help in the description and classification of the various volcanic units and ore facies mapped as SKOROVAS.

(5) Co-author of a paper that was presented at a Volcanic Studies Group Symposium in London Jan. 1976, entitled "Geological Setting of the Skorovas orebody within the Allochthonous Volcanic Stratigraphy of the Gjersvik Nappe, Central Norway", - (in press with the Institute of Mining and Metal., London) by C. Halls, A. Reinsbakken, I. Farriday, A. Haugen and A. Rankin.

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 volçanic affinity at the Köli structural level.

FIGURE 1 SYNOPTIC GEOLOGICAL MAP OF THE SCANDINAVIAN CALEDONIDES SHOWING THE MAIN DISTRICTS OF STRATIFORM VOLCANOGENIC ORES AT THE KÖLI STRUCTURAL LEVEL.

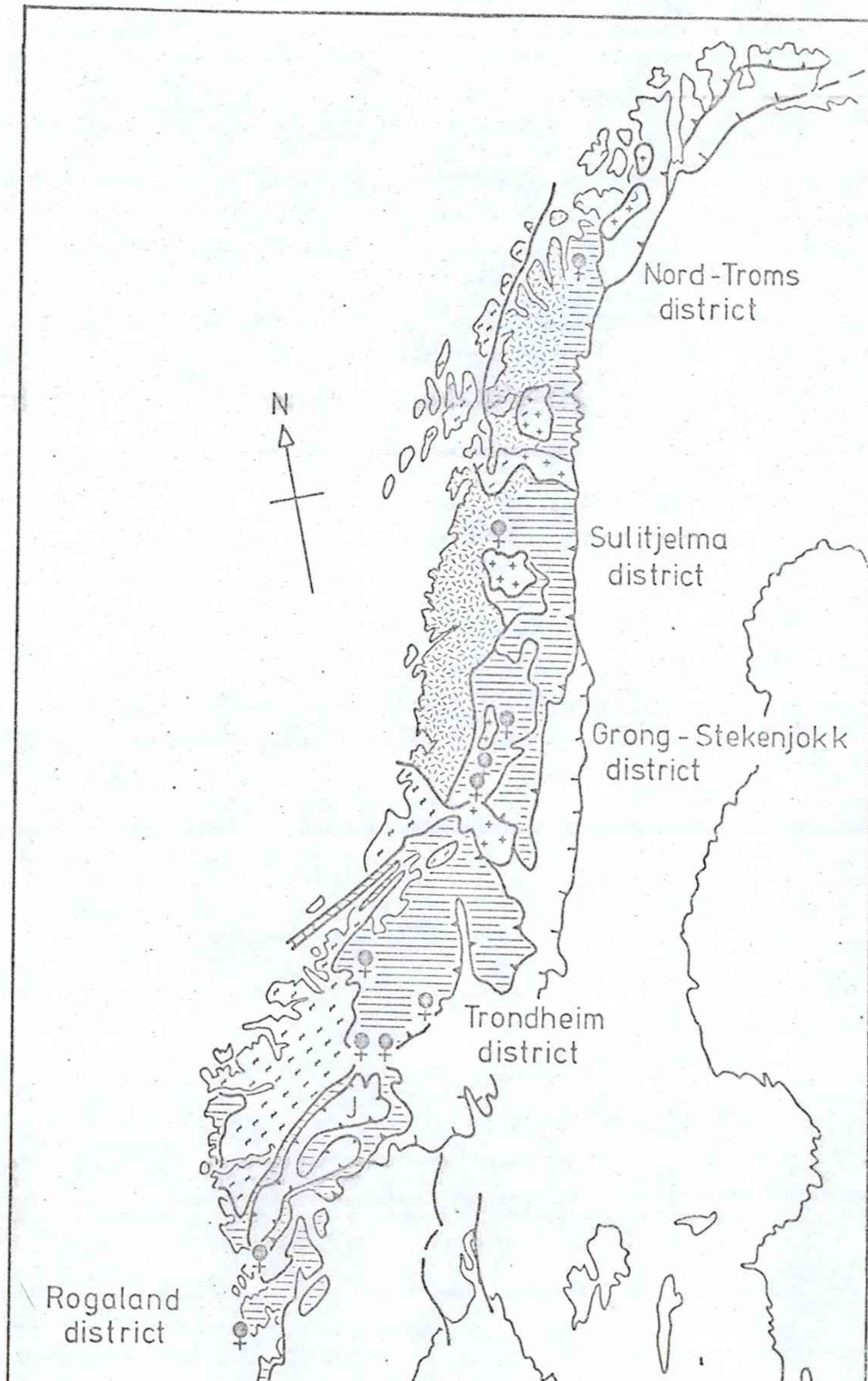


FIGURE 1 (from : Halls C, et al, 1977)

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).

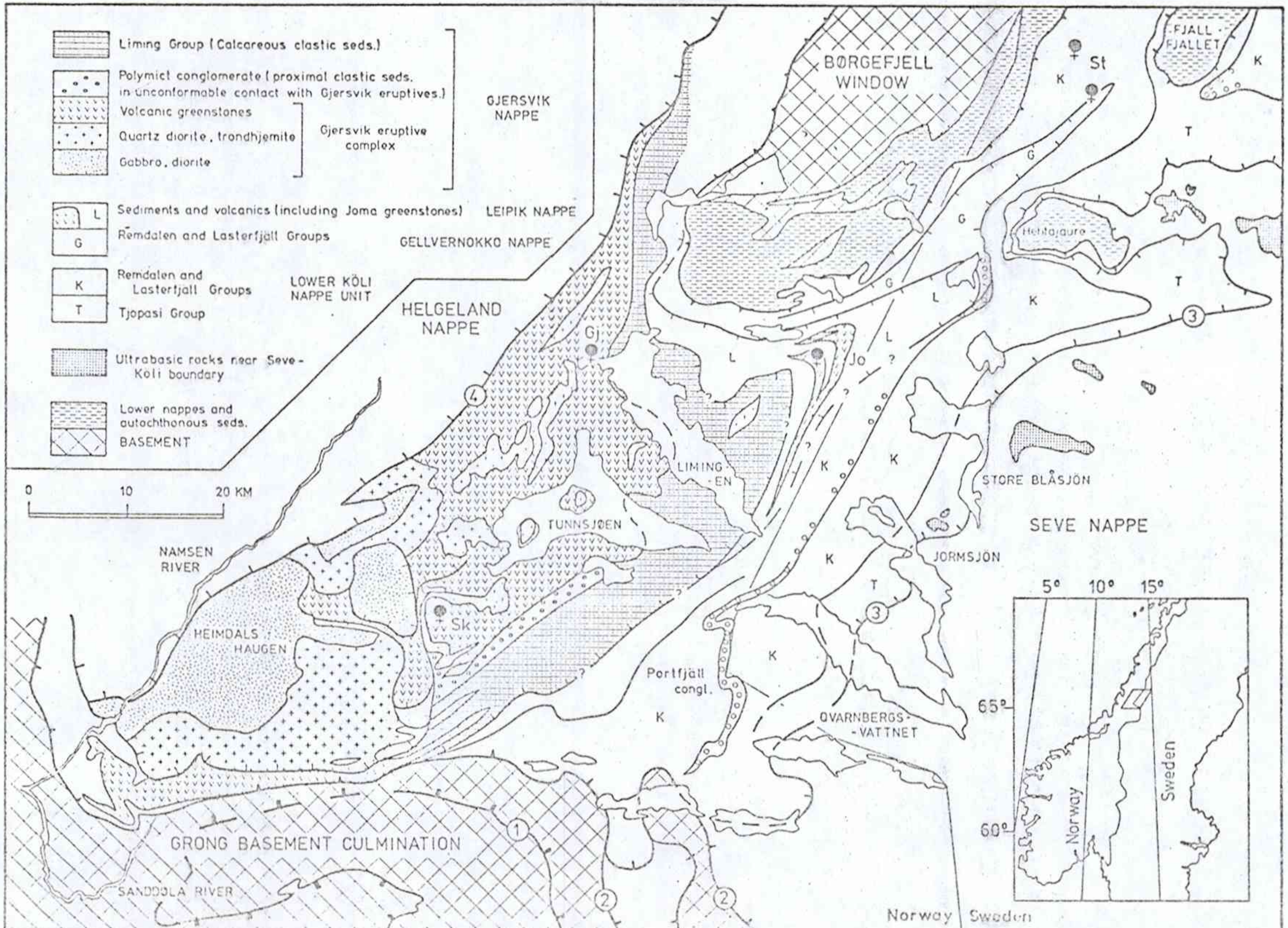


FIGURE 2 (from: Halls C. et al, 1977)

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

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

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. (from: Halls C, et al, 1977)

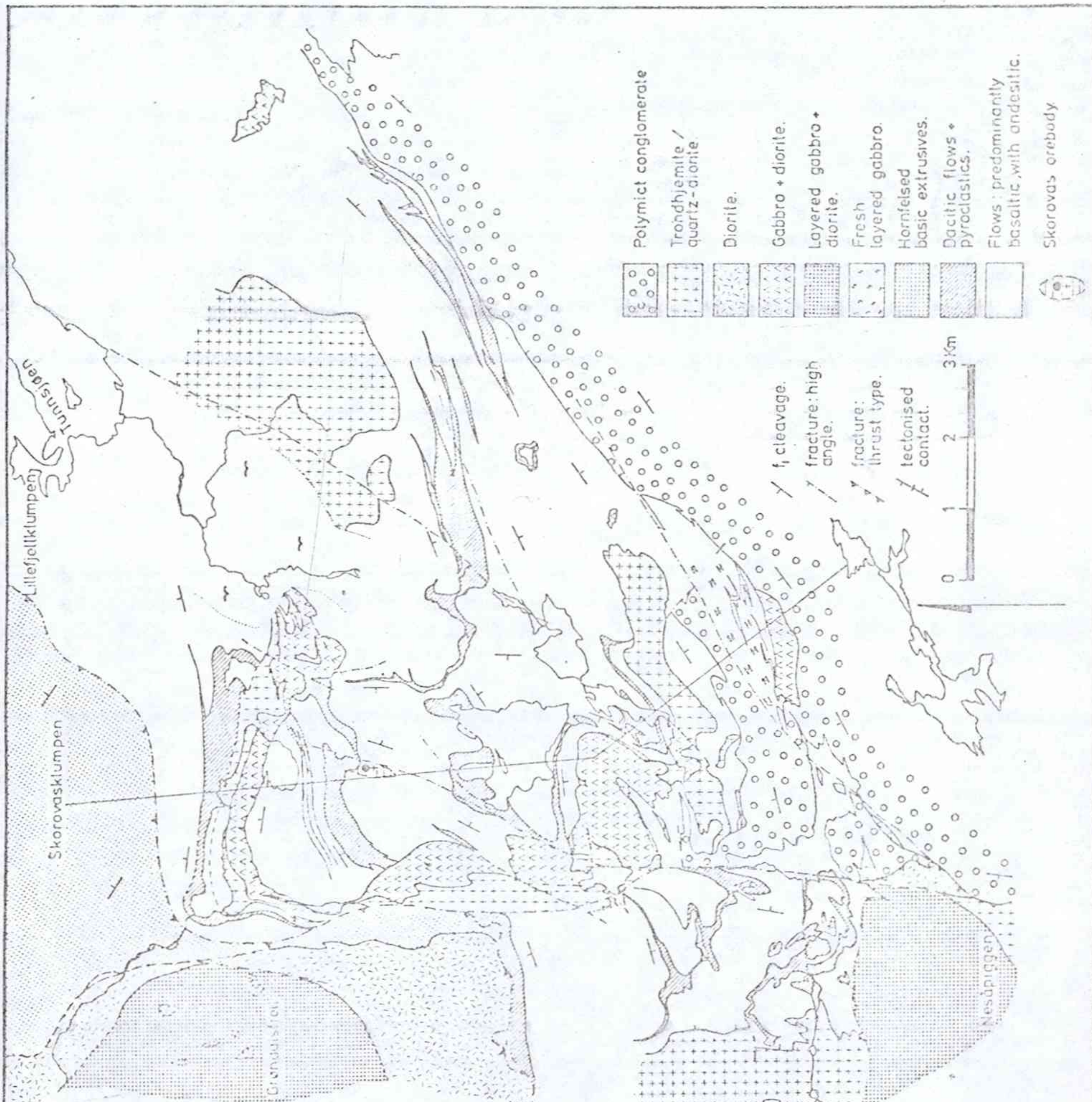


FIGURE 4

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 (from: Halls C, et al, 1977)

PART I GENERAL GEOLOGY

1. Introduction

As the main purpose of this report is to document the results that have accumulated from this project regarding the detail geology of the SKOROVAS orebody, the more regional geological aspects regarding the geological setting of the SKOROVAS orebody has already been presented as a joint paper entitled the "Geological Setting of the SKOROVAS Orebody within the Allochthonous Volcanic Stratigraphy of the Gjersvik Nappe, Central Norway", co-authored by C. Halls, A. Reinsbakken, I. Farriday, A. Haugen and A. Rankin, at a symposium in London (Jan. 9-10, 1976) sponsored by the Volcanic Studies Group and is presently to be published in the Inst. of Mining and Metal. Bulletin-London.

The publication is the direct result of five years regional geological investigations under the guidance of Dr. C. Halls from Imperial College, ant this NTNF project has contributed to the major details regarding the SKOROVAS Orebody and its relationships to the enclosing volcanic rocks. The author would refer the reader to this paper for a better understanding of the regional geological setting of the SKOROVAS Orebody. A brief summary will be given here of the conclusions drawn from the paper to-gether with the abstract and several of the diagrams to give the reader a better perspective of the SKOROVAS Orebodies position within the Caledonian Lower - Ordovician greenstone belt in Scandinavia.

ABSTRACT: (Halls C. et al, 1977 - in press)

"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."

Diagrams that accompany this publication show:

Figure 1 (page 11) A synoptic geological map of the Scandinavia Caledonides showing the position of the Grong district in Central Norway.
Figure 2 (page 13) shows the location of the main oredeposits in the Grong - Stekenjokk district and their relationships to the main stratigraphic and structural units within the Köli Nappe (of which the Gjersvik Nappe is a part).
Figure 3 (page 14) shows the inferred stratigraphic correlation between the Lower Paleozoic sequences in the Grong - Stekenjokk region to those in the W. Trondheim region.
Figure 4 (page 15) shows a simplified geological map of the Skorovas area indicating the close spacial relationship between the Skorovas orebody and the dacitic flows and pyroclastic horizons.

The following conclusions are drawn from the paper (Halls C. et al).

(1) The volcanic succession has suffered extremely from the effects of deformation (penetrative schistosity) and low grade metamorphism under conditions of the Greenschist facies.

(2) That the spilitic character of the SKOROVAS volcanic sequence is the result of metamorphism which accompanied the sea floor metamorphism of the volcanic rocks during Lower Ordovician Times.

(3) 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. The basaltic rocks showing a distinct trace element concentration characteristic of Island Arc Tholeiites with a noticeable trend towards the calc-alkali Basaltic field.

(4) That the orebody is situated within a part of the volcanic sequence displaying distinctly Calc-Alkaline character, (Dacitic pyroclastics and flow units) marked by episodes of explosive dacitic volcanism and associated fumerotic activity.

(5) That it is appropriate to consider the morphology and mineralogy of the ore deposit and the peripheral exhalite mineralization of the Skorovas region in terms of the exhalative volcanic hydrothermal origin which was proposed by Oftedahl (1958).

(6) That the eruptives of the Skorovas area are the constituents of an immature Island arc of Lower Ordovician age - formed within an ensimatic setting peripheral to the Scandinavian Craton. The following volcanic suite characterize immature Tholeiitic Arcs. Basalts Andesites Dacites and Rhyolites.

(7) That the eruptive sequence, its magmatic evolution having 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.

- - - - -

From previous work in the Grong district, "it has long been recognized that the Gjersvik (Skorovas) greenstones are composed of a sequence of basic to acid rocks, including basalts, andesites and keratophyres of distinctly spilitic offinity" (Halls C. et al 1977) and Oftedahl Chr. (1958) writes of greenstone layers, under water lava flows and keratophyre agglomerate that represent rhyolite bombs and acid explosive breccias and Tuffs, and Gjelsvik, T. (1968) mentions of a "sequence of greenstones of submarine volcanic and sedimentary origin .... stratisfication thought to represent successive submarine lava flows".

According to Furnes, H. (1972), "pillow lava sequences are well known within the Lower Paleozoic strata of west Central Norway, especially within the Støren Group of the Lower Ordovician in the Trondheims region (Vogt 1945, Torske 1965, Roberts, Springer and Wolff, 1970)", and have also been documented in West Norway from the Solund district in the Sognefjorden area (Furnes 1972) and from Os area south of Bergen (Torske 1972). Primary volcanic structures such as amygdules, close-packed pillow structures and associated pillow breccias and hyaloclastites, agglomerates, flow breccias and banded tuffs have never before been described from the Skorovas area, or from the Grong district in general, and the present study is an attempt to document the various 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. An attempt has been made to use these primary volcanic structures and textures to help in identifying and separating the various volcanic units within the volcanic stratigraphy and to outline the depositional environment for these volcanic rocks hosting the Skorovas orebody.

The primary volcanic structures found in the Skorovas volcanics demonstrate that these volcanics were originally deposited as submarine basic flows mixed with pyroclastics, acid keratophyric breccias and tuffs, and associated jasper and magnetite bearing cherty bands, typical of the volcanics found in the Island Arc model that has been suggested for the origin of these Skorovas volcanics.

The recognition of these primary volcanic structures has led to the introduction of a great number of special terms that has been used in the description of these structures from the literature. A list of all the terminology with definitions can be found in APPENDIX I of this report, in hopes of standardizing the usage of such terminology in the Skorovas area. Pictures of the various structures are found in APPENDIX III.

It is furthermore recognized that these volcanics have undergone both pretectonic seafloor metamorphism (Halls et al, 1977) and a pervasive penetrative schistosity associated to the overthrusting emplacement of these rocks upon the Fennoscandian Craton during the climactic events of the Caledonian orogeny in the Mid.Silurian. It is also recognized, through total silicate whole rock analyses, that these volcanics have undergone pervasive spilitization, that is to say, these volcanics have undergone an intense metamorphism whereby the sodic content (Na_2O) is highly enriched at the expense of the depleted potassic (K_2O) content, which is typical for the Spilite suite. The Skorovas volcanic rocks should therefore rightfully be called metavolcanics of spilite and keratophyre affinity. However, since the recognition of primary volcanic structures has helped to subdivide the rocks into the various units of the volcano-stratigraphy and to outline their environment of deposition, and with the help of the detailed chemical classification of these volcanics from total silicate analyses, the author would therefore prefer the usage of such terms as Basalt - Andesite - Dacite and Rhyo - Dacite for the volcanic material that was deposited on the sea floor, and thereby diverging from the much too vague greenstone and keratophyre-terminalogy that has been used so frequently by previous authors. The author would also prefer to omitt the prefix "meta" when refering to the Skorovas volcanics in this report, although the author recognizes that these volcanics have undergone destructive metamorphism.

2. Classification of Volcanic Rocks.

The author has attempted here to standardize the classification of the volcanic rocks in the Skorovas area, using an accepted classification (Table 1 pp. 31) that has been modified from Travis (1955) and shows the volcanic divisions, igneous equivalents, the average compositions for fresh unmetamorphosed volcanic rocks, and the essential mineralogy expected in such rocks. Figure 5 (pp. 32), after Irving and Baragar (1971), shows the volcanic rock series expected in a Calc-Alkaline Series of which some of the volcanics in the Skorovas area are equivalent to.

The definitive boundaries between the various volcanic divisions are still under dispute, according to the classification one chooses to use. However, one useful classification based on the SiO_2 and K_2O contents has been given by Taylor (1969) which defines the boundaries between the volcanic divisions as:

(1) BASALT (high-Al basalt) < 53% SiO_2 (44-53% SiO_2)

(2) ANDESITE 53-62% SiO_2 (0.7-2.5% K_2O)

(3) DACITE 62-68% SiO_2

(4) RHYOLITE > 68% SiO_2

In his classification, Taylor further divides the Andesite group into Low-Silica Andesites, Low-K Andesites and High-K Andesites according to the SiO_2 and K_2O contents. This classification by Taylor has been used in subdividing the Skorovas volcanics. It has also been noted (Hatch + Wells 1961) that the average SiO_2 contents for the Tholeiitic Basalts from Japan, which has been given as 50% SiO_2, correlates well with the basalts in the Skorovas area, when considering the Low-K Tholeiitic Island Arc model that has been proposed for the formation of these volcanics in Skorovas (Halls et al 1977).

Table 2 (pp. 33) shows the six volcanic units, that have been separated in the Skorovas area according to their morphology, stratigraphic position and their chemical composition, and that these units fit well into the classification scheme given above (Basalt + Andesite + Dacite + Rhyo-Dacite). The major silicate and trace element analyses have been immensly helpful in defining the various volcanic units and outlining their compositional ranges, especially since the volcanics in the Skorovas area show an extremely fine grained to aphanitic nature and an almost complete compositional transition within the intermediate (Andesite) to acid (Dacite) fields.

3. Stratigraphy.

The Skorovas area has proved to be a very difficult locality to demonstrate a reliable volcano-stratigraphy because of the complexities associated to the intense volcanic activities found in an acid volcanic centre such as the Skorovas area, reflected by the irregular overlapping nature of the original flow surfaces, and the intense cross-cutting dyking system associated to such active centres, and also because of the complexities produced by the superimposed destructive polyphase deformation to which the area has been subjected.

The intermediate to acid volcanic sequence is much thicker and more complex here in the Skorovas area, and it has been through work outside the area, east to the Havdalsvatn area, and north in the Hausvik forekomst area, where the individual volcanic units are much thinner and the volcanic activity has bee much less severe, that the volcano-stratigraphic units have been easiest to define. However, through the help of detailed mapping of the primary volcanic structures, intrusive relationships of the various volcanic units and through the major whole rock and trace element analyses, it has been possible to formulate a volcanic stratigraphy, that in its simplified form can be interpreted as a structurally overturned, inverted volcanic sequence represented by:

(Youngest) (1) Calc-Alkaline Andesite + Basalt

(2) Acid to intermediate sequence (Andesite to (Rhyo-Dacite)

(Oldest) (3) Low-K Tholeiitic Basalt (of Island Arc affinity)

- with the Skorovas orebody occupying the space between the acid volcanic complex and the younger Calc-Alkaline volcanic sequence, which is what has been suggested for deposits in similar volcanic environments in the Caledonian greenstone belts (Gale and Roberts 1974, Vokes and Gale 1976). Figures 10a and 10b (pp. 42+43) show roughly the stratigraphic position of the Skorovas massive sulphide orebody within the volcanic pile.

4. Description of the Volcano-Stratigraphic Units.

The reader is here refered to the simplified stratigraphy diagrams Figures 10a and 10b and Table 2 (pp. 42+43) showing the average composition of the various volcanic units in the Skorovas area. The author will here describe in some detail, the various volcanic units, their characteristic features, such as volcanic structures, textures, mineralogy and their chemical compositions etc., beginning with the oldest volcanic units and progressing stratigraphically upwards to the youngest units. The reader should bear in mind that, as a general rule, the stratigraphy is inverted, or at least partially inverted within the Skorovas area.

a) Lowermost Volcanic Unit: Chloritic Basalt, epidote bearing. (Unit nr. 5 from Table 2, pp. 33).

The lowermost basaltic sequence forms the major part of the volcanic sequence both overlying and underlying the ore zone to the west of the mine area (see geological map 1:2000 scale), and is distinguished by its dark to bright green, chlorite rich, moderately schistose character. These lowermost chloritic-basalts generally occur as very massive, dense flows with noticable epidote knots and fragments, epidote and free calcite filled amygdules and fractures, and minor pyrite disseminations. These basalts are only very slightly magnetic.

Close packed pillow lavas occur in thick sequenced within this volcanic unit immediately to the west and above the mine up on Grubefjell. The individual pillows, approx. 1 to 1½ meters in length and in places extremely flattened, are characterized by having a reddish-brown weathering pillow rim and with minor epidote and predominantly white cherty cusps filling the pillow intersticies. Minor zones of well banded chlorite and epidote rich tuffs and pillow breccias, with associated magnetite bearing cherts and jaspilite horizons are found intercalated with the pillow lavas to the west of the mine area.

These chloritic basalts are generally extremely fine grained (less than 1 mm) and often exhibit a remnant ophitic volcanic texture under the microscope (plate 19, AR 42) showing an intergrown mossaic of albitic plagioclase set in a fine grained chloritic matrix. However, as previously mentioned, the dominating Greenschist Facies regional metamorphism has generally completely destroyed all traces of primary volcanic textures and the primary mineralogy has been completely replaced or pseudomorphed by assemplages composed of chlorite, albite, epidote, actinolite, calcite and sphene.

The average chemical composition of unit nr. 5 from Table 2 is typical for basalts and shows a moderate enrichment in CaO compared to the other Skorovas volcanic units, which is reflected in the field by the overwhelming amount of epidote and free calcite filling amygdules and fractures and in sheared zones. Trace element data (Ti-Zr discrimination, Figure 9) shows that these lowermost basalts are typical of the Low-K Tholeiitic Basalts from island ares with some affinity towards Ocean Floor Basalts.

An interesting curiosity regarding this basaltic unit is the observation of a dwarf form of the flower "Viscária Alpina" or Copper flower that has been found growing on close-packed pillows to the west of the mine. This could possibly be a reflection of the high Cu content in these basalts, which do infact contain up to 150 ppm Cu, as found in one sample from whole rock analyses.

b) Iron-rich Basalt - (unit nr. 6, Table 2)

This unit occurs as a rather thin distinct band of well developed close-packed pillow lavas and associated pillow breccias and hyaloclastites. The pillows contain very distinct white (magnetic) cherty cusps filling the spaces between the individual pillows (plate 24, pp. 108). The Iron-rich basalts are extremely fine grained to aphanitic, typically dark bluishgrey to greyish green and very magnetic due to an extremely finely divided magnetite dissemination, which also accounts for the bluishgrey color imposed on these basalts. The extreme darkish green color is attributed to an Iron-rich chlorite which has a typical purplish birefringence color under the microscope, a chlorite which differs very much from the pale to medium greenish, calc-rich chlorite of the lowermost chloritic-basalt sequence. A rather strangely radiating epidote has also been found, as tiny epidote knots that could well represent amygdules or variolite structures, and appear to be an epidote pseudomorphing a primary radiating zeolite mineral. Also typical of this Iron-rich basalt unit is a prominant disseminated pyrite porphyroblast developed in the chlorite rims of strongly deformed pillows. In the area beneath the white Rhyo-Dacite explosion breccia unit, in the Gruvetippen area and to the NE, occurs a very dominant rusty, sulphide-veined, magnetic, pillow lava sequence which is very similar to the dark greenish chlorite and magnetic basalts occurring within the mine at the east and footwall zone of the Eastern orebody, where the sulphide stringer-feederzone, with its associated hydrothermal wall-rock alteration cuts through the basalts.

This highly magnetic Iron-rich Basaltic unit most probably represents a distinct facies development of the lowermost basalt sequence and could in fact represent a highly oxidized flow-top found at the uppermost contact of the thicker lowermost basaltic lava pile. This could well account for the extremely high quantities of finely disseminated primary magnetite and also for the irregular nature and thickness of this peculiar Iron-rich Basaltic unit.

The Iron-rich Basaltic unit (nr. 6, Table 2) is chemically distinct from the lowermost chloritic-Basalt sequence, showing an extreme enrichment in total Fe (approx. 16% Fe_2O_{3tot}), very unusual when compared to the other volcanic units within the Skorovas area. These Iron-rich Basalts also show a marked depletion in both CaO and Na_2O. The trace element discrimination data shows that this Iron-rich Basalt unit has a Low-K Tholeiitic affinity, very similar to the lowermost chloritic Basalt sequence and therefore suggests that they have a common heritage.

c) Intermediate Volcanic Complex: Andesites to minor Dacites (Unit nr. 2 from Table 2)

Within the immediate mine area, the intermediate volcanic sequence occurs as very irregular zones of varying thickness, intimately associated with the acid extrusive bands and intrusive domes, and the intermediate volcanic sequence noticeably thickness to the SW on Grubefjell, away from the mine area.

The intermediate volcanics are generally very massive, dense, hard, extremely finegrained, and are generally light to medium grey in color, reflecting the increased silica content and also the ubiquitous finely disseminated magnetite content, which accounts for the moderate magnetic nature of these rocks. Stilpnomelane occurs throughout this sequence as fine disseminations or as patchy concentrations. The increased stilpnomelane content imparts a light brownish weathering surface and an accompanying increasing schistose nature, which makes this intermediate unit easily recognizable on weathered exposures. Increase in stilpnomelane contents appears to be confined to the more acid Dacitic end member of this sequence, however, stilpnomelane has also been found in the more basic Andesitic end member, generally extremely patchy and usually confined to amygdules and fracture fillings along with quartz.

The dacitic varieties of this intermediate complex are more intimately associated with the acid extrusive bands (ie, locality GF 236 along the vannledning south of the Gråbergstoll) and a complete gradation to the acid volcanic varieties (Rhyo-Dacite) has been found in the area NW and N of the Gråbergtoll at localities GF 61 and GF 81. These Dacitic-Andesitic varieties are extremely fine grained to aphanitic, massive and dense, almost flinty in nature. They are characterized by a minor, fine grained, albitic-plagioclase phenocryst texture, which is set in an aphanitic groundmass. They are also characterized by numerous zones of quartz and minor stilpnomelane filled amygdules, the individual amygdules often extremely large, occuring up to 2-3 cm in diameter. The dominating feature of these Andesitic-Dacitic units is their fragmental nature, which is characterized by the rubbly nature of the flowtop breccias and agglomerates which are found near the acid volcanics north of the Gråbergstollen.

These Intermediate volcanic rocks are characteristically Andesite in composition, which has been enriched in Na_2O and depleted in both CaO and MgO compared to the other Skorovas volcanic units. The trace element discrimination data (Figure 9, pp. 41) suggests that these stilpnomelane-bearing intermediate volcanics show a Low-K Tholeiitic affinity.

d) Dark-greyish Basaltic-Andesite (unit nr. 4, Table 2)

A very irregular and patchy sequence of dark grey to bluish-grey, extremely fine grained and very magnetic Basaltic-Andesite occurs closely associated to the stilpnomelane bearing Andesites of the intermediate volcanic sequence. The dark grey Basaltic-Andesites also contain minor stilpnomelane as amygdule and fracture fillings and the minor stilpnomelane patches within the dark grey Basaltic-Andesite suggests an intimate relationship to the stilpnomelane bearing Andesites described above.

This dark grey Basaltic-Andesite invariably occurs as well developed close-packed pillow lavas (individual pillows being up to 1 meter in length), with associated broken pillow-breccias and hyaloclastites (aquagene tuffs), and generally host a strongly magnetic white to grey cherty horizon along its upper contact. The macroscopic similarities between this very magnetic pillow lava sequence (unit Nr. 4) and the Iron-rich Basaltic unit (unit nr. 6), described above, are striking and has often led the author to believe that they could in fact be one and the same unit. However, because of the great distance which separates these two units, a closer investigation is needed to solve this problem.

The chemistry of this dark grey Basaltic-Andesite unit shows a distinct difference to the lower Iron-rich Basalts in having a much lower, more normal, total Iron Content, and an extreme enrichment in Na_2O (8.56%) compared to the other Skorovas volcanic units. The extreme Na_2O content could well be accounted for by sea floor metamorphism of the pillowed sequence, however, as mentioned before, a much more detailed chemical investigation is needed to solve this problem. Trace element discrimination data for this dark-grey Basaltic-Andesite unit shows however a distinct similarity to the Iron-rich Basalts, both having a Low-K Tholeiitic affinity.

e) <u>Acid Volcanic Sequence:</u> Rhyo-Dacites and minor Dacites (unit nr. 1, Table 2)

The acid volcanics, Dacite to Rhyo-Dacite in composition, found in the Skorovas mine area form a very complicated and very irregular sequence of intrusives and related extrusives and pyroclastics. They vary considerably in form and thickness and show intimate relationships to the Skorovas orebody and its peripheral transitional mineralization. The acid volcanics show extremely sharp boundaries to the adjoining volcanic units, however, as previously mentioned, transitional gradations into contact dacites and dacitic-andesites have been found. The acid volcanics are easily distinguished from the other more basic volcanic members by their dominating whitish to light-greyish color, their extreme hard, flinty nature and their prominant, rather large white cherty to quartz fragments and amygdules and their large quartz filled tension gashes and fractures. The intrusive members are invariably phenocrystic and the extrusive varieties generally show a pyroclactic texture, the angular fragments ranging from blocks and bombs down to fine ash size particles, they are generally rusty with sulphide impregnation and are associated with thin jaspilite and magnetite bearing cherty siliceous bands.

