Bergvesenet

Postboks 3021, N-7441 Trondheim

BÆRBAR MASKIN

Rapportarkivet

Bergvesenet rapport nr	Intern Journal nr	Internt arkiv nr	Rapport lokalisering	Gradering
6855				

Kommer fra ..arkiv	Ekstern rapport nr	Oversendt fra	Fortrolig pga	Fortrolig fra dato:
Grong Gruber AS		Grong Gruber a.s.		

Tittel

Exploration Geology in the Area south-west of Gaizervatn, Grong District, Norway

Forfatter	Dato	År	Bedrift (Oppdragsgiver og/eller oppdragstaker)
Samson, Andrew D.J		1983	Grong Gruber AS

Kommune	Fylke	Bergdistrikt	1: 50 000 kartblad	1: 250 000 kartblad
Røyrvik Namsskogan	Nord-Trøndelag		1823 1 1823 4	Grong

Fagområde	Dokument type	Forekomster (forekomst, gruvefelt, undersøkelsesfelt)
Geologi		Gaizervatn Heimdalhaugen

Råstoffgruppe	Råstofftype
Malm/metall	Cu,Mo

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

BSc & BSc (Hons) Degree in Geology at Dept of Geology, Portsmouth Polytecni

Hensikten med arbeidet var å få et detaljert geologisk kart over området ved Gaizervatn der det er observert Mo-mineralisering.
Det er antatt at mineraliseringen opptrer innen intrusive leucotrondhjemitter og granodioritter sammen med grønnsteiner av Gjersvikgruppen.
Mineraliseringen opptrer som disseminert Mo i kvartsårer og som smurt ut på stikk og bruddplan.
Typen er en calc alkaline porfyry relatert til subductin sonen.

PORTSMOUTH POLYTECHNIC

DEPARTMENT OF GEOLOGY

EXPLORATION GEOLOGY IN THE AREA SOUTH-WEST OF GAIZERVATN, GRONG DISTRICT, NORWAY.

Name: ANDREW DAVID JON SAMSON

Course: B.Sc. & B.Sc. (Hons) C.N.A.A. Degree in Geology

Year: III (1983)

2

Some Aspects of the Geology of an Area South-West of Gaizervatn, Grong District, Norway.

By

Andrew David Jon Samson

B.Sc. and B.Sc. (Hons) Degree in Geology (C.N.A.A.)
Portsmouth Polytechnic,
Department of Geology.

1983

ACKNOWLEDGEMENTS

Acknowledgements must go to Dr. M.J. Ryan, Grong Gruber A/S and the technical staff who aided in the preparation of this project.

CONTENTS

TABLES

FIGURES

PHOTOGRAPHS

ABSTRACT

The aim of the fieldwork and resultant research was to contribute information to a regional study of molybdenum mineralisation in the Grong district of Norway. The text presented here is the result of the work which was carried out. It includes information about the geological setting of the region in which the fieldwork area is situated, as this is essential to the understanding of its geology. Previous work in the area is as follows:

1958 - N.G.U. 100,000 geological map.

1974 - N.G.U. Grong project, 1:20,000 geological map and stream sediment geochemistry.

1979-80 - Vokes and Haugen reconnoitred the Gaizervatn area.

The main objectives of the fieldwork were to compile a detailed geological map of the area, work out rock ages and sequences, study their lithologies and to work out their various field relationships. Relationships in the granodiorite, trondhjemite, greenstone complex were of particular interest. Metamorphism and deformation were also studied. Probably the main area of interest was the mineralisation in the field area. With the mineralisation, the main aims were to map in detail the areas around known sulphide-molybdenum showings and anomalies, molybdenum being of most interest, with the objective of assessing the state of molybdenum mineralisation and the potential of the area as regards to future work.

Laboratory work, including x-ray diffraction, ore microscopy and thin section examination was later carried out to reinforce the fieldwork findings. The findings from both laboratory and fieldwork were written up to form much of the following text.

The result of this work is that the author believes the mineralisation occurs within the intrusive leuco trondjhemites and granodiorites, associated with the greenstones of the Gjersvik Group. It is of the calc alkaline porphyry, subduction zone related type. It occurs as disseminated molybdenum in quartz pyrite veins and as a 'dry paint' along joint planes and fractures.

INTRODUCTION

INTRODUCTION

Aims and Objectives

The work was part of a regional study of molybdenum mineralisation in the Grong district, by Dr. M. J. Ryan in association with Grong Gruber A.S., part of Grong Gruber's prospecting programme in Norway. The aim of the project was to map the area in and around known molybdenum showings and geochemical anomalies, with the objective of assessing the degree of molybdenum mineralisation, the potential for future exploration work and the petrology and structural setting of the mineralisation.

Geographic Setting

The Grong district is situated approximately 150 km north-east of Trondhiem in the Nord Trøndelag district of Norway. Grong itself lies in a large valley at the convergence of the Sanddøla and Namsen Rivers, the latter being the principle river of the area. It is surrounded by steeply rising mountains, attaining heights of up to 1160 m in places. The actual field area is located roughly 30 km to the north-east, in a mountainous area on the south-west of Gaizervatn.

Topography and Vegetation

The study area has an average height of 800 m and lies well above the tree line. It exhibits a typical post glacial topography with glacial lakes in depressions in the ground and generally smooth well rounded peaks. Frost action has emphasized jointing, giving the rocks a tabular appearance. The rocks themselves are deeply weathered often with rust zones where any mineralisation has been weathered.

The vegetation is generally sparse and tundra like with about 45% rock exposure and any soils present are very thin. Mosses, lichens and heather are predominant, and in sheltered areas small patches of dwarf birch are found. In lower areas pine forests are dominant, along with marshy areas of spagnum moss and rushes.

A plant of specific interest, with respect to the mineralisation is Lychinis Alpina (Northern Copper Flower) which thrives on cupriferous soils and thus may give an indication of any copper mineralisation.

Logistics

The whole expedition lasted six weeks,with five weeks field work and one week travel. All materials used, including food and tents, had to be carried 13 kilometres into the field area from the mine at Skorovas.

GENERAL VIEW OF MAPPING AREA

(Blaumuren in the background)

EASTERN SECTION OF MAPPING AREA

Regional Geology and Stratigraphy

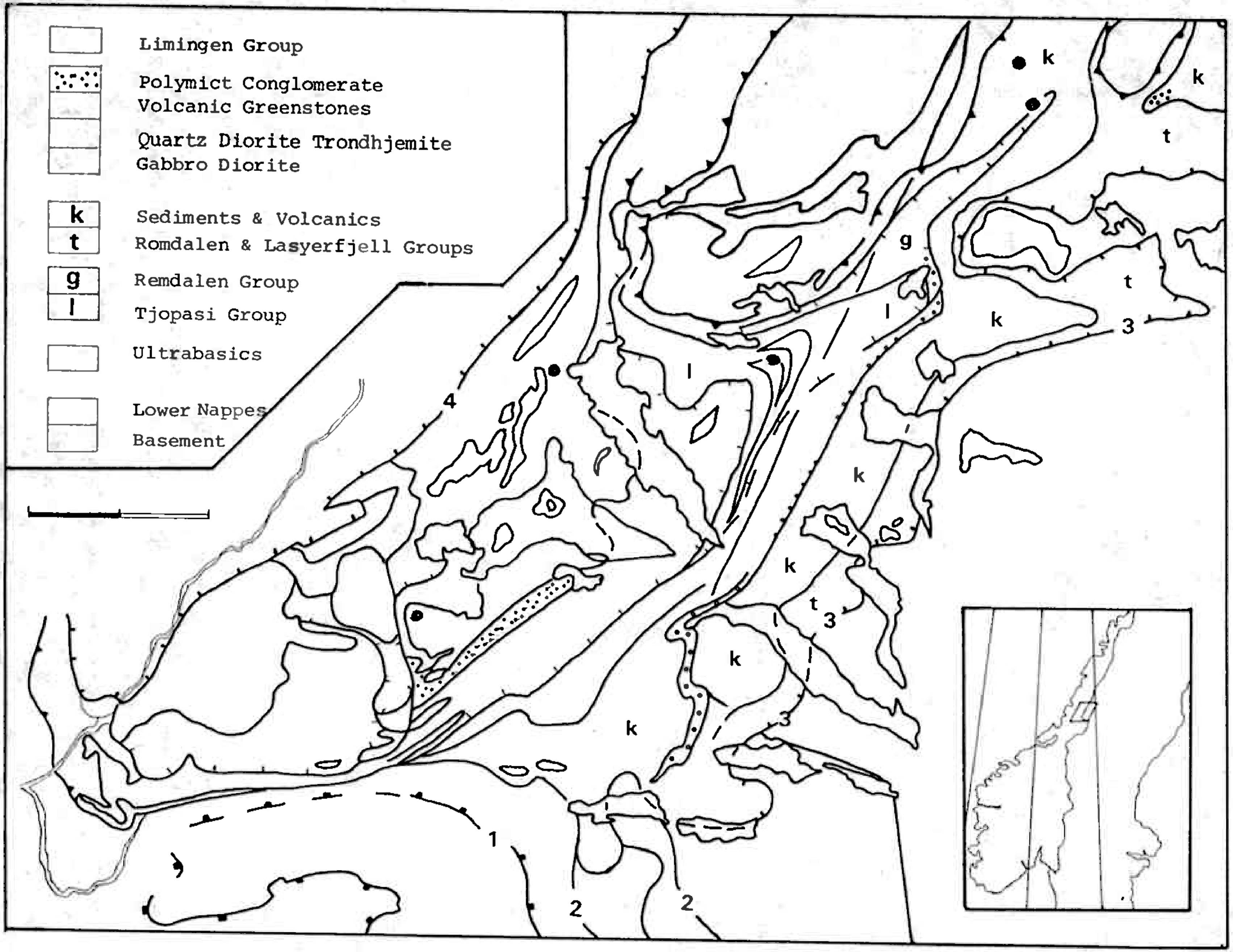
Rocks of Caledonian age extend for almost the entire length of Norway except for the southern area around Oslo which consists mainly of Permian igneous rocks and Precambrian metamorphics. The Grong district forms a moderately large depression with Caledonian rocks between two Precambrian massifs. The Borgefjell Massif to the north and the Grong Culmination to the south. It is composed of great thicknesses of eugeosynclinal deposits assumed to be of Precambrian to Silurian age, that have been divided into three main Tectonostratigraphical units (Kollung 1979), an eastern and lower unit, a central unit, and a western and upper complex.

The Eastern Complex consists of the Seve Nappe of probable Precambrian to Cambrian age and a lower Roli Nappe overlying it with Ordovician and Silurian rocks. The central complex of the Rantser Nappe is thought to be inverted and of Cambrian to Silurian age. The western complex is inverted and comprise:

(1) Limingen Nappe of Ordovician age

(2) Helgeland Nappe, overlying the Limingen Nappe consisting of rocks presumed to be of Precambrian to Cambrian age.

The field area lies for the most part within this western complex.



LOCATION MAP OF GRONG AREA AND LOCAL GEOLOGY

The Stratigraphy of Norwegian Caledonides in Grong District (After Kollung 1979)

<table>
<tr><td rowspan="3">WESTERN
COMPLEX</td><td>HELGELAD NAPPE</td><td>NAMSEN GROUP</td></tr>
<tr><td rowspan="2">LIMINGEN NAPPE</td><td>GJERSVIK GROUP</td></tr>
<tr><td>LIMINGEN GROUP</td></tr>
<tr><td rowspan="2">CENTRAL
COMPLEX</td><td rowspan="2">RANTSER
NAPPE</td><td>RØYRVIK GROUP</td></tr>
<tr><td>HUDDINGSDALEN GROUP</td></tr>
<tr><td rowspan="3">EASTERN
COMPLEX</td><td rowspan="2">LOWER
KOLL
NAPPE</td><td>RENSELVANN GROUP</td></tr>
<tr><td>NORDLI GROUP</td></tr>
<tr><td>SEVE
NAPPE</td><td>HARKJOLEV GROUP
DAERGAFJELL GROUP</td></tr>
</table>

BASEMENT BASEMENT BASEMENT

Namsen Group

The Namsen Group lies within the Helgeland Nappe, and is composed of garnet mica schists and limestones as well as amphibolites in the north at Steinfjell. These rocks have undergone amphibolite facies metamorphism, the grade increasing towards the south to produce gneissic rocks in the Transfjell area which in turn have been intruded by granodiorites and leucotrondjiemites.

Gjersvik Group

The Gjersvik Group was originally considered as a separate nappe, but is now considered part of the Liminoen Nappe, along with the Limingen Group. The Gjersvik Group is of special interest for prospecting as it contains most of the mineralisations of the area. It is divided into six fairly distinct units, although all of the six units do not occur together in any area.

Unit 1

Banded Hornblende Gneiss occurs from west of Tromsvann southwards as far as Grondalen. It has a well developed foliation with alternating bands varying from dark amphibolitic to light quartz-dioritic.

The origin of these rocks is uncertain, however they are thought to be volcanics, with the bands suggesting tuffs.

Unit 2

Banded Amphibolite. This unit is fairly heterogenus, with bands varying from fine dark amphibolite to rather coarse and massive quartz dioritic composition. The coarse material often forms lenses and schlieren. Within this unit there are also numerous keratophyric bands.

Unit 3

Homogenous Amphibolitic Greenstone. This unit is fairly restricted and is deformed in large isoclinal folds. It is a dark green to greenish-black fine-grained rock with a fine, well developed schistocity.

Unit 4

Older Greenstone. This greenstone unit is continuous over long distances and is different from the younger greenstones of the area in that it generally displays a marked banded structure. Altinolite is the main amphibole and subordinate massive greenstone layers form a distinctive lithology. In the south-west this banding becomes much stronger, and with this increase in metamorphic grade horneblende replaces actinolite.

Acid volcanics, keratophyres, are fairly abundant, and most markedly schistose and rich in mila; they are thought to have originated as tuffs. They sometimes occur in alternating bands with basic and intermediate material.

Unit 5

Middle Greenstone. This is the thickest unit of the Gjersvik Group. To the south-east three greenstone units within the Limingen Group sediments are considered to be correlatives of this unit. These occur: (a) fron near Borvann to Ingulsvann; (b) from Gaizervann to Skarfjell; and (c) from Blåmuren to the Grong area.

Lavas of basaltic to andesitic composition are the main constituents. They are typically fine-grained and dark green and most are massive to moderately schistose. Amygdaloidal textures are common, very often with epidote as a main mineral. Epidote-rich segregations are extremely numerous in parts of the volcanics, though mostly rather small. Good pillow structures are rare, but are more abundant in the Skorovas area. Main minerals are plagioclase, chlorite, epidote $\pm$ amphibole (mostly actinolite) $\pm$ quartz $\pm$ calcite. The plagioclase is secondary albite, typically with anhedral form and little altered.

Keratophyres are abundant in the north-west, but subordinate in the south-eastern belts. They are fine-grained, and vary from massive to schistose. The most common minerals are acid plagioclase, quartz, muscovite, chlorite and pyrite. Colour varies from light grey to green. The darker green varieties which are chlorite-rich may be transitional to quartz-rich greenstones.

Unit 6

Younger Greenstones. This greenstone generally occurs in direct contact with the Limingen Group. Near Skorovatn it occurs in complex folds together with Unit 5.

This unit is typically somewhat lighter and finer-grained than the Middle Greenstone, and schistocity varies from weak to penetrative. As in the Middle Greenstones basaltic lava is the dominant lithology. Pillow structures are common from Ingulsuann to Nesådalen, in many places the pillows are closely packed, constituting the greater part of the rock.

Acid igneous rocks are abundant. Some are fine-grained keratophyres, and are thought to have originated as tuffs. A greater part of these rocks, however, show a somewhat coarser porphyritic texture. In some places they penetrate adjacent rocks and are thus clearly intrusive. Most, however, are considered to be of extrusive origin.

Intrusives

The volcanics of the Gjersvik Group are intruded by a large variety of plutonic rocks, indeed the intrusives are approximately as widely distributed as the volcanics. Acid and basic rock types predominate, but there are also intermediate members. The basic rock types have gabbroic to dioritic compositions, often with minor amounts of quartz. Metagabbros are more widespread, gabbros occurring only in the south-west. The acidic rocks are trondhjemmites and granodiorites. Quartz diorites, somewhat more basic than trondhjemites show transitions to diorite. The intrusives were emplaced either earlier than, or contemporaneously with the first deformation phase. They often show a foliation parallel to the schistocity of the adjacent rocks. The intrusives can be divided into three provinces north-western, north-eastern and southern.

1. North-western Province. The intrusives of this province are medium to fine-grained granodiorites and metagabbros/diorites and occur within units 1 to 4.

2. North-eastern Province. Trondhjemites and metagabbros/diorites, often in close association in the same massif, are the main intrusives. They occur within the greenstones an units 4 to 6.

3. Southern Province. This consists of two massifs, the Grøndalsfjell Massif, and a large Southern Massive which is predominantly basic in its northern part (The Hiemdalshaugen Gabbro), but mostly acidic in the south and east.

Structures

The main strike trend over most of the district is NE-SW. Dips are generally to the NW, although a central belt from Jomafjell to Skorovas does dip south-easterly.

This generalised picture is complicated by abundant folds, these can be divided into (a) early folds; and (b) late folds. In brief the 'early' structures are those which formed at the same time as the main schistosity whereas the 'late' folds include a variety of structures which post-date the schistosity.

Clear and continuous tectonic boundaries are scarce in the Grong district. It is believed, however, that several thrusts are present, and that the lack of visible tectonisation is due to later recrystallisation eradicating the effects of the earlier phase of thrusting. Thrust planes are also deformed at late folds.

MOLYBDENUM

Geochemistry of Molybdenum

Molybdenum which has an atomic number of 42, belongs to group VI of the periodic table. Chemically it occurs in valencies of 4^+. 5^+ and 6^+, but in practice only the 4^+ and 6^+ valencies are of any importance. Of these 4^+ characteristics reducing environments and 6^+ oxidising environments. It has seven fairly stable isotopes, although 100^{te} may be produced when 100^{to} acts as a beta transmitter.

Considering radii and ionic changes, there are several ions which should in principle be able to substitute for Mo^{4+}, in molybdenite, namely, Ti^{4+} Cr^{3+} Nb^{4+} Sn^{6+} Zr^{4+} Fe^{3+} and W^{4+}. However, the peculiar trigonal arrangement with 6-fold co-ordination of Mo^{4+} in this sulphate means that only Re^{4+} and W^{4+} satisfy the conditions, and that tungstens high oxygen affinity tends to exclude it from the combination with sulphur. Due to this fact, rhenium is the only foreign element substituting in molybdenite. Molybdenum is rarely found in other minerals, although it is concentrated in the lithosphere by magnetite. Only a few rare occurrences of the element entering the silicate phase in igneous rocks have been recorded. A noteworthy case is the molybdenum sodalite of Vesuvius.

Molybdenum occurs as several mineral forms within the Earth's crust, however the only mineral of any importance is molybdenite. Other molybdenum complexes do exist, but the remainder of the molybdenum generated magmatically is found in mineral substitutions with other elements in crystalline mineral structures.

^{92}Mo	15.86%
^{94}Mo	9.12%
^{95}Mo	15.70%
^{96}Mo	16.50%
^{97}Mo	9.45%
^{98}Mo	23.75%
^{100}Mo	9.62%

The Seven Stable Isotopes of Molybdenum and their Abundances in the Earth's Crust.

Jordisite	$Mo\ S_2$
Molybdenite	$Mo\ S_2$
Molybdite	$Mo\ O_3$
Lundgenite	$Ca_3\ (Mo\ O_4)_2\ (OH)_2$
Wulfenite	$Pb\ Mo\ O_4$
Koechinite	$(B_1\ O)_2\ Mo\ O_4$
Ferrymolybdite	$Fe\ (Mo\ O_4)_3 \cdot 7H_2O$
Ilsemanite	$Mo_3\ O_8\ .\ n\ H_2O$

Main Mineralogical Occurrences of Molybdenum.

Occurrence of Molybdenum in Igneous Rocks

Generally igneous rocks exhibit approximately 15 ppm molybdenum with as little as 3 ppm in more basic varieties of rocks, (Goldschmidt 1958). The greatest concentrations corresponding to biotite, hornblende and accessory minerals such as magnetite. However, this contribution to the total amount of molybdenum is low due to the small amounts present in the rocks. Feldspars, however, store more than 50% of the molybdenum, in spite of the low concentrations, quartz and muscovite are completely barren of the element.

Tungsten and molybdenum commonly occur together, although in any ore deposit, one of them is more dominant. The geochemical distribution of these elements in igneous rocks is characterised by their presence in the late products of magmatic fractionation, thus they tend to be associated with more alkaline/acdic rocks and pneumatolytic events. Molybdenum under these conditions has a greater mobility, thus there may be a transfer of the element from more basic rocks into the final, more acid crystallisation. The molybdenum is often removed by halogen gases and water during final crystallisation and therefore due to its high mobility, the amouht of concentration of molybdenum in in the final intrusive rock may not necessarily represent the contents of the original magma. Post magmatic alteration (albitisation, chloritisation, epidotisation and silicification) which greatly adjusts the molybdenum content of the rock, may even remove all of the element from the rock itself, besides changing the amount present. This leaching process, if followed by a concentration phase, would possibly be sufficient for generating molybdenum deposits from enriched magmas.

In the pneumatolytic stage molybdenum migration is only feasible above 373^{o}C and upon a low pH. On cooling water and any halides present react and are hydrolysed. The formation of minerals that remove flourine and chlorine will cause   of molybdenum, sililarly a high concentration of sulphur ions will cause deposition of molybdenum.

Weathering and Sedimentation of Molybdenum

In the weathering zone the only molybdenum minerals of any importance are Wulfenite and Powellite, the latter occurring in the oxidation zone of load deposits. These secondary minerals, including illsemanite are often the only indications of the presence of molybdenum.

Most of the molybdenum in igneous rocks goes through a solute phase before it is precipitated. This takes place more obviously in oxidate sediments, espeically where Mn^{III} or Mn^{IV} is being precipitated.

In the sedimentary cycle, under strongly oxidising conditions, molybdate ions may become mobile and migrate, along with vanadium, through sediments. Under these sort of conditions molybdenum is precipitated as molydenite, e.g. in the Kupfershiefer, where it is concentrated in amounts up to 1500 p.p.m.

Types of Molybdenum Deposits

Molybdenum deposits may be classified under five broad headings (Jensen and Bateman 1970):

1. Porphyry or Disseminated Ore.

   Included here are stockworks and breccia pipes, and examples of this type of deposit are found at Climax, Urad Henderson, Bingham and numerous porphyry copper-molybdenum deposits.

2. Contact - Metasomatic deposits.

   These include Pine Creek, California; Helvetia, Arizona; and deposits in Russia, Morocco and Norway.

3. Stockwork Quartz Veining Type.

   The best example of this type of deposit is found at Questa, New Mexico, where the molybdenite occurs in massive quartz veins in a stockwork of discontinuous veinlets and disseminated flakes in a fractured zone, several thousand meters wide. It is possible that the molybdenum in the Gaizervann area occurs in this type of deposit, but on a much smaller scale.

4. Pegmatites and Aplite Dykes.

   Examples of this type of deposit include Most Mine Quebec; Vol.D[1] Or and Preissal Quebec.