The acid volcanic sequence, in general terms, can be subdivied into two members depending on their stratigraphic relations to the Skorovas ore horizon and the overlying Calc-Alkaline volcanic sequence.

(1) <u>Lower Acid Volcanics:</u>

This sequence of acid volcanics is confined to the immediate footwall of the Skorovas orebody and to its thinned laterally equivalent mineralization horizon as shown by the rusty, sulphide impregnated acid volcanic horizon to the NE and SE of the Gråbergstoll. These massive acid extrusive are usually very dense, hard and flinty, reflecting their extreme aphanitic nature. They vary in color from whitish to medium dark grey depending on the finely divided magnetite content, which also reflects the varying magnetic nature of these acid rocks. Zones with large, rounded quartz filled amygdules and cherty fragments and ubiquitous quartz filled tension gashes characterize the massive extrusives and intrusives of this lower acid volcanic sequence. These acid extrusives in the immediate mine area are extremely aphanitic (plates 3-6 and 14), containing a matrix grain size of between 0.1 - 0.2 mm in diameter, and are dominated by a tightly interlocking mossaic of quartz and albitic plagioclase, which are extremely difficult to distinguish under the microscope. The footwall acid volcanics in the immediate vicinity of the ore body, are invariably cut by thin sulphide and quartz filled veinlets which often show hydrothermal wall rock alteration or bleaching associated with the sulphide vein boundaries (plate 3, pp. 97). Local occurrences of intense sulphide veining and alteration have been found near both the East and Main orebodies at Skorovas.

In direct contact with the massive footwall acid volcanic sequence lies an irregular zone of extremely coarse to fine grained acid pyroclastics which show intimate relationships to this massive acid volcanic sequence and are thought to be derived from the explosive brecciation of the massive acid volcanics. This acid pyroclastic sequence shows tremendous variations in both thickness and lateral extention and also shows great variations in fragment size, from large blocky and extremely flattened breccia fragments, demonstrated by the blocky explosion breccia near the mine enterance (plate 32, pp. 112) and the light greyish-white "Quartz-eye" porphyry Rhyo-Dacite breccia between the two orebodies at the southern parts of the mine (plate 4, pp. 97), through to densely compacted lapilli tuffs (plates 5 and 16) and down to extremely fine grained, sulphide impregnated, "quartz-eye" fragmental, pale sericite schists, presumably of tuffaceous derivation (plate 7).

A thick section of white Rhyo-Dacite explosion breccia and rusty sericite schists are well exposed between the mine enterence, at the Gråbergstippen, and the Nygruva area, where the sulphide impregnated "quartz-eye" fragmental sericite schists grade laterally, southward, with increasing sulphide impregnation and pyrite banding, directly into massive pyritic ore near the 25 S profile area (see Profile O N-S accompanying report). This rusty "quartz-eye" fragmental sericite schist (tuff) unit outcrops in the Nygruva area immediately overlying the massive pyritic ore and appears to form the uppermost stratigraphic or the lateral transitional facies to the thick acid explosion breccia pile in this area. This rusty, mixed, coarse pyroclastic and fine acid tuff (sericitic schists) zone found adjacent to the massive pyritic orebody, forms a strongly stratabound horizon that can be followed for several kilometers away from the mine area, represented by the rusty "quartz-eye" sericite and chlorite schists which show a strong association to the magnetite bearing cherty and jaspilite exhalite bands to the SW of Dausjøen and the rusty well-banded tuffs to the SE of the mine area.

The massive acid volcanics at Skorovas (Rhyo-Dacites, unit Nr. 1, Table 2) have compositions typical to quartz keratophyres of the spilite suite, showing a silica content of approx. 70% and a noticable enrichment in Na_2O at the expense of the depleted K_2O. The sulphide impregnated, "quartz eye" sericitic schists (tuffs) from the impregnated part of the ore-zone shows, in contrast, a K_2O content varying between 1.2 to 3.3% and equalamounts of Na_2O (Table 3, pp. 34), very similar to the compositions for the quartz keratophyres and sericitic schists quoted by Juve, 1974 and Rui, 1973 (Table 5, pp. 40), which leads one to speculate on the origin of these K_2O enriched schists.

(2) Uppermost Acid Volcanics

The uppermost acid volcanics are characteristically more dome or plug-like in form and appear to have cross-cutting, intrusive relations to the Calc-Alkaline Andesites stratigraphically overlying the orebody. The uppermost acid intrusives, found between Nordre Grubefjell and Gråbergstollen, are generally brighter to paler green than the lowermost acid volcanics, although aphanitic, dark grey, magnetite-rich varieties occur (Nordre Grubefjell), and they are typically porphyritic, containing large (2-4 mm), elongate albitic-plagioclase lath-like phenocrysts with singular Carlsbad twinning set in an aphanitic quartz and plagioclase mossaic matrix (plate 14, pp. 103). The typical apple-green color is caused by the complete chloritization of the original minor mafic minerals and a slight breakdown of the sodic plagioclase into sericite, zoicite and minor chlorite, especially in the more schistose, sheared varieties. These acid intrusives are generally far less sulphide impregnated than the lower acid units.

Within the vicinity of the Orebody, these porphyritic acid intrusive domes are intimately associated with rather massive, pale yellowish-green "quartz-eye" fragmental, epidote-rich felsic tuffs and their chlorite rich "chlor.fleck" equivalents, which are believed to represent original "crystal tuff" material (plates 9 and 10, pp. 100). Agglomeratic facies of these pale green "quartz-eye" porphyritic felsic tuffs are found in immediate contact to a plagioclase porphyry Rhyo-Dacite body immediately west of the Gråbergstollen at locality GF 227.

A quartz and feldspar porphyritic variety of the upper acid volcanic series occurs to the SE of the mine area, between gruvetjøna and Nesåklumpen, and lies here in direct contact with well-banded felsic and chloritic tuffaceous schists and calc and epidote rich pillow breccias of the uppermost Calc-Alkaline volcanic sequence.

The pale green epidote-rich massive tuffs, which are intimately associated to the plagioclase porphyritic Rhyo-Dacite intrusives, show a marked MgO and Na_2O enrichment compared to the other acid (pale) tuffs in the Skorovas area, conditions which are very similar to the Calc-Alkaline Andesites and Basalts, and since these felsic tuffs are separated from the massive ore and associated sulphide impregnated acid tuffs by a noticable jaspilite and magnetite bearing cherty exhalite horizon, it is believed that the pale greenish epidote rich massive tuffs are in fact related to the stratigraphically uppermost Calc-Alkaline Basalt and Andesite series.

The chemical compositions of the plagioclase porphyry upper intrusives are similar to those of the massive Rhyo-Dacites from the lower acid series.

The tremendous volcanic activity which facilitated in the buildup of an acid volcanic complex related to the formation of a synvolcanic massive sulphide deposit such as Skorovas, is reflected by the numerous acid dykes that are seen cutting through the basalts in a belt NE from Nygruva and Gråbergstollen. Similar acid dyke systems have been noticed to the E of the mine area in the Ollatjøna - Havdalsvatn direction.

f) Uppermost Volcanic Sequence: Calc-Alkaline Basalts + Andesites
(unit nr. 3, Table 2)

Calc-Alkaline Basalts and Andesites occupy the stratigraphic uppermost position in the Skorovas area and are rather limited in extent, occurring at the south end of Dausjøen below the acid pyroclastics, at the west end of Reservedammen below the acid volcanics, and infolded into the acid intermediate volcanic sequence immediately south of the Nygruva and Gråbergstollen area.

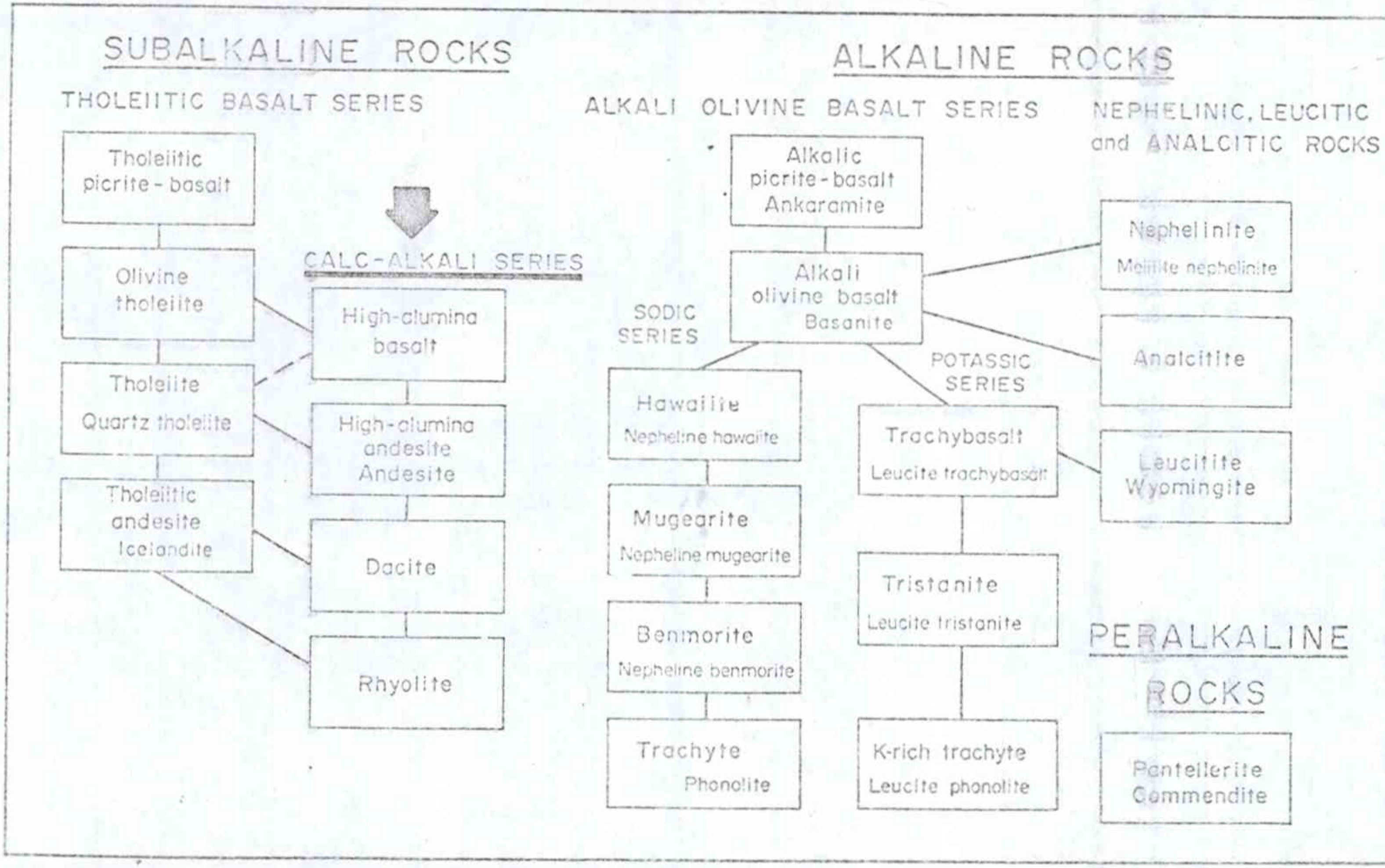
These lavas are characteristically much paler-green in color, reflecting the increased, zoicite and epidote rich groundmass (plate 21, pp. 106), and are noticably coarsergrained than the stratigraphic lower volcanic rocks. They are also typically non-magnetic and appear to be slightly more schistose, especially in the Dausjøen S area and south of the Nygruva area. However, this could only be a reflection of a more intense shearing deformation in the areas where these rocks occur. Some coarse grained flow varieties from is sequence carry a metagabbroic texture and their sheared varieties have often been mistaken as sheared gabbros, amphibolites and even as "chlor.fleck" tuffs found near the Skorovas massive ore contact.

Massive flows of this Calc-Alkaline Basaltic-Andesite sequence contain numerous epidote knots and fragments and invariably contain epidote and carbonate and minor quartz amygdules (plate 26, pp. 109). Close-packed pillow structures with epidote rich rims and epidote filled zoned amygdules, and associated pillow breccias and hyaloclastites are typical for this unit in the Reservedammen W area (plates 25-29, pp.109+110) and East of the mine area at the west side of Gruvetjøna. Numerous dykes of these younger Calc-Alkaline volcanics are found intruding all the older volcanic units in the area and are especially noticable in the acid explosion breccia zone near Rauberget (plate 31, pp. 111) and through the rusty Iron-rich Basaltic pillow lavas found to the NE of the mine entrance area near locality GF 148.

The stratigraphic Uppermost volcanic sequence contains flows having a Basaltic-Andesite average composition, however, the silica content varies somewhat and flows of both basaltic and andesitic composition are found. These lavas are typically enriched in both MgO and CaO compared to the lower volcanic units (Table 2, pp. 33), and the trace element discrimination data, low Ti and high Zr content, reflects the Calc-Alkaline nature of these volcanics. Individual dykes of this Calc-Alkaline volcanic sequence have an exceedingly coarse grained nature, almost a gabbroic texture, and are characterized by an almost ultrabasic composition, containing 40% SiO_2 and 10% MgO. This dyke material is somewhat characteristic of Gjelsvik's "amphibolite" found south of the Skorovas mine area.

TABLE. 1 Classification of Volcanic Rocks. (modified after Travis, 1955)

VOLCANICS	RHYOLITE	DACITE	ANDESITE	BASALT
Igneous equivalent	Granite	Granodiorite - Quartz Diorite	Diorite	Gabbro
Essential minerals	potash feld. > 2/3 total feldspar. quartz > 10%	plagioclase feldspar > 2/3 total feldspar		
		potash feld. > 10% total feld. quartz > 10%	potash feld. < 10% total feld. sodic plagioclase qtz. < 10%, feldspathoids < 10%	potash feld. < 10% total feld. calcic plagioclase qtz. < 10% feldspathoids < 10%
Color Index	10	20	25	50
Chemical composition				
SiO_2	71.50	65.30 -- 61.60	58.20	48.60
Al_2O_3	14.00	16.10 -- 16.20	17.00	16.80
Fe_2O_3	1.50	2.10 -- 2.50	3.20	4.80
FeO	1.40	2.30 -- 3.80	3.70	6.00
MgO	0.60	1.70 -- 2.80	3.50	5.10
CaO	1.60	3.90 -- 5.40	6.30	8.90
Na_2O	3.40	3.80 -- 3.40	3.50	3.70
K_2O	4.30	2.70 -- 2.10	2.10	1.90
K_2O/Na_2O	1.26	0.71 -- 0.62	0.6	0.5
FeO*/MgO	4.58	2.46 -- 2.16	1.88	2.02



[redacted] General classification scheme for the common volcanic rocks. The lines joining boxes serve to outline common associations. The rocks indicated by small print within the boxes are variants of the main rock.

Figure 5 (from: Irving and Baragar, 1971)

TABLE. 2 The Average Chemical Composition of the various volcanic divisions within the Skorovas mine area.

	1 △ Rhyo-Dacites	2 ⊙ Massive Andes.	3 + Calc. Basalts + Andesites	4 ⊖ Dark, Magnetic Basaltic- Andes.	5 ● Epidote Rich Chlor.-Basalt	6 ⊡ Fe - Rich Basalts
samples	11	8	5	2	3	2
SiO_2	70.21 ±	55.28 ±	52.77 ±	50.59 ±	47.99 ±	47.05 ±
TiO_2	0.55	1.13	1.18	1.44	1.27	1.61
Al_2O_3	12.07	13.98	13.81	13.87	14.05	14.07
Fe_2O_3	2.42	3.65	2.96	3.44	3.97	1.28
FeO	2.16	6.91	7.53	7.57	7.54	13.50
MnO	0.09	0.18	0.20	0.17	0.17	0.50
MgO	0.80	3.59	5.46	4.55	4.92	6.34
CaO	1.16	3.58	5.08	4.93	6.79	2.35
Na_2O	6.84	6.26	4.63	8.56	5.69	2.67
K_2O	0.31	0.19	0.06	0.70	0.05	0.01
P_2O_5	0.11	0.20	0.18	0.16	0.16	0.13
Total	98.28	97.92	97.04	98.31	96.84	94.37
Ign. Loss		2.86	3.17	2.34	4.25	4.79
K_2O/Na_2O	.05	.03	.01	.08	.009	.004
FeO*/MgO	5.42	2.84	1.87	2.34	2.26	2.28

TABLE 3 Average compositions of the schistose tuffaceous units at SKOROVAS.

	"Qtz eye" porphyry felsic tuffs from Impreg. Sulf. ore zone. (3)	felsic tuffs minor "Qtz eye" non sulfide impreg. above ore zone. (3)	Intermed. - Basic Tuffs. Strat. above ore Zone. (3)	Sheared (schistose) Calc - Alkaline Basalt above Massive ore zone	Basic Tuffs - Magnetite bearing Chloritic schists (5)	Chlorite schists Basic Tuffs in contact with massive ore.
SiO_2 %	49.80 ± 6.9	59.58 ± 4.5	51.34 ± 0.8	47.44 ± 3.2	44.25 ± 4.1	32.02 ± 9.2
TiO_2	0.94 ± 0.29	0.93 ± 0.3	0.95 ± 0.4	0.91 ± 0.3	1.35 ± 0.1	1.27 ± 0.3
Al_2O_3	11.85 ± 1.9	13.94 ± 0.7	14.46 ± 1.7	14.22 ± 1.2	14.41 ± 1.0	15.28 ± 1.6
Fe_2O_3	10.00 ± 3.8	1.66 ± 0.8	1.45 ± 0.4	1.05 ± 1.4	3.25 ± 0.8	8.88 ± 2.1
FeO	5.53 ± 3.7	6.21 ± 1.6	8.63 ± 1.0	8.78 ± 1.4	11.06 ± 3.4	19.06 ± 11.4
MnO	0.17 ± 0.05	0.23 ± 0.03	0.32 ± 0.2	0.21 ± 0.1	0.13 ± 0.06	0.50 ± 0.2
MgO	4.22 ± 1.6	7.67 ± 1.3	7.38 ± 1.6	6.90 ± 0.4	9.38 ± 1.8	6.10 ± 0.9
CaO	0.22 ± 0.08	0.57 ± 0.5	2.32 ± 1.1	4.07 ± 4.1	2.33 ± 0.6	1.34 ± 1.2
Na_2O	0.11 ± 0.04	3.65 ± 0.1	4.57 ± 1.8	5.22 ± 1.8	3.99 ± 1.9	1.93 ± 2.6
K_2O	2.24 ± 1.0	0.22 ± 0.1	0.05 ± 0.06	0.02 ±	0.09 ± 0.09	0.82 ± 1.0
P_2O_5	0.12 ± 0.07	0.13 ± 0.03	0.15 ± 0.1	0.18 ± 0.1	0.09 ± 0.04	0.15 ± 0.06
Ig loss.	8.22 ± 2.3	4.01 ± 0.4	4.28 ± 0.4	5.19 ± 3.2	5.22 ± 0.9	6.46 ± 1.3
Total	93.48 ± 1.7	98.80 ± 4.4	95.90 ± 1.6	94.16 ± 0.3	95.55 ± 1.2	93.75 ± 1.5
K_2O/Na_2O	20.36	0.06	0.01	0.004	0.02	0.4

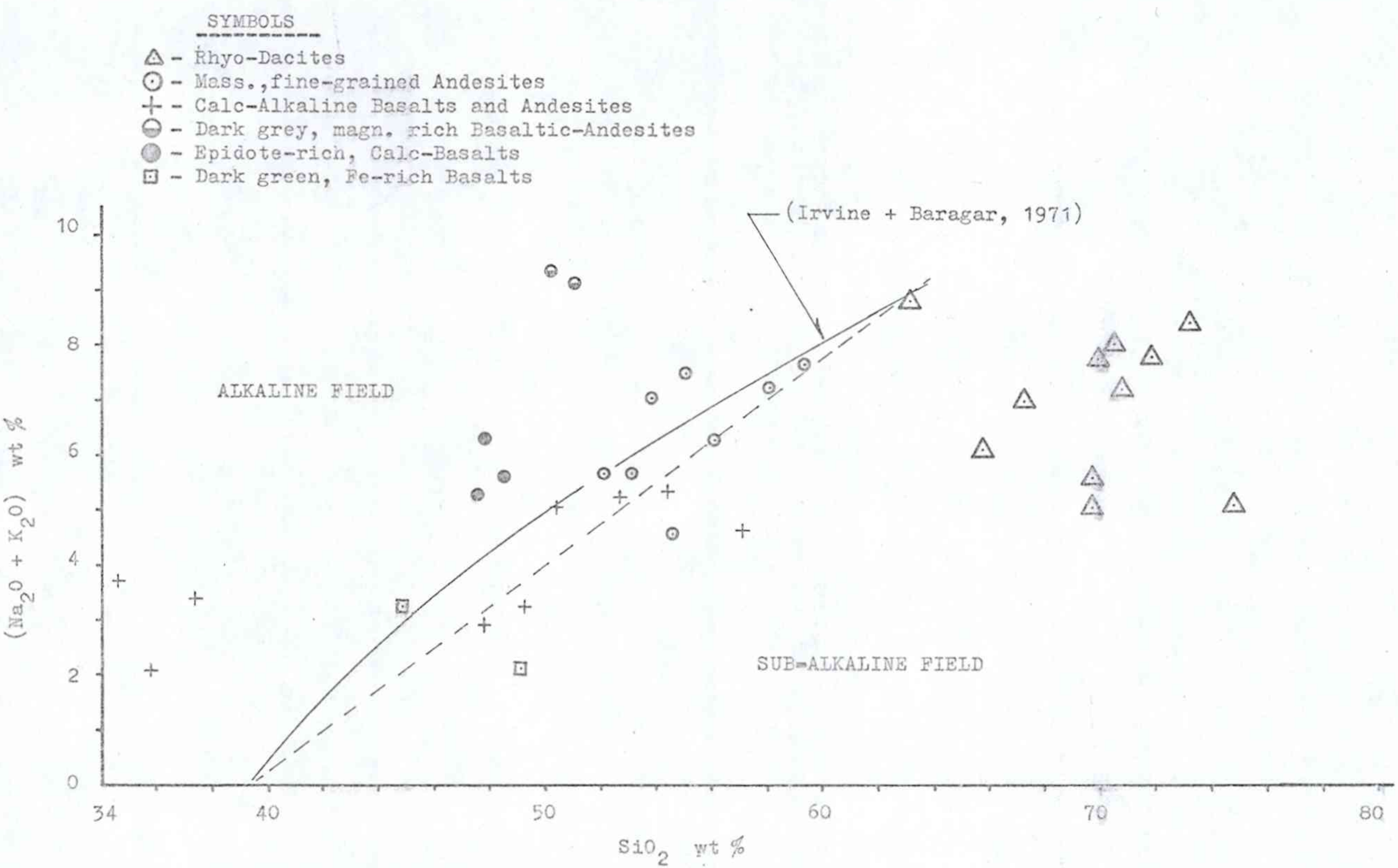


Fig. 6 Alkali-Silica plot (weight %) of the Skorovas volcanics (after Irvine and Baragar, 1971). The solid division-line separates Alkaline from Sub-Alkaline compositions.

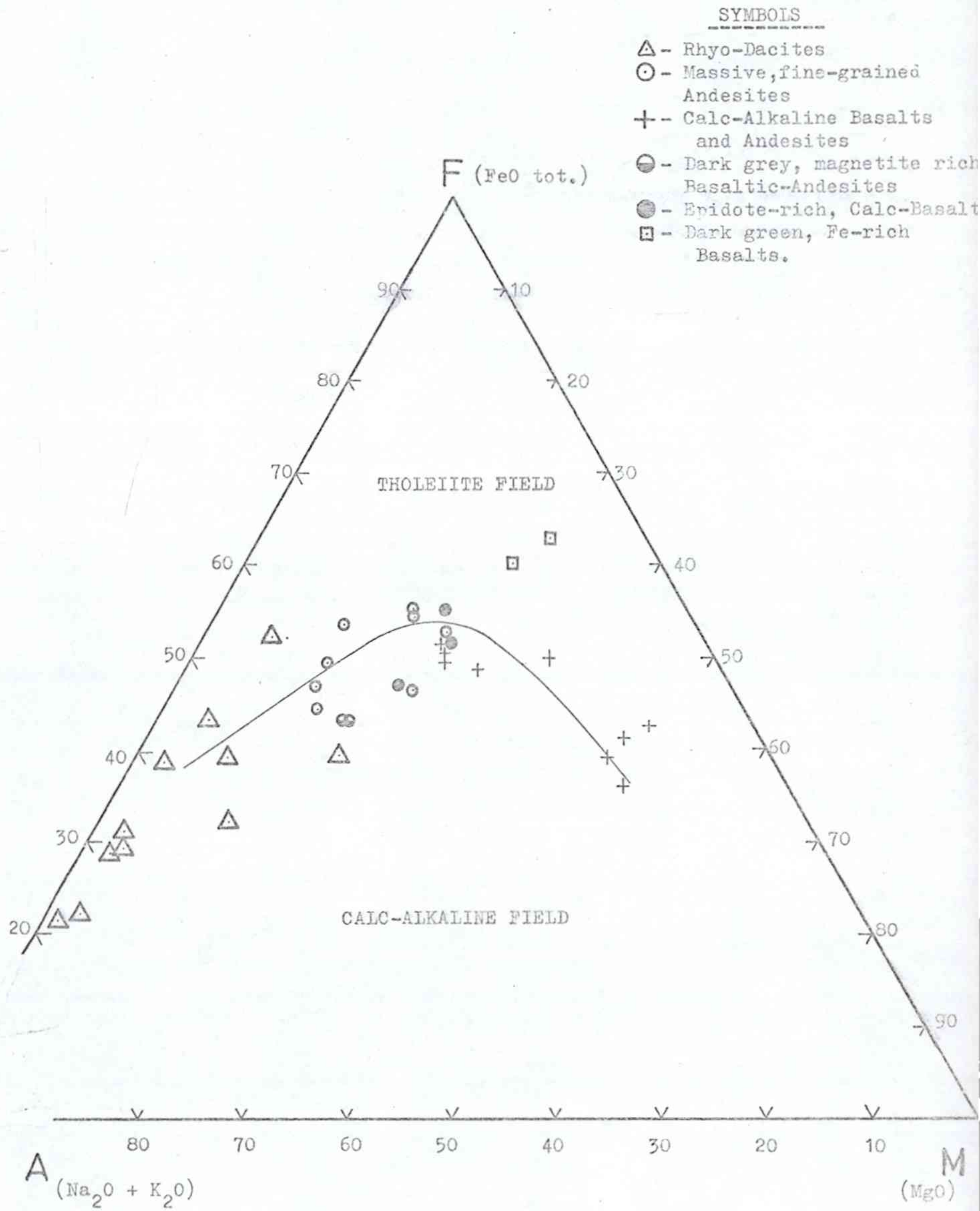


Fig. 7 AFM triangular diagram of the Skorovas volcanics. (after Irvine and Baragar, 1971). FeO tot. = FeO + .8998 Fe_2O_3 (All in weight %

division line from [illegible] – separates Tholeiite compositions from Calc-Alkaline compositions.

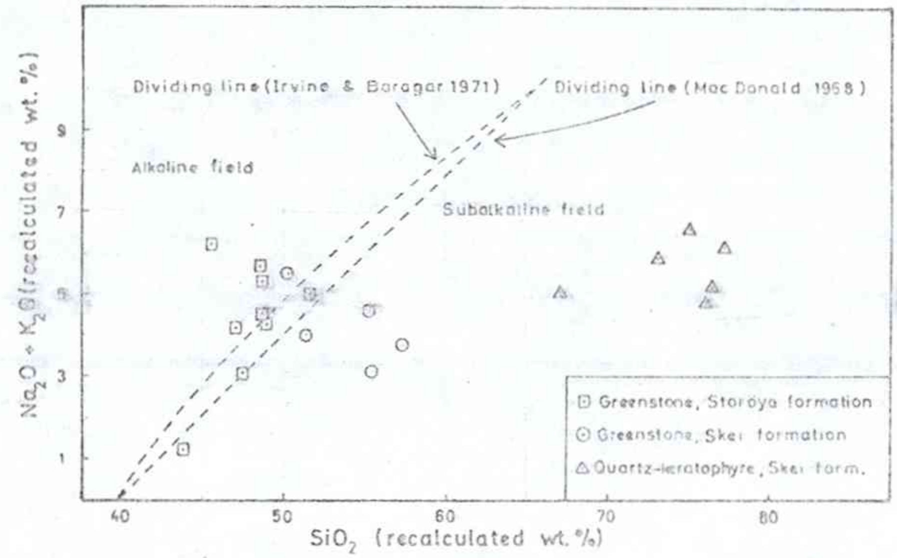


Fig. 14. Alkalis-silica diagram (after Irvine & Baragar 1971).

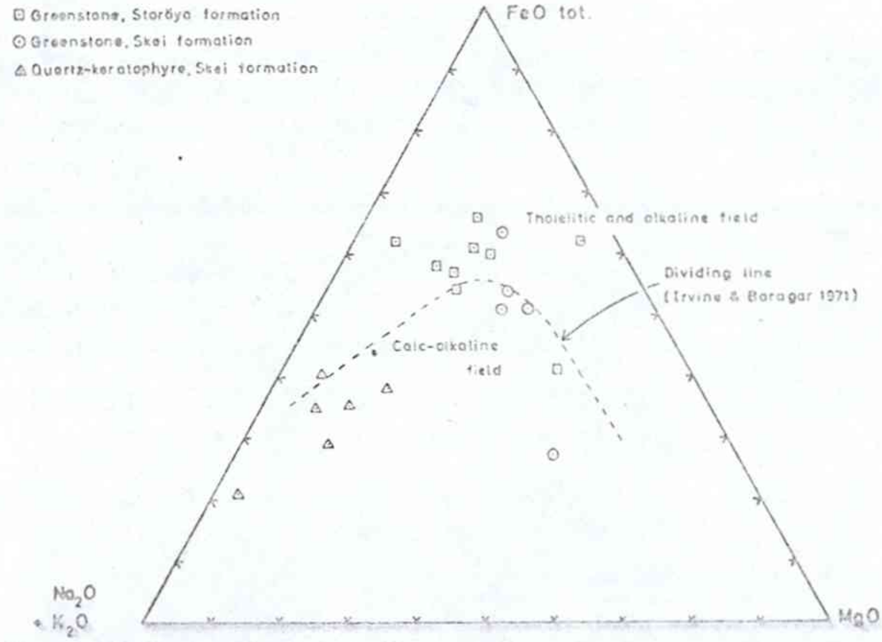


Fig. 15. AFM-diagram (after Irvine & Baragar 1971).

Figure 8. (from Prestvik T., 1974)

TABLE. 4a Average Chemical Composition of Volcanics from the Grong Field.