5. Bedded Deposits in Sedimentary Rock.

   Sandstone uranium type deposits occur in Arizona, Utah, Colarado, New Mexico, Wyoming, South Dakota and Texas.

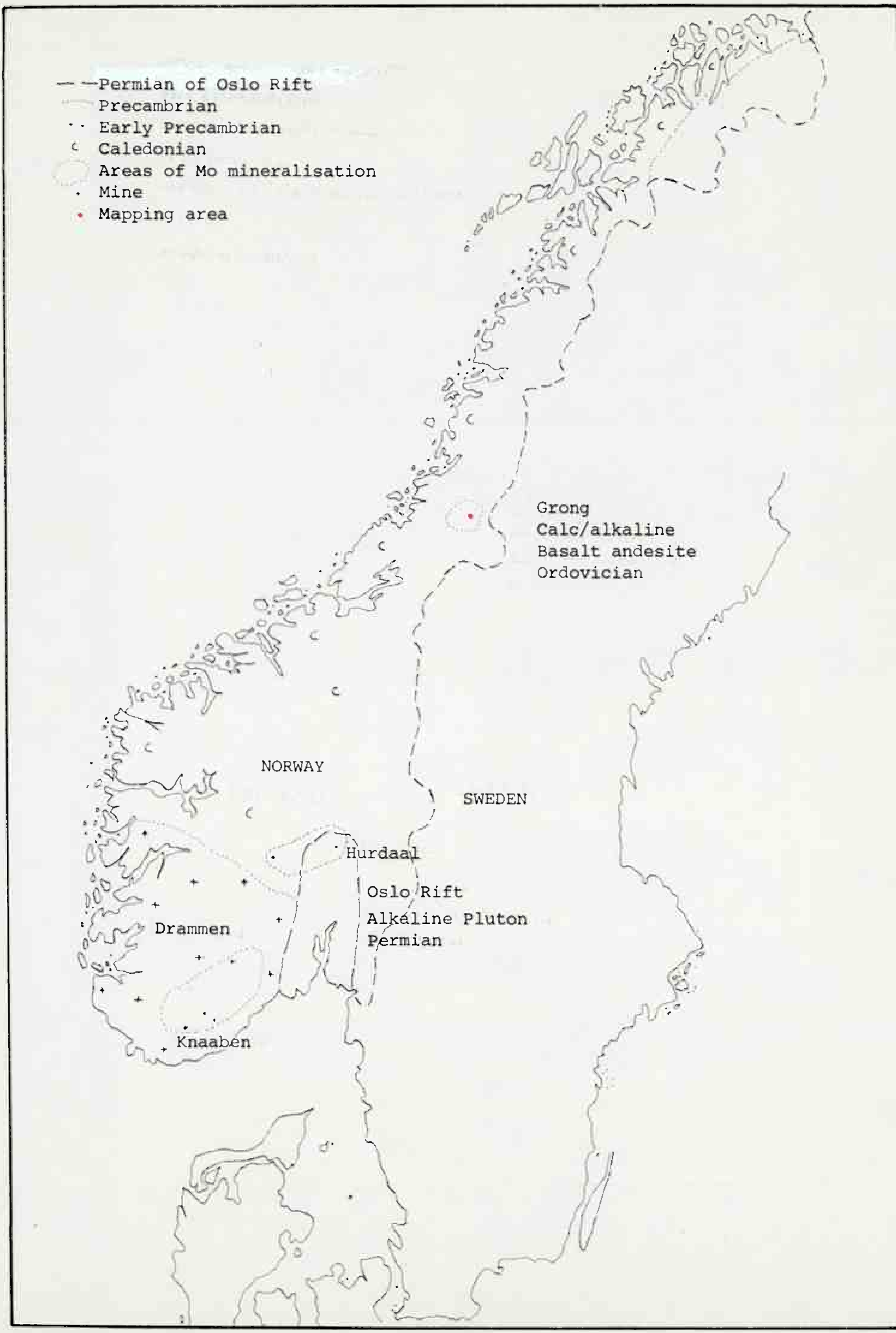
Molybdenum Deposits in Norway

According to Bugge, there are four main types of Norwegian molybdenum deposits; molybdenum mineralisation in amphibolitic gneisses, slightly impregnated with sulphides. Disseminated molybdenite in granites, molybdenite bearing aplites and granite pegmatites, and molybdenite bearing quartz veins and lenses associated with sulphides.

The main areas of molybdenum veining were at Knaben, where proved reserves of MoS_2 were 2,500,000 tons with a grade of 0.15%, with estimated reserves of a similar amount. At Ørsdalen there is a molybdenum-tungsten mine, where MoS_2 is extracted along with tungsten, scheelite and wolframite. Native bismuth and bismuthinite have also been identified. There are also mines at Flottorp, about 20 km south-west of Knaben and Gursli, 40 km south-west of Knaben. In the Telemark area Dalen Mine produced about 100 tonnes of Molybdenite and Bandaksli 15-20 tonnes of MoS_2.

Molybdenum has also been discovered at Fremsterfjiell, near Grong, about 10 km south-east of the Gaizeruann area.

NORWEGANN MOLYBDENUM DEPOSITS



PETROLOGY

INTRODUCTION

The Gaizervann belt of volcanics is a mixture of greenstones and greenschists which can be traced from Skarfjell in the south-west to Storgaizervann in the north-east. Apart from an isolated, indistinct possible pillow, primary volcanic structures were not observed and the majority of the basic volcanics are massive with a weak schistocity which suggests they were probably originally lavas. In several localities the rocks were found to be well foliated.

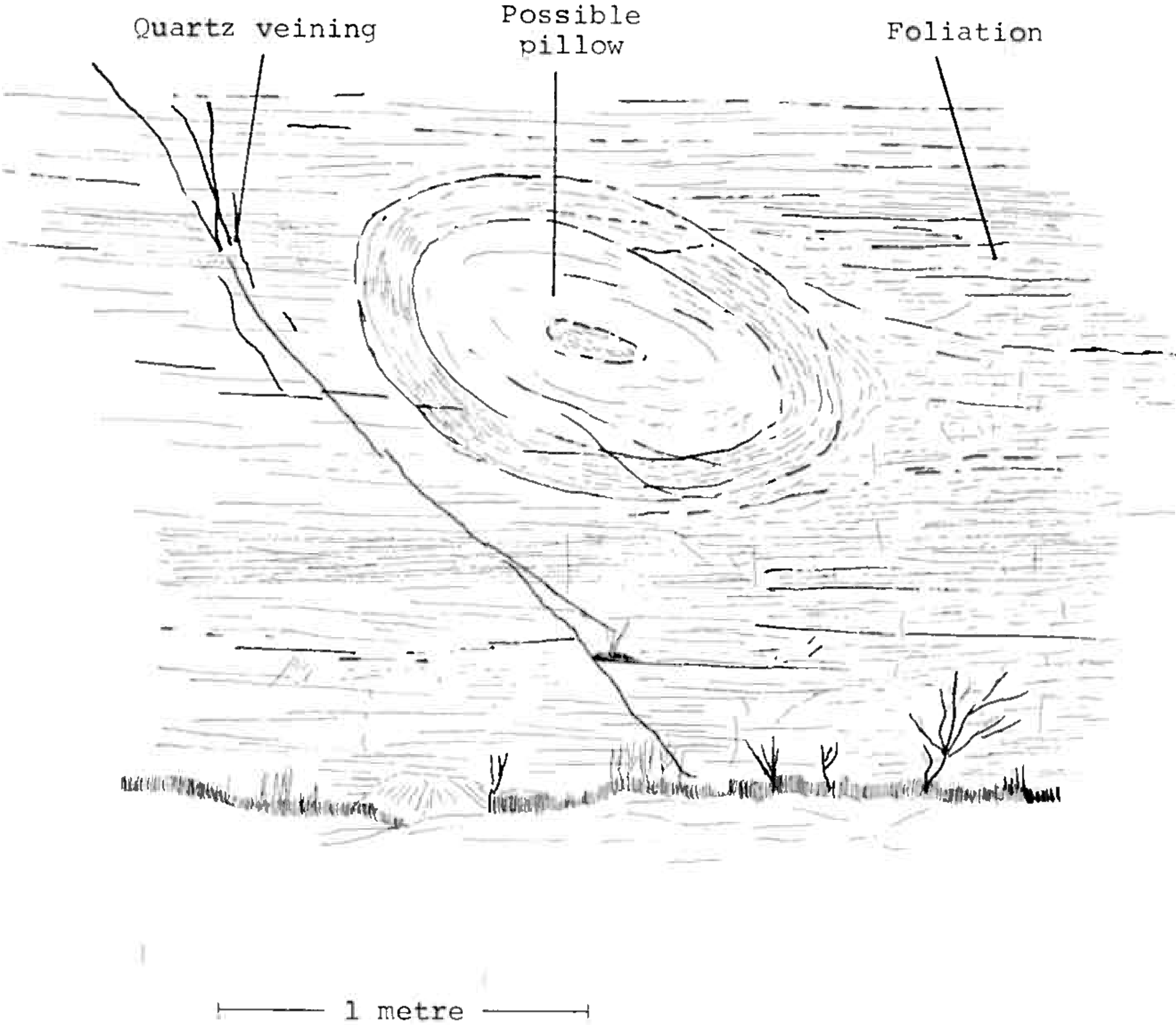
The Gaizervann volcanics have been severely dissected by a series of trondhjemite/granodiorite intrusions, presumably related to the main trondhjemite mass. The differences between the trondhjemite and granodiorite were found to be slight and thus the two rocks were napped as one unit.

The trondhjemite/granodiorite is dominantly medium-grained but contains fine-grained mineralised zones of pyrite, e.g. south of Gaizervann. The trondhjemite/granodiorite intrudes the greenstone and may completely engulf large blocks of greenstone which now remain as isolated rafts within the trondjemite/granodiorite. Elsewhere it occurs as veins and small stocks cutting the greenstone.

The Gaizervann greenstone belt is essentially a body of greenstone that has been intruded by a small stock of trondhjemite/granodiorite. The centre of this stock is probably located between Gaizervann and Gaizjavre where the greenstones occur as rafts within the intrusive mass. Two ages (or phases) of intrusion are clearly present in this area. The earliest phase of intrusion is fine- to medium-grained and pyritized. This was later intruded by a medium-grained non-pyritic trondhjemite.

These rocks were eroded to form the polymict greenstone trondhjemite/granodiorite conglomerate which was laid down on top of them. No evidence of the age relationship between the later intrusive phase and the conglomerate along the east contact of the Gaizervann greenstone belt was seen. However, this conglomerate may be equated with the polymict conglomerate overlying greenstones north-west of Pervatn. If the medium-grained trondhjemite/granodiorite of the Gaizervann greenstone belt can be shown to be older than the polymict conglomerate, then there must be at least two intrusive phases in the area.

POSSIBLE PILLOW LAVA IN MAPPING AREA



Granodiorite

Of all the coarse-grained, quartz-rich rocks, granodiorites, are quantitatively the most important; and indeed are more widespread than all the coarse-grained intermediate and basic rocks combined. In order to avoid confusion it is best to regard granodiorite as having at least two-thirds feldspar and being quartz-rich, while rocks such as tonalite and diorite contain quartz as an accessory only, and not as an essential component. Granodiorites, then, are coarse-grained igneous rocks containing essential quartz, with plagioclase dominant, though alkali-feldspar may occur, but must not exceed one-third of the total feldspar present. These felsic minerals are usually accompanied by a varying proportion of coloured silicates and accessory minerals, of which biotite and horneblende are usually present in the former and sphene and magnetite in the latter.

Granodiorites in which alkali-feldspar is completely (or almost completely) suppressed, have been termed trondhjemites, which are also found in the Gaizervann area, are also dealt with in this section.

The granodiorites of the Gaizervann area have the following element characteristics:

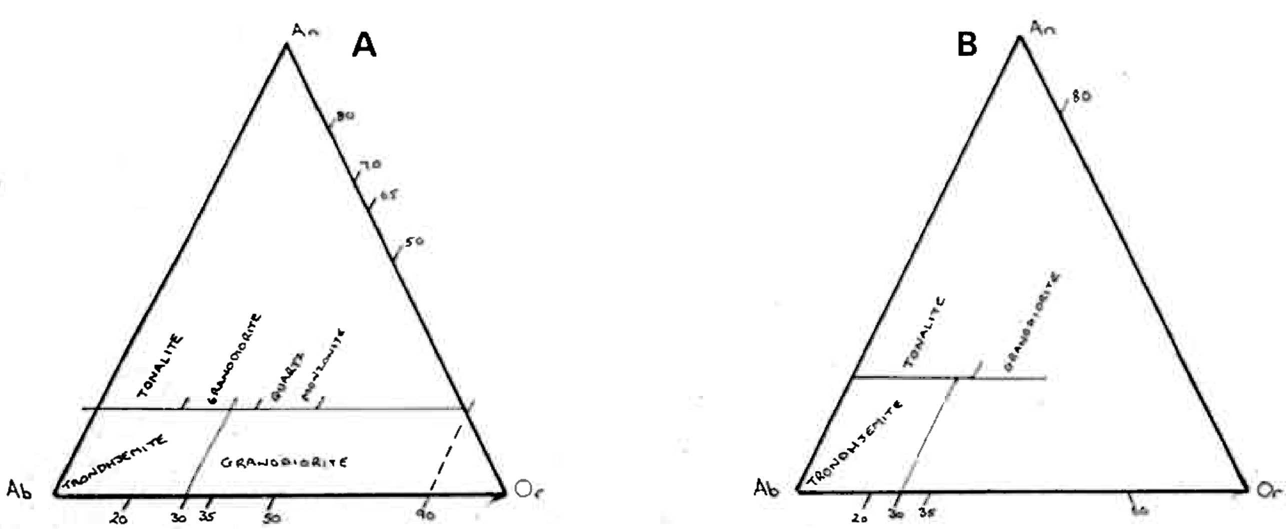
Feldspars	41%
Quartz	27%
Epidote	17%
Pyrite	4%
Chlorite	3%
White Mica	6%
Spinel	2%.

Within the rock large feldspars are present which in places are somewhat patchy and appear 'dirty' towards the centre. This 'dirty' and patchy nature of the feldspars is possibly due to alteration effects, elsewhere in the rock feldspar alteration to white mica and sericite is widespread. There is also some apparent zoning of the feldspar crystals. Also the crystals may be idiomorphic in nature, with fresh specimens indicating on oligoclase/andesine composition with little or no potash feldspar.

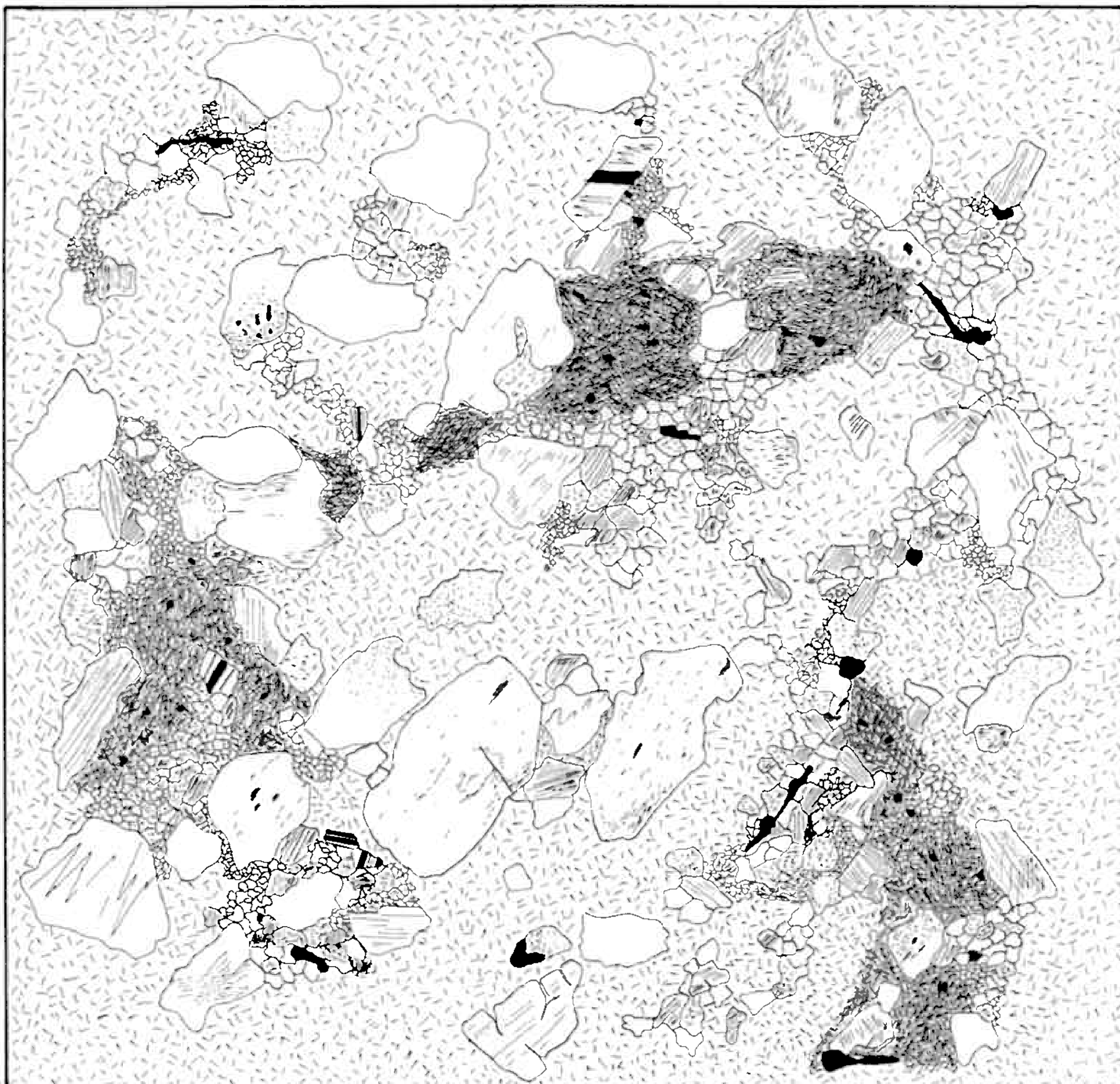
Epidote occurs in large amounts in anhedral crystals, possibly due to the decomposition of feldspar. Small epidote veinlets are also common and are probably due to late stage epidotisation of the granodiorite mass.

Surrounding the feldspars and quartz is a finer-grained groundmass of quartz, feldspar (orthoclase), white mica and lath-shaped chlorite crystals, giving the rock a hypidio-morphic texture; i.e. feldspars exhibit crystal faces yet other minerals are anhedral.

Sphene is also present in the groundmass in the typical envelope-shaped euhedral crystals indicating formation at an early stage. No mafic minerals (biotite and amphibole) which are normally associated with granodiorites are present, and it is probably best to regard this rock as a biotite/ amphibole free granodiorite.



Normative plots of Ab-Or-An showing fields of some siliceous plutonic rocks. A after O'Connor 1965, B suggested Modification.

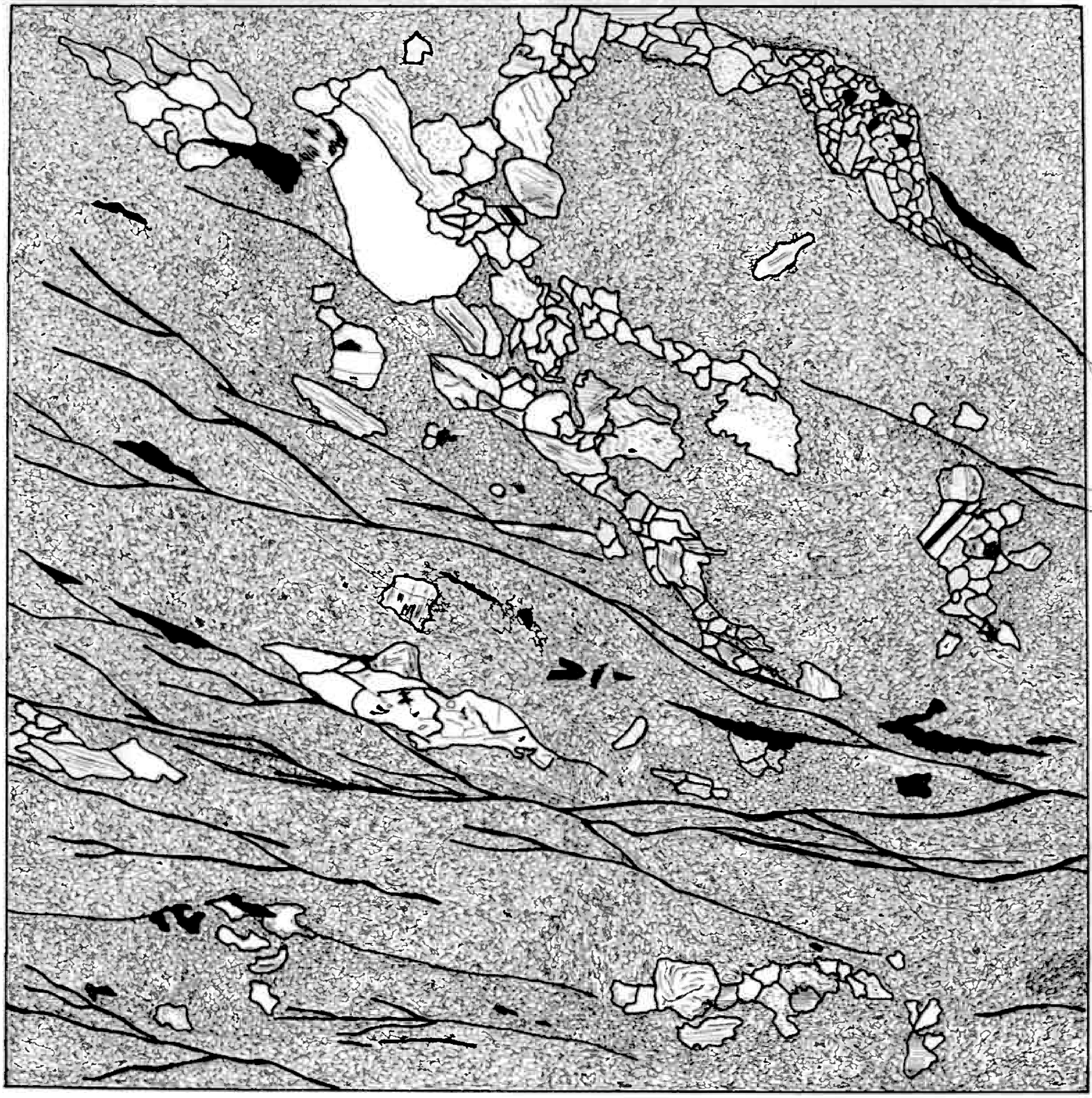


Field of view 1 cm x 1 cm

Granodiorite/Leucogranodiorite

Quartz	Chlorite
Plagioclase	Muscovite (sericite)
Epidote	Sphene

The ore mineral is pyrite groundmass of quartz, plagioclase, chlorite and sericite.