A. From G. Gale, NGU report, 1974.

	Gjersvik Basalts 13 samples		Gjersvik Andes. 4 samples		Gjersvik Acid Vol. 10 samples	
SiO_2	48.20	± 2.2	55.20	± 3.0	76.61	± 2.2
TiO_2	1.39	0.4	1.40	0.2	0.44	0.09
Al_2O_3	15.40	1.3	13.30	0.7	11.39	0.48
Fe_2O_3 Tot.	12.60	1.6	13.30	1.4	3.19	1.2
FeO						
MnO	0.22	0.03	0.29	0.05	0.04	0.03
MgO	6.40	2.13	3.60	1.0	0.57	0.49
CaO	7.80	2.2	4.90	1.5	1.04	0.7
Na_2O	4.32	1.3	5.02	0.9	5.66	1.8
K_2O	0.27	0.1	0.26	0.1	0.67	1.1
P_2O_5	0.07	0.04	0.10	0.05	0.03	0.02

B. From S. Kollung, Grong Project Report, 1974.

	Oldest Volcan. Unit well-banded, pale		Middle Unit Gjersvik Gst. dark-green		Youngest Volcan. Unit well-banded, pale	
SiO_2	47.83	± 0.8	50.43	± 0.9	48.88	± 0.8
TiO_2	0.89	0.09	1.28	0.17	0.76	0.16
Al_2O_3	16.15	0.5	16.00	1.0	16.58	0.23
Fe_2O_3	3.78	0.1	6.04	0.35	2.87	0.08
FeO	5.48	1.1	6.55	0.01	5.29	0.97
MnO	0.18		0.24		0.23	0.08
MgO	7.83	0.3	4.79	0.88	7.41	0.7
CaO	12.60	0.2	6.03	2.21	9.06	2.3
Na_2O	3.13	0.6	5.91	0.26	4.52	0.2
K_2O	0.34	0.3	0.28	0.3	0.32	0.03
P_2O_5	0.05	0.01	0.09		0.07	0.01

TABLE. 4b Average Chemical Composition of Volcanic Rocks from Leka, Nord-Trøndelag. (after Prestvik, 1974)

	Storøya Formation Basalts		Skei Formation	
	porphyritic gst.	pillow lavas	greenstones	qtz. keratophyre
SiO_2	46.03	46.77	49.05	72.96
TiO_2	3.12	2.43	2.13	0.29
Al_2O_3	18.74	17.59	15.73	12.84
Fe_2O_3	8.07	3.64	2.75	1.71
FeO	4.02	8.14	9.28	2.17
MnO	0.13	0.07	0.18	0.08
MgO	2.47	3.79	5.49	1.03
CaO	9.66	8.07	5.40	1.93
Na_2O	3.35	4.13	3.80	5.47
K_2O	1.28	0.63	0.27	0.25

TABLE. 5 Comparison of the Skorovas acid volcanics to other Scandinavian Caledonian acid volcanics, and acid volcanics from a typical Calc-Alcaline Suite as publ. in Irvine and Baragar,1971.

	Skorovas meta-Rhyo-Dacites 11 samples (Reinsbakken 1977)	Gjersvik Acid Volcanics lo samples (G.Gale,NGU 1974)	Leka Qtz-Keratophyre Skei Fm. (Prestvik 1974)	Stekenjokk Qtz.-Keratoph. (Juve,1974) 72 samp.	Killingdal Qtz-sericite schists. (Rui,1973) 10 samp.	Calc-Alkaline Suite. (Irvine+Baragar,1971) Rhyolite	Dacite
SiO_2	70.21	76.61	72.96	70.15	71.41	73.23	69.68
TiO_2	0.55	0.44	0.29	0.25	0.54	0.24	0.36
Al_2O_3	12.07	11.39	12.84	13.12	11.13	14.03	15.21
Fe_2O_3	2.42	3.19(tot.)	1.71	0.82	13.53(tot)	0.60	1.08
FeO	2.16	---	2.17	2.11	---	1.70	1.90
MnO	0.09	0.04	0.08	0.06	0.01	0.02	0.04
MgO	0.80	0.57	1.03	3.05	0.89	0.35	0.91
CaO	1.16	1.04	1.93	1.76	0.02	1.32	2.70
Na_2O	6.84	5.66	5.47	3.54	0.24	3.94	4.47
K_2O	0.31	0.67	0.25	1.39	3.14	4.08	3.01
P_2O_5	0.11	0.03	--	--	0.05	0.05	0.10
K_2O/Na_2O	0.05	0.1	0.05	0.4	13.1	1.04	0.67

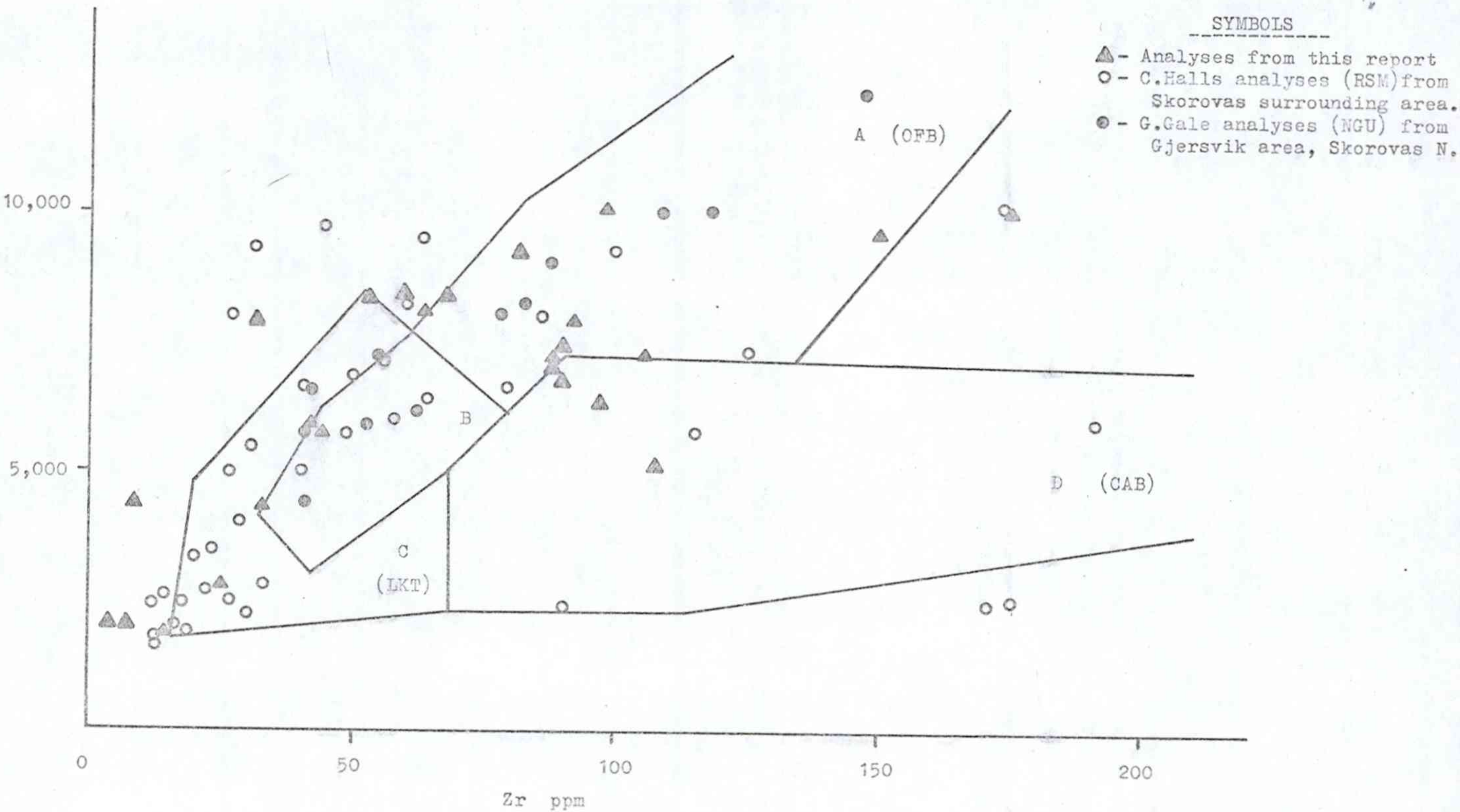


Fig. 9 Ti - Zr discrimination diagram for the Skorovas volcanics. (after Pearce and Cann, 1973) Fields represented: A=Ocean-Floor Basalts (OFB), B=Ocean-Floor Basalts and Low-Potassium Tholeiites (LKT) from Island-Arcs, C=Low-Potassium Tholeiites from Island-Arcs, D=Calc-Alkaline Basalts and Andesites (CAB).

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20-2-77.)

Fig. 10a SCHEMATIC DIAGRAM SHOWING THE ROUGH STRATIGRAPHIC RELATIONSHIPS BETWEEN THE VARIOUS VOLCANIC UNITS AND THE POSITION OF THE SKOROVAS OREBODY.

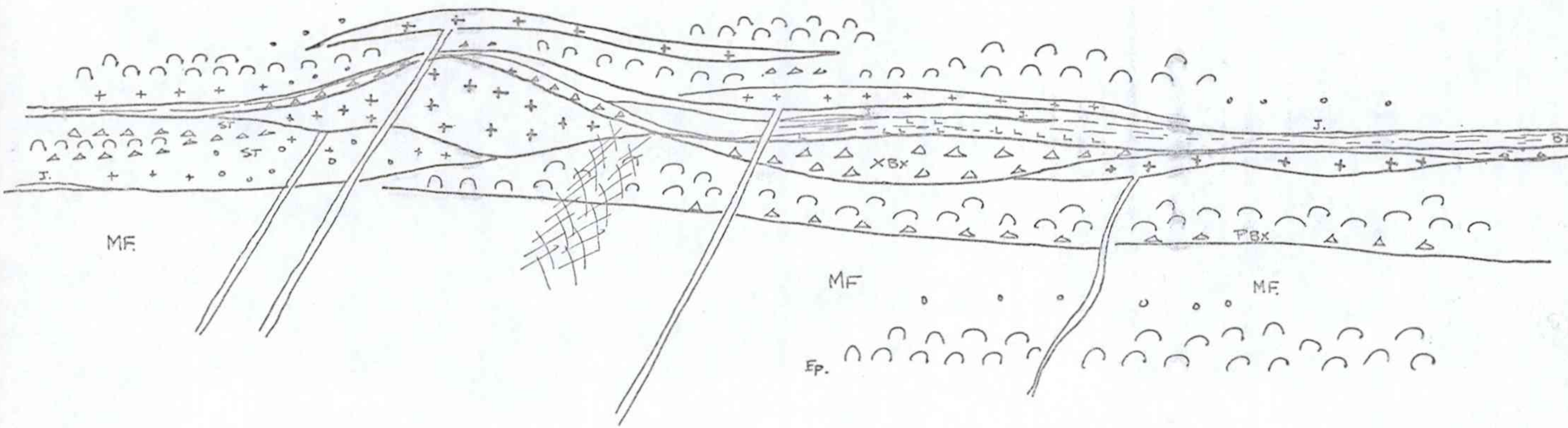

FIGURE. 10 b Alternative schematic diagram of the stratigraphic relationships between the various volcanic units and the position of the Skorovas massive sulphide ore-body.

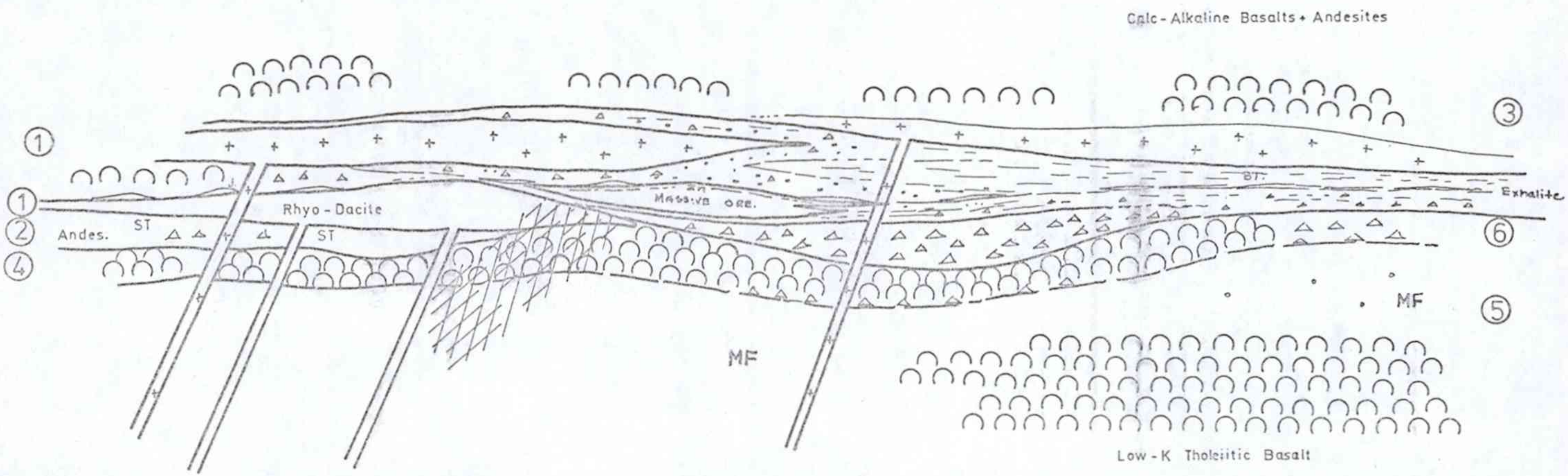

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FIG. 11 Diagram showing the stratigraphic development of pillow-breccias and hyoclastites associated with close-packed pillow lavas. (after Furnes,1972, and Carlisle,1963)

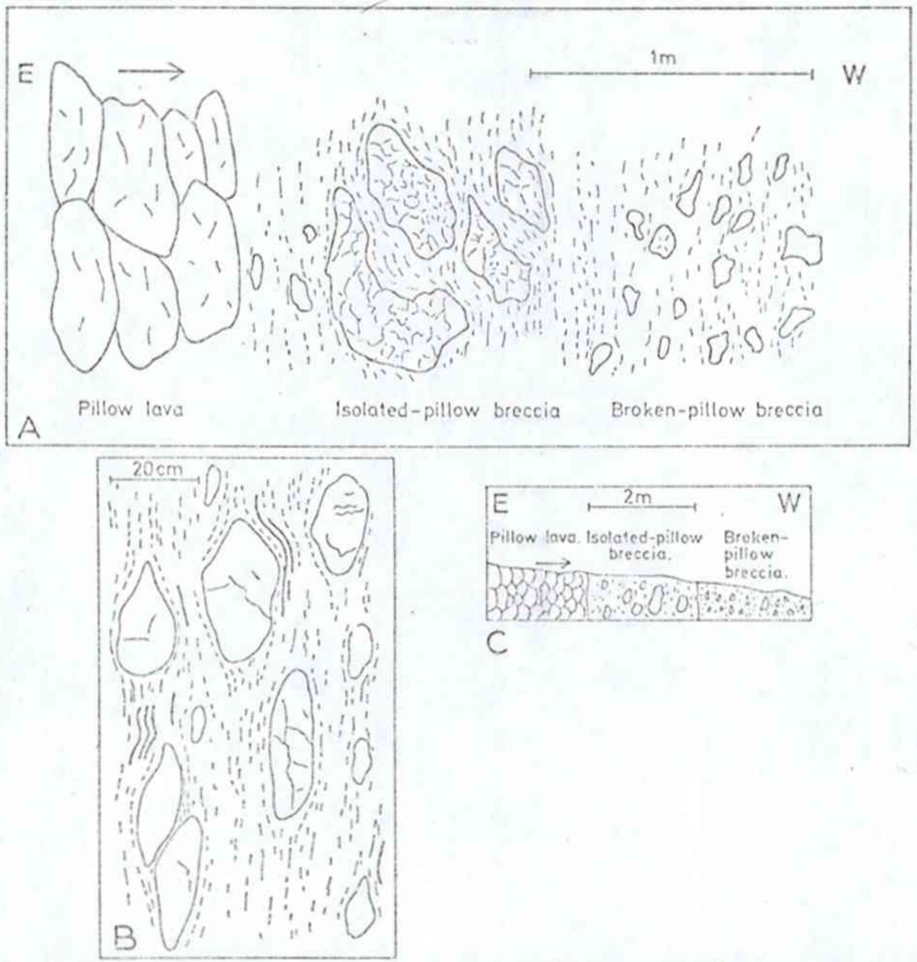


Fig. 2. (A) shows the development from pillow lava to isolated-pillow breccia to broken pillow breccia at Humrevåg, Oldra. (B) shows isolated-pillow breccia from the NW-part of Oldra. (C) shows a schematic profile from the same locality as (B) indicating a similar development as in (A). The arrows in (A) and (C) indicate the younging direction of the pillows. (AFTER FURNES.H, 1972)

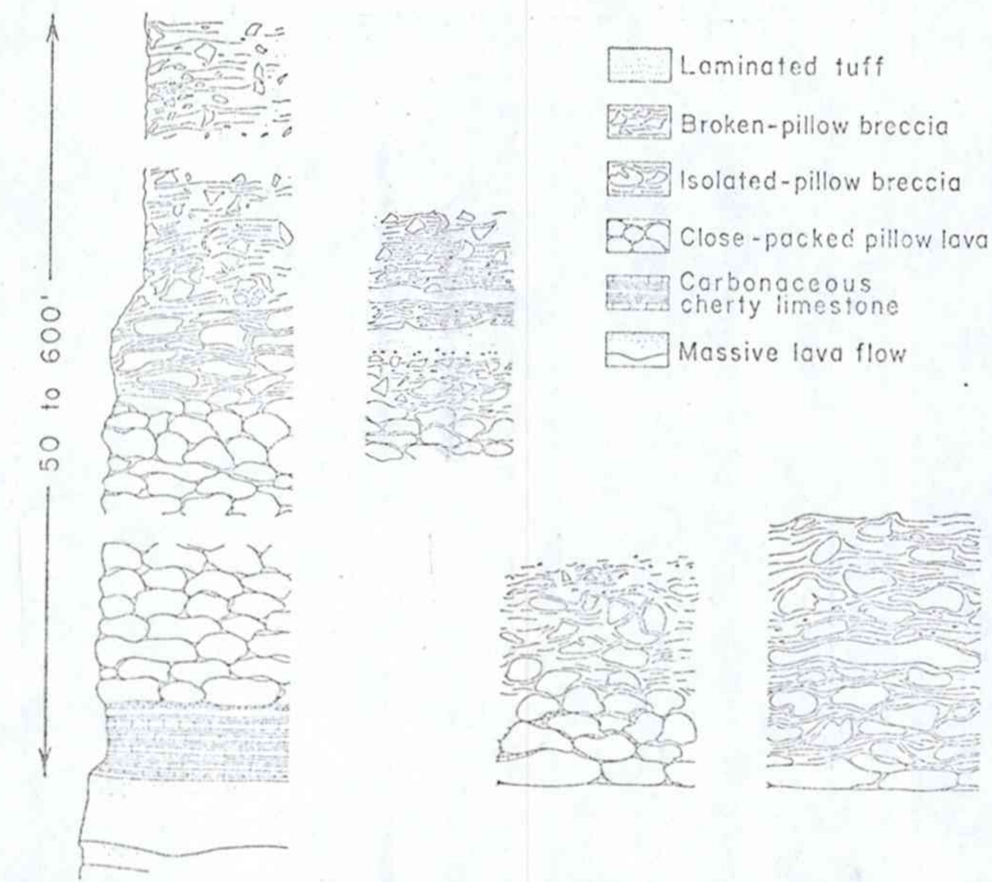


FIG. 2.—Diagram showing some typical successions in pillow-breccia occurrences on Quadra Island (AFTER . CARLISLE.D, 1963)

PART II ORE GEOLOGY

1. General Ore Geology

On discussing the Skorovas orebody, it is worthwhile to reiterate from the previous descriptions of the volcanic host rocks, that the orebody is intimately associated with acid extrusives and pyroclastic horizons and is situated at the contact between the volcanic sequences displaying distinctly Low-K Tholeiitic and Calc-Alkaline character, and that the eruptive sequence originated in an immature ensimatic island arc of Lower Ordovician age. It is appropriate to consider the morphology and mineralogy of the ore deposit and the peripheral exhalitive mineralization of the Skorovas area in terms of the exhalitive volcanic hydrothermal origin which was proposed by Oftedahl (1958). A more detailed discussion of the origin of the Skorovas orebody can be found in Halls, C. et al (1977), however, a generalization will be given here along with a detailed description of the various ore facies (ore types) found in the Skorovas mine, and their possible usage for stratigraphic controls within the orebody itself.

The orebody can be described as an en-echelon array of closely spaced massive sulphide lenses, the distribution of which has created an elongate ore zone lying in a N to NE orientation, with a width of approx. 200 meters and a length in excess of 800 meters (see 1:2000 cross sections, O N-S Profile). The orebody at the present state of development consists of ca. 10 million tons of massive sulphides of which 1.5 million tons are essentially pyritic ore devoid of appreciable base metal contents. Production from the period 1952-1976 has yielded 4.7 million tons of milled pyrite fines having an average grade of 1.2% Cu, 1.8% Zn and 45% S. Present reserves are calculated as approximately 2 million tons with an average grade of 1.15% Cu and 2.29% Zn, reflecting the present interest in the zinc rich portions of the complex lens-like peripheries to the massive pyritic bodies that have already been mined. The bulk composition of the Skorovas orebody reflects a comparatively simple mineralogy, dominated by pyrite, sphalerite, chalcopyrite and magnetite in decreasing order and containing accessory amounts of tennantite (fahlerts), arsenopyrite and minor galena. Pyrrhotite is conspicously absent. The principle gangue minerals are chlorite, quartz and calcite, together with minor sericite, talc and locally stilpnomelane.

Peripheral enrichments of base metal values and the separation between maximum zinc and copper values in the massive pyritic ores has earlier been documented by Gjelsvik (1960 and 1968) through a systematic analytical study of the major base metal contents in ore along selected profiles spanning the length and breadth of the orebody. Gjelsvik's profile (Figure 21, pp. 61) shows that the zinc and copper contents varied antipathetically, zinc showing a tendency towards enrichments in the peripheral zones of the orebody and copper tending to concentrate in the core areas - with an overall content of zinc and copper showing an increase towards the south end of the orebody. Starting from this position, the author has attempted to classify the massive sulphide parts of the Skorovas orebody by studying the variations in the Cu-Zn-S contents within the massive sulphides along the whole length of the orebody, through selected E-W profiles which provided adaquate drill hole coverage and good base metal analytical data across both the East and the Main orebodies, and spaced at even intervals to give a representation of the ores present in Skorovas. The E-W profiles included from north to south: Profiles 25, 34, 42-43, 48-49, 55, 60-61, 67, 74-76 and 85, plus numerous control samples of the various oretypes found during the detailed geological mapping within the mine. It must be emphasized here that the results do not take into account the thickness or the amounts of the various ore facies (types) represented by the chemical data and should therefore not be regarded as quantitative. The results do, however, demonstrate the qualitative variatious within the Skorovas massive ore as a whole and can be used in comparisons with the various ore type divisions outlined in this report (Table 6, pp. 51). Massive ore, as refered to in this report, has been designated as ore with 30% and greater S content.

2. Compositional Features of the Skorovas Massive Ore

The frequency distribution diagrams (Figure 13-15, pp.53-55) for copper and zinc values from the Skorovas orebody show positive skewed distributions having regular T shapes. Both the copper and the zinc values show characteristics of multi-population distribution as demonstrated by the peaks on the copper histogram at 0.5% and 2.25% Cu values (Figure 13, pp. 53). The zinc values show a similar multi-peak distribution. The copper verses zinc scatter diagram (Figure 16, pp. 56) shows a very strong antipathetic correlation between copper and zinc, which reflects the copper and zinc zonation found in the massive ores by Gjelsvik (1960 and 1968) (Figure 21, pp. 61).

As previously mentioned, an attempt has been made here to classify the various ore types (ore facies) found at Skorovas, based on the morphological and mineralogical features and supplemented by analytical data to show their chemical data for the overall massive ore itself and a comparison can be made to see how the individual ore-types fit into the general Skorovas massive ore distribution scheme. Figure 17 (pp. 57) shows a Cu verses Zn scatter diagram for the distribution of the various ore types and demonstrates that the copper-rich pyritic ores (I-C) and the zinc-rich pyritic ores (I-D) show a good separation. The Skorovas vasskis type (I-a) (base metal deficient pyritic ore) plots near the exhalative-sulphide or vasskis band from outside the Skorovas mine area. Ore types II, IV-a and IV-b plot very near each other and interestingly enough they are also found in contact or near contact with each other in the orebody itself, which might suggest some primary distribution in the base metal contents of these ores. Figure 18 (pp. 58) is a triangular plot Cu-Zn-S and shows a strong concentration of all the ore types up in the S corner as the 45-50% S content in the Skorovas ores dominates completely. Therefore, all the S values were divided by 20 to bring them down within the same range

(2 - 2.5%) as the Cu and Zn values found in the Skorovas ore. Figure 19 (pp. 59), a Cu-Zn-S/20 triangular plot, shows the scatter distribution of all the data for the massive ores and shows a very good spread in the data with noticable concentrations in the S/20 and Zn corners. Figure 20 (pp. 60 is a similar triangular plot (Cu-Zn-S/20) for the Skorovas ore types which demonstrates a good separation between the various ore types and appears to be a good diagram for use in classifying the massive ores at Skorovas. Again the reader will note that the Skorovas vasskis type (I-a) is found alone up in the S rich corner, and that the ore types II, IV-a and IV-b (the quartz-zinc banded pyritic ore, the magnetite + quartzbanded ore and the carbonate rich ore) show a close grouping in the Zn rich side of the diagram.

One of the goals for this project was to investigate the morphology, mineralogy and the chemical characteristics of the various ore facies that have been found in Skorovas during the detailed geological mapping and to investigate their lateral extensions throughout the orebody as a possible marker horizon to help separate the possible stratigraphic levels in the massive ores. The ore types (ore facies) within the Skorovas mine are extremely varied and complete gradations have been recognized between the various facies, especially within the massive pyritic ore classification type Ia to d (Table 6, pp. 51) and (Figure 12, pp. 52). However, most of the oretypes discussed here have distinct morphological, mineralogical and chemical characteristics which have helped to distinguish several suitable stratigraphic marker horizons within the ore and has helped in the formulation of a simplified model for the basin of deposition of the Skorovas ores (Figure 12, pp. 52).

Although tectonic deformation has destroyed almost all clues of primary sedimentary structures, certain primary textural evidence has been found to indicate that certain ore facies are probably of chemical-sedimentary origin and that the essential copper-zinc zonation pattern is a primary dispersion effect within the basin of deposition and can be interpreted in terms of a stratigraphic zonation, the copper concentrating at the bottom and the zinc at the top, which resembles that found in orebodies of undisputed submarine synvolcanic exhalative origin in such undeformed areas as the now famous Kuroko deposits of the Miocene Green Tuff belts of Japan (Lambert and Sato, 1974). Final evidence of the operation of chemical-sedimentary processes in the ore formation is provided by the occurrence of magnetitic and haematitic chert bands (jasper) in the hangingwall of the orebody stratigraphically overlying the magnetite and zinc rich ore facies (sequence is now inverted). Figure 12 (pp. 52) shows the working model of the basin of deposition for a syngenetic stratiform massive sulphide orebody deposited under submarine conditions as a result of emmission of metal-rich fluids in the vicinity of an acid eruptive centre.

3. Skorovas Ore Types (Table 6, pp. 51)

A description will be given here of the characteristic features of the various ore-types or ore facies that have been distinguished at Skorovas. Table 6 (pp. 51) gives the base element compositional variations of the various ore-types and Figure 12 (pp. 52) shows their stratigraphic distribution within the synvolcanic chemical-sedimentary basin of deposition that has been proposed for the Skorovas orebody.

Type Ia-d: The major part of the Skorovas ore deposit consists of extremely massive, dense, fine grained pyritic ore which shows a great variation in base metal contents (Cu and Zn), Table 6 (pp. 51) ore types Ia to d, and a complete gradation has been found from extremely copper rich (type I-c) to zinc rich varieties almost devoid of copper content (type I-d). The dominating portion of the massive fine grained pyritic ores (type I-b) contains roughly 1% Cu and 2% Zn, a 1:2 Cu to Zn distribution, and this ore type is characterized by its dense, homogenous, compact, extremely fine grained nature, the individual pyrite grains varying from 0.01 to 0.1 millimeter (plates 43 and 55). The individual pyrite grains are tightly packed with quartz, and minor sphalerite and chalcopyrite as matrix constituents. Zones of copper and zinc rich ores have been found where the chalcopyrite and sphalerite minerals form visible coarse-grained fracture fillings within the massive compact pyritic ore. This compact pyritic ore forms the major central zone of the two major ore lenses, the East and the Main orebodies (see figure 23, pp. 67), and most likely corresponds to the central part of the depositional basin (Figure 12, pp. 52). Copper-rich varieties (type I-c) of this compact pyritic ore facies have been found containing up to 5% Cu, however, such high copper contents are rather rare and the ores generally average about 2 to 3% Cu and are usually very low in zinc, 0.5 to 1% Zn. This copper-rich pyritic ore facies is rather restricted to the eastern and south-eastern extremities of the East orebody, in the immediate vicinity of a thick acid volcanic complex and closely associated to a zone of intense sulphide veining and hydrothermal wall rock alteration, of which some similar pale acid volcanic material has been found mixed with the copper rich pyritic ores (plate 45, pp. 119). The copper-rich pyritic facies (type I-c) corresponds to the lowest stratigraphic position in the basin of deposition as shown in Figure 12 (pp. 52).

Towards the stratigraphic upper parts of the orebody, increase in zinc contents are noticable, reflecting the increase in sphalerite content within the matrix and also the occassional sphalerite band that occurs beneath the sphalerite concentrations of ore types II and III. Zinc contents of 4 to 5% Zn represnets an appreciable amount of matrix sphalerite.

Type II: Near the upper parts of the orebody, towards both the hangingwall and footwall of the Main orebody at Skorovas, lies a very curious, extremely irregularly banded (tectonic) quartz and minor sphalerite rich and thin compact pyritic banded ore (plate 48, pp. 120). This unit is characterized by boudinaged, very irregular, dark bands of quartz and finely divided sphalerite (up to 4% Zn average) contrasting sharply to the pale yellowish, compact, visibly sheared pyrite bands. These bands show typical tectonic structures, however, they probably represent original compositional banding, now superimposed by the effects of deformation. This ore type has been found at various localities towards the footwall and hanging wall along the whole length of the massive ore zone and appears to be a consistant through-going markerband. This facies probably represents lateral quartz and zinc rich transitions of the upper stratigraphic parts of the orebody (Figure 12, pp. 52).

Type III: Another very unique ore type or facies found at the Skorovas mine is a thin band of almost totally massive, dark-brown sphalerite, carrying minor contents of chalcopyrite, galena and silicates, a dark amphibole which could be grunnerite (plates 52 and 53, pp.122-123). This thin sphalerite band occurs very locally in the extreme NE corner, at the footwall of the Eastern orebody, where it is in contact with well-banded pyrite and minor sphalerite ore above, (plate 50, pp. 121) and jaspilite fragments and dark green chlorite schists below. This ore facies, which has been called "Zn-Pb-Cu peripheral ore", represents a very special horizon within the Skorovas orebody as its extremely high base metal contents show , 42% Zn, 4% Pb and 1.4% Cu. Besides being the only ore facies in which detectable quantities of Pb have been found, this unit also shows completely different textural features from the dominating pyritic facies by containing an almost totally schistose character (plate 57, pp. 125). This Zn-Pb-Cu rich ore represents a peripheral, laterally transitional facies of the zinc rich orezone at the uppermost stratigraphic parts of the depositional basin (Figure 12, pp. 52).

Type IVa + b: Another lateral facies of the uppermost stratigraphic ore zone within the Skorovas orebody is the magnetite and grey quartz and white carbonate banded facies interbanded within the pyritic ore (plates 46, 47 and 49). These facies also contain an average of 3 to 5% Zn, although minor copper-rich bands have also been found. These ores display extremely well banded (tectonic) features and are generally much coarser grained (0.1 cm) than the compact pyritic ores. The magnetite and carbonate rich facies lies in immediate contact and could be in part gradational to an extremely well-banded, primary sedimentary banded pyrite and chlorite impregnated ore (type Va) which forms the footwall impregnated ore zone of the Main orebody at the Profile 42-E-W level (Figure 23, pp. 67) Magnetite banding is also found here in minor amounts, however, it is the dominance of chlorite, carbonate and minor sphalerite banding that characterizes this impregnated ore zone, which forms a definite stratigraphic horizon having sharp contacts to the compact pyritic ores above.

Ore facies V-a: (plates 50 and 51, pp.121+122) has been described above. This ore facies probably represents the extreme lateral carbonate exhalite facies of sulphide mineralization within the Skorovas depositional basin and shows evidence of both basic tuff (chloritic schists) and carbonate rich additions to the sulphide mineralization in this area (Figure 12).

Type VI: exhalite sulphides - vasskis (plate 54, pp. 123)
This unit represents the extreme distal exhalative mineralization feature of the Skorovas ore mineralization event, and the extreme well-bedded nature (primary sedimentary features) of the aphanitic pyrite and black graphitic rich silicate bands, reflects the more quiescent manner of deposition.

Type V: sulphide impregnated keratophyre (plate 42, pp. 117
This unit occurs as erratic zones of white to pale grey acid volcanic breccia material (keratophyre) or original hydrothermal alteration, wall-rock bleaching and silicification and albilization, that has been mixed with and intensely veined by coarse grained pyrite (plate 42). Some of this acid material has also been found as inclusions within the copper rich pyritic ores (plate 45, pp. 119).

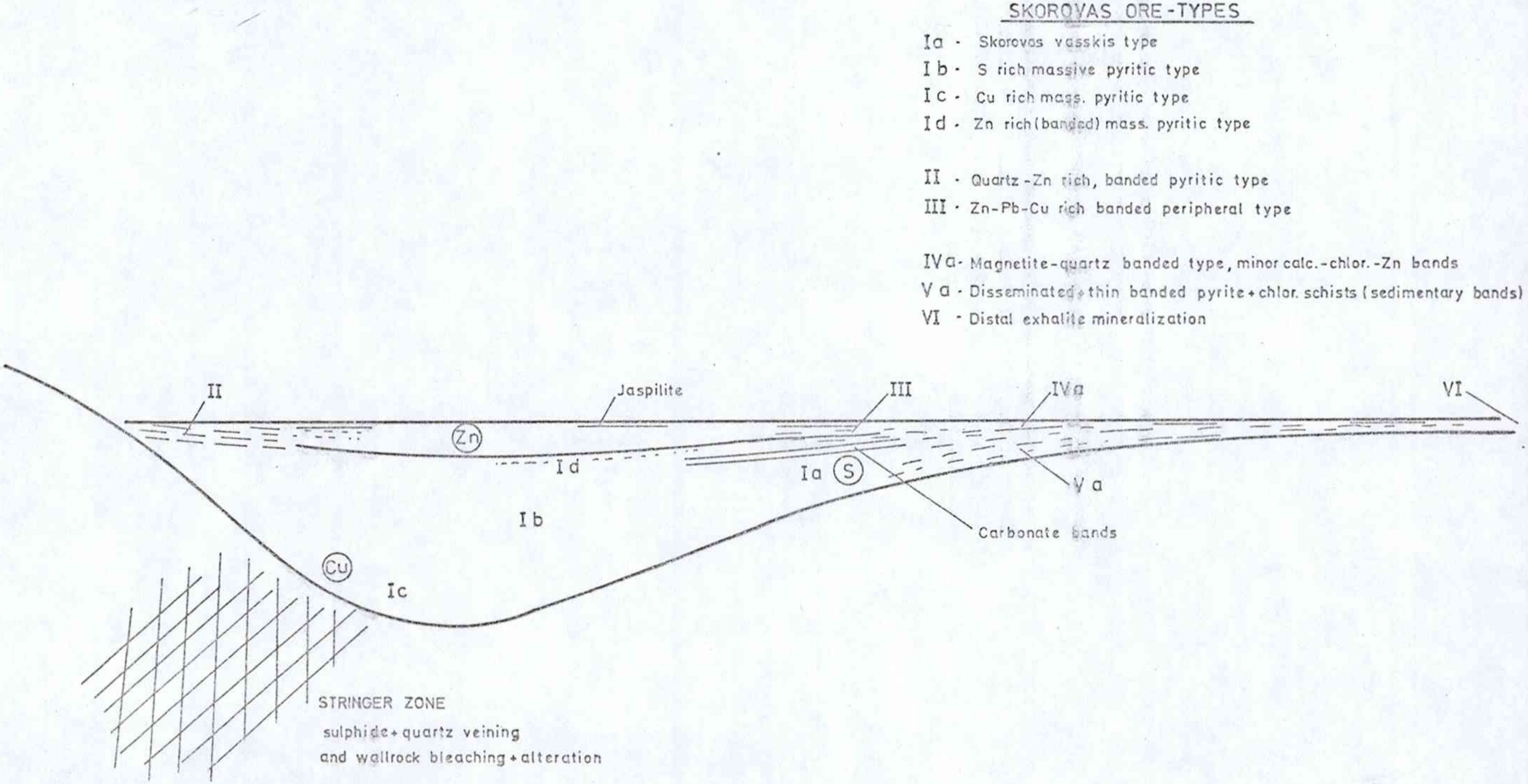
A possible genetic association of these keratophyres to the wall rock bleaching, hydrothermal alteration product associate with the intense sulphide-veining from the "Feeder Zone" or "Stringer zone" found stratigraphically below the massive ore zone (Figure 12), can be suggested from the photos in plates 39-42 (pp. 116-117).

Extreme high contents of both copper and zinc have been found in isolated localities in the Skorovas mine and are thought to represent areas of sulphide remobilization as they are generally confined to areas of intense deformation, especially where the earlier tight F_1 structures have been refolded by zones of large intense F_2 crenulation structures. Extremely coarse grain pyrite porphyroblasts (up to 2 cm across) and visible concentrations of white quartz, chalcopyrite and sphalerite occupy pressure shadows and attest to remobilization.

TABLE. 6 Average chemical composition of the Skorovas ore-types.

ORE TYPES	S	Cu	Zn	Pb	Zn/Cu (Cu/Zn)
I-a Skorovas vasskis	51.06	0.20	0.41	nd	2.02 (0.67)
I-b mass. S-rich, fine- gr. pyritic ore	46.97	1.10	2.14	0.05	1.96 (0.51)
I-c mass. Cu-rich pyritic ore	45.58	2.63	0.77	0.04	0.38 (2.65)
I-d mass. Zn-banded pyritic ore	42.28	0.79	9.33	nd	11.86 (0.08)
II mass. quartz- Zn rich tectonic banded pyritic ore	36.21	0.41	3.95	0.11	9.70 (0.10)
III Zn-Pb-Cu rich peripheral ore	27.50	1.40	42.53	3.98	30.48 (0.03)
IV-a mass. mag.+ quartz banded, minor Zn rich ore	39.87	0.99	3.90	0.06	3.92 (0.26)
IV-b Carbonate banded + impreg. pyritic ore	34.23	0.49	4.05	nd	8.31 (0.12)
V-a Sedimentary (primary) banded + impreg. Chlor. + carbonate + pyrite ore	33.54	1.09	1.03	0.01	1.08 (0.93)
V-b Sulphide impreg. acid volcan. + tuffs (kerat.)	34.60	0.40	0.67	0.02	1.68 (0.60)
VI Exhalative sulphide bands from Skorovas E.	nd	0.06	0.02	0.01	0.28 (3.53)
VII Typical remobilized ore	24.00	19.00	9.30	nd	0.50 (2.0)

Fig. 12 Simplified sketch of the original basin of sulphide deposition showing the stratigraphic relationship of the various Skorovas ore-types



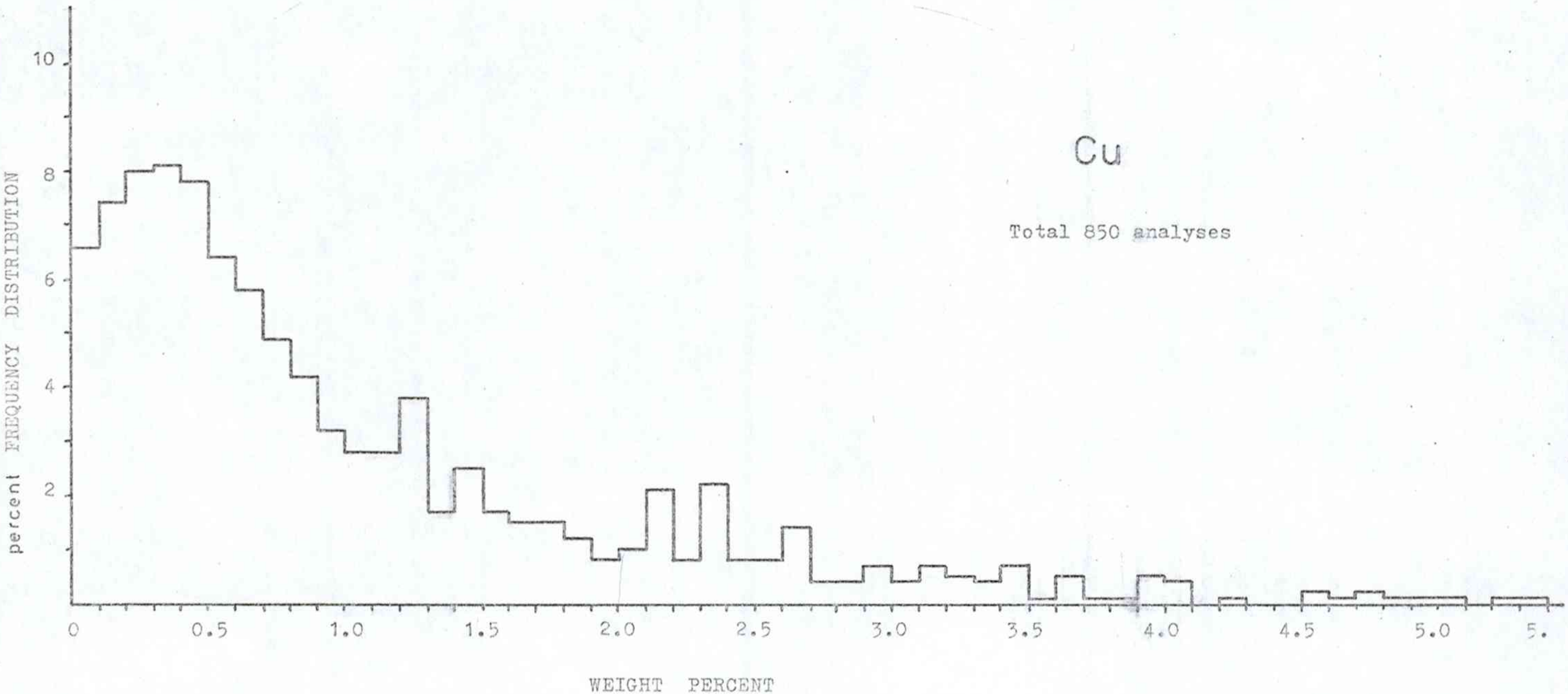


Fig. 13 Histogram showing the frequency distribution (weight percent) of Cu in the Skorovas massive-sulphide ores, from both the Main and Eastern ore-bodies. Note 30.00 % S arbitrary cutt-off for massive ore, less than 30.00% S used as disseminated- ore.

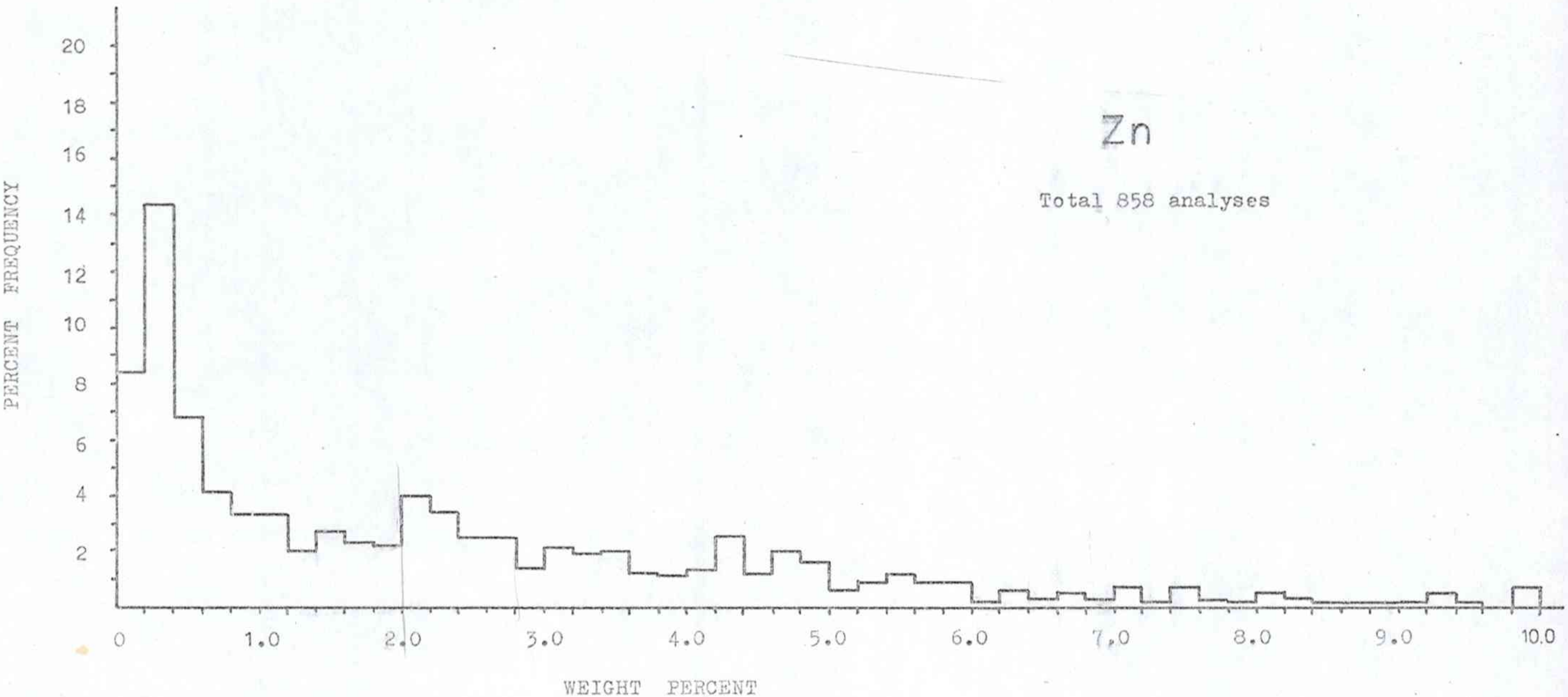


Fig. 14 Histogram showing frequency distribution (weight percent) of Zn in the Skorovas massive-sulphide ores.

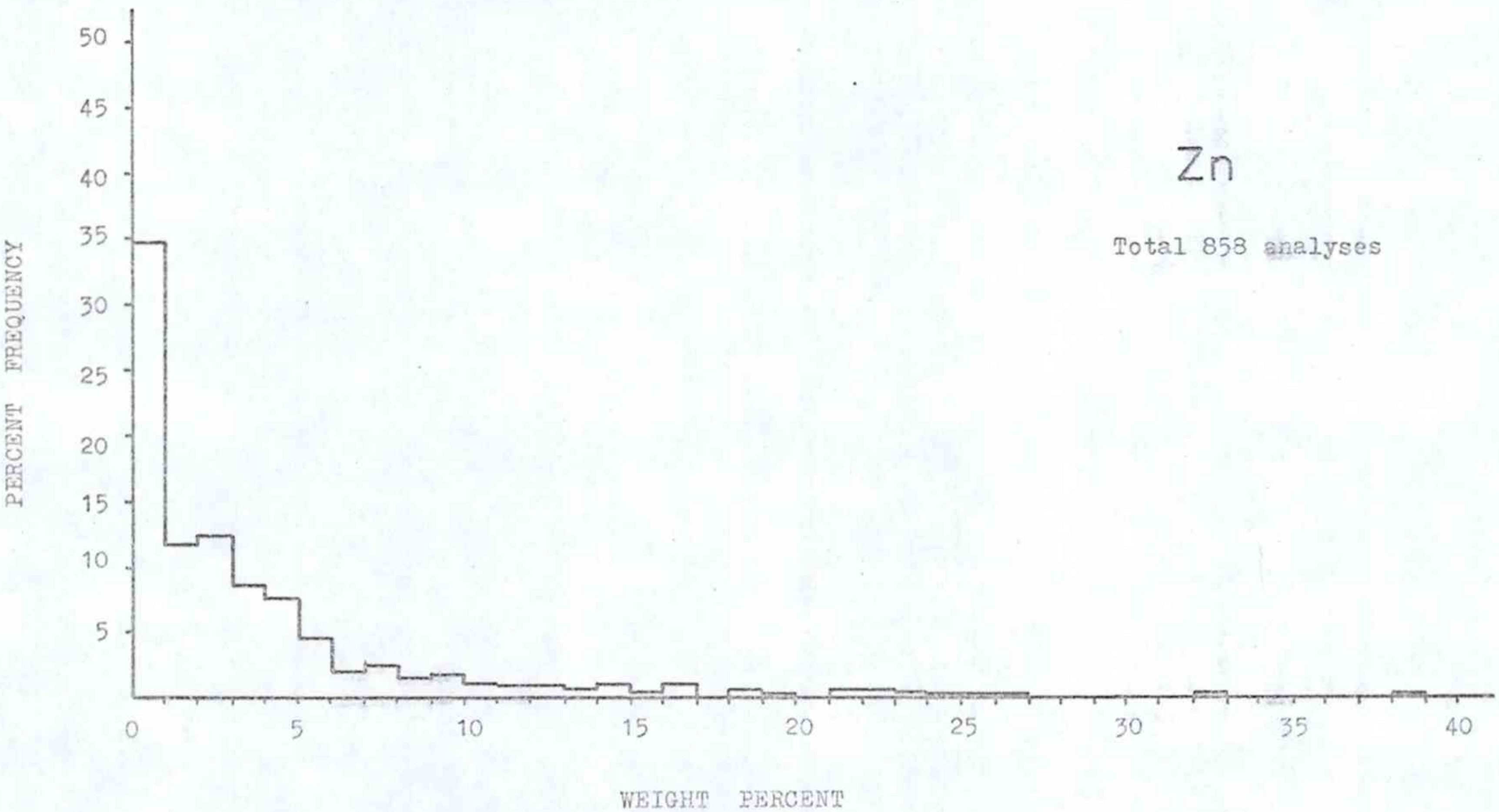


Fig. 15 Histogram showing frequency distribution (weight percent) of Zn in the Skorovas massive-sulphide ores.

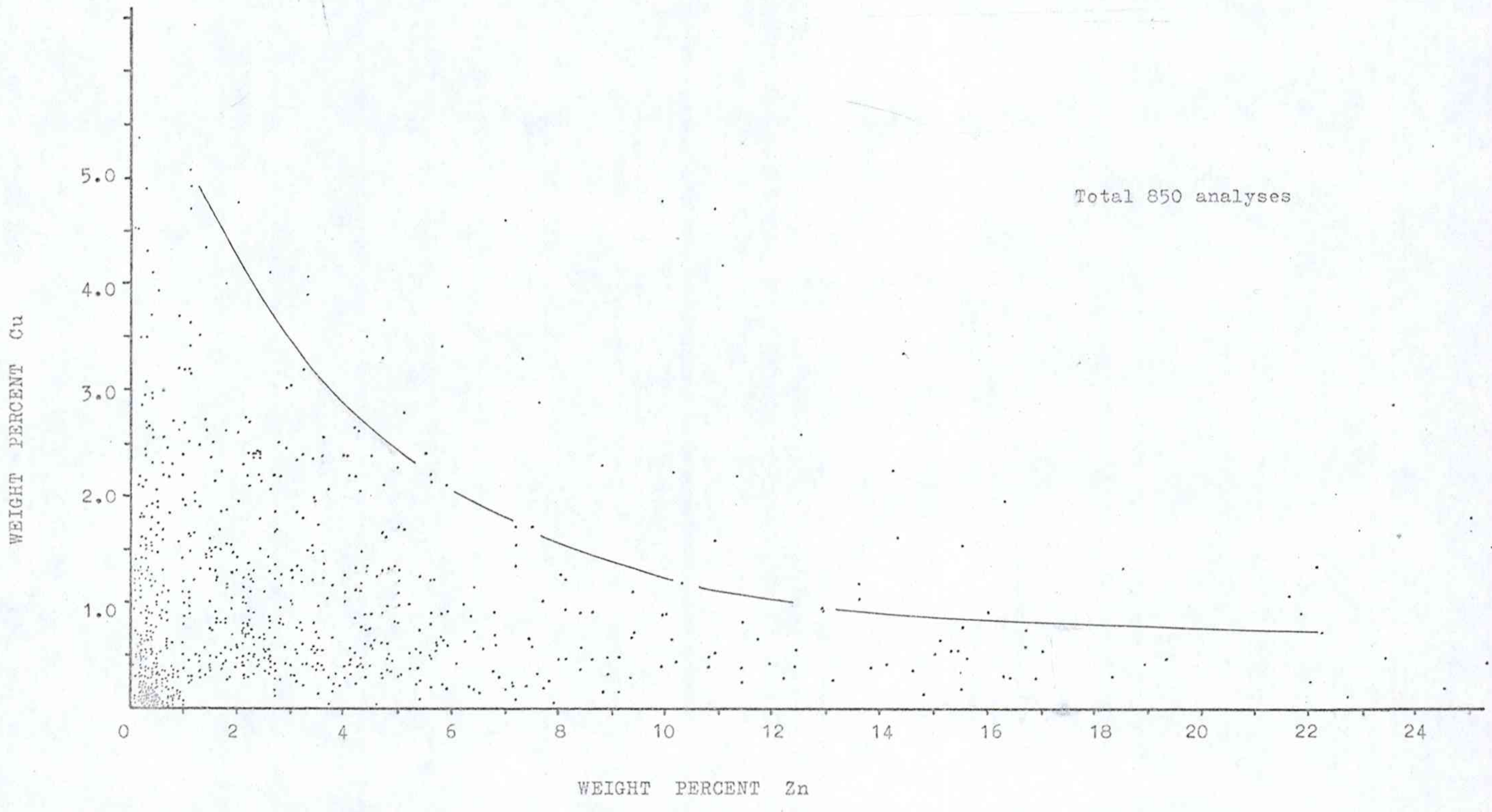


Fig. 16 Scatter diagram (Cu vs Zn) showing the distribution of Cu vs Zn in the Skorovas massive-ores. Note the antipathetic correlation between Cu and Zn.

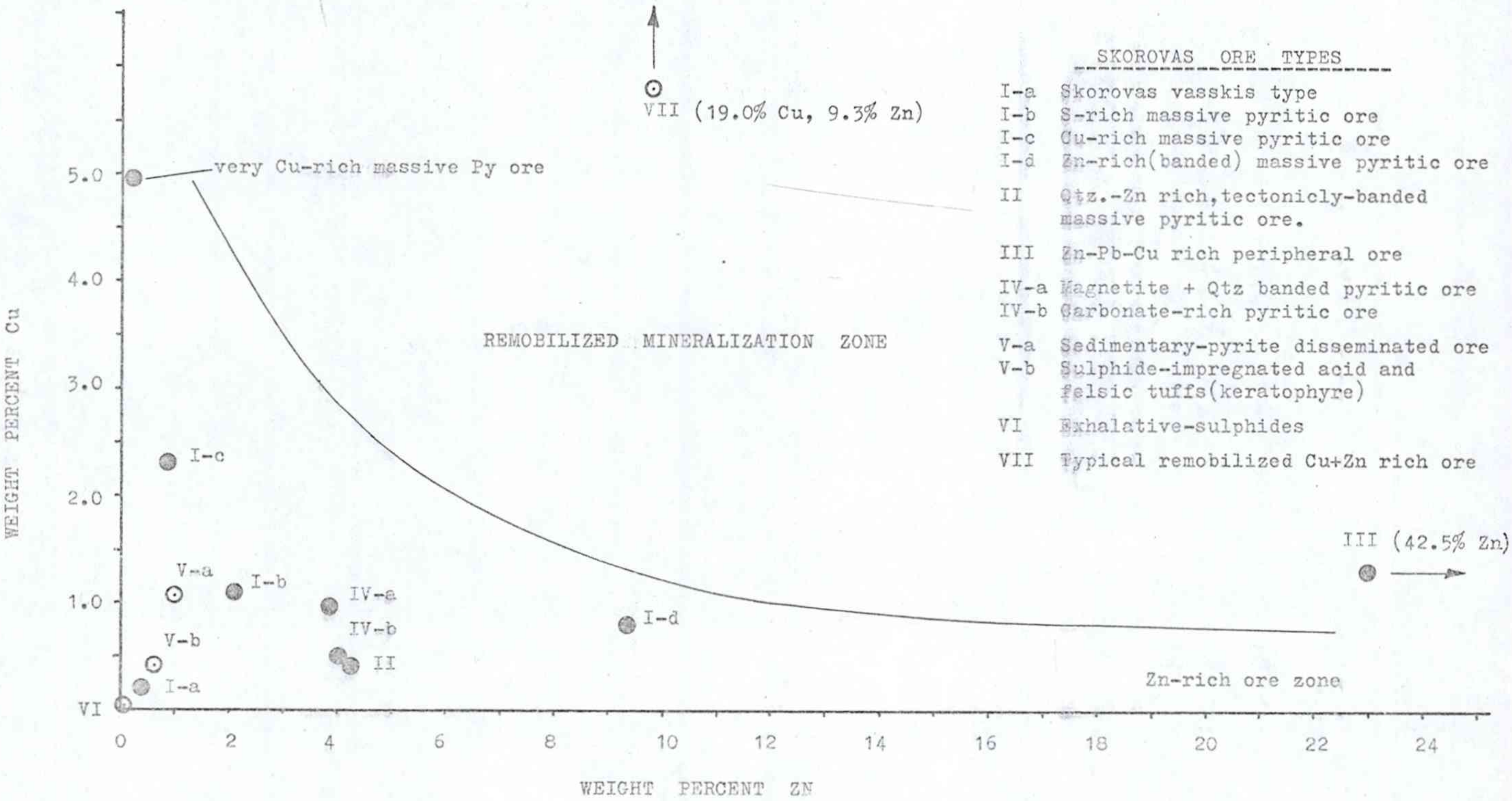


Fig. 17 Scatter diagram (Cu vs Zn) showing the distribution of the various Skorovas ore types, characterized in Table . The dashed division- line separates the zones of primary mineralizaton and remobilized mineralization.

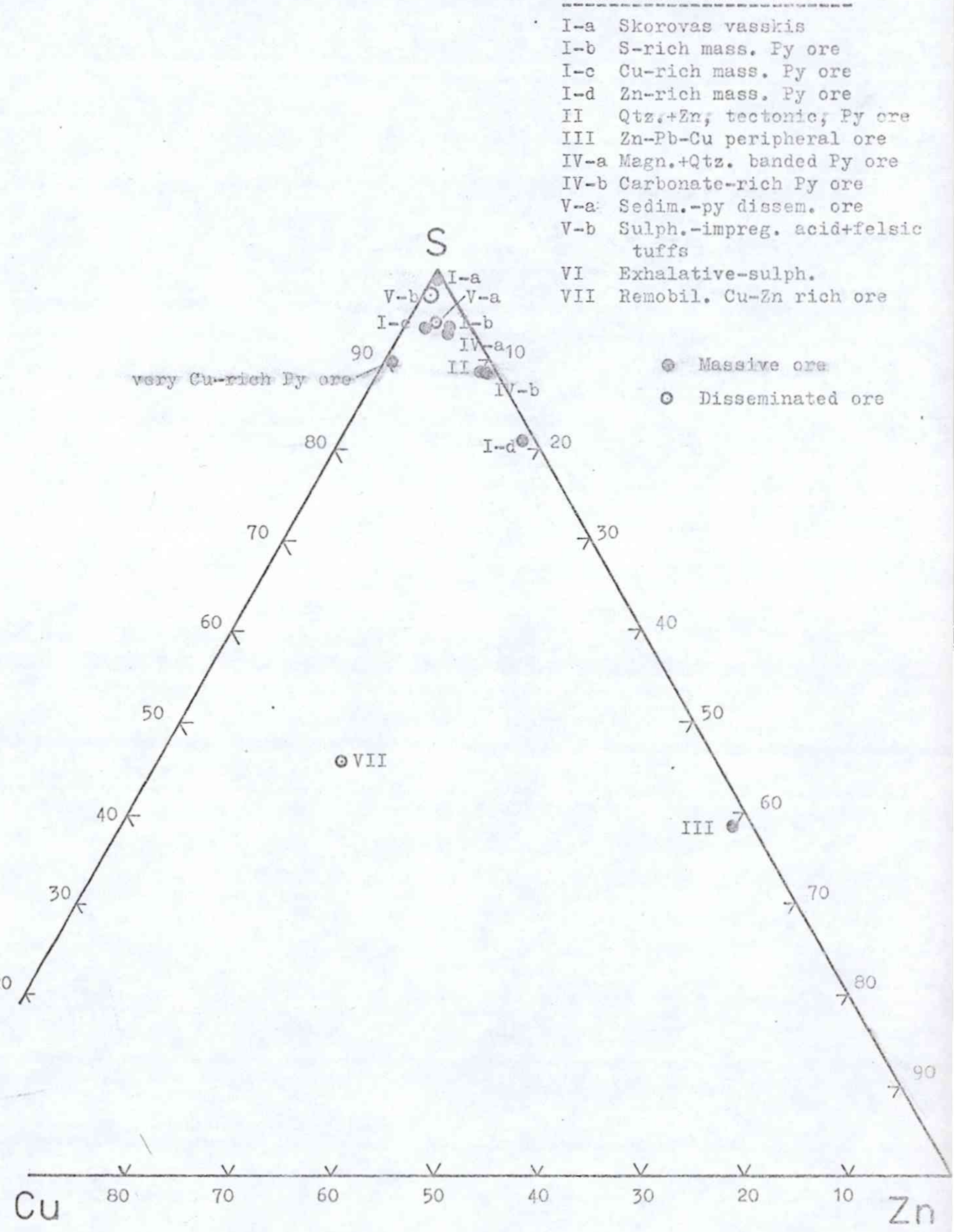


Fig. 18 Triangular plot of weight percent S, Cu and Zn of the Skorovas ore types.

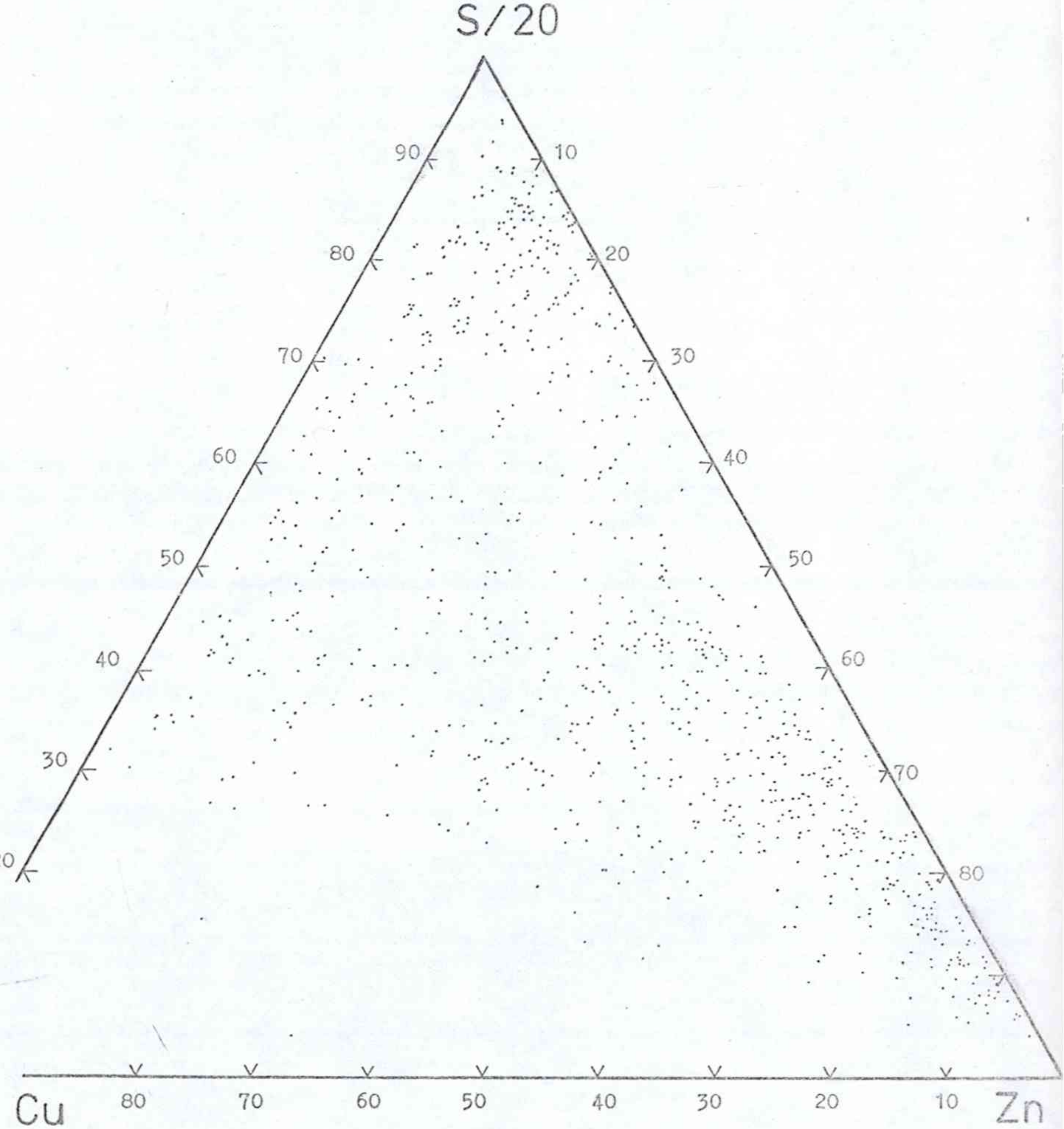


Fig. 19 Triangular plot, scatter diagram of weight percent S/20, Cu and Zn in the Skorovas massive ore. Total 840 analyses.