Field of view 1 cm x 1 cm

Schistose Granodiorite

Plagioclase	Calcite
Epidote	Quartz
Chlorite	Sericite

Highly schistose grandiorite, numerous epidote stringers, pyrite is the ore mineral groundmass of fine quartz, sericite, plagioclase and chlorite.

<u>Greenstones</u>

The greenstones of the Gaizervann belt were found to vary from massive greenstones to foliated greenschists. An average mineral composition is as follows:

Chlorite	25%
Epidote	20%
Biotite	16%
Feldspar	14%
Amphibole	7%
Quartz	6%
Pyrite	4%
White Mica	4%.

Epidote is found in large amounts, and is of the pistacite variety, identifiable by its yellow/green colour and its high relief. It is often associated with amorphous chlorite crystals, some of which may originate from epidote decomposition. The epidote itself occurs in large subhedral clots and small veinlets throughout the rock.

Amphibole occurs as sub-anhedral crystals, pale to dark grey/green in colour and is often in evidence as intergrowths with epidote.

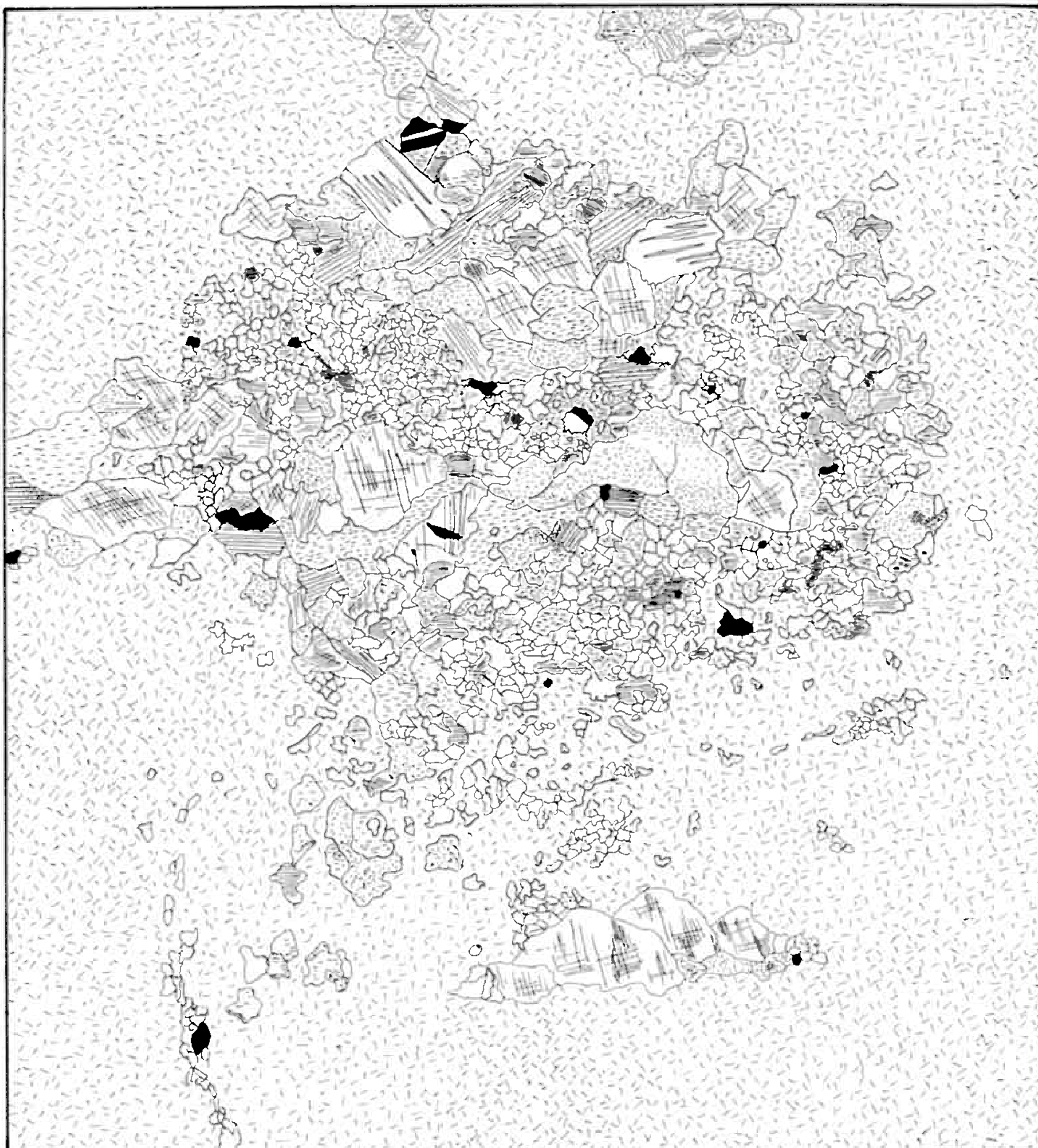
The groundmass is mainly fine quartz and plagioclase feldspar of probable oligoclase/andensine composition. Mica is also present and gives a linear fabric to the assemblage epidote and chlorite are also present in the groundmass, as are small amounts of actinolite.

Quartz and calcite occur in small clusters of crystals and in small veinlets and stringers. It seems reasonable to assume that these were originally the infills of vesicles or amygdales within the lava, from which the greenstones were derived, after metamorphism to greenschist facies.

Within the main greenstones were found two quartzo-feldspathic lenses of rock, with up to 50% pyrite, mostly in small well formed sub-parallel veins. These probably originated as sea floor geysers exhaling sulphide material on to the sea floor, during the formation of the main lava mass.

The rock was probably originally some type of volcanic lava or tuff with a pyrite exhalative, later metamorphosed and recrystallised.

Small amounts of pyrite are virtually ubiquitous to the greenstones and appear to have developed during or after recrystallisation. Towards the mineralised area the amounts of pyrite increase, and small veinlets become quite common, giving the rocks a rusty weathered surface.



Field of view 2 cm x 1.5 cm

Basic Greenstone

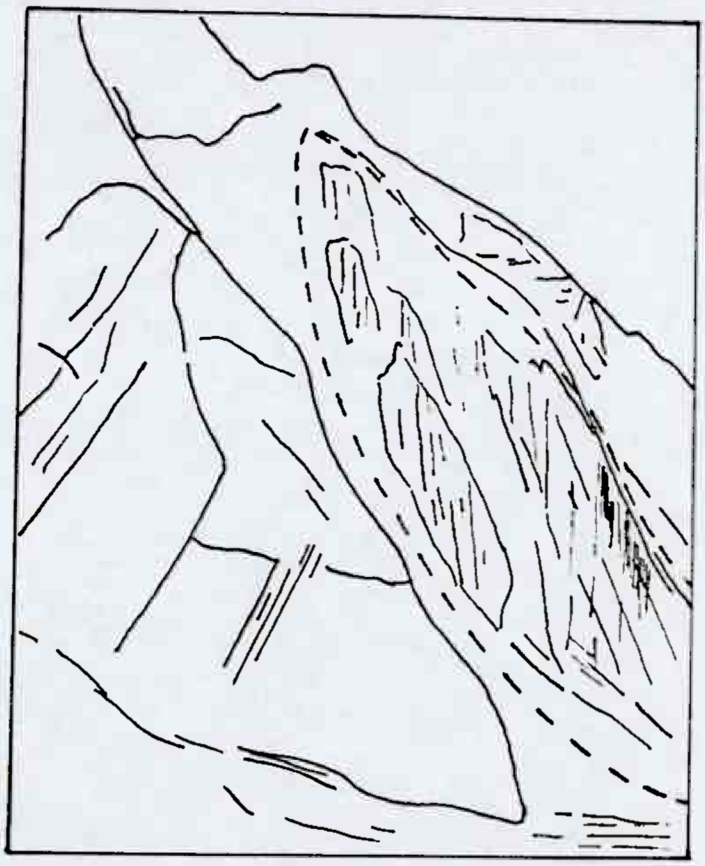
Chlorite	Plagioclase
Epidote (Pistacite)	Quartz
Actinolite	Calcite

The ore mineral is pyrite; biotite, chlorite and epidote form most of the section, quartz and calcite form amygdales groundmass of quartz, plagioclase, sericite and chlorite.

Grandiorite

Grandiorite

Basic
greenstone
lens



Grandiorite

Grandiorite

Basic
greenstone
lens

– – – – Boundary of greenstones

LENS OF GREENSTONE WITHIN GRANDIORITE

Trondhjemite

Goldsmidt first defined trondhjemite in 1916, giving the type area as trondheim-gebeit, however, it was not a quantitative definition and furthermore, the intrusions of the type area have had much of their original mineralogy obliterated by metamorphism to greenschist facies. It is probably more useful to use the IUGS definition of trondhjemite as an albite or oligoclase bearing leucotonalite, and to have andesine bearing leucotonalite termed calcic trondhjemite.

The major element characteristics of trondhjemites, as defined by the IUGS are:

SiO_2 > 68%, usually about 75%

Al_2O_3 typically > 15%

FeO + MgO < 3.5% while in calcic trondhjemites typical values are in the order of 1.5% - 3%

Na_2O typically 4.0% - 5.5%

K_2O < 2.5% typically 2%.

The separation of trondhjemites into low Al_2O_3 and high Al_2O_3 types should be made at 15% Al_2O_3 and at 70% SiO_2.

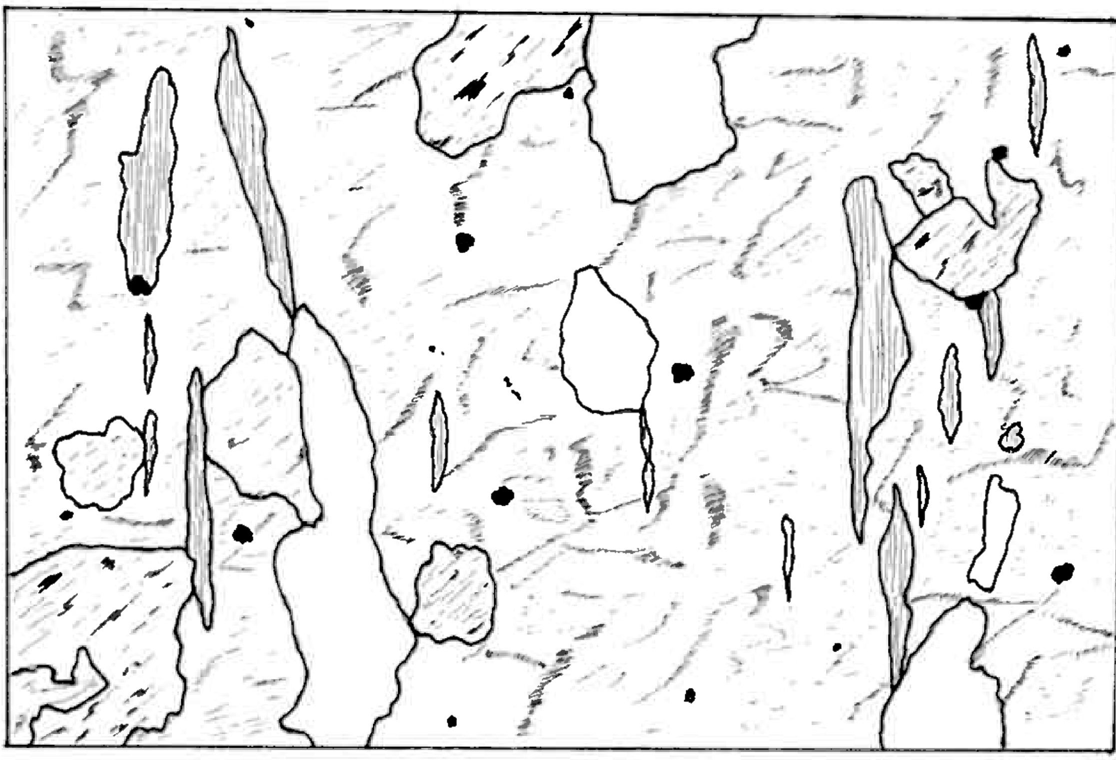
The major element characteristics of the trondhjemites in the Gaizervann area are as follows:

Feldspars	40%	(plagioclase in the range of oligolase to andesine)
Quartz	31%	
Epidote	14%	
White Mica	10%	
Pyrite	4%	
Chlorite	75%	
Spinel	25%	

A high proportion of the feldspars present appear to be highly sericitised with replacement of the feldspars by white mica, due to this high degree of alteration, a determination of the feldspar composition is hard to obtain, however, some crystals do exhibit ghost lammelae twinning and fresh specimens indicate an oligoclase/andesite composition. Epidote comprises a noticeable amount of the rock and occurs within clots, of up to .5 mm across, and in narrow veinlets, which probably contain most of the epidote present. These small veins occur over a wide area, and were found to be similar to veins which contained large amounts of pyrite in the mineralised zone.