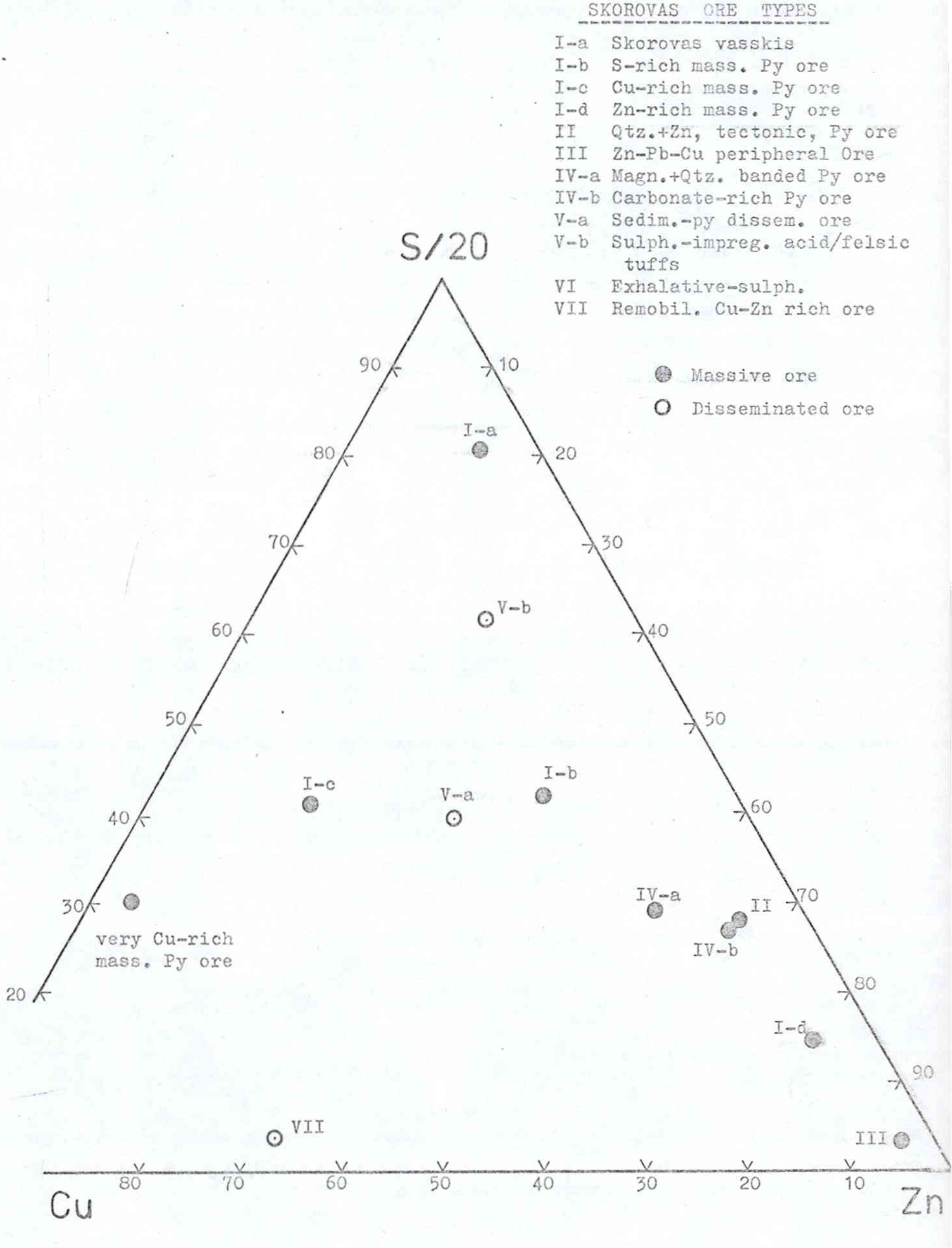


Fig. 20 Triangular plot of weight percent S/20, Cu and Zn of the Skorovas ore types.

FIGURE 21

(FROM: GJELSVIK, 1960)

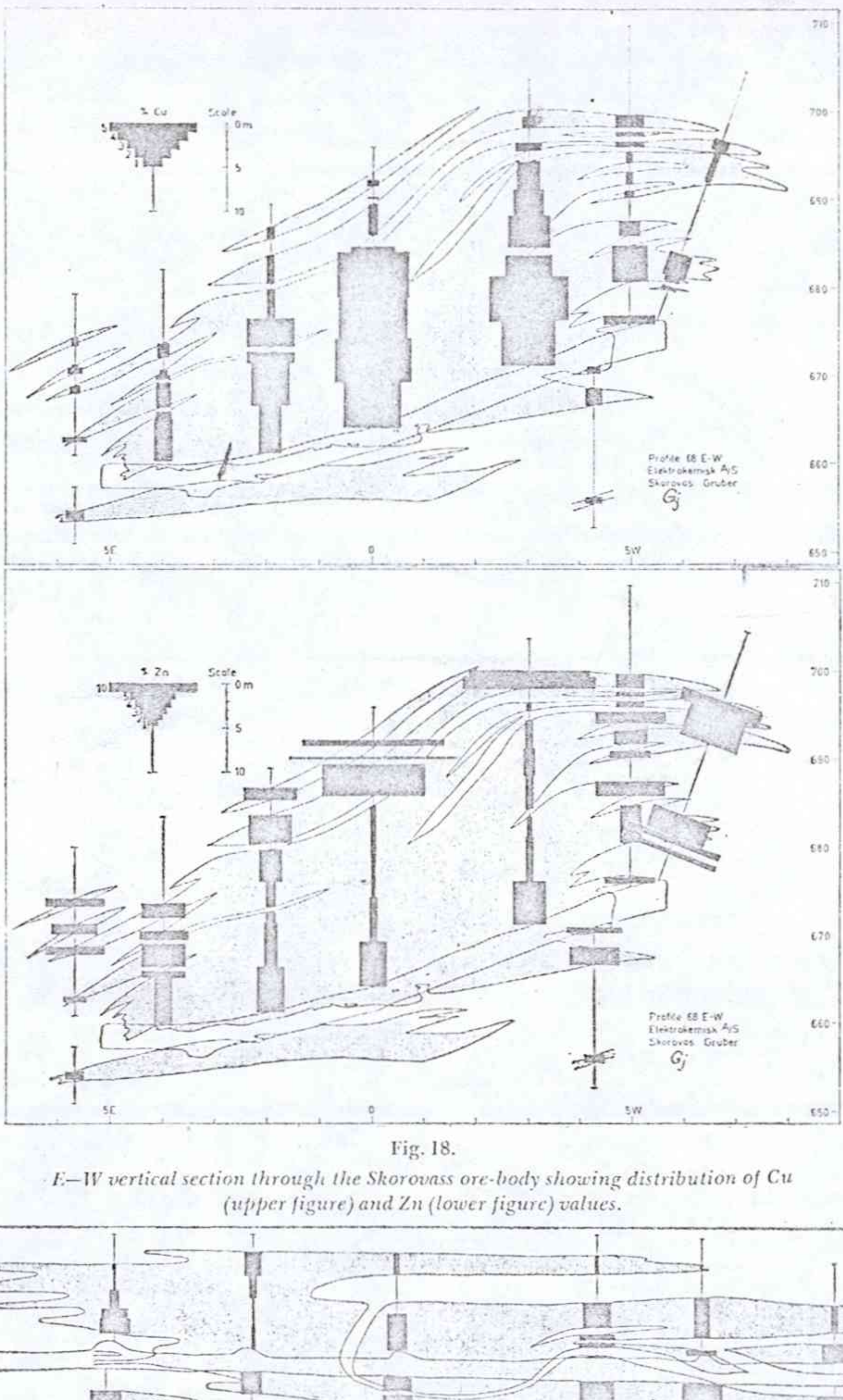


Fig. 18.
E—W vertical section through the Skorovass ore-body showing distribution of Cu (upper figure) and Zn (lower figure) values.

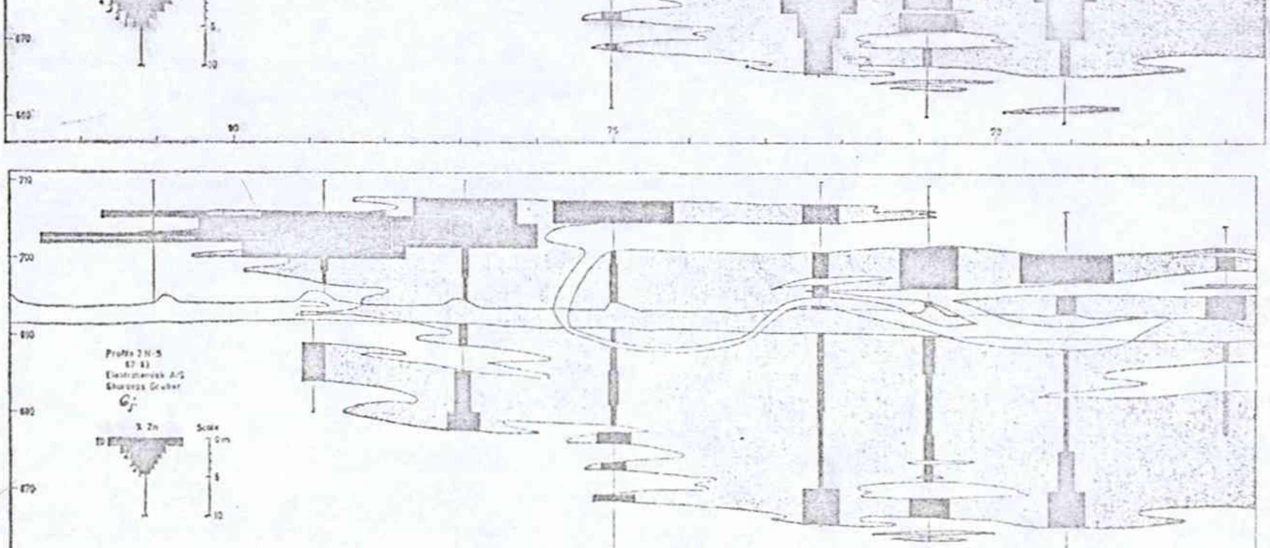


Fig. 19.
N—S vertical section through the Skorovass ore-body showing distribution of Cu (upper figure) and Zn (lower figure) values.

PART III TECTONICS

1. General Summary

Although the problems concerning the deformation of the massive sulphide ore and its enclosing volcanic rocks are still under investigation, enough data has been collected concerning the structural deformation and the tectonic style (geometry) to give the author some authority in presenting here the more general aspects of the structural geology surrounding the Skorovas orebody. A more detailed and complete description of the regional structural and stratigraphic setting and the tectonic style within the Skorovas area of the Gjersvik Nappe, and its relationship to the surrounding Caledonian structural units and their emplacements onto the Fennoscandian craton during the climactic stages of the collision tectonism of the Caledonian orogeny in Silurian times, has already been dealt with by Halls, C. et al (1977-in press) and the reader is refered to this paper. However, a brief summary will be given here concerning the structural elements and tectonic style found within the immediate mine area.

According to Halls, C. et al (1977),"at the present level of erosion, the volcanic sequence in the Skorovas district lies inverted within the lower limb of a major S.E. facing fold, the identity of which can be breadly equated to the Gjersvik Nappe".
The area has undergone two periods of destructive deformation during which the orebody and its enclosing volcanic rocks have obtained their present configurations of complex lensoid en echelon geometry.

2. Deformation: Phases and Style

The first phase of deformation (Phase I) was produced during the period of overthrusting and emplacement of the Gjersvik Nappe onto the Fennoscandian basement, where the supracrustals underwent a period of major destructive penetrative deformation, producing early isoclinal folding accompanied by the creation of a penetrative axial plane schistosity (see Figure 22, pp. 66). During this stage of main thrusting and sliding, horizons separated into massive wedges along planes of high tectonic stress and overrode each other. Such planes generally can be seen along the major intrusive contacts of the trondhjemitic and gabbroic bodies within the Grong district. Such planes of stress existed in several lesser orders within the volcanic sequence - and were formed at lithological boundaries showing marked contrasts in competency and can partly be explained in terms of componental movement along the thinned and extended limbs of isoclinal folds. Such planes can be seen along the contacts of the acid volcanics to the east of Nordre Gruvefjell , towards Nygruva. The least compitant rocks, pillow lavas, breccias and tuffs, suffered a complete penetrative reorganization of their mineralogy, with accompanied flattening and a production of a "lenticulate style".

Because of the gross differences in compitencies between the various rock types, a particular heterogeneous style of deformation characterizes the intermediate levels of the Gjersvik Nappe - the pattern being controlled on the larger scale by the form of the more compitent members, i.e. intrusive massifs of gabbros and trondhjemites, and to a lesser degree the more compitant acid extrusive and intrusive dyke members exert a more local influence. The various volcanic units have therefore behaved differently according to their original forms and relative compitencies.

Minor fold structures of the early generation (Phase I) are not conspicuosly evident within the volcanostratigraphy and are best observed in the finely stratified tuff bands and associated more compitant cherts and Iron-rich chlorite schists of the exhalite facies. Phase I minor isoclines are also preserved at the contacts of the massive ore to the surrounding schistose envelope and within the well-banded zinc rich facies of the massive ore itself, ie primary banded chlorite, carbonate, magnetite and sphalerite bands within the massive pyritic ore.

Phase I.

The early isoclinal structures (phase I) display gentle axial alignment in the S to SSW direction which roughly parallels the elongation of the massive ore zone, and have axial phanes (S_1) dipping at approximately 25° towards the SE. Tectonic banding within the ores parallels the S_1 penetrative schistosity in the enclosing schist envelope and represents an axial plane layering accompanying the Phase I isoclines. (Figures 23-27, pp. 67-71). This Phase I axial alignment is reflected in the axial elongation of the orebody (see profile O N-S). Individual lenses are apparently the products of partial disjunction of fold limbs within the fold system (Figure 25, pp. 69). The lateral extremities of the ore lens system characteristically show multiple digitation and bifercation (Figures 23 and 24, pp.67-68).

Discordance is locally observed between the contacts of some massive ore lenses and massive volcanic units, and the schistosity of the wall-rock or enclosing volcanic units. It is possible to explain the local discordancies between early schistosity and the contacts of the massive units, in terms of the contrasts in the mechanical behavior of the pyritic lenses and the schistose volcanic rocks during the flattening and isoclinal folding of the first stage of deformation. The early deformation in the immediate contact zone of the orebody was sufficient, due to the contrast in compitencies, to create a schistose tectonic facies composed predominantly of chlorite, carbonate and locally talc. These components were derived by segregation from the altered host rocks; andesites, basaltic-andesites and dacites. Such sheared host rocks can be seen above the massive ore in the Nygruva south area where thick sequences of calcite-rich, pitted weathered, chlorite schists occur. The massive acid volcanic units, on the other hand, contain very thin (10-50 cm) schistose envelopes in contact with the massive ore lenses.

The creation of this schistose envelope facilitated the continuence of componental movement within the vicinity of the ore contacts during later deformation.

Phase II.

The second stage of deformation (Phase II), superimposed on the grain of the early isoclines and S_1 schistosity, has created an open system of broad folds which have resulted in an irregular pattern of dome and basin structures (Halls, C. et al, 1977). The formation of these open dome and basin structures has been accompanied by further movements along the low angle planes generated during Phase I, and these movements have led to the creation of minor fold crenulation and a second stage crenulation cleavage. (Phase II axial plane cleavage).
The Phase II crenulation folds show a consistant southwest trend plunging approx. 12-15^{o} in a 164^{o} SW direction and with axial planes dipping moderately to the NW. (See Figures 24-27, pp. 67-71). This period of post schistosity deformation has produced folds of varying magnitude from tiny crenulations (also microscopic) and dragfolds to rather large open undulating folds as shown at the foot wall ore contact in Figure 25 (pp. 69). In immediate ore contact zones, small folds up to meters in wavelength occur sporadically in response to local variations in the ore geometry.

Zones of intense Phase II crenulation folding cut across the main ore zone at regular intervals with approximately 200 meters wavelength and large amplitudes, producing areas of extremely irregular ore lens geometry and irregularities in the early Phase I isocline trends - typical for areas of polyphase deformation. Areas of ore contact and S_2 cleavage discordance occurs in hinge zones of these large amptitude Phase II open folds, and the accompanying S_2 cleavage has often been mistaken for earlt S_1 schistosity.

The orebody as a whole was folded on a broad open style, typical of late deformation in the Skorovas area.

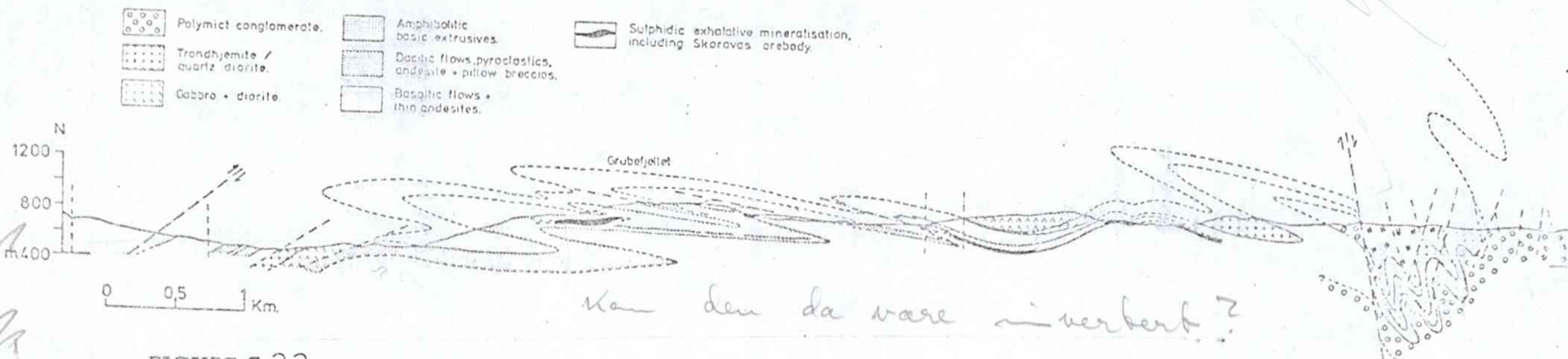
The final episode of deformation is marked by a complex system of high angle faults and fractures, dominated by NNE to NE trending, steeply eastward dipping fractures and minor NW to E-W vertical conjugate fractures (see 1:2000 geological map and Figure 23, pp. 67). Low vertical displacements have been recorded (max. 2-3 meters). These fractures postdate the main periods of folding in the area and produce many problems within the mine concerning the stability of the pillars in certain areas. Faults of this style also cut through the massive ores and numerous interesting "glidespeil" polished pyrite mirror surfaces have been found along such faults . Calcite and quartz filled druzy cavities also occur along some of the NW trending fractures.

3. Tectonic Effects on the Ores

Where tectonism has had a pervasive effect on the ore, the textures are distinctly of tectonic style as shown in plates nr. 45, 47 and 48 (pp. 119). Plate nr. 55 shows the deformation of the compact, fine grained pyritic ore, which is marked by the mutual impaction and cataclastic nature of the constituent grains. According to Halls, C. et al (1977) any gross tectonic flattening or extension of the lenses must have been accomplished by relative movements between the individual grains accompanied by cataclastic degradation. This mechanism has been described as macroscopic ductility by Atkinson (1975), who has also shown that cataclasis is probably the only significant deformation mechanism available to pyrite under dry conditions in the P-T range appropriate to the Greenschist Facies.

Textural evidence strongly suggests that, within the massive pyrite ores, cataclasis was the dominant deformation mechanism. Atkinson (1975) also noted that the strength of polycrystalline pyrite is strongly and inversely dependent on porosity. Large volumes of the Skorovas orebody are composed of nearly monomineralic close-packed aggregates of pyrite with low porosity and, when lithified, these masses must have behaved in a highly competent manner relative to the adjacent chloritized lavas and pyroclastics. Under the influence of the tectonic stresses prevailing during the Phase I 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 accomodated. 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 within the compact pyritic ores.

The zinc rich and banded ores, on the other hand, appear to have behaved differently under the Phase I penetrative deformation and most of the sphalerite rich ores in Skorovas display a well developed planar fabric comparable to the enclosing chlorite schists, and appear therefore to have accommodated deformational strains by a shearing phenomenon.
Phase II crenulation clearage planes are also developed in the zinc rich ore bands in much the same manner as in the enclosing chlorite schists, and Plate nr. 57 (pp. 125) shows such clearage planes cutting the dominating S_1 schistosity, here filled with remobilized chalcopyrite and galena. Increase in porphyroblastic pyrite grain size and outsweating and remobilization of white quartz, chalcopyrite, sphalerite and minor fahlerts, are typical for pressure shadow areas produced during the refolding of earlier structures.



Kan den da være invertert?

FIGURE 22

Simplified geological section through the Skorovas area. (from: Halls C, et al, 1977)

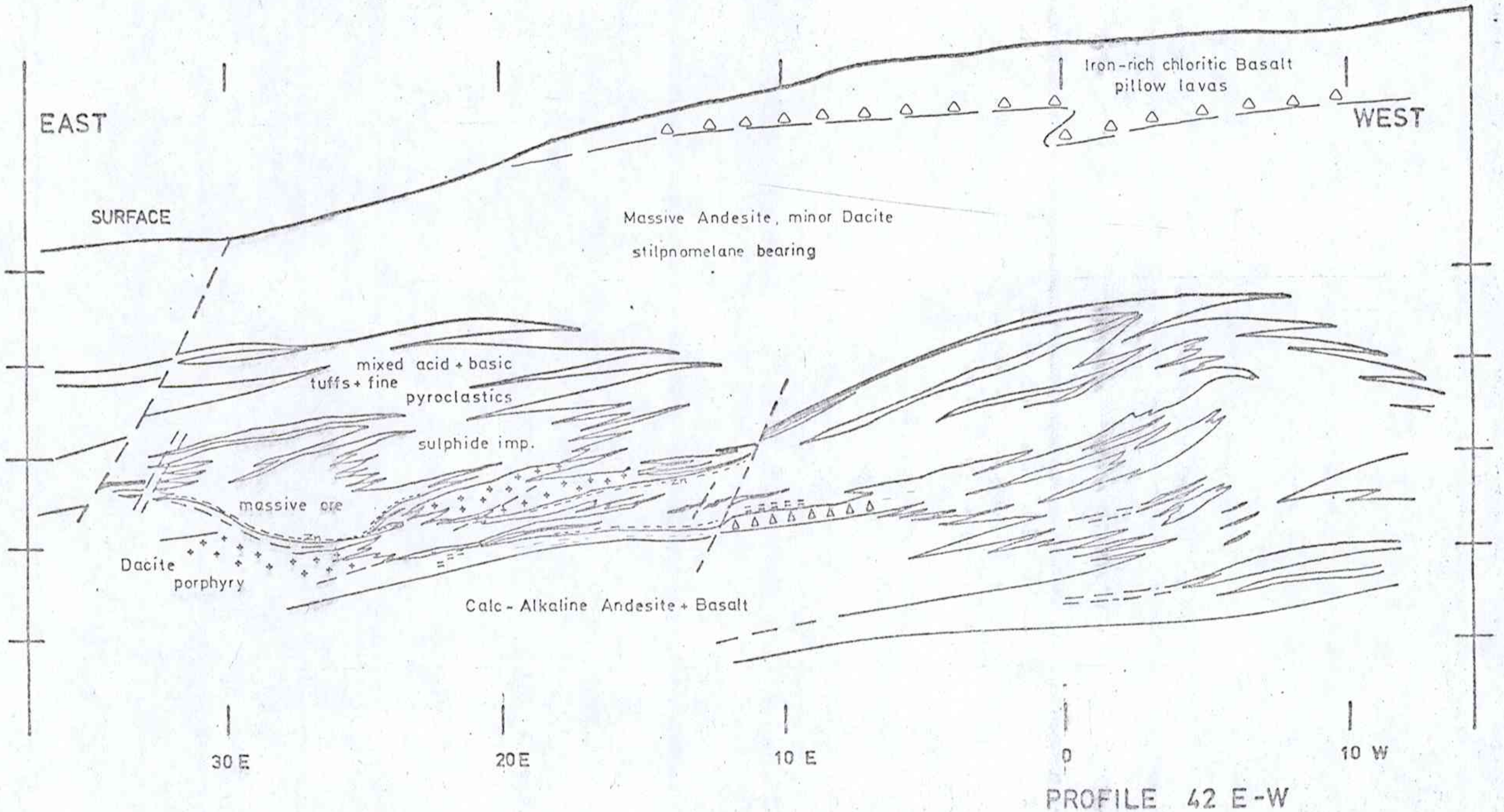


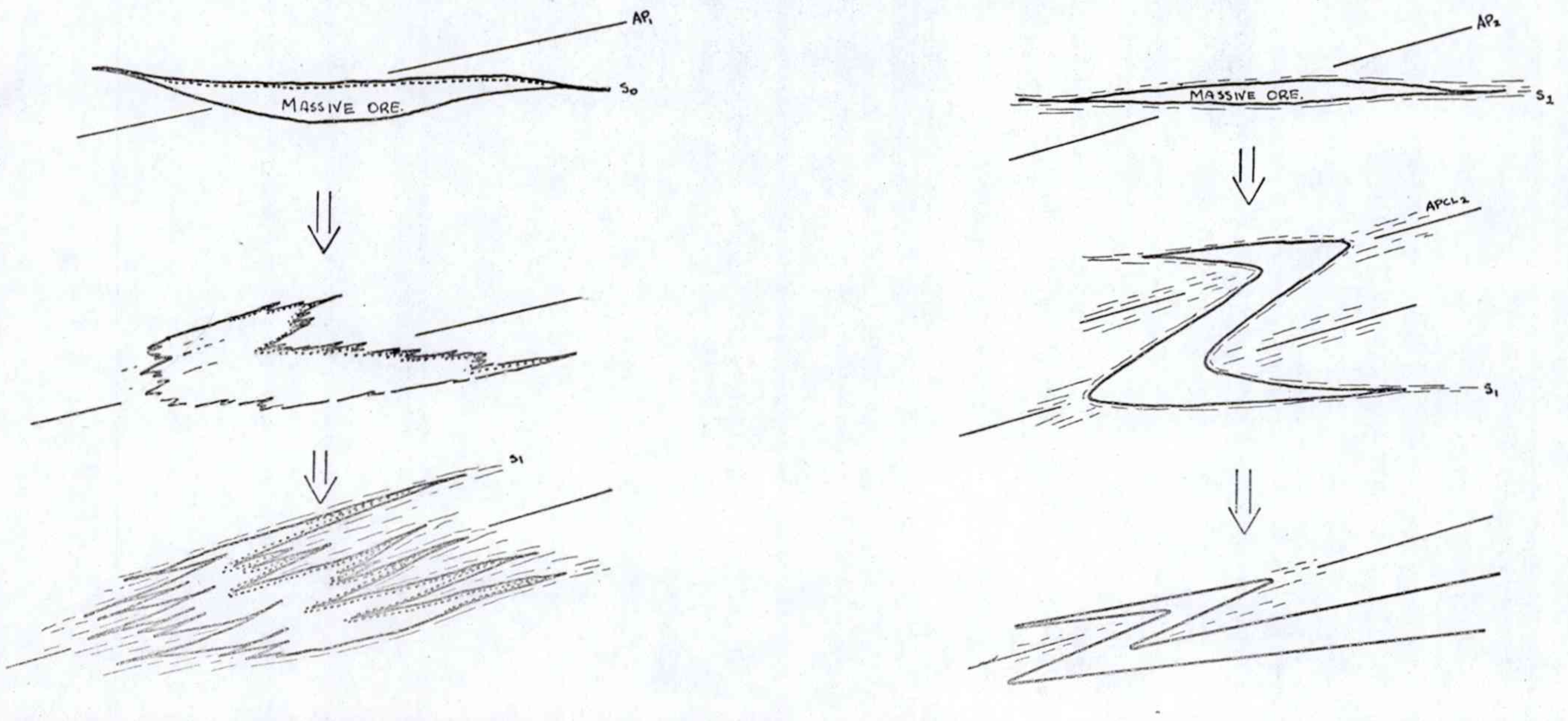
FIGURE. 23 Simplified diagram profile 42 E-W at Skorovas showing the relationship between the East and Main ore-bodies.

FIG. 24

SCHEMATIC DIAGRAM SHOWING THE DEVELOPEMENT OF THE TWO MAJOR DEFORMATIONAL PHASES AND THEIR TECTONIC STYLES AS FOUND AT SKOROVAS.

PHASE I - ISOCLINAL SHEAR TYPE FOLDS.

PHASE II - CRENULATION TYPE FOLDS.



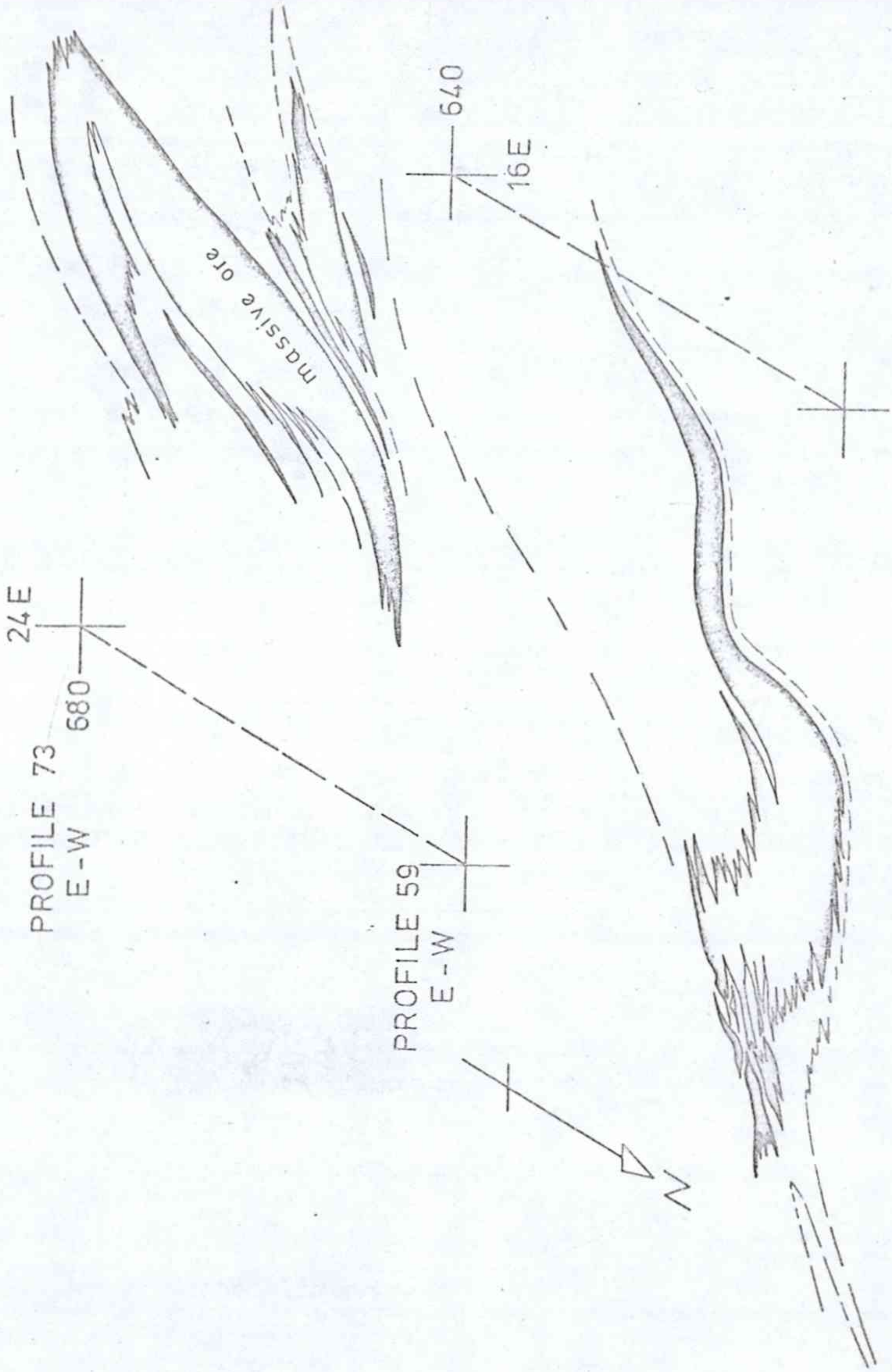


FIGURE 25 TWO SECTIONS OF THE E. OREBODY AT PROFILES 59 AND 73 E-W SITUATED 140 M. APART ALONG THE MORPHOLOGICAL AXIS OF THE OREBODY. THE PROGRESSIVE DEVELOPMENT OF A FIRST PHASE ISOCLINAL FOLD IS ILLUSTRATED TOGETHER WITH THE COMPLEX DIGITATED STYLE OF THE ISOCLINAL CLOSURES. THE OPEN STYLE OF THE SECOND FOLD PHASE IS SHOWN BY THE UNDULATION OF THE LOWER CONTACT OF THE ORE ON PROFILE 59 E-W.