The groundmass of the trondhjemite in this area is mainly quartz, white mica and small amounts of chlorite, which give the rock a weak linear fabric in places.

Some of the larger quartz crystals appear to be elongate with white micas "flowing" round the tips of the crystals. This is very variable and is either due to original flow in the magma or secondary alignment due to deformation effects. Some orthoclase may be present but it is subordinate to the oligoclase/andesine types, any sphene is in the form of euhedral envelopes and is thus early in origin during the rock's formation.



Field of view 1 cm x .5 cm

Leuco Trondhjemite

Plagioclase Relicts	Altered Plagioclase
Quartz	Muscovite

The ore mineral is pyrite, the plagioclase has been albitised and sericitized epidote is also present in small amounts.

Meta Conglomerate

A thin unit of conglomerate, with fragments from pebble up to cobble-size occurs along the south-west edge of the Gaizervann greenstones. The included fragments include basalt and granodiorite/trondhjemite set in chlorite rich basic matrix. The rocks exhibit vague bedding in places and are generally steeply dipping, but in places appear to be flat-lying and unconformably overlying the greenstone and granodiorite trondhjemite. This unit, is in faulted contact with the younger arkoses and has been cut out by that fault in several places and can be followed for some distance westwards. On the basis of the lithology of the fragments, matrix and stratigraphic position, this conglomerate is considered equivalent to the conglomerate overlying the Nesabvaan greenstones. Thrusting and faulting causes the small thicknesses encountered here.

Arkose

The arkose found in the area proved to be a medium-grained quartzo-feldspathic rock with about 8% calcite on average, and minor muscovite. It was found both on the shores of Gaizervann and further to the south-west, associated with the conglomerate. The arkose was found to exhibit relict cross-bedding structures in places, which were indistinct, but still fairly recognisable, and extensive. The arkose and conglomerate in the south-west appear to merge north-west of Storgaizervann,and in the literature are referred to as one formation, the Havdalsvann formation. These rocks represent a heavily deformed and metamorphosed sediment, and are considered to overlie, conformably the calcareous sediments to the north-west of Gaizervann.

Calcareous Sediments

The calcareous sediments occurring to the north and west of Garervann consist of puyllite, silts, limestone-conglomerate rock and arkosic units. These sediments appear to overlie the greenstones, granodiorites and trondhjemites, and may, in fact, be gradiational into them. However, this was not established as outcrop and exposure was found to be poor in the area of contact. It is possible to consider the differing rock types as originally a marine sequence, in which the component units have reacted differently to the effects of deformation and metamorphism. The more arkose units were found to be of a similar nature to those found further south, adjacent to these sediments. This could possibly support the idea of a gradational boundary, with the original marine arkose grading into deeper water sediments of silt and limestone, with occasional shallows represented by areas of arkose within the deeper water rocks. The limestone conglomerate has a calcareous matrix, the conglomerate being formed at a similar time to the other sediments. The area was not mapped in detail due to poor exposure and was considered as one unit. The contact with the greenstones, is one of faulted nature.

Calc Psammites

Brown weathering calcareous sediments were found to the south-west of Gaizervann, adjacent to the greenstones and the belt of calcareous sediments. Bedding was difficult to recognise due to the presence of a strong penetrative regional foliation which has removed and destroyed any original layering that may have been present. Carbonate weathering along the foliation planes often gives an impression of layering. This unit overlies the greenstones and is probably faulted against the calc sediments.

Structure

The earliest tectonic structures in the area are a schistocity S_1, and a particle lineation L_1. The schistocity is present in all rocks of the area, while the lineation possibly slightly predates the schistocity. The lineation in the conglomerates and arkoses in the south-west approximates to the hinge of an upward facing F_1 isocline in these rocks. This is the only F_1 fold identified in the mapping area, although the metasediments were not mapped in detail.

North-west trending F_4 open folds, are probably the cause of broad gentle warping in the metasediments to the north-west of Gaizervann.

There are up to three phases of faulting in the mapping area, and it appears that the metasediments to the north and south of the mapping area are bounded against the greenstones by faults of this age.

Cross-bedding and cut-fill structures are present in the arkoses of the area, pillows may be present in the greenstones but were not positively identified as such.

Polished Sections

A number of polished sections were prepared from hand specimens collected in the field, and numbered A to I.

Gaizervan A

This section of the volcanic exhalative rock found in the mapping area. It comprises pyrite and minor chalcopyrite set in a shaley silica-rich amorphous groundmass. The pyrite is in the form of anhedral crystal masses and has a pale yellowish-white colour in reflected light. The specimen contains approximately 35% pyrite and .5% chalcopyrite. Chalycopyrite may be differentiated from pyrite because of its brassy-yellow colour, it also has an anhedral form. There is a suggestion of crude banding.

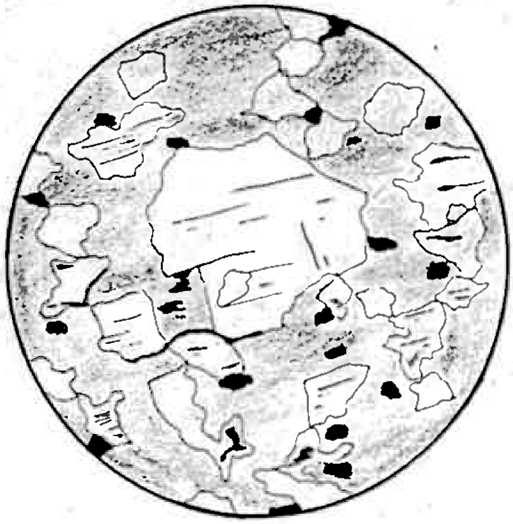
Gaizervan B

Section B contains pyrite and epidote in veins, set in quartz-rich matrix. Pyrite in the veins is in the form of anhedral masses, although one or two euhedral cubes are visible, and is fairly coarse-grained. No chalcopyrite was found. The veins are closely related, although they do not cut each other.

Gaizervan C

This was found to be another example of the volcanic exhalative rock. It is rich in pyrite, this mineral constituting up to 45-50% of the section. Chalcopyrite was again present, although in small quantities, comprising only about .5% of the section. Both pyrite and chalcopyrite occur as medium- to coarse-grained anhedral aggregates, set in a grey-black silica-rich matrix. This matrix has a banded appearance, and the pyrite and chalcopyrite occurs in small subparallel layers, possibly along the cleavage planes.

GAIZERVANN A



2 mm

 Pyrite

 Chalcopyrite

 Silica rich groundmass

GAIZERVANN C

2 mm

 Pyrite

 Chalcopyrite

 Silica rich shaley groundmass

Gaizervan E

This is again a volcanic exhalative rock, however, with pyrite as the dominant mineral present. The pyrite is in the form of coarse anhedral crystals and comprise over 55% of the slide. It is associated again with minor chalcopyrite, comprising about .5% of the slide. These minerals are set in a silica-rich amorphous groundmass.

Gaizervan F

This section was found to be similar to Gaizervan C, containing coarse pyrite and minor chalcopyrite set in a silica-rich groundmass.

Gaizervan G

The predominant feature of this section is the amorphous silica-rich groundmass in which are set small anhedral pyrite crystals, and possibly some minor feldspar. Epidote is present in fairly large amounts. The amount of pyrite is much smaller in this section, comprising approximately 20% of the section.

Gaizervan H

Pyrite comprises the major feature of this section, the crystals being up to 2 mm in size and having an anhedral form. Chalcopyrite comprises less than .1% of the rock. The Groundmass is again of silica-rich shaley material.

Gaizervan I

This section is composed of quartz and minor scattered pyrite. Small specks of fine molybdenum were located, but not as much as was expected. The hand specimen being rich in coarse molybdenum. This lack of molybdenum was probably due to the desctruction of the molybdenum flakes in the preparation of the section.

GAIZERVANN H

2 m

Pyrite

Quartz

Silica rich groundmass

* the deposit is not disseminated!

Mineralisation

Pyrite occurs in the Gaizervann area in a disseminated deposit and in veins associated with quartz and molybdenum, often with minor chalcopyrite. Lenses of silicified greenstone contain up to 50% pyrite in small subparallel veins, associated with minor chalcopyrite. No molybdenite was found in these lenses. The ground around the silicic lenses is also highly pyritised, and the area is considered to be an early intrusive phase of the granodiorite containing drafts of greenstone, which was later intruded by post-mineralisation granodiorite. The silicic pyritised lenses themselves are presumed to be of a sea floor exhalative origin.

Molybdenite bearing quartz and quartz pyrite veins were first discovered in the pyritised area in 1973. Close study of the area revealed that molybdenite was present in quartz veins as random to subparallel tiny (< 0.1 mm) hexagonal plates embedded in the vein-filling quartz. It was also found as a "dry paint" along joint planes and fractures. As many as nine individual quartz/pyrite/chalcopyrite/molybdenite veins were located, often with visible molybdenite. The strike of the quartz molybdenum was found to be approximately 080°. The most spectacular example of a quartz molybdenum vein was found adjacent to Gaizervann in the pyritised area. This was a large grey quartz vein, up to 2 metres wide and 50 metres long, containing large amounts of coarse-grained molybdenum. Small amounts of pyrite and chalcopyrite were present along the vein margins. Chalycopyrite itself was found in minor amounts throughout the pyritised area.

The mineralisation, therefore, occurs within the trondjhemites and granodiorites, associated with the middle "greenstones of the Gjersvik Group. It occurs as molybdenite in a number of individual veins of quartz/quartz-pyrite and as a "dry paint along joint planes and fractures of the host rock. Two probable phases of molybdenisation were produced by hydrothermal solutions intruding the igneous rocks of the greenstone belt. It is of the calc alkaline porphyritic type, associated with subduction zones.

In view of the mineralisation found in the Heimdaalshaugen area (8 km SW). These initial findings are encouraging. It is possible that as in the Heimdaalshaugen area, drilling will reveal mineralisation at depth, putting the surface molybdenum showings into perspective.

Mineralisation in the Gaizervann Area

Pyrite: Both disseminated and in veins.

Disseminated throughout rock 2%.

In mineralised area 10-15%, in silicified greenstone ≈ 50%.

Both veins and disseminated forms. In veins with quartz, molybdenum and possibly chalopyrite.

Chalcopyrite:

Small amounts in veins with quartz
Possible very small disseminated amounts with pyrite
} in mineralised area

Molybdenum:

In veins in mineralised area, with grey quartz, pyrite and possibly chalcopyrite. Veins from as little as 1 cm up to large .5m-2m wide vein. Rough vein trend 080°.

Above are merely surface traces, the mineralisation probably continues at depth.

Origin of the Ores

The genesis of porphyry-type deposits has been the subject of considerable study and remains, in part conjectural. All these deposits occur within, or very close to orogenic zones; however it appears that there is a distinction between the two major types with Cu-bearing porphyries lying along consuming plate margins, whereas Mo-bearing porphyries are typical of tensional (rifting) margins. Sillitoe (1972) has suggested that the porphyry bodies represent partially melted oceanic rocks that have transported metals originally emplaced at mid-oceanic ridges, been subducted, and then transported and emplaced along continental margins.

The emplacement of a porphyritic magma to within 0.5 to 2 km of surface established convective motions in the adjacent groundwater system if the surrounding rocks have reasonable permeability. Hot chemically potent solutions rise above the stock as new, initially cool, solutions circulate in toward the stock. As a result of the cooling, the outer shell crystallizes; the shell is subsequently highly fractured by pressure building up from H_2O released from the crystallizing magma. The central core is quenched to a porphyry, cut by a stockwork of quartz and quartz-feldspar veinlets as heat is rapidly lost to the groundwater system. Precipitation of the sulphides, molydenum and quartz in these veins occurs at temperatures as high as 725° C in the potassic zone and around 300-390° C in the argillized zone.

Fluid inclusion studies by several workers have shown that the fluids that deposited ores in the cores of copper-molybdenum deposits were highly saline (often containing more than 60% salts), underwent extensive boiling, and were trapped at temperatures up to $725^{\circ}C$. In some deposits distinct zones of the hypersaline inclusions correlate not only with the ore zones but also with the fracture systems believed responsible for the introduction of metals.

Photogeology

Clearly visible, and possibly the most striking feature of the aerial photographs are the linear features situated in the south of the mapping area, in the series of conglomorates and arkoses. These linear features run parallel to the apparent strike of the rocks (roughly E-W) and appear to run uninterrupted along the rock outcrop visible in the photographs. There are as many as twenty of these features, all of which run approvimately parallel to each other.

It is possible to assume that these features are a series of faults or shears in a zone, but as the linear features occur in rocks of a sedimentary origin, it is probably more reasonable to assume that these linear elements are, in fact, relict bedding structures, the bedding dipping north or south at steep angle. These features occur suddenly and cease at the boundary of the sediments with the greenstone belt to the north.

Similar structures were also found in an area of arkosic sediments to the north of the greenstone belt, adding weight to the idea of relict bedding. In the field these features were not as obvious, but study revealed them to be indeed relict bedding structures.

To the north of these sediments lies the Gaizervann greenstone belt, consisting of greenstones granodiorites and trondjhemites. On the photographic evidence it is impossible to differentiate between these rocks, and it is enough to state that these three rock types form a belt which runs through the centre of the photographs.

To the north of the greenstone belt, its boundary with the calcareous sediments to the north appears to be marked by a zone of faulting or shearing running in a north-west/ south-east direction. There appears to be no relict bedding visible in these calcareous sediments, although the terrain has a distinct grain or fabric running in a north-west/ south-east trend. This is possibly due to the phyllitic nature of much of these rocks.

Possibly the greatest value of these photographs is in the location of large faults. There are numerous faults in the area, including the zone of faulting mentioned before, some of which appear to be fairly extensive and of large size. The majority appear to have a north-west/south-east or east-west trend. They occur on all rock types and have been marked on the photographs and final map.

Finally the photographs are of use in gaining an idea of the terrain encountered in the field area, and to give an indication of the outcrops and their patterns.

REFERENCES

BUGGE, J.A.W., 1978. Mineral deposits of Norway. In: Bowie S.H.U., Kvalheim, S. and Haslam, H.W. (Ed), Mineral Deposit of Europe. Volume 1 North-west Europe. The Mineralogical Soc. London, pp. 199-249.

BUGGE, J.A.W., 1963. Norges Molybdenforekomster, Norg Geol. Unders 217, pp. 134.

GALE, G., 1975. Geology and sulphide mineralisation in the Sandøla-Gaizervann area, Grong, Nord Trøndelag, Norges Geol. Unders. Report 1293. Unpublished.

HATCH, F.H., WELLS, H.K. and WELLS, M.K. Petrology of the Igneous Rocks. Thirteenth Edition. Allen and Unwin London.

JENSEN, M.L. and BATEMAN, A.M. Economic Mineral Deposits. Third Edition. J. Wiley and Sons, London.

KOLLUNG, S., 1979. Stratigraphy and major structures of the Grong District, Nord-Trøndelag. Norges Geol. Unders. 354 pp. 1-51.

Kollung, S. Geological Report 1976, Grong Gruber A/S; 1976.

Oftedahl, CHR, 1958, A theory of exhalative sedimentary ores.

Geol. För. Stockholm Förh. 80.

ROBERTS, D. 1978. Caledonides of South Central Norway. In: Schenk, P. (Ed): The Caledonides of North Atlantic Region. Geol. Survey of Canada Paper, 78-13.

RAHEIM, A., GALE G, & ROBERTS, D., 1979: Rb/Sr ages of Basement genisses and supracrustal rocks of the Grong Areá, Nord-Trøndelag, Norway. Norges Geol. Unders. 354, 131-142.

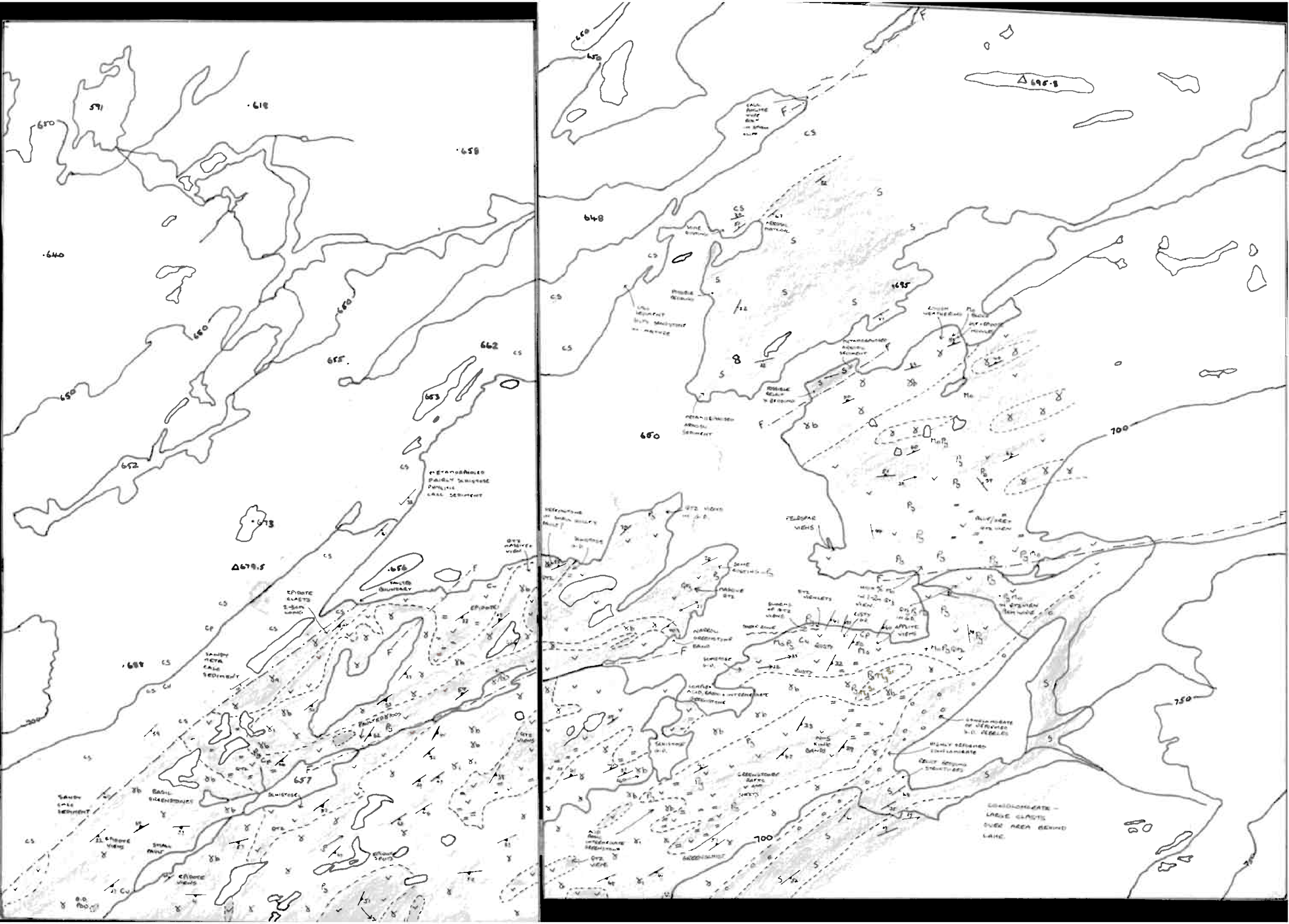
STRAND, T. and KOLLING, O., 1972. Scandinavian Caledonides. Wiley - Interscience, London.

VOKES, F.M., 1969. A review of the metamorphism of sucphide deposits.
Earth Science Review 5, pp. 99-143.

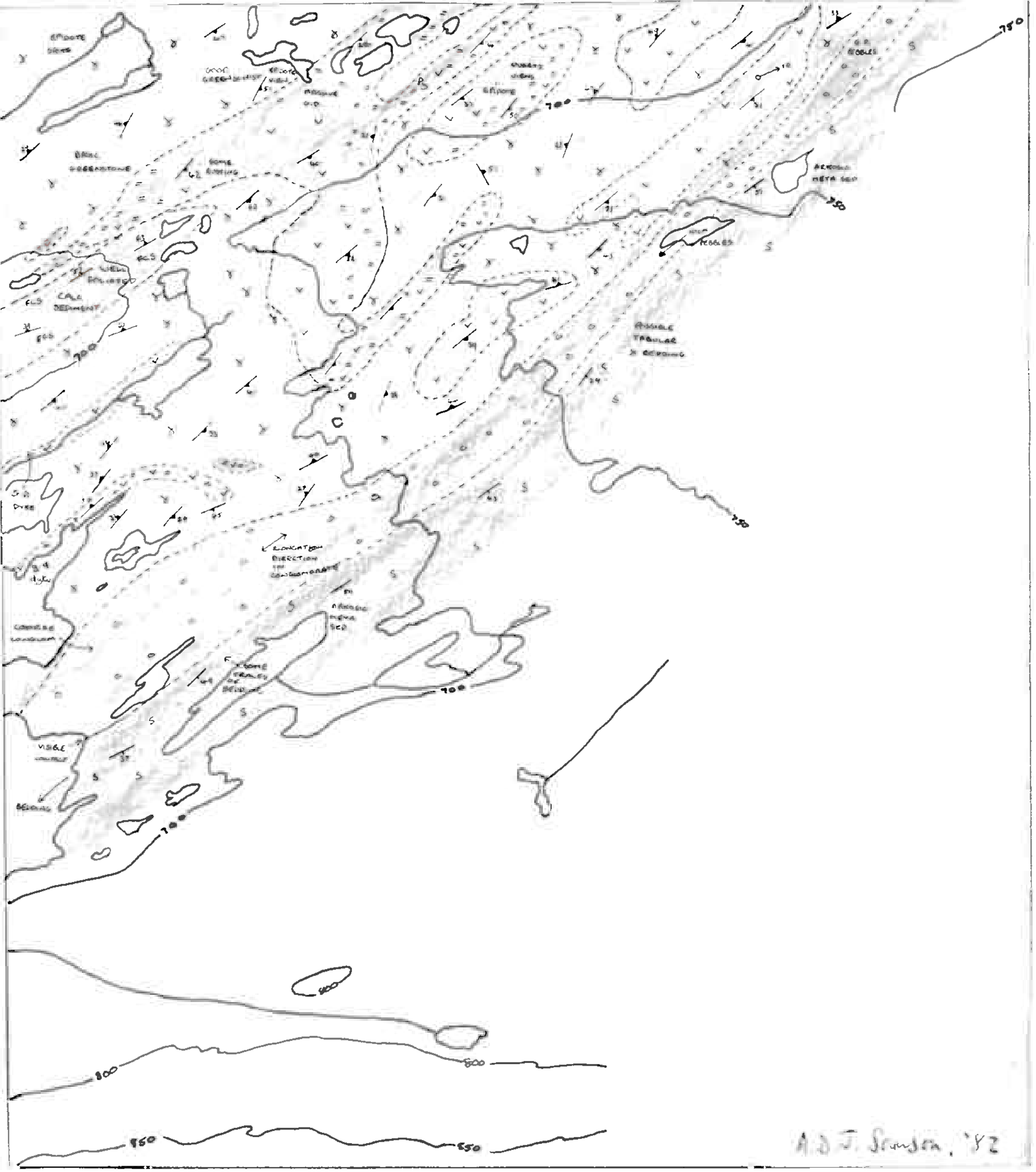
VOKES, F.M., 1963. Geological studies on the Caledonian pyritic zinc-lead ore body at Bleikvassli, Nordland, Norway. Norg Geol. Unders 222, pp. 126.