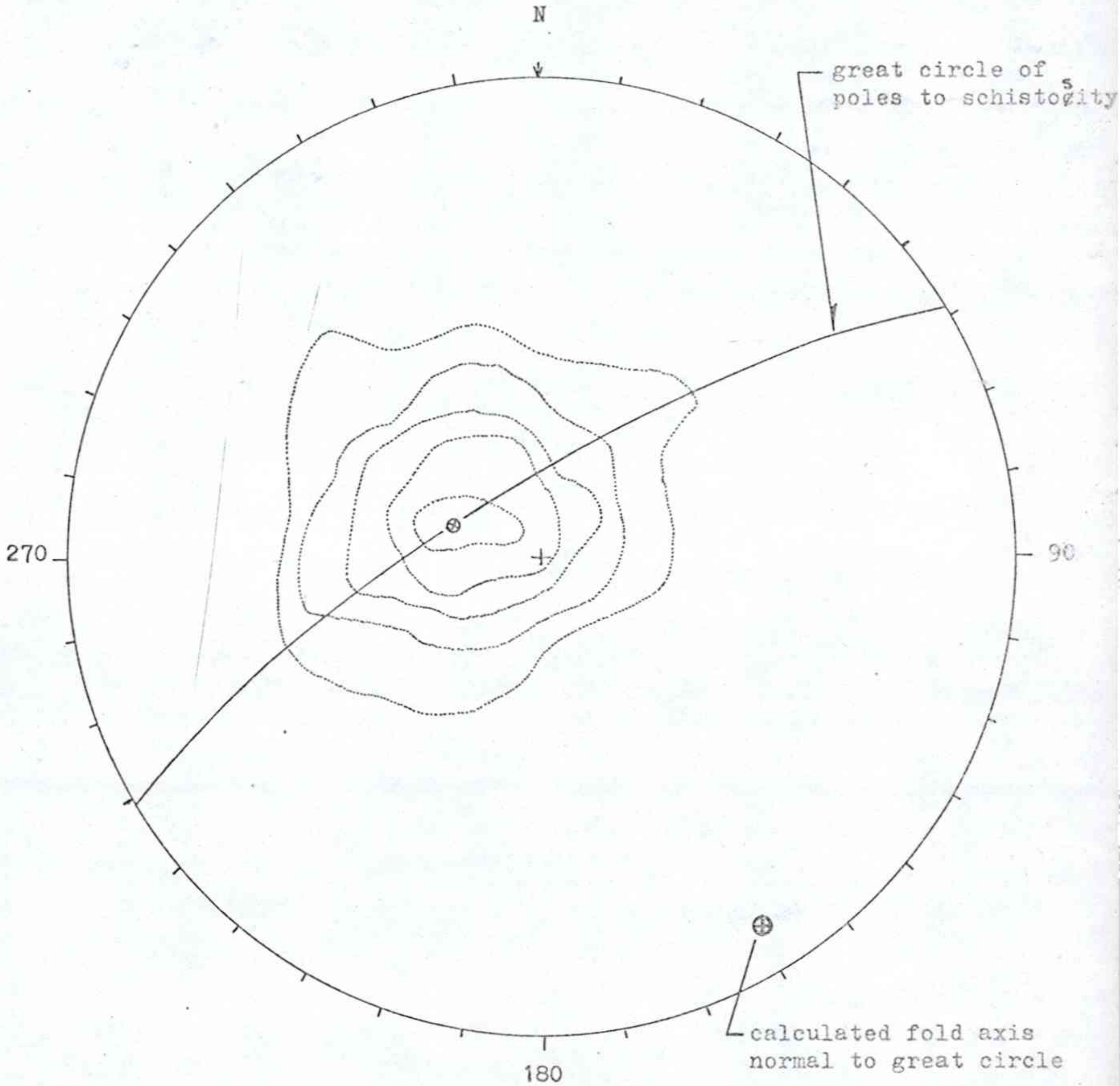
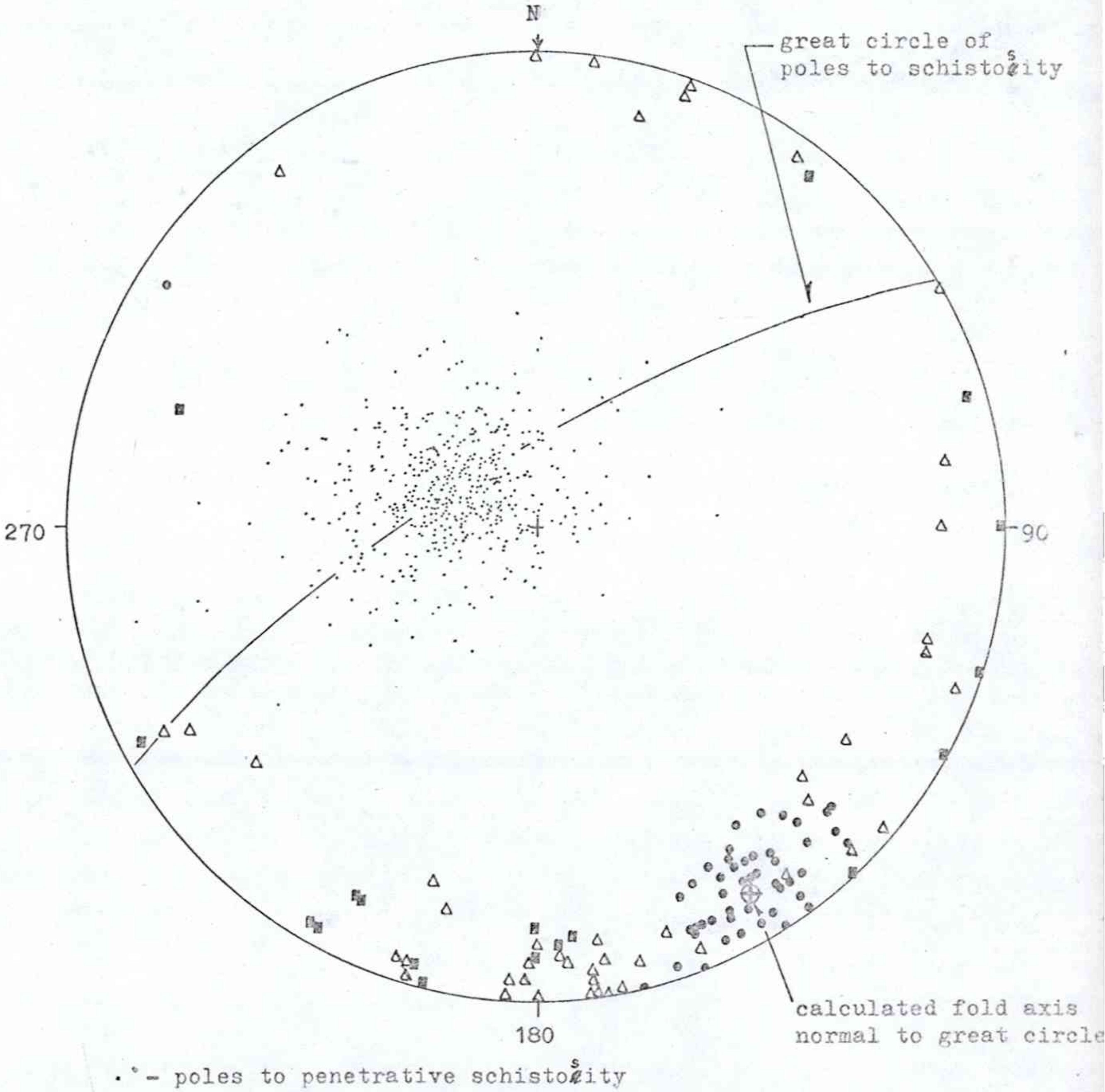


Fig. 26 Contoured equal-area projection of 450 poles to penetrative schistosity from the Skorovas area. Contours at .5%, 2%, 5%, 10%, 20%. Average schistosity plane at 022/29°(020/26°). Calculated fold axis 164/12°(148/11°) Used Schmidt equal-area net (southern hemisphere).



. ° – poles to penetrative schistosity
Δ – projection of phaseI fold axes and liniations
• – projection of Phase II fold axes and liniations
▪ – projection of Phase III fold axes and liniations

Fig. 27 Equal-area projections of structural elements from the Skorovas mine area. Total of 450 poles to schistosity. Average and calculated Phase II fold axis 164/12° (148/11°).

F. PART IV CONCLUDING REMARKS

1. Difficulties Encountered under Geological Mapping

While engaged in detailed geological mapping, both within the mine and on the surface, and during the drill-core logging, certain difficulties were encountered which are worth mentioning as they may be of benefit to future geological investigations:

a) Mapping of fresh surfaces withing the mine and drill-core descriptions produced problems when trying to compare these units to their more weathered surface equivalents. As a general rule, the chloritized schistose basic members on surface exposures are much lighter-green to greyish in color (the feldspar and mafic minerals being well contrasted by weathering), as compared to the very dark green of the fresh surfaces within the mine. The acid volcanic members have weathered light-grey to whitish, reflecting the high plagioclase contents. The stilpnomelane bearing members have weathered to a characteristic medium to light brown, and the magnetite bearing members are very distinct in their dark greyish to bluish-grey weathering phenomena.

b) The extreme fine-grained to aphanitic nature of much of the volcanics surrounding Skorovas has caused numerous difficulties in distinguishing the fine grained members (contact units) from each other - especially within the Intermediate Volcanic Complex. However, epidote knots and fragments, and quartz, calcite and stilpnomelane filled amygdules have helped to separate these units. It is almost impossible to distinguish between the quartz and albitic plagioclase constituents of the acid volcanic members.

c) The dominant chloritic content of the intermediate and basic lavas has produced inumerable problems as the individual lava flow units show varying grades of chlorite content depending on the shearing deformation and the accompanying breakdown of the various primary basic volcanic minerals. In all the volcanic units the primary mineralogy has been partially or completely replaced or pseudomorphed by assemblages composed of chlorite, albite, epidote, actinolite, calcite and minor sphene and pyrite, and within intensely sheared massive basic flows, the complete breakdown of both the mafic and plagioclase minerals has produced a chlorite and calcite bearing schist that has often been mistaken for well-banded tuffs.

d) The pervasive penetrative schistosity that dominates the structure throughout the area has often produced prominant benches within the massive lavas, which has previously been mistaken as individual lava flow units. The original compositional banding in most places has been completely masked through shearing and the development of the penetrative schistosity structure.

2. Suggestions for Future Investigations.

As a conclusion to this report the author would like to make a list of the various projects and areas that should be investigated in the future. The author believes that the detailed disection of such a complex orebody as Skorovas, through detailed geological mapping, chemical analyses, and structural investigations, will give invaluable information towards the understanding of the stratigraphic position of the orebody within the lava pile in the Skorovas area, and will undoubtedly help in future exploration within the immediate mine vicinity and also in the understanding of similar massive sulphide deposits within the Scandinavian Caledonian Lower Ordovician greenstone belts.

a) A detailed investigation of the presently developed SW corner of the Main orebody, Profile 77 E-W and south area, by geological mapping and structural analyses to explain the complex nature of the numerous ore lenses found in this area. Previous work has shown these lenses to be very irregular and structurally controlled. This area also presents an opportunity to study in detail the extremely well-banded ore and its relationship to the stratigraphically uppermost lavas, an opportunity which will certainly be absent once the ore has been removed.

b) Much general geological mapping inside the mine is still needed to fill in the E-W and N-S profiles throughout the length of the orebody to study the relationships of the various ore lenses to the volcanic host rock units.

c) Investigate the older drill holes for possible Zn contents in areas not previously analysed for zinc ie, the carbonate, chlorite and sulphide impregnated ore zone that forms the footwall to the Main orebody in the Profile 40-42 area.
Thin zinc bands have been found here.

d) Investigate the possibility of using the ore type divisions proposed here as stratigraphic units, mappable throughout the whole length of the orebody. If so, these easily recognizable ore types could be useful in predicting the expected base metal contents, and through further investigations could also indicate what milling and flotation problems that could be expected. A detailed investigation of the various ore types, their thicknesses and positions in the magazines and pillars that are to be blasted out, could well be used as a warning system to indicate what ores could be expected in the concentration plant, by periodically checking the shoots and ore cars transported to the main crusher. These investigations of the base metal contents and the milling and flotation properties of the various ore types could be of tremendous help in the future mine planning and transportation and control of the various ores driven to the mill.

e) Further work is needed to investigate the use of the various volcanic units as stratigraphic and marker horizons throughout the Skorovas area. The magnetite - rich lavas - pillow lavas and pillow breccias, and the stilpnomelane rich lavas appear to form such a horizon. Magnetite bearing cherty horizons are found at the contact of this horizon and is therefore easily recognizable throughout the area.

f) Accompanied with the continued detailed geological mapping to the south area, where present exploration drilling is being carried out, a detailed structural analyses should be carried out to help unravel the structurally complex polyphase folding that the area has undergone, and to help build up a paleogeographical model of the orebodies original form and extension. The almost total rock exposures in the Skorovas area presents a golden opportunity for unprecedented detailed investigations that are strongly needed to unravel the complexities of a deposit such as Skorovas. Such a detailed investigation will undoubtedly have significant influence on the future exploration philosophies within the Grong District.

g) Total silicate analyses plus trace element investigations, accompanied by microscopic investigations should be continued to help distinguish the more questionable volcanic units - this will help to unravel the volcanic stratigraphy within the Skorovas area.

h) Geological mapping should be continued to the NE of Reservedammen, across the Trondhjemite intrusive arc, to help tie up the acid volcanic sequence across this disrupted zone. Many interesting features point in this direction, towards the Staldvik's myra area.

i) A compilation should be made at 1:10,000 scale, of all previous geological mapping in the Skorovas area including the 1:2,000 detail map accompanying this report and the more regional mapping completed by the Imperial College group under the leadership of Dr. C. Halls. The volcanic units, color codes, and the volcanic structure symbols used in the area should be standardized.

j) Indirectly related to the Skorovas area: Other mineralized areas to the north, of which the author has had previous aquaintence, should be reinvestigated in light of the volcanic stratigraphy that has been formulated from the Skorovas work.

k) Also of interest in this context, is the morphological form, mineralogy, and chemical investigation of all the acid volcanic sequences and related mineralization from the Grong Field district in an attempt to catagorize and classify the various mineralized horizons and to investigate the possibility of the occurance of several periods of acid volcanism and related mineralization. This would hopefully be a helpful tool in predicting future targets for more intense exploration.

G. REFERENCES

Atkinson, B.K. (1975) Experimental deformation of polycrystalline pyrite: Effects of temperature, confining pressure, Strain rate and porosity (Econ.Geol. V70, 1975, pp. 473-487).

Bloknina, L.I. et al (1959) Principles of classification and nomenclature of the ancient volcanic clastic rocks. (Inter. Geology Review, vol. 1 nr. 22 Dec. 1959, pp. 56-61).

Carlisle, D. (1963) Pillow Breccias and their Aquagene Tuffs, Quadra Island, British Columbia. (The Journal of Geology, vol. 71 nr. 7, pp. 48-71.)

Gale, G. and Roberts, D. (1974) Trace element geochemistry of Norwegian Lower Paleozoic Basic volcanics and its Tectonic Implications. (Earth and Planetary Sci. Letters, vol. 22, pp. 380-390.)

Gale, G. (197) Ocean Floor Type Basalts from the Grimeli Formation, Stavenes Group, Sunnfjord. (NGU series - in print.)

Gjelsvik, T. (1960) The SKOROVAS Pyrite Deposit, Grong Area, Norway. (XXI International Congress.)

Gjelsvik, T. (1968) Distribution of Major Elements in the Wall Rocks and the Silicate Fraction of the SKOROVAS Pyrite Deposit, Grong Area, Norway. (Econ. Geol. vol. 63, pp. 217-231.)

Gustavson, M. (1969) The Caledonian Mountain Chain of the Southern Troms and Ofoten Areas: Part II Caledonian Rocks of Igneous Origin. (NGU series nr. 261.)

Halls, C. and Reinsbakken, A. et al (1977) Geological Setting of the SKOROVAS Orebody within the Allochtonous Volcanic Stratigraphy of the Gjersvik Nappe, Central Norway.
(Inst. of Mining and Metal - in Print.)

Hatch, F.W., Wells, A.K. and Wells, M.K. (1961) Petrology of the Igneous Rocks.
(Book 12th Edit., pub. T. Murby and Co.)

Irving, I.N. and Baragar, W.R.A. (1971) "A Guide to the Chemical Classification of the Common Volcanic Rocks." (Can. Jour. of Earth Sci, vol. 8, pp. 523-548.)

Juve, Gunnar (1974) Ore Mineralogy and Ore Types of the Stekenjokk Deposit, Central Scandinavian Caledonides, Sweden.
(S.G.U. ser C nr. 706. Årsbok 68 nr. 13.)

Lambert, I.B. and Sato, T. (1974) The Kuroko and associated Ore Deposits of Japan. A review of their features and metallogenesis.
(Econ. Geol. vol. 69, 1974, pp. 1215-1236.)

Malvik, T. (1974) Kvantitative Malmmikroskopiske Metoder, anvendelse i vurdering av malmer og oppredningsprodukter. (Bergverkenes Landssammenslutnings Industrigruppe Teknisk Rapport nr. 28/1.)

Miyashiro, A. (1973) "The Troodos Ophiolitic Complex was probably formed in an Island Arc."
Earth and Planetary Sci. Letters vol. 19, pp. 218-224.

Miyashiro, A. (1974) "Volcanic Rock Series in Island Arcs and Active Continental Margins." (Am. Jour. of Sci. vol. 274, pp. 321-355.)

Oftedahl, Chr. (1958) Oversikt over Grongfeltets skjerp og malmforekomster. (Norges Geol. Undersøkelse nr. 202.)

Oftedahl, Chr. (1974) Norges Geologi, en oversikt over Norges regional Geologi. (Tapir - Trondheim.)

Padfield, T. and Gray, A. (1971) Major Element Rock Analyses by X-Ray Fluorescence - A Simple Fusion Method. (Philips Bulletin - by Analytical Equipment Dept., N.V. Philips, Glocelampen fabrieken, Eindhoven. The Netherlands - Aug. 1971.)

Pearce, J.A. and Cann, J.R. (1971) Ophiolite Origin Investigated by Discriminant Analyses using Ti, Zr and Y. (Earth and Planetary Sci. Letters, vol. 12, pp. 339-349.)

Pearce, J.A. and Cann, J.R. (1973) Tectonic Setting of Basic Volcanic Rocks determined using Trace element Analyses. (Earth and Planet. Sci. Letters, vol. 19, pp. 290-300.)

Powers, M.C. (1960) Topaz, LiF, NaCI, EDDT and ADP crystals. (Publ. Philips Electronic Instruments - Mount Vernon NY - 1960.)

Prestvik, T. (1974) Supracrustal Rocks of Leka, Nord-Trøndelag. (NGU nr. 311, pp. 65-87.)

Rittman, Volcanoes and their Activity.

Roberts, D., Springer, T. and Wolff, Fr.Chr. (1970) Evolution of the Caledonides in the northern Trondheim Region, Central Norway: A Review: (Geol. Mag. vol. 51, pp. 133-145.)

Rui, I.J. (1972) Geology of the Røros District, south-eastern Trondheim region with a special study of the Kjøliskarvene - Holtsjøen Area. (N.G.T. vol. 52, nr. 1, 1972.)

Rui, I.J. (1973) STRUCTURAL Control and Wall Rock Alteration at Killingdal Mine, Central Norwegian Caledonides. (Econ. Geology, vol. 68, 1973, pp. 859-883.)

Rui, I.J. and Bakke, I. (1975) Stratabound Sulphide Mineralization in the Kjøli Area, Røros District, Norwegian Caledonides. (N.G.T. vol. 55 nr. 1.)

Taylor, S. (1969) Trace Element Chemistry of Andesites and Associated Calc-Alkaline Volcanic Rocks. (Proceedings of the Andesite Conferance of the International Upper Mantle Project, vol. 16, pp. 43-63.)

Torske, T. (1965) Geology of the Mostadmarka and Selbustrand Area, Trøndelag. (NGU nr. 232, p. 83.)

Torske, T. 1972) Interconnected Pillow Structures in Greenstones in the Os Area, Western Norway, with remarks on Pillow Terminology. (NGU nr. 273, Bull. 2, pp. 37-42.)

Travis, R.B. (1955) Classification of Rocks. (Quarterly of the Colorado School of Mines, vol. 50 nr. 1.)

Vokes, F.M. (1963) Geological Studies on the Caledonian Pyritic - Zinc - Lead Orebody at Bleikvassli, Nordland, Norway. (NGU nr. 222.)

Vokes, F.M. (1966) On the Possible Modes of Origin of the Caledonian Sulphide Ore Deposit at Bleikvassli, Nordland, Norway. (Econ. Geol. vol. 61, pp. 1130-1139.)

Vokes, F.M. (1968) Regional Metamorphism of the Paleozoic geosynclinal Sulphide Ore Deposits of Norway. (Inst. of Mining and Met. trans sect. B vol. 77, pp. 1353-1359.)

Vokes, F.M. (1969) A Review of the Metamorphism of Sulphide Deposits. (Earth Sci. Reviews vol. 5, pp. 99-143.)

Vokes, F.M. (1971) Some Aspects of the Regional Metamorphic Mobilization of Preexisting Sulphide Deposits. (Mineral Deposita (Berl.) vol. 6, pp. 122-129.)

Vokes, F.M. and Gale, G.H. (1976) Metallogeny relatable to Global Tectonics in Southern Scandinavia, in Strong D.F. (Editor) Metallogeny and Plate Tectonics, Geol. Assoc. Canada Special Paper 14 1976, pp. 413-441.)

Winkler, H.G.F. (1967) Petrogenesis of Metamorphic Rocks (Revised Second ed. publ. Springer Verlag, New York, p. 237.)

Whitten, EHT (1966) Structural Geology of Folded Rocks (Book p. 663, publ. Rand McNally and Co.)

APPENDIX I

Geochemical Analytical Methods Used at Geologisk Institutt, NTH.

During the course of the detailed geological mapping in the Skorovas Mine Area, approximately 100 rock samples were collected for total major element analyses, of which 55 samples were chosen as representative of the various volcanic units mapped (11 acid volcanic, 11 intermediate volcanic, 13 basic volcanic and 19 basic and acid tuffaceous units). Fifteen (15) samples of massive and impregnation sulphide ore were also selected for base metal (Cu-Zn-Pb) analyses. All the analytical proceedures were carried out by the author during the period October 1975 to June 1976.

Analytical methods for major and trace element silicate analyses.

1) X-Ray Fluorescence Spectrometry (PHILIPS PM 8000)
   SiO_2, TiO_2, Al_2O_3, Fe_2O_3 (tot), CaO, K_2O, P_2O_5
   and trace elements Rb, Sr, Zr and Y.

2) Atomic Absorption Spectrometry (PERKINS-ELMER 503)
   MgO, Na_2O, MnO and base elements Cu, Zn, Pb and Mn.

3) Wet Chemical Titration ($K_2Cr_2O_7$ indicator)
   used to analyse for FeO
   Fe_2O_3 was then calculated from the formula:

$$Fe_2O_3\ tot = FeO + 0.8998\ Fe_2O_3$$

or

$$Fe_2O_3 - FeO \times 1.111\ factor = Fe_2O_3$$

Rock Preparation:

Rock samples were collected in the field from relatively fresh unweathered, unoxidized outcrops free from noticably quartz, calcite and sulphide veining and quartz, calcite and epidote filled amygdules. The individuel samples were collected in the 1-2 kg range (12 x 8 x 6 cm approx.) and should be fairly representative because of the extremely fine-grained nature of the volcanics in the Skorovas area. Several smaller sized samples from the same locality were also taken to ensure representative sampling. The samples were then trimmed of any oxidized and weathered surfaces and then crushed down to approximately 0.8 cm^2 size using a stainless steel "Fly Press Rock Crusher", instead of a common tungsten carbide jaw crusher, then split to a suitable size and growned to a powder form using an Agate Ball-Mill Rotation Unit, at 710 rotations/minute for a 2 minute duration. The Agate Ball Mill was used to minimized trace element contaminations. All crushing and grinding instruments were thuroughly cleaned after each sample preparation to minimize possible contamination. Samples were also crushed in series of first acid volcanics then Intermediate and last basic volcanics and chlorite schists to also minimize possible contamination.

Sample Preparation for X-Ray Fluorescence Analyses.

The analytical method used here follows the procedure set down by Padfield and Gray (1971), with minor modifications as suggested by T. Prestvik at the Geologisk institutt, NTH, to be consistant with the U.S.G.S. standards and the Iceland volcanic rock samples that has just been analysed by him.

Procedure: One part (200 mgr. exact weights measured) of powdered rock sample is mixed with seven parts (1400 mgr.) of anhydrous sodium tetraborate ($Na_2B_4O_7$).
The mixture is melted in a carbon crucible, inside an oven at 1050^oC for 13 minutes to ensure a homogeneous melt in the glass bead. The glass beads are then cooled and then crushed to a fine powder using a tungsten carbide swing mill for one minute, to ensure a constant grain size of the glass powder. The powder is then pressed into discs using dry boric acid powder as a backing material. The U.S.G.S. standards were prepared in the same manner to ensure consistancy.

In conjunction with the XRF major element analyses procedure described above, one must also analyse for the loss of weight due to ignition (the H_2O^+ crystal water, H_2O - hydroscopic water, CO_2, S, F and all organic matter that is lost during ignition or glass bead preparation).

The ignition loss analytical procedure follows as such:

1. the ceramic crucibles are ignited for 1 hour at 950^oC to drive off the water.
2. crucibles cooled for one hour in decanter (evacuated)
3. crucible weighed exactly
4. rock sample powder weighed exactly (approx. 500 gr)
5. crucible with weighed sample set in oven for two hours at 950^oC
6. crucible cooled in decanter for one hour
7. ignited crucible and sample weighed exactly
8. weight percent sample lost under ignition is calculated

XRF Analytical Procedure

As mentioned above, various major silicate elements were analysed for, and a general description will be given here for the procedure of SiO_2 calculations to give an example of the analytical procedure. The newly purchased PHILIPS PM 8000 XRF instrument at the Geologisk Institutt, NTH, was used with the following parameters for the SiO_2 analyses:

1. Cr X-ray tube
2. PE crystal
3. Flow counter detector
4. Fine collimator
5. Vacuum (90% argon and 10% methane)
6. power: 40 mA and 50 Kv
7. Counter per 100 seconds
8. Si Kα, peak = 109.18 2θ

Five similarly prepared USGS standard powder discs, chosen to be representative of the SiO_2% range from basalts to granits - similar to that which would be expected for the Skorovas volcanics, were run through the XRF several times to obtain stability, and then their true SiO_2% contents (corrected for theoretical ignition loss) were plotted against the obtained radiation intensity/100 seconds, producing a good linear curve as shown in Figure 28, (pp. 88).

Sample AR20 (SiO_2 = 69.80%) was chosen as an internal standard from the Skorovas volcanic samples and was analysed every 5th to 10th sample to check on the drift of the radiation peak (SiKα), which can be caused by:

1. heating of the analysing crystal (PE)

or

2. fluxuation of the electrical current delivered to the power unit.

The SiO_2% values for the Skorovas volcanic samples were calculated using the curve from Figure 28, plotting the obtained radiation intensity for each sample against the SiO_2% and later correcting the values for ignition losses.

FeO^{+2} Calculations: wet chemical titration

The following recipe was used in performing the FeO^{+2} calculations:

1. approximately 0.8 grams powdered sample (exact weight) placed into a platinum crucible

2. 10 ml H_2SO_4 (1:1) added and cooked for 5 minutes

3. 5 ml conc. HF added and cooked for 5 minutes

4. The totally dissolved sample is poured into a 400 ml beaker containing 200 ml disstilled H_2O, 15 ml H_2SO_4 (1:2) 5 ml conc. H_3PO_4, 25 ml H_3BO_3 (ca. 2% dissolved), plus 3-4 drops of difenylsulphonate indicator

5. This is quickly titrated, while stirring, with 0.1 N $KCrO_4$ (0.2% normal) until the mixture just turns from greenish to a purplish-pink color. The indicator, 1/10 N $K_2Cr_2O_7$, has a factor 0.9887.

   The following formula was used to calculate the FeO% in the sample:

$$\%FeO = \frac{71.038 \text{ (formula wt.FeO)} \times \text{ml } CrO_4^{-2} \text{ used}}{\text{grams sample weight} \times 100}$$

$$= \boxed{\frac{71.038 \times \text{ml } (CrO_4^{-2})}{\text{grams sample}}}$$

After this procedure, one can easily calculate the amounts of Fe_2O_3 in the sample from the Fe_2O_3 total obtained by XRF and FeO wet chemical analyses, using the following formula:

$$Fe_2O_3 = Fe_2O_{3(tot)} - (FeO \times 1.111\text{(factor)})$$

the factor 1.111 is calculated from

$$\frac{\text{molecular wt. } Fe_2O_3}{\text{molecular wt. FeO}} = \frac{79.85}{71.84} = 1.111$$

Atomic Absorption Spectrometry.

The major elements Na_2O, MgO and MnO were analysed at the Geologisk Institutt, NTH, using the AAS from a method of total dissolution set up by Tore Prestvik (Nov. 1975 - B løsning).

1. 200 mgr sample (exact weight) placed into a platinum or tephlon crucible
2. dissolved in 1.5 ml $HClO_4$ plus 5 ml HF, under a fume hood, in a water bath at 95°C - until dissolved
3. 1 ml $HClO_4$ added and crucible placed on a sand bath at 150 - 160°C - until all the HF is driven off
4. the dissolved solution was thinned to 100 ml in a volumetric bottle (for 200 mgr samples) - gives a thinning factor of 1/50

The Na_2O contents in the samples were calculated using pure emission spectrometry (without the Na_2O lamp), plotting the values of the standards between 10-100 ppm Na, against the pure emission spectrometry values for these standards producing a well-fitting curve (Figure 29 A, pp. 89). The curve was then used to calculate the true ppm Na values in the Skorovas volcanics from the emission values obtained for each dissolved sample. The ppm values were then recalcuted to percent using the formula:

$$Na_2O\% = \frac{\text{ppm solution} \times 100 \text{ ml}}{2000 \times 10{,}000}$$

$$= \boxed{\frac{\text{ppm solution} \times 10}{200}}$$

The MgO and MnO contents were similarly calculated, however, instead of ppm standards, using true % values for five USGS standards and plotting them against the obtained emission values to obtain the curve shown in Figure 29B (pp. 89) from which the obtained emission values for the Skorovas volcanics was plotted to calculate the true MgO and MnO contents.