VOKES, F.M., 1972. A discussion: Supracrustal rocks and Mo-Co bearing veins in Dalen, Norway. Norsk Geol. Tidsskr, 52, pp. 323-6.

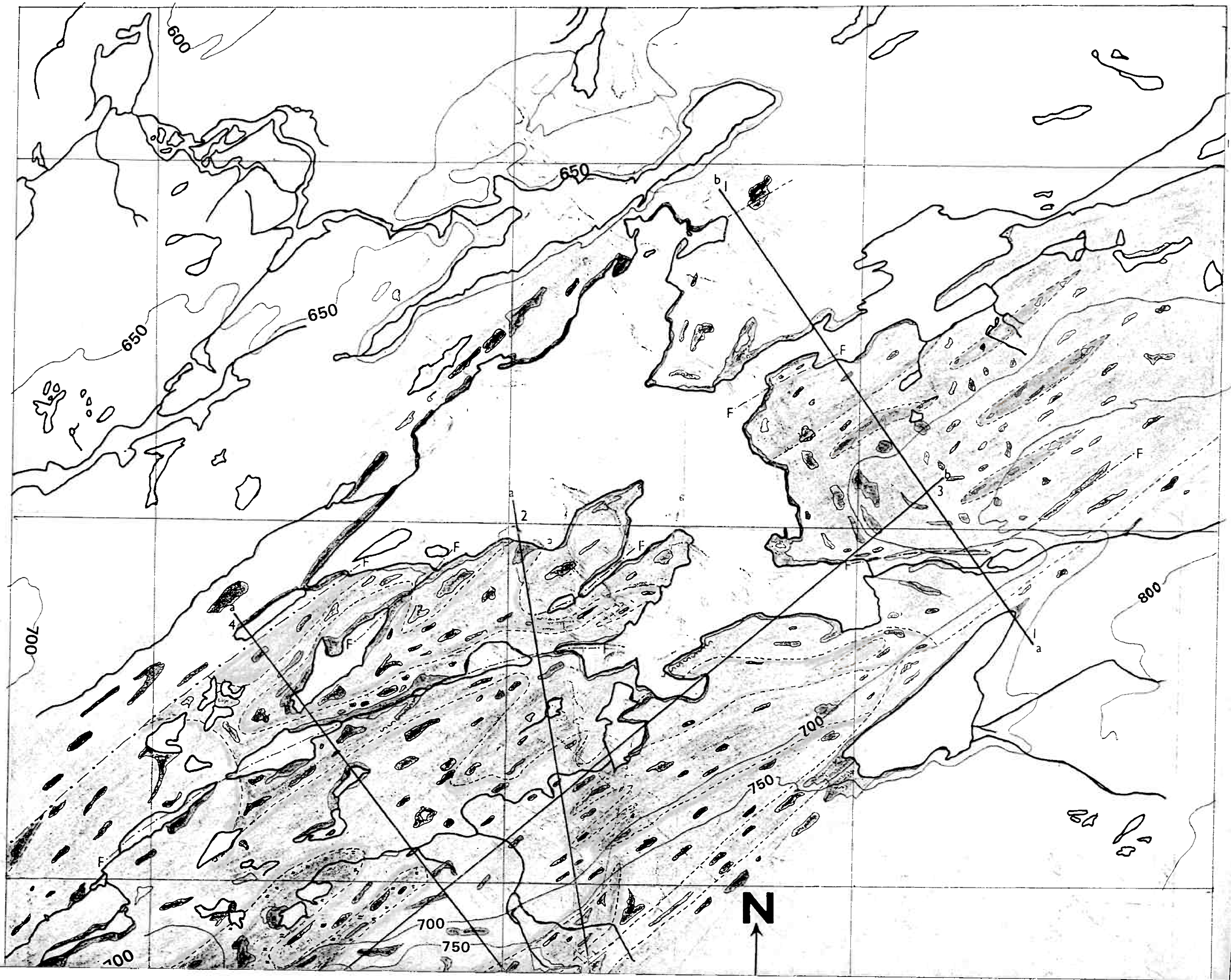
VOKES, F.M., 1960. Mines in south and central Norway. Guide to Excursion C10. Norg. Geol. Unders, 212m, pp. 73.

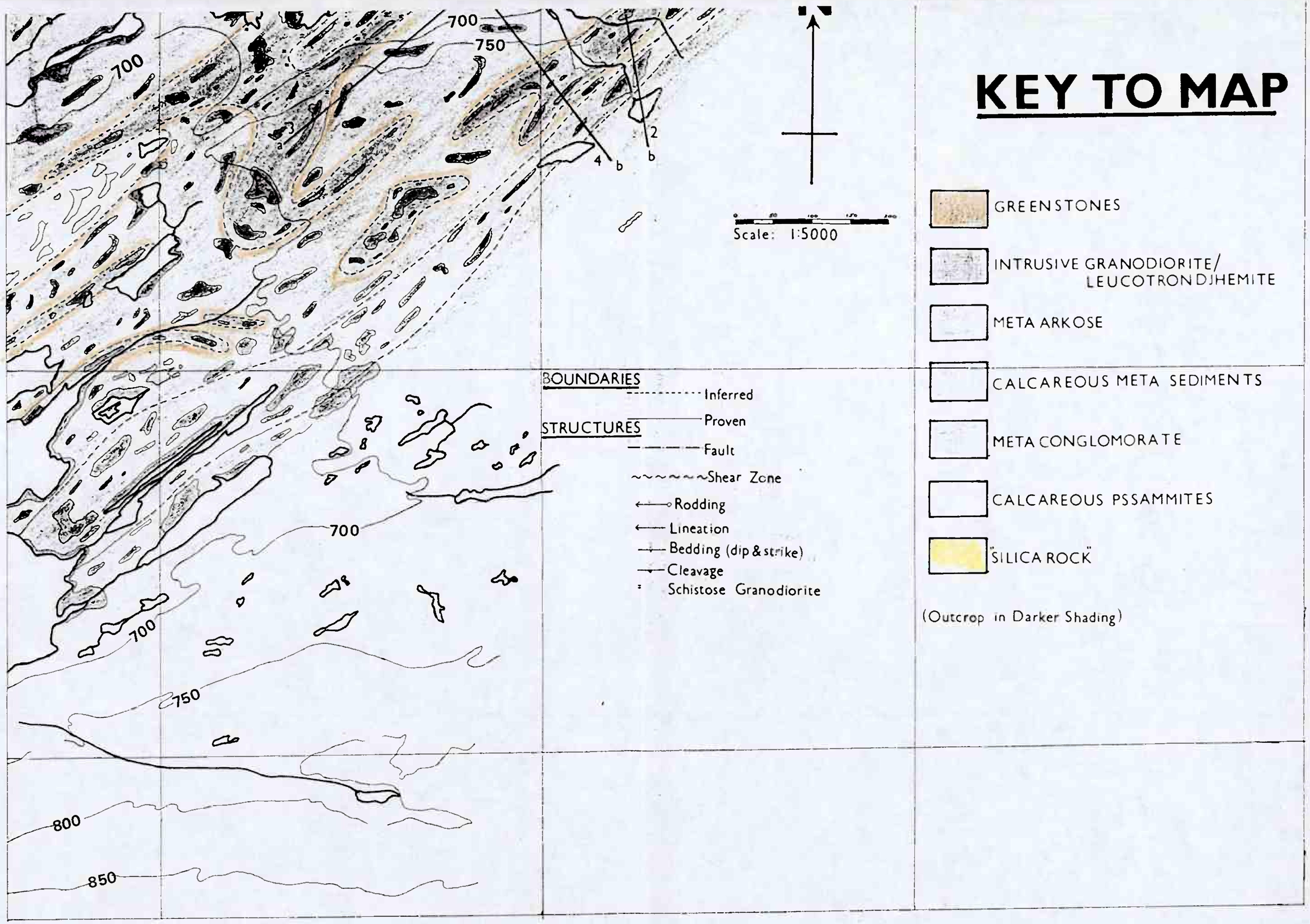


591
.618
.658
.640
650
660
655
662
653
652
METAMORPHOSED FAIRLY SCHISTOSE PELITIC CALC SEDIMENT
Δ679.5
.656
657
.688
SCHISTOSE
BASIC GREENSTONES
Δ695.8
648
.695
700
750
CONGLOMERATE - LARGE CLASTS OVER AREA BEHIND LAKE


EPIDOTE VEINS
GREENSCHIST
EPIDOTE VEIN
MASSIVE G.S.
EPIDOTE
BASIC GREENSTONE
SOME BEDDING
WELL FOLIATED
CALC SEDIMENT
POSSIBLE TABULAR X BEDDING
ARKOSIC META SED
ELONGATION DIRECTION OF CONGLOMERATE
SOME TRACES OF BEDDING
VISIBLE CONTACT
BEDDING
700
750
800
850
A.D.J. Swanson, '82

A GEOLOGICAL MAP OF S.W. GAIZERVATN





KEY TO MAP
GREENSTONES
INTRUSIVE GRANODIORITE/ LEUCOTRONDJHEMITE
META ARKOSE
CALCAREOUS META SEDIMENTS
META CONGLOMORATE
CALCAREOUS PSSAMMITES
"SILICA ROCK"
(Outcrop in Darker Shading)
BOUNDARIES
Inferred
Proven
STRUCTURES
Fault
Shear Zone
Rodding
Lineation
Bedding (dip & strike)
Cleavage
Schistose Granodiorite
Scale: 1:5000
700
750
800
850

KEY

V - GRANODIORITE

γ - GREENSTONE

CS - CALCAREOUS SEDIMENT (METAMORPHOSED)

S - SEDIMENT (METAMORPHOSED)

O - DEFORMED CONGLOMORATE

FCS - FOLIATED CALCAREOUS SEDIMENT (METAMORPHOSED)

≡ - FOLIATED GRANODIORITE

QTZ - QUARTZ

Py - PYRITE

Cp - CHALCOPYRITE

Ep - EPIDOTE

Mg - MAGNETITE

Si - SILICA ROCK (VOLCANIC EXHALATIVE?)

- BEDDING

- CLEAVAGE / SCHISTOCITY / FOLIATION

- RODDING

- BOUNDARY UNCERTAIN

- BOUNDARY CERTAIN

- FAULT

- GRANODIORITE

- FOLIATED CALC SEDIMENT

- GREENSTONE

- DEFORMED CONGLOMORATE

- CALCAREOUS SEDIMENT

- SILICA ROCK

- META SEDIMENT

M 1:10.000