Heavy elements (Cu, Zn, Pb and Mn) were also analysed with the Atomic Absorption Spec. using the following method of partial dissolution of the sample to extract the heavy elements in sulphides and trace elements in micas, epidote, calcite etc.:

1. amounts of powdered sample used (exact weights)

a)	massive sulphides	0.1 gram (approx.)
b)	sulphide impregnation	0.25 gram
c)	pure rock sample	0.5 gram

2. sample was dissolved in 10 ml HNO_3 plus 5 ml HCl (Lunges Veske), cooked up to 100°C (overnight) until completely dissolved and dried

3. then dissolved in 10 ml conc. HCl and cooked at 150°C until sample boils

4. solution washed out into a 100 ml precision flask

The percent heavy metal calculations from ppm in solution were obtained using the following formula:

$$\% \text{ (Cu, Zn, Pb)} = \frac{\text{ppm solution} \times 100 \text{ ml}}{\text{grams sample} \times 10{,}000}$$

Trace Element Analyses: Rb, Sr, Zr, Y

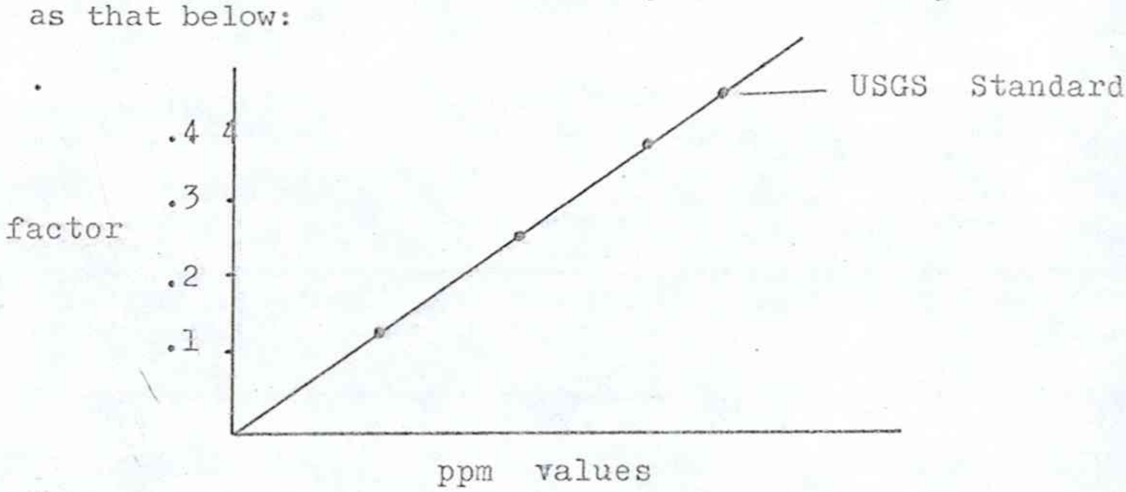
Analyses of the trace elements Rb, Sr, Zr and Y were performed at the Geologisk Institutt, NTH, by Jostein Sandvik with the X-ray Fluorescence spec. using the following procedure:

1. XRF - tungsten X-ray tube

2. approx. 1.2 gram sample (exact weight) spiked with 1000 ppm (exact) MoO_3 + SiO_2 (approx. 60 mgr of spike)

3. mixed about 10 minutes until homogeneous and pressed into discs with Boric acid backings

The Mo spike was used as an internal standard - measuring the top and the background values of the trace elements in the USGS standard samples and then calculating a factor using a similar curve as that below:



The ppm trace element values in the Skorovas volcanic samples are then calculated from the above curve.

Experimental Error: for the chemical analyses

1. XRF instrumental error is 0.01% maximum on the counter stastics - this is negligable compared to errors accumulated during sampling and sample preparations.

2. AAS instrumental errors are low - better than ± 1% relative

3. ± 2% relative error can occur in the greater part of samples where SiO_2 and Al_2O_3 are the major components.

4. According to I. Rømme, 98% total for silicate analyses with ignition loss - not having accounted for H_2O ± and Co_2, are very good results. The major part of the total silicate analyses for the Skorovas volcanics (acid - intermediate - basic lavas) have 97-98% total, which indicates that these analyses are justifiable. Some of the chlorite schists and tuffs have very low total values, 94-96%, and probably reflect the enormous CO_2 and H_2O ± and sulphur contents driven off during crushing and grinding and under ignition.

While the author was at the Skorovas mine, engaged in detailed geological mapping underground, numerous massive and disseminated sulphide ore samples, which were incorporated into the chemical classification of the ore types in this report, were analysed at the Skorovas assay lab. for S, Cu and Zn. The coarse crushing was done with a stainless steen jawcrusher and the fine crushing with a tungsten carbide swing ball-mill. Analytical procedures prior to 1975 were totally wet chemical, the S done by gravimetric methods (precipitated out as SO_4). Analyses of Cu and Zn after 1975 was done using a Varion Techtron atomic absorption Spec.

Several Skorovas ore type samples, analysed at Skorovas, were also analysed at the Geologisk Institutt, NTH, giving very good correlations (± 0.2 - 0.3% for both Cu and Zn).

FIG. 28 PLOT OF SiO_2% VERSES XRF INTENSITY FOR 5 U.S.G.S. STANDARD SAMPLES SHOWS LINEAR CORRELATION. SKOROVAS VOLCANICS SiO_2% CALCULATIONS WERE MADE FROM THIS CURVE USING AR20 (69.80% SiO_2) AS AN INTERNAL STANDARD.

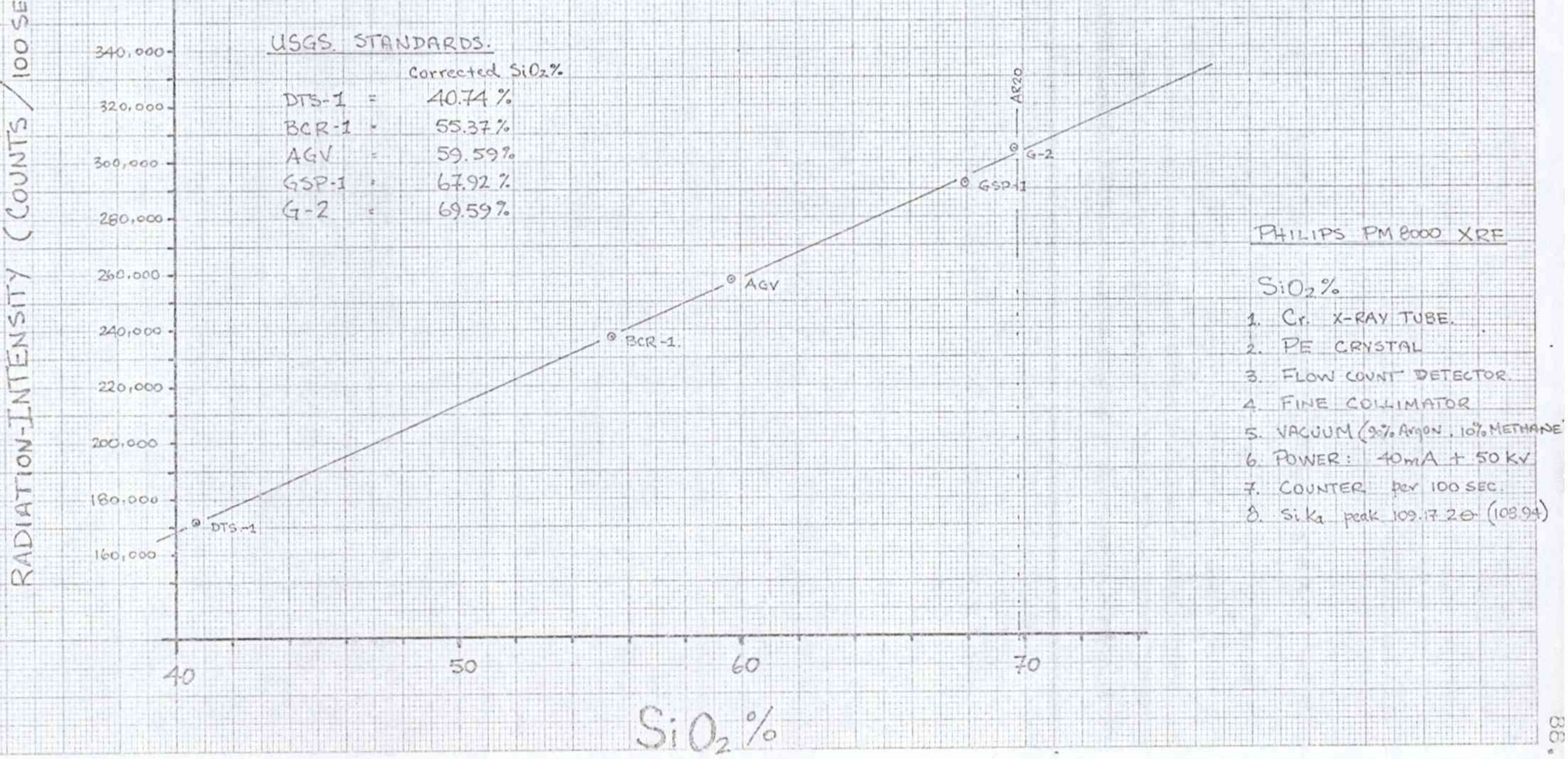
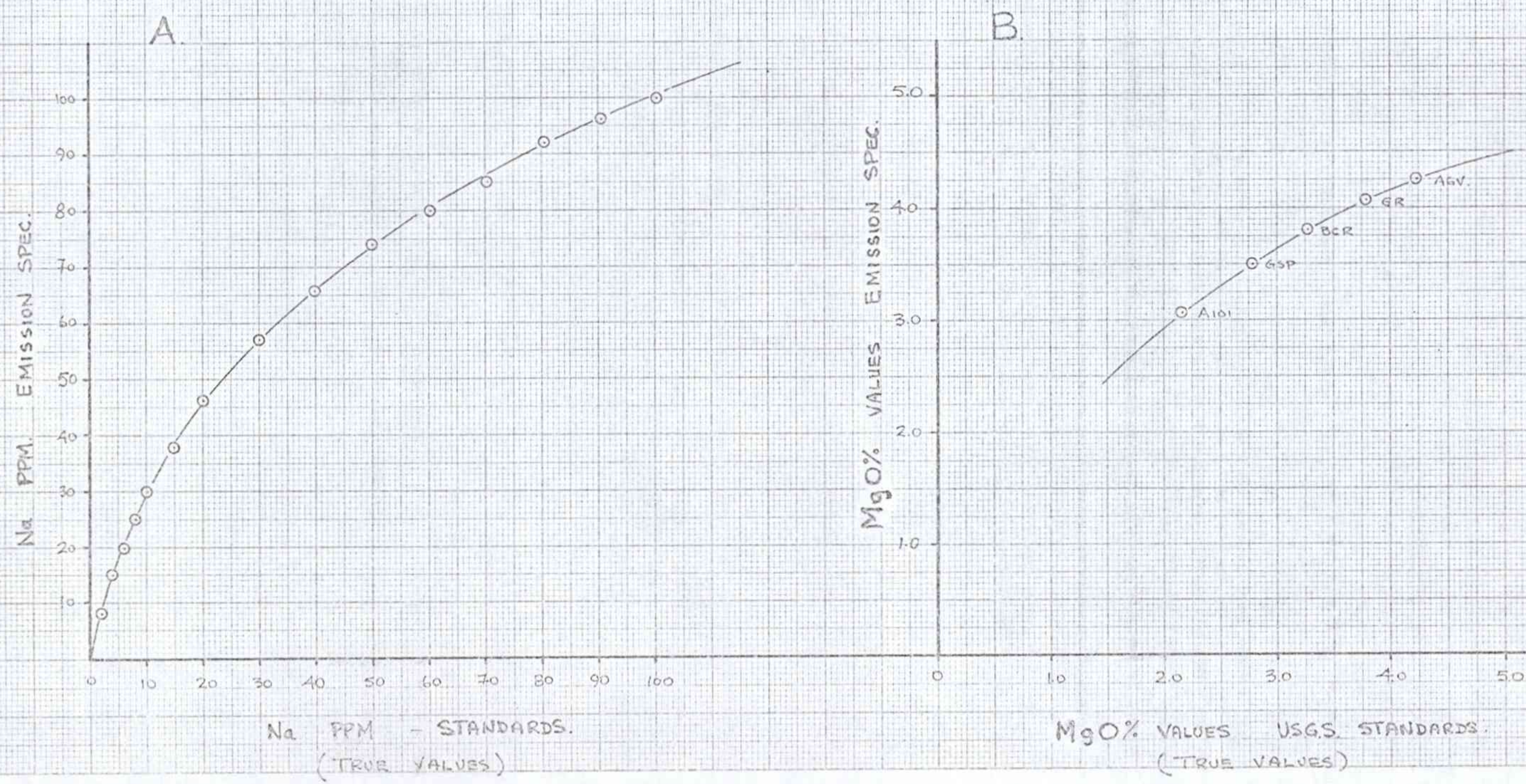


FIG. 29 DIAGRAM OF CURVES USED FOR Na_2O% CALCULATIONS USING NORMAL EMISSION SPECTROMETRY (P-E 503 ATOMIC ABSORPTION SPECTROMETER)



APPENDIX II

Terminalogy of Volcanic Textures and Structures.

The following is a list of volcanic terminalogy for textures and structures of both massive lavas and fragmentals that have been used in this report. Much of the terms are from the "Dictionary of Geological Terms", except where designated.

A. Massive Lava Flows

1. Lava Flows

Lava flows are described as :

a) a stream of fluid or viscous, or solidified fragmental lava which issues from a singular vent or fissure in relatively quiet fashion with little or no explosive activity.

b) the solidified mass of rock formed when lava streams congeals, generally tabular, elongate in the main direction of flow. Their form and internal structure depends chiefly on the fluidity of the lavas, a function of the composition. Thus, basic lava flows (basalts), are usually highly mobile, and flow for great distances, quickly, forming thin sheets and elongate streams, whereas silicic lavas, such as rhyolites and trachytes are ordinarily sluggish in their flow, commonly fragmental and form bulbous domes and associated fragmental piles generally from explosive activity.

In Skorovas, these massive lava flow (a Basaltic - Andes. composition) are generally very thick, and very fine grained to aphanitic with minor ophitic to trachytic textures: - also minor microporphyritic and amygdaloidal.

2. Ophitic texture

(diabasic) texture characteristic of diabases or dolerites in which euhedral or subhedral crystals of plagioclase are embedded in a mesostasis of pyroxene crystals, usually augite.
(discrete crystals or grains of pyroxene fill the interstics between lath-shaped feldspar crystals)

3. Trachytic texture

applied to the groundmasses of volcanic rocks in which neighbouring microlites of feldspar are arranged in parallel or subparallel fashion, bending around phenocrysts, and corresponding to the flow lines of the lava from which they were formed. - texture common in trachytes!

4. Amygdules

small gas bubbles in lavas, filled with secondary minerals such as zeolites, calcite, quartz etc.

B. 1. Pillow lavas (close-packed pillows) (after Carlisle, 1963)

A close packed accumulation of unbroken pillows. Pillow structures are exhibited by some basic lavas, basalts and andesites and especially spilites, and are the result of submarine or subaqueous deposition.
They consist of an agglomeration of rounded masses resembling pillows - fitting closely upon one another and the intervening spaces are usually filled with such sedimentary material as chert and carbonate. Individual pillows have a fine grained or glassy skin, are vesicular within, and in cross-section exhibit a banded concentric structure.

2. Pillow breccias

in part broken pillows or pillow-derived and in part cogenetic basic tuff or lapilli tuff.
Two types of pillow breccias are designated that are intimately associated with pillow lavas.

a) Broken pillow breccias - consist mainly of pillow fragments of various sizes in a tuffaceous (hyaloclastite) matrix

b) Isolated pillow breccias - consists of irregular but wholy unconnected pillows in a tuffaceous matrix

3. Aquagene tuff = Hyaloclastite (glass fragments)

a formation of volcanic tuff entirely beneath water, the tuff is intimately related to pillow structures, and is composed largely of basic glass - usually identical with the pillow rims, but altered in varying degrees.

C. Flow breccia

a type of lava flow, usually of a more silicic composition, in which fragments of solidified or partly solidified lava, produced by explosion or flowage, have become welded together or cemented by the still fluid parts of the same flow

Flow top breccia

similar to above - occurring at the top of consecutive flows.

Explosion breccia

D. Pyroclastics - volcanic ejecta (from Travis, 1955)

a general term for fragmental deposits of volcanic ejectamenta, including volcanic conglomerates, agglomerates, tuffs and ashes. Fragments of volcanic rock, of any size that has been explosively or aerially ejected from a volcanic vent. This represents a combination of igneous and sedimentary activities.

Size classification of pyroclastic rocks. (Table after Blokhina et al 1959.)

Tuff			Volcanic Breccia	
Ash		Lapilli	Bombs	Blocks
5 mm		5-30 mm	30-200 mm	200 mm
medium gr.	1-5 mm			
fine gr.	0.1-1 mm			
v.fine gr.	0.1 mm			

Volcanic ejecta

1. Ash

   unconsolidated volcanic fragments smaller than 5 mm diameter

2. Tuff

   consolidated ash - a rock formed of compacted volcanic fragments generally smaller than 5 mm, consolidated by the action of water, generally well stratified

   tuff materials

   a) Vitric - volcanic ash predominantly composed of glassy fragments

   b) Crystic - volcanic ash dominated by crystalfragments

   c) Lithic - indurated deposit of volcanic ash composed of previously formed rock fragments. ie., accessary pieces of earlier lavas in the same cone.

3. Lapilli

   small ejecta with diameter of 5-30 mm, usually consists of old lavas, - more rarely of broken pieces of some older rocks present in the vent.

4. Volcanic breccias

   angular volcanic particles sized 30-200 mm

5. Volcanic blocks and blocky breccias

large fragments greater than 200 mm diameter, few kg's to 10's of Tons, consists of lava from older flows or domes, ripped off during explosive volcanic activity.

Agglomerate (volcanic conglomerate)

a pyroclastic with greater than 25% bombs or breccia fragments in proportion to the tuffaceous matrix

Tuffite

submarine deposits of pyroclastic material often mixed with fine sediments, usually bedded and sorted according to grain size (graded!). Sedimentary structures seen, plus marine shells irregularly distributed throughout.

Chaotic tuff

formed from the deposits of glowing clouds and mud streams and slumps.

Welded tuffs (ignimbrites)

overflowing glowing clouds in fissure eruptions of very acid magmas. The incandescent ash particles are intimately fused to one another forming a massive and compact rock.

Crystal tuffs

tuffs that consist dominantly of ejected volcanic crystals and single crystal fragments, intratelluric crystals blown out during a volcanic eruption. Tuffs with 75% by volume of crystals.

"Quartz-Eye" tuff

felsic crystal tuff with large rounded glassy quartz fragments. Quartz and feldspar crystal tuff.

Volcanic rock-name definitions

Rhyodacite - the aphanitic equivalent of a granodiorite

Spilite - a basaltic rock with albitic feldspar. The albitic feldspar is usually accompanied by autometamorphic minerals or minerals characteristic of low grade greenstones such as chlorite, calcite, epidote, calcedonic silica or quartz, actinolite and others.

Keratophyre - a name originally applied to trachytic rocks containing highly sodic feldspar, but now more generally applied to all sodic lavas and dyke rocks characterized by containing albite or oligoclase, chlorite, epidote and calcite. Keratophyres are commonly associated with spilitic rocks and interbedded with marine sediments.
Varieties containing quartz are known as quartz-keratophyres.

Color Index - (petrology) the sum of the dark or colored minerals in a rock expressed in percentages, applied to the classification of igneous rocks. The rocks are divided into:

leucocratic (color index 0-30)

mesotype or mesocratic (C.I. 30-60)

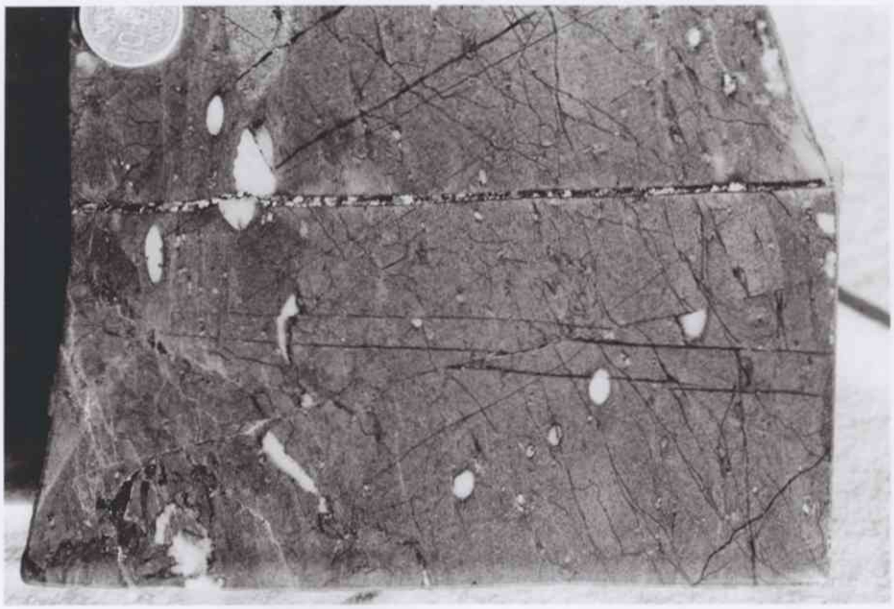
and melanocratic (C.I. 60-100)

APPENDIX III PHOTOGRAPHIC PLATES

Macro and Micro Photographic Plates of the Various Volcanic Rock Units Found at Skorovas.

SKOROVAS VOLCANIC ROCK TYPES

①



②

③

Plate 3 : (local. Brøn. St.30ø nr.20 , near AR43)

Massive,dense,fine-grained,medium-grey Rhyo-dacite with quartz amygdules. Note sulphide veinlets with slight hydrothermal alteration haloes.

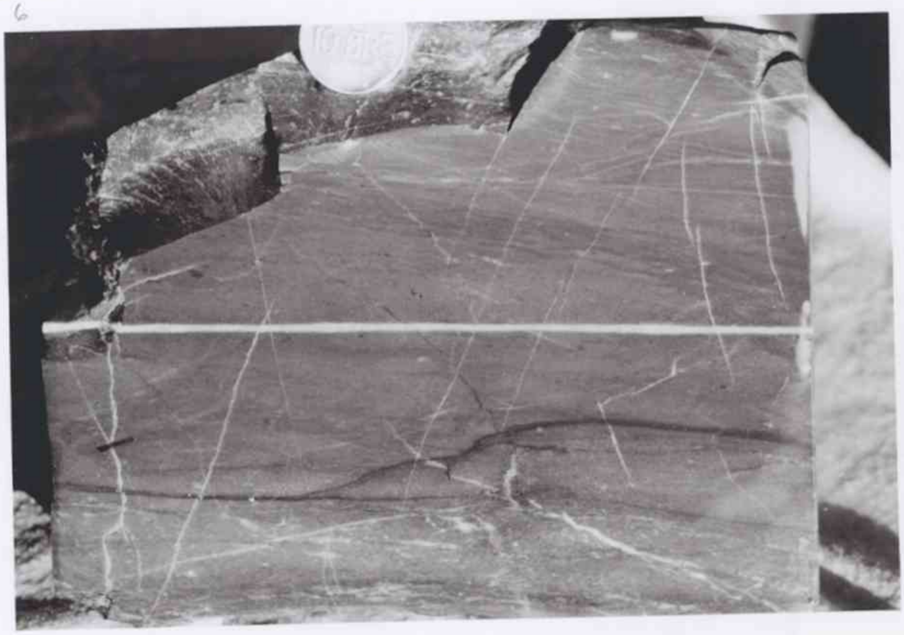
4

5

Plate 5 : (local. V.St.O. 52-13ø nr 4)

Dacite : dense, medium greyish, fine-grained "Quartz eye" porphyry lapilli tuff. Shows very compact welded tuff texture. Note - individual light colored felsic, lithic fragments.

6



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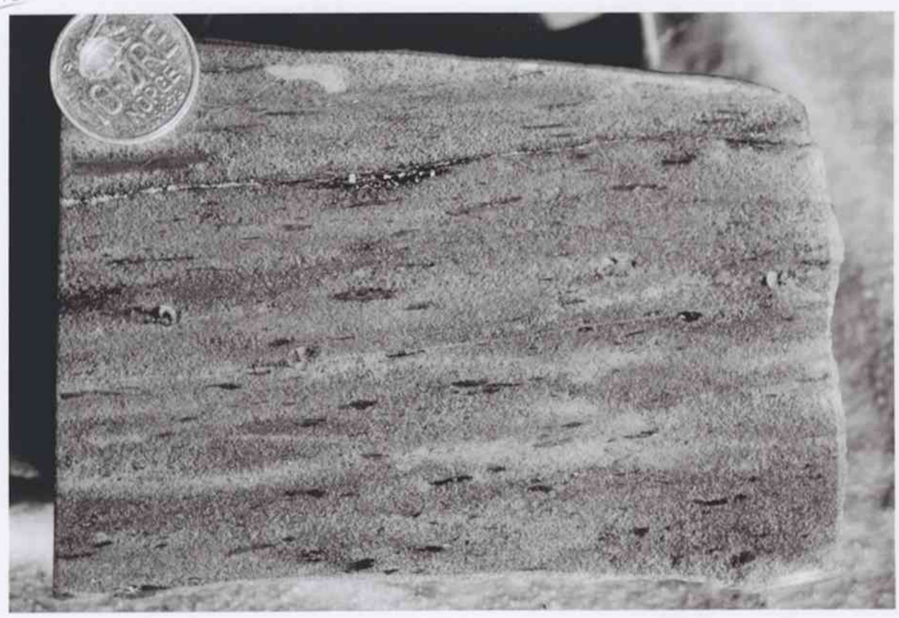


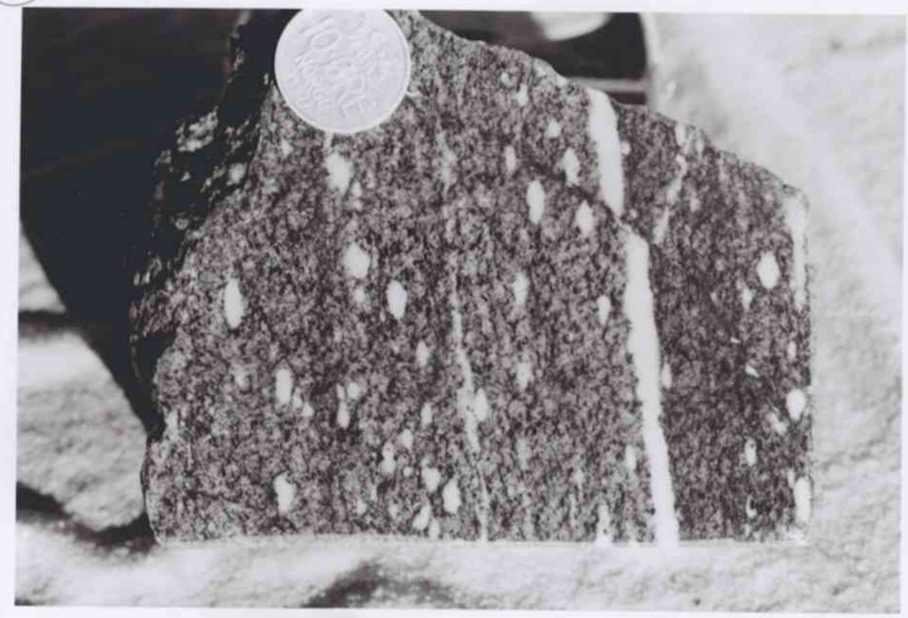
(11)

(12)

Plate 12 : AR 24 (local. Sk.O. 48A nr. 5a)

Basaltic-Andesite: extremely aphanitic, dark-grey, highly magnetic flow contact zone. Numerous white carbonate and quartz filled amygdules.

(13)



MICROP HOTOGRAPHS

Showing volcanic textures of various volcanic rocks from Skorovas.

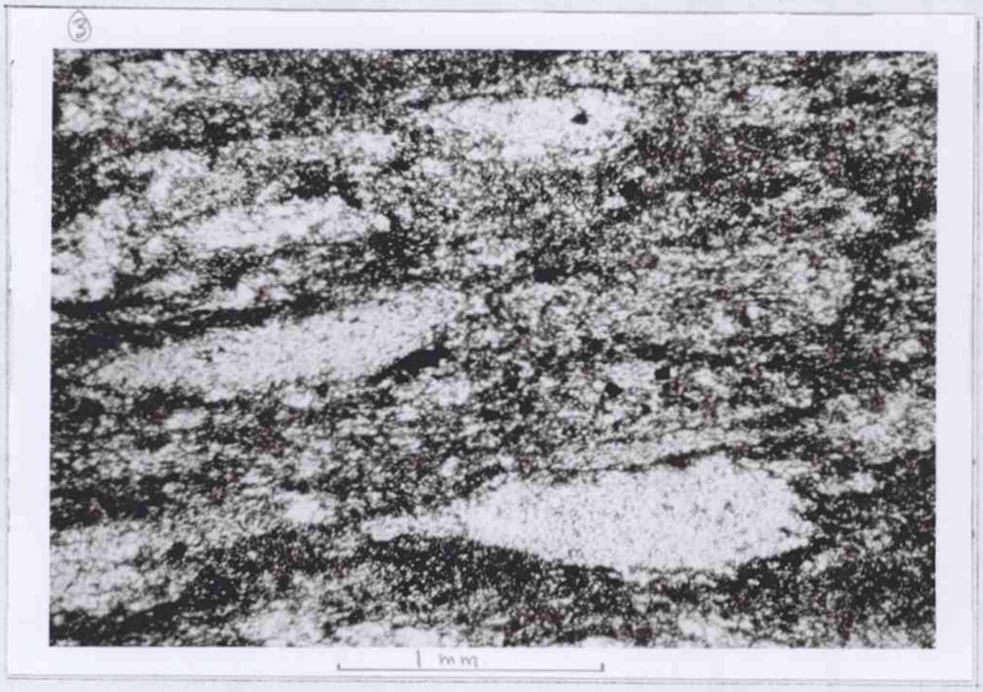
Acid Volcanics

Plate 14 : AR 44 (local. GF 88)

Rhyo-dacite porphyry :(under X-nicols) shows elongate albitic-plagioclase phenocrysts (singular Carlsbad - twinned),set in aphanitic quartz and plagioclase matrix, dusted with extremely fine-grained magnetite (opaques).

Plate 15 : AR 43 (local. R.30ø nr.4)

Sheared fine-grained Dacite,minor porphyrytic. Shows much more alignment of minerals and stronger chlor.(grey) and sericite alteration than above.



P late 16 : AR 57 (local. GF 34)

Acid fragmental - lapilli tuff: Acid fragments (light) set in a chloritized, schistose basic tuff matrix, plus minor acid-felsic material.

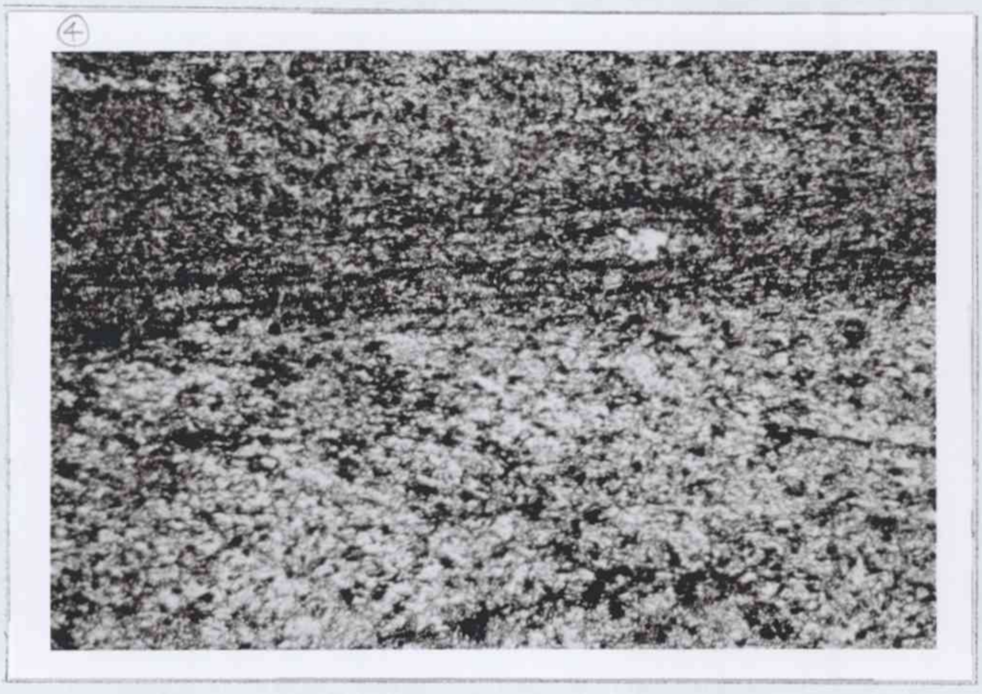
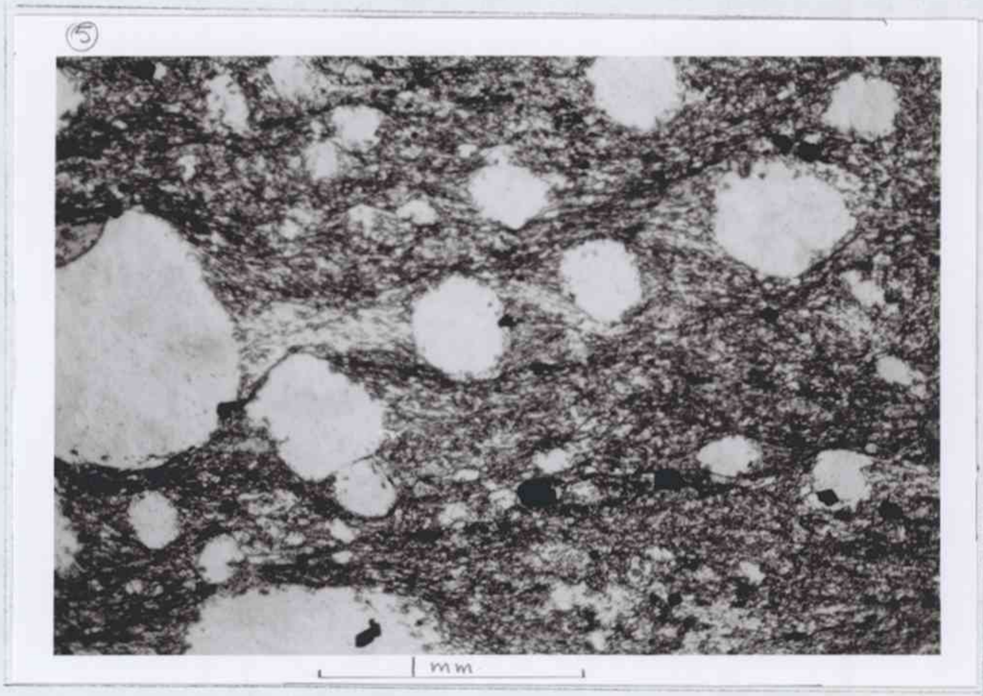


Plate 17 : AR 30 (local. Sk.0.43A nr.11)

Well-banded tuffs : chloritic(dark) and felsic(light) bands, with very fine-grained dusting of magnetite (opaques).



P late 18 : AR 35 (St. 0.15-8ø nr. 12)

"Quartz-eye" fragmental felsic tuff. Note, rolling of quartz fragments with pressure shadows and bending of the sericite schistosity.

P late 19 : AR 42 (local. 13ø/45/615)

Fine-grained chloritic Basalt: shows remnants of ophitic texture - random intergrowth of plagioclase microcrysts. Epidote and chlorite in matrix.

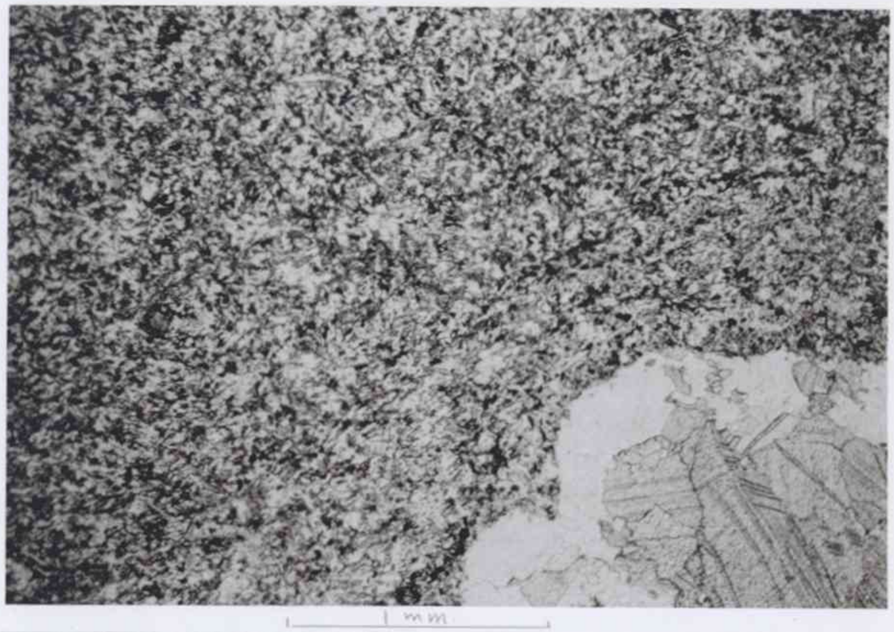


Plate 20 : AR 24 (local. Sk.O. 48A nr.5a)

Extremely aphanitic Basalt(tholeiitic) : shows very tightly packed groundmass,chloritized matrix, minor pyroxene, and epidote knots. Note, quartz rimmed calcite filled amygdules.

Plate 21 : AR 73 (local. GF 51)

Calc-Alkaline Andesitic-Basalt : with random oriented plagioclase microcrysts (white), chloritized matrix(grey) and numerous epidote grains (high relief), plus opaques (pyrite ?).

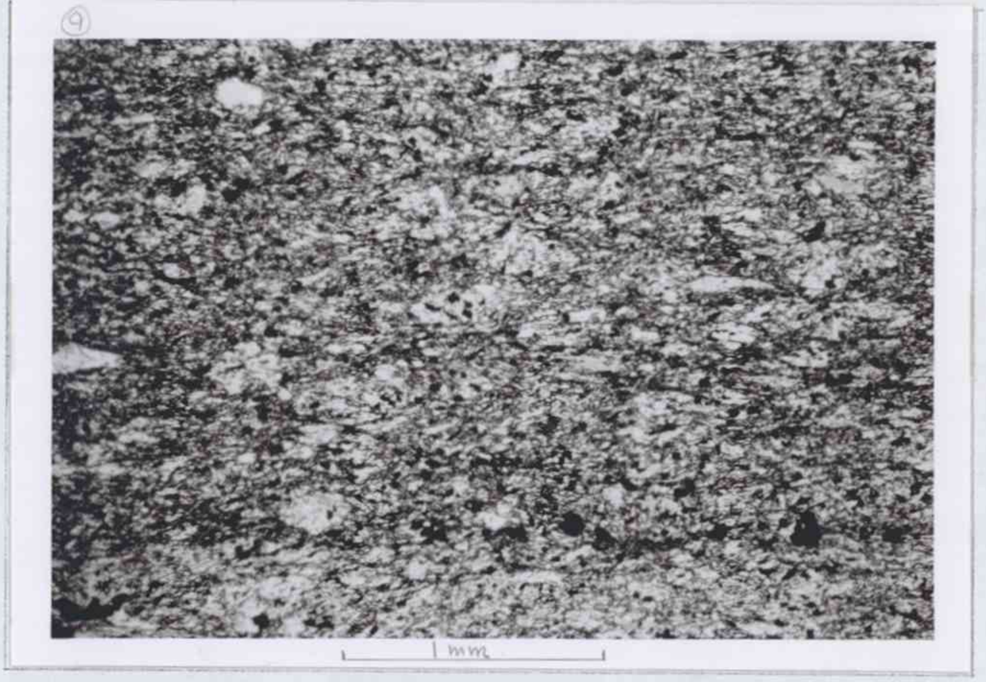


Plate 22 : AR 22 (St.0.40-21ø nr.1)

Very schistose, highly sheared Calc-Alkaline Andesite: Note, elongate plagioclase fragments - with strong penetrative chlorite schistose matrix. Opaques (sulphides). Non-magnetic.

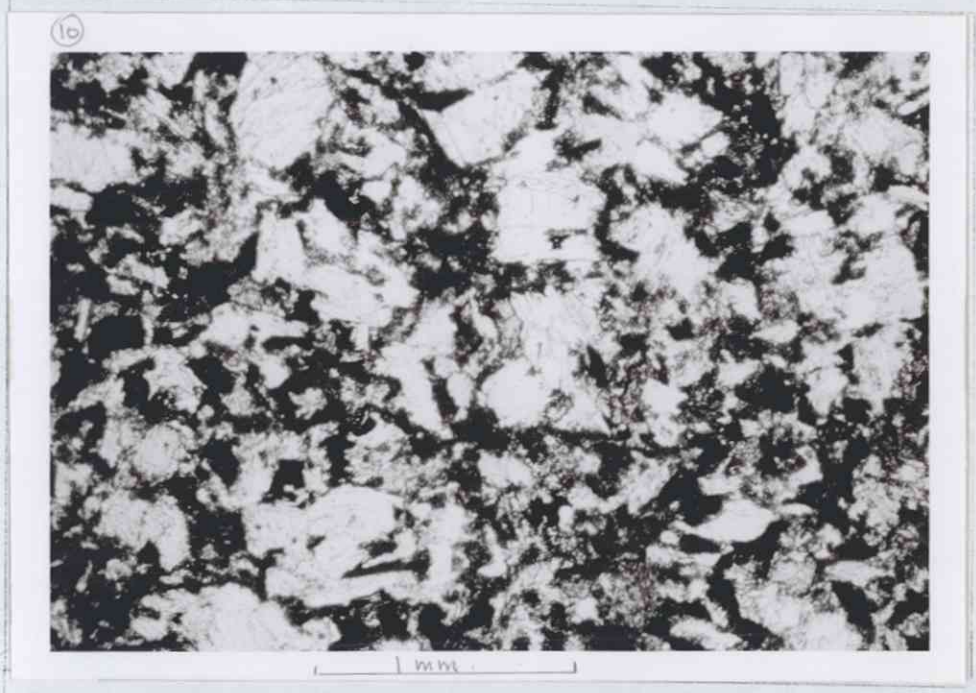


Plate 23 : AR 72 (GF 87)

Calc-Alkaline volcanic dyke : extremely coarse grain size. Find large sericite, epidote and minor talc altered plagioclase - chloritized matrix and sphene as opaques ? Equivalent to the gabbroic textured greenstone - Gjelsviks "Amphibolite".

VOLCANIC STRUCTURES

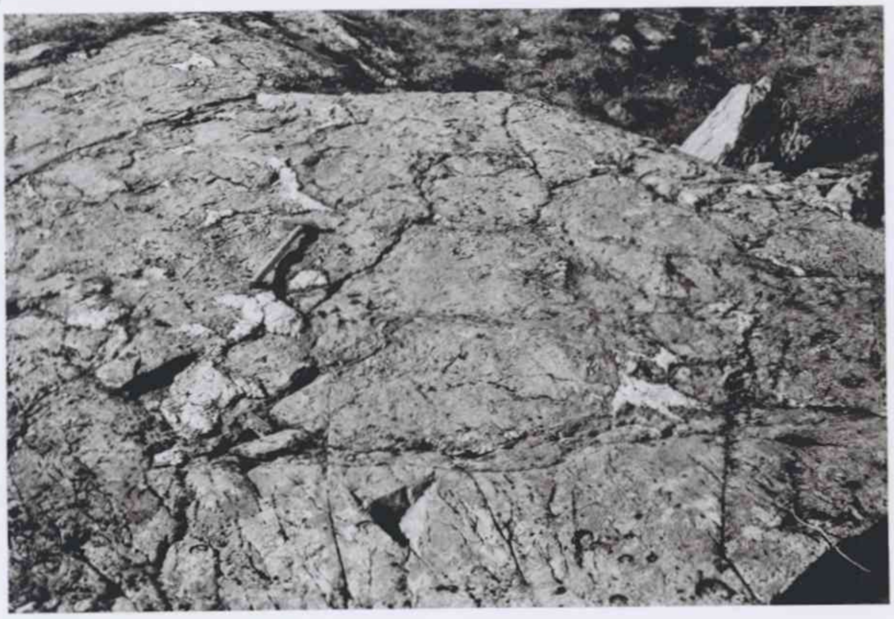


Plate 24 : (local. GF 135) west of Gråbergstippen.

Well-developed, close-packed pillow structures within the lowermost volcanic sequence, dark-green, chloritic Basalt. Individual pillows are rimmed by a reddish-brown, epidote and hematitic rich, weathered surface. White cherty-cusps fill the spaces between the individual pillows.

Plate 25 :

(local. GF 168) west end of Reservedammen.

Shows epidote-rimmed Basaltic-Andesite, close-packed pillows from the uppermost CAB volcanic sequence. Note, epidote and quartz filled, zoned amygdules in each pillow.

P late 26 : (local. GF 278) west end of Reservedammen.

Large white quartz and epidote rimmed,calcite filled amygdules from the uppermost Basaltic- Andesite sequence. Note, amygdules can be up to 3 cm. in diameter, elongated and flattened.

Plate 27 : (local. GF 167) SW corner of Reservedam.

Very coarse, angular, broken pillow-breccia (light colored), set in a fine-grained hyaloclastite(dark) matrix - a chloritized glassy tuff derived from the pillow-rims and fine broken pillow fragments.

Plate 28 : (local. GF 278) west end of Reservedam.

Fine pillow-breccia material, large light-colored fragments set in a fine-grained hyaloclastite (aquagene tuff) matrix, dark, chlorite rich.

Plate 29 : (local. GF 278)

End view of above picture. Hyaloclastite - fine pillow-breccia, flattened fragments.

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Plate 30 : (local. GF 175) between Gråbergstollen and Reservedammen.
Typical pitted-weathered, very schistose, carbonate-rich chlorite schists, or extremely fine-grained tuffs? Agglomerate found directly above this unit.

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P late 31 : (local. GF 30) immediately NW of Nygruva - south of Rauberget.
Looking north along a 1½ meter thick, almost vertical, Calc-Alkaline Basalt, gabbroic-textured, schistose greenstone dyke that cuts through the rusty acid tuffs and coarse pyroclastic zone. Schistosity in dyke is same as in host rock, approx. 30 to SE. This dyke is therefor emplaced prior to deformation.

Plate 32 : (local. immediately above mine enterance)

White Rhyo-dacite explosion-breccia : - shows very angular, unsorted, flattened acid fragments, set in a darker sericite and chlorite, fine tuff matrix.

VOLCANIC TEXTURES -as seen in drill cores.

Plate 33 : (local. DDH 10045 -profile 85s/10E)

Acid volcanic-breccia : shows light-grey, quartz amygdules. Flattened Rhyo-dacite fragments, set in a dark, chlorite and magnetite rich tuff.

P late 34 : close up view of above picture.

Dark to medium-grey color - reflects fine-grained magnetite content. Rims of fragments are darker. Numerous white quartz amygdules. Similar to acid breccia in Plate 4.

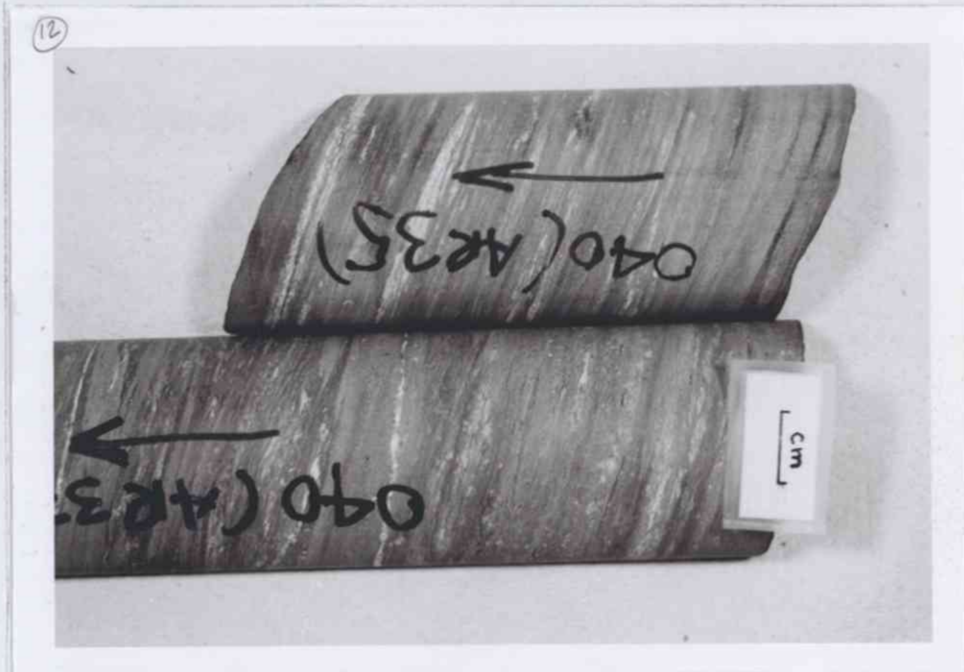
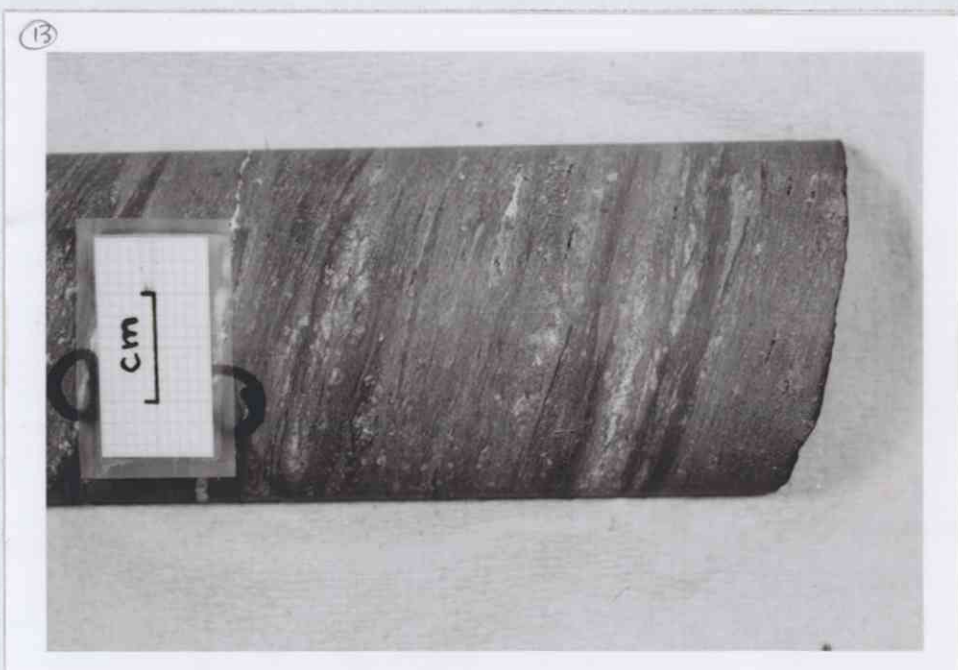


Plate 35 : (local. DDH 10040 - Gruvetjøna)

Well-banded tuffs : felsic, epidote-rich (light colored), and basic, chlorite-rich (dark). Penetrative schistosity is now dominating structure.



P late 36 : close up view of above picture.

Shows penetrative schistosity cutting compositional banding (S_0) at a slight angle (dark and light bands).

Plate 37 : (local. DDH 10045, ca. 85S/10E)
2 meters under surface.
Well developed hyaloclastite or meta-glassy, tuffaceous matrix to the pillow-breccias found in this area.

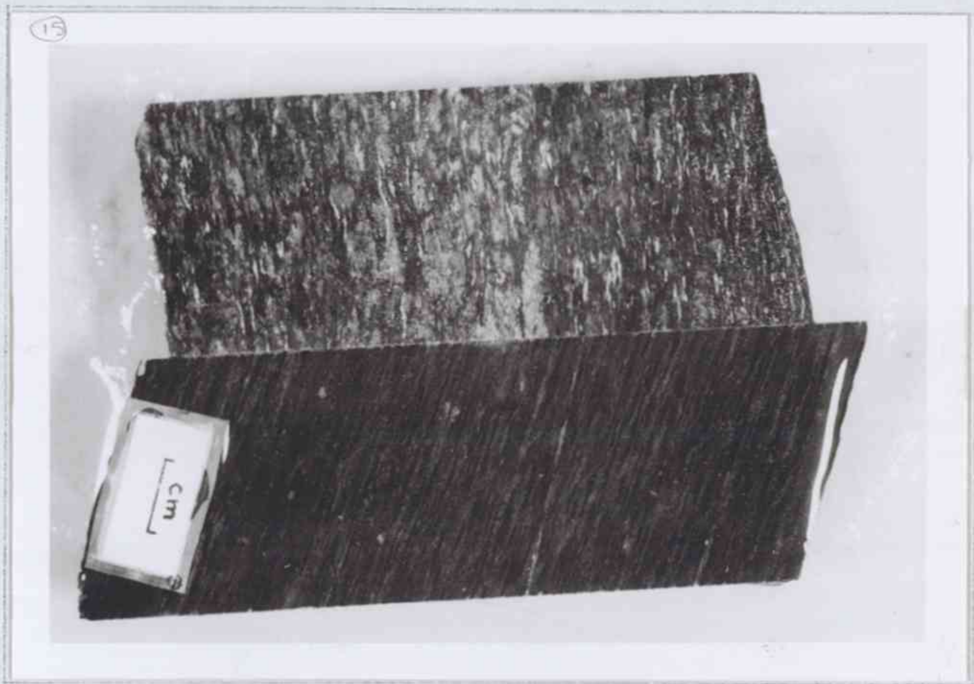


Plate 38 : (local. DDH 10040 - Gruvetjøna area
east of the mine.)
Shows textures found in highly sheared Basaltic-Andesites, stratigraphically above the mineralized zone in the Skorovas area. "Chlor.-fleck" texture lowest sample.

SKOROVAS MINERALIZATION and ORE TYPES

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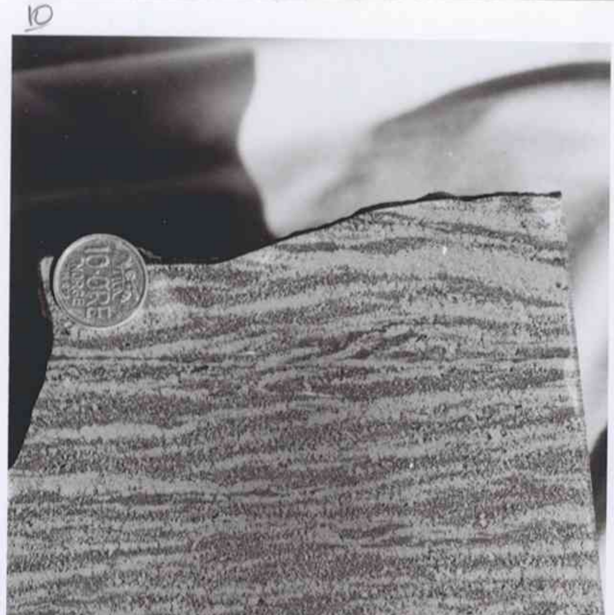

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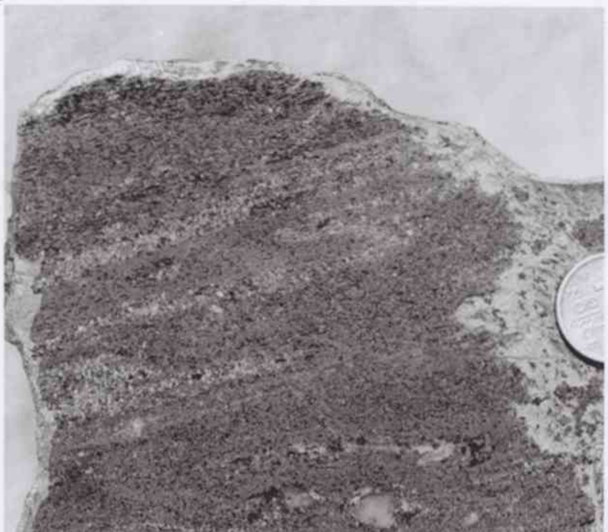

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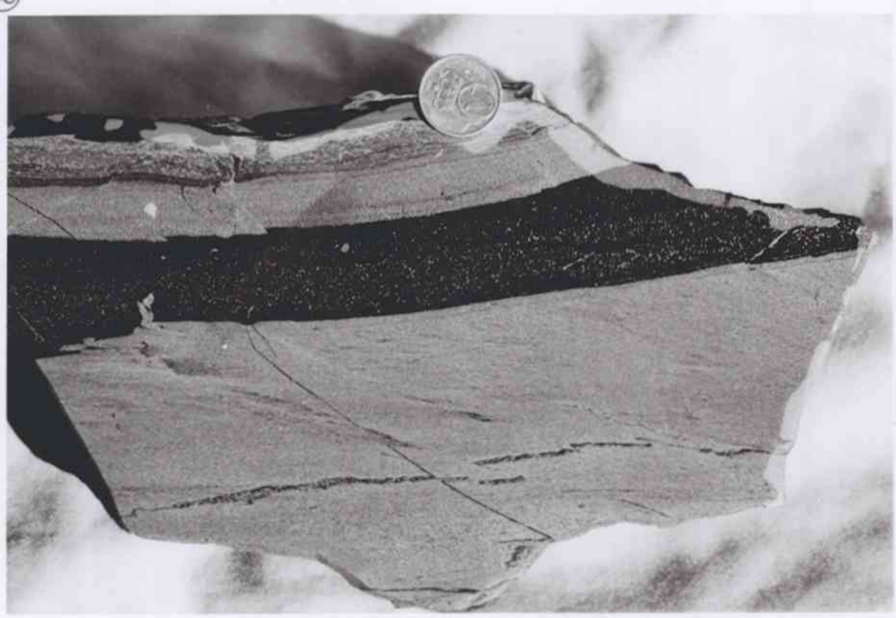

MICROPHOTOGRAPHS OF ORE· STRUCTURES

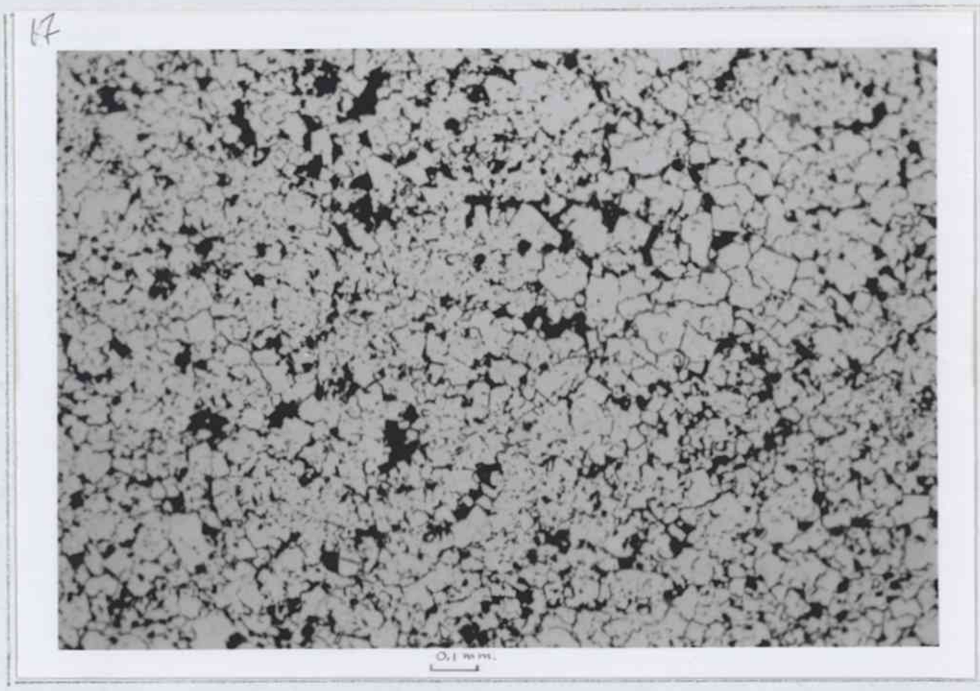

Plate 55 : AR 9 (local. L.M.Str.41V/S1 nr.6)

Microphotograph of extremely fine-grained, massive pyritic ore. Shows cataclasticly deformed pyrite grains(cubes), with quartz filled matrix(black) and minor sphalerite(medium grey). Note, zones of shearing with more finely growned pyrite.

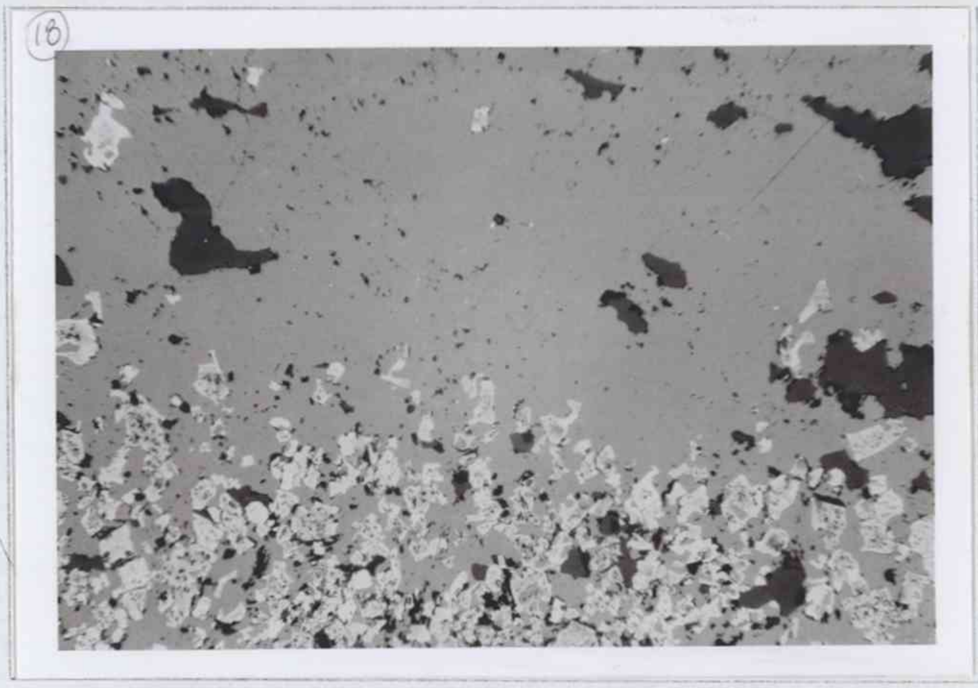

Plate 56 : (local. Dec. 7/75 nr. 5)

Massive sphalerite from SW Main Orebody : from tectonicly banded Zn-rich ore. Zn-rich band in a pyritic ore band, shows massive sphalerite(grey) with reaction contacts(replacement embayments) to the pyrite cubes(white to light-grey color).

(19)

Plate 57 : AR 2 (local. B.O. 32Ø nr4)

Microphotograph of Zn - Cu - Pb peripheral ore band. Shows extreme sbhistose nature of ore - which corresponds to the penetrative schistosity (S_1) of the surrounding volcanics. Silicates(dark grey to black), sphalerite(med. grey), and chalcopyrite and galena(white). Note, remobilized sphalerite, chalcopyrite and galena found concentrated in cross-cutting cleavage fractures (S_2).


E
W
METERS
SURFACE
PROFILE ca. 80 E-W
SKOROVAS
PROFILE 42 E-W
SCALE 1:2000
Antall
Gjenstand
Nr.
Material
Anmerk.
Målestokk
Tegn.
Trac.
Kfr.
Erstatning for:
Dato
Forandr.
Elkem-Spigerverket a|s
Skorovas Gruber
Erstattet av:

SKOROVAS

PROFILE 0 N-S

SCALE 1:2000

AR 30.3.77

Antall	Gjenstand	Nr.	Material	Anmerk.
				Målestokk · Tegn. · Trac. · Kfr.
				Erstatning for:
Dato · Forandr.	Elkem-Spigerverket a/s Skorovas Gruber			Erstattet av:


E
W
METERS
SURFACE
PROFILE ca. 80 E-W
SKOROVAS
PROFILE 42 E-W
SCALE 1:2000
AR 30-3-77
Antall
Gjenstand
Nr.
Material
Anmerk.
Målestokk
Tegn.
Trac.
Kfr.
Erstatning for:
Dato
Forandr.
Elkem-Spigerverket a|s
Skorovas Gruber
Erstattet av: