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Tittel

Porphyry-type Mo - Cu mineralization in the Norwegian Caledonides: The Stockwork type Cu - Mo mineralization at Fremstfjell, Grong district, Central Norwegian caledonides.

Forfatter	Dato	Bedrift
Magne Martinsen Frank M Vokes	27.02 1987	SINTEF

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Fagområde	Dokument type	Forekomster
Geologi	Rapport	Fremstfjell
Råstofftype	**Emneord**	
Malm/metall	Cu Mo	

Sammendrag

Rapporten inngår som en del av rapport plikten i forb. med håndgivelsesavtale.

Vedlegg 1 omfatter:
The Stockwork type Cu - Mo mineralization at Fremstfjell, Grong district, Central Norwegian caledonides.

Vedlegg 2 omfatter:
Liste over interne årsrapporter som tar for seg Fremstfjell.

Grong Gruber A/S

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LEIE AV STATENS BERGRETTIGHETER - TJERNRØLE

Vi viser til tidligere korrespondanse om rapportering av ovenfornevnte, senest Deres brev av 24.11.89 om sluttrapportering.

Den bergrettighet som her sluttrapporteres er knyttet til en leieavtale av 29.04.82 og benevnt NM 34/1978-TB. Selv om den var del av en gruppe mutinger kalt Tjernrølet, ligger den sentralt i Fremstfjell og er derfor benevnt som dette i all rapportering.

Fra arbeidene startet i Fremstfjell og områdene omkring i 1974 i Grong Grubers regi (i begynnelsen sammen med NGU på geokjemi), og fram til de siste arbeidene i 1986, er det produsert en lang rekke delrapporter innen geologi (inkl.boring), geofysikk og geokjemi. Disse redegjør, enkeltvis, for mesteparten av de arbeider som er gjort i feltet. Vi har i vedlegg 1 satt opp alle disse delrapporter og bakgrunnsdata, fordelt på de 3 hovedgruppene geologi, geofysikk og geokjemi.

På geologisiden er det i en del utstrekning benyttet en studentgruppe fra Portsmouth Polytechnic. Disse har produsert flere delrapporter. Disse avsluttende rapporter er opplistet til slutt i vedlegg 1. Her må nevnes at bidraget fra A.R.I.M. Elamin var feltdelen til et doktor-arbeid utført hos P.T. Dette gir en total vurdering av geologien og mineraliseringen i feltet.

I tillegg er vedlagt som bilag 1 rapport fra SINTEF (STF 36 F87023) som er kommet i stand gjennom norsk deltagelse i EF's forskningsprogram for mineraler og råmaterialer. Også denne gir en gjennomgang av geologi med mineralisering, dog med en annen innfallsvinkel.

Under arbeidet med Mo-mineraliseringene i Fremstfjell og områdene omkring, har det hvert år i Grong Gruber blitt laget en intern årsrapport over de utførte arbeider (som det også gjøres over arbeid i andre områder). Her er resultatene sammenfattet, det er gjort konklusjoner og det er blitt foreslått nye arbeider. I vedlegg 2 er opplistet de interne årsrapporter som tar for seg Fremstfjell.

Det rapport-materialet det ovenfor er referert til, forefinnes hos Grong Gruber. De vil være lett tilgjengelig for Bergvesenet om nødvendig, suplert med et tegningsarkiv.

Konklusjonen på Fremstfjell er at den kjente mineralisering er for liten og for fattig til å være økonomisk interessant. Det er en del usikkerhet om utviklingen mot dypet, og det er mulig det kan finnes potensialer andre steder i det aktuelle geologiske nivået. Mineraliseringen er interessant og unik i norsk, kaledonsk sammenheng.

Vi håper denne oversikten dekker behovet for rapportering vedrørende denne bergrettigheten. Grong Gruber takker for den fleksibilitet og forståelse som departementet har vist for å hjelpe oss med å få avsluttet denne saken.

Vennlig hilsen
Grong Gruber A/S

Ivar Dybdahl
Verksdirektør

Arve Haugen
Prosp.leder

VEDLEGG

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GRONG GRUBER A/S
Prospekt.avd.

VEDLEGG 2

OVERSIKT OVER GRONG GRUBER A/S INTERNE RAPPORTERING FRA FREMSTFJELL-OMRÅDET, GRONG KOMMUNE

Så lenge Grong Gruber har hatt en aktiv prospektering, er resultatene i de enkelte områdene grundig sammenarbeidet, kommentert og konkludert i årlige interne årsrapporter, fulgt av nødvendig kartmateriale.

Under følger en opplisting av årsrapportenes bearbeidelser fra Fremstfjell-området:

ÅR	Områdebetegnelse	pp-pp
1974	Fremstfjell	12-13
1975	Trondhjemitt-området	29-32
1976	" "	11-12
1979	Trondhjemitt-området	
	a) Vurdering av tidl. materiale	12-13
	b) Befaring i Fremst-fjell-feltet	13-14
1980	Trondhjemitt-området	
	a) Geologi	11-12
	b) Geofysikk	12-13
	c) Prøvetaking	13-14
1981	Trondhjemitt-området	
	a) Fremstfjell	11-14
1982	Trondhjemitt-området	
	1) Fremstfjell	7-9
	2) Befaring Skarfjell	9
1983	Trondhjemitt-området	
	1. Fremstfjell	
	a) Geologiske undersøkelser	9-10
	b) Røskeresultater	10-11
	c) Geofysiske måleresultater	11-13
	d) Status Fremstfjell	14-15
	2. Reko av Mo-feltet mot NØ	15

Des-89

A.Haugen

UTFØRTE ARBEIDER/EKSISTERENDE RAPPORTER ,FREMSTFJELLOMRÅDET I DET SYDLIGE GRONGFELTET

	GEOLOGI	GEOFYSIKK	GEOKJEMI
1958	Sanddøla 1:250.000.S.Foslie. Trones -------"-----------		
1970	Geologisk kart over søndre del av konsesjonsområdet.Huseby,Skorovas gruber.		Kartblad Røyrvik/Andorsjøen Namsskogan,bekkesedimenter, D.C.Smith,NGU nr.1573.
1971		Langtjern-Sanddøldal,SP,magn.,NGU.	
1972			Zn i bekkesedimenter, D.C.Smith,NGU nr.1546.
1973	Geologien i Sanddøla-Blåmuren-omr. NGU nr.1189,G:H:Gale.		
1974		Amøbetjern-Fremstfjell VLF,GG.	Magn. og elmagn. målinger fra helikopter.NGU nr.1274. Prelim.report,Smith,NGU nr1289.
1975			Geokjemiske kart,D.C.Smith, NGU nr.1368.
1976		Fremstfjell-Smaltjern VLF,GG.	A review of the available geol. and geochem. data on the Sanddøla-Nesåv. Mo-Cu-prospects.NGU nr.1289/3,4.

ÅB/A.H - 12.12.89.

GG = GRONG GRUBER A/S

	GEOLOGI	GEOFYSIKK	GEOKJEMI
1977			
1978			
1979	Mo-Cu-min. i Fremstfjell-Neså-piggen-Gaizervatn.Foreløpig vurd. NGU.F.M.Vokes, Rapport over befaring.NTH,F.M.Vokes.		
1980		IP-og magn. målinger i søndre del av Grongfeltet.NGU nr.1815.	
1981	Fremstfjell geol.kart.M.Ryan. Diamantboring,9 hull,GG.		
1982	Portsmouth.Polytechnic,B.Sc.degree R.N.Hocking.		
1983	Portsmouth Polyt.B.Sc.degrees: P.J.F.Davis,G.Wilcock,J.L.Enderby, S.P.Swatton. Røsk,GG. Liten geol. skisse,M.Ryan.	IP-,ledningsevne-,SP-og magn.målinger. NGU nr.84.002.	Grongfeltets molybden-potential.NTH,R.S.Larsen.
1984	Portsmouth Polyt.M.Ph.degree: A.R.I.M.Elamin Diamantboring,2 hull,GG.		

	GEOLOGI	GEOFYSIKK	GEOKJEMI
1985		Fremstfjell øst VLF,GG. NTH, Inst. f. Petroleumsteknologi og anvendt geofysikk, rapp 2/87/716.SOHE: Electromagnetic Frequency Soundings, Fremstfjell, Grong Distr. Norway	
1986	EF-prosjekt Mo,M.Martinsen, SINTEF nr.36 F87023 : Porphyry-type Mo-Cu Mineralisation in the Norwegian Caledonides.	"	
1987			
1988			
1989	Considerations about Cu-Mo-min, S.Vlad.		

Titler på arbeidene fra Portsmouth Polytechnic:

R.N.Hocking	The geology of an area of molybdenum mineralization within the Norwegian caledonides-Fremstfjell.
J.L.Enderby	Geology and mineralization of Fremstfjell, and a comparison with Gaizervatn and Skardfjell.
S.Swatton	Some aspects of the geology of an area to the north of Fremstfjell.
P.J.F.Davis	Some aspects of the geology of an area to the south-east of Fremstfjell.
A.R.I.M.Elamin	The geology of the molybdenum mineralized area at Fremstfjell.
G.Wilcock	?

STF36 F87023

BILAG 1 .

PORPHYRY-TYPE Mo-Cu MINERALIZATION IN THE NORWEGIAN CALEDONIDES

1987-02-27

SINTEF

DIV. OF ROCK AND MINERAL ENGINEERING

RAPPORT

RAPPORT

SINTEF REPORT

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Abstract

Detailed geological studies show that the Fremstfjell Mo-Cu stockwork mineralization occurs as a contact phenomenon partly within a porphyritic trondhjemite and partly within an overlying gabbro-greenstone complex. Albite alteration and quartz-sericite alteration occur frequently together with epidote alteration. A weak potash feldspar alteration is also observed. Lack of zonation indicates that small amounts of hydrothermal fluids were involved.

	Indexing terms: English	Norwegian
Group 1	Rock and Mineral Eng.	Bergteknikk
Group 2	Geology	Geologi
Key terms selected by author(s)	Stockwork	Stockwork
	Mo-Cu	Mo-Cu
	Caledonides	Kaledonidene

SUMMARY

The objective of the project was to investigate the geological and petrochemical aspects of occurences of porphyry-type Mo-Cu mineralization in the Gjersvik Nappe of the central Norwegian Caledonides, in order to arrive at a complete geological picture of the main area of mineralization and to construct a model of this type of deposit which can be applied to the assessment of other potential areas.

A total of about two months fieldwork during the summers of 1985 and 1986 was carried out. This work consisted mainly of detailed mapping of surface geology and the geology of the drill holes. Samples of different rock and mineralization types were collected, and later prepared for mineralogical and fluid inclusion studies. These studies were performed during the winter periods. A few samples were analysed geochemically.

The Fremstfjell mineralization lies at the southeastern border of a large Caledonian trondhjemite body of batholithic dimensions, which is intruded into the dominantly volcanosedimentary sequences of the Gjersvik Nappe.

There seem to be two suites of rocks in the area, one with tholeiitic and one with calc-alkaline trend; the latter seems to be related to the mineralization.

The intruding batholith is made up of gabbroic, dioritic and trondhjemitic varieties. Its dimensions are approximately 25 x 30 km, with its longer axis trending NE-SW. The northern part of the batholith is dominated by gabbro and diorite, while the southern half is mainly trondhjemite.

The batholith intruded a gabbro-greenstone belt in the east, in which the gabbro underlies the greenstones. The greenstones and metavolcanites are of both mafic and felsic composition. Lens-

like bodies of volcanic rocks and gabbro occur as roof pendants in a zone close to the boundary, while dykes of trondhjemite occur in the overlying greenstones further away from the boundary.

A trondhjemite with porphyritic border facies was formed and this porphyritic rock acted as a impermeable roof, beneaath which highly differentiated fluids were trapped. These fluids were presumably enriched in Cu and Mo.

Such fluids will break through the roof if the pressure inside is high enough or if movements provide openings to the surface. They may then migrate upwards until they meet a more saline cooler fluid. This sudden interaction will create an intense stockwork and zone of alteration.

The stockwork at Fremstfjell varies in intensity and is only locally very dense. The alteration zones are also locally very intense, but no good zonation of the different types can be mapped out. This fact indicates that the hydrothermal convection cell was of limited size.

The conclusion is that the Fremstfjell mineralization is much too small to be of economic interest, but it shows that also in the Norwegian Caledonides there are stockwork Cu-Mo type of mineralization as there are other places in the same orogenic belt. So far, no economic Cu-Mo mineralization related to porphyritic intrusions has been found in the European Caledonides, and the chance of finding a mineralization big enough to exploit seems rather unlikely.

THE STOCKWORK TYPE Cu-Mo MINERALIZATION AT FREMSTFJELL, GRONG DISTRICT, CENTRAL NORWEGIAN CALEDONIDES.

M. Martinsen & F. M. Vokes

INTRODUCTION

The Fremstfjell area is situated in the southeastern part of the Grong district, central Norway, some 180 km northeast of Trondheim (fig. 1). It lies approximately 8 km north of the valley of the Sandøla river, through which the nearest road runs.

The area lies totally above treeline in an area of tundra-like vegetation. Cover is variable, mainly in depressions and small river valleys. There is good exposure of the rocks in the area of interest, though a pervasive rusty weathering makes detailed identification often difficult.

The area is the site of a porphyry or stockwork-type mineralization, the first of its kind to be identified in the Scandinavian Caledonides. This mineralization appears in many ways comparable to the ones already reported from the Scottish Caledonides (Fortey, 1980, Evans 1977, Leake & Brown 1979).

PREVIOUS WORK/HISTORY OF INVESTIGATION

The Grong district is best known from an ore geological point of view for its many deposits of stratabound Cu- and Zn-sulphide deposits (Oftedahl 1956). These include one presently producing deposit, Joma (Olsen 1980, Odling 1986, Reinsbakken 1986 a) and two past producers, Skorovas (Halls et al 1977, Reinsbakken 1980) and Gjersvik (Reinsbakken 1986 b). Other types of mineralization so far known are quite minor in importance, including the PGE bearing Ni-Cu-Fe-S deposit of Lillefjellklumpen (Grønlie 1984, 1986) and the Fremstfjell Cu-Mo deposit reported on here.

The geology of the Grong district was originally mapped by Foslie (1927). A new series of maps at scales of 1:250 000 and 1:50 000 are at present in preparation by the Geological Survey of Norway.

Following the discovery and investigation of the stratabound sulphides earlier this century, mineral exploration was for a long time on a minor scale. However, in the 1970's work was intensified considerably. A geochemical stream sediment sampling programme was started in 1975, the analytical results of which showed, among other things, several Cu and Mo anomalies, some of these in the area around Fremstfjell.

Gale (1975) had observed occurences of molybdenite in this area a few years earlier. A few years later Vokes (1979) refocussed attention on the porphyry- or stockwork-like character of this Mo-mineralization.

In the period 1980 to 1985 a detailed study of the mineralized area was undertaken, which included mapping, geophysical surveys (included induced polarisation and magnetometry) trenching and sampling, followed by the drilling of 11 drillholes. The results are reported in three university theses (Hocking 1982, Enderby 1983 and Elamin 1984) and several unpublished reports.

A further investigation has been carried out on the Fremstfjell mineralization between 1985 and 1987 as part of the recently initiated Norwegian participation in the EEC Mineral Raw Materials Research Programme, funded by the Norwegian Council for Scientific and Technical Research (NTNF). This phase has comprised detailed remapping of the geology and further studies of petrography, mineralogy and geochemistry. The results of this new work are presented below.

Further geophysical surveying was undertaken in 1985, and this work will be reported on separately.

Regional geological setting

The Fremstfjell mineralization lies at the southeastern border of a large Caledonian trondhjemite body of batholithic dimensions, which is intruded into the dominantly volcanosedimentary sequences of the Gjersvik Nappe (Halls et al. 1977). These form part of the Køli sequence of the Upper Allochthon of the Central Caledonides (Roberts & Gee 1986).

The Gjersvik rocks, which also host important sulphide deposits, are mainly in the greenschist facies of regional metamorphism and are intruded by metagabbros and diorites as well as the trondhjemite.

Lithologies

Volcanic rocks.

The volcanosedimentary rocks which form the roof to the trond-hjemite batholith dominate the geology in the eastern half of the investigated area (fig. 2). They are representatives of the supracrustal components of the Gjersvik eruptive complex and are dominated by greenstone metavolcanites of both basic and felsic compositions, including basalts, andesites and keratophyres of distinct spilitic affinity (Halls et al. 1977).

Locally the greenstone contain interlayers, up to several meters thick, of reddish and bluish magnetite-rich jasperoids, with which are often found chalcopyrite and pyrite bearing veins of the order of decimetres in thickness.

In places, horizons with agglomeratic textures occur intercalated in the greenstones.

The rocks are often strongly deformed, making it difficult and time-consuming to delineate and map the variations in the metavolcanic lithologies.

Plutonic rocks

The intruding batholith is made up of gabbroic, dioritic and trondhjemitic varieties (fig. 1). Its dimensions are approximately 25 x 30 km, with the longer axis trending NE-SW. The northern part of the batholith is dominated by gabbro and diorite, while the southern half is mainly trondhjemite (fig. 1) (Halls et al. 1977).

The gabbroic part of the intrusive is often distinctly layered with a composition varying from olivine gabbro to hypersthene gabbro, although metamorphisme has altered most of the rocks to hornblende gabbros or diorites (Halls et al. 1977).

The earliest intrusives appear to be represented by fresh, layered olivine gabbros occuring as rafts or xenoliths up to 70 x 120 m in dimensions in a matrix presently consisting of metamorphosed gabbro and hornblende diorite (Halls et al. 1977).

The peripheral contacts of the fresh layered gabbro with the diorite display a distinctive pattern of retrograde alteration (Halls et al. op. cit).

At the margin of a hornblende diorite in the northern part of the batholith quartz diorite/trondhjemite facies occurs locally (Halls et al. op. cit, Kollung 1979).

East of the Heimdalshaugen gabbro the intrusion is dominated by more felsic varieties. Here the rocks vary from diorites and quartz diorites to trondhjemite and granodiorite. No attempt was made to differentiate between these varieties during the present work.

While these rocks are light grey to white in colour and coarse-grained in the western part of their outcrop (A. Reinsbakken. pers. comm., 1986), in the eastern part they are characterised by green and red colours due to epidotisation and albitization and they commonly show a porphyritic texture.

The local geology of Fremstfjell deposit

As already outlined, the Fremstfjell Cu-Mo mineralization occurs at the border between the trondhjemite pluton and its meta-volcanic and gabbroic roof rocks to the east (fig. 2 and 3).

It is possible to distinguish two types of volcanic rock in the area. In the northeast, the volcanites are fine grained and dark green, locally with alternating mm-thick lighter felsic bands. Pillows and other primary volcanic structures are not well exhibited in the area investigated, although these structures have been well recognised on a regional scale (Halls et al. 1977). The rocks are dominantly massive, but locally highly schistose. The schistosity trends generally E-W, and dips 50-60° to the north (Elamin 1984).

In the southwest, and around the central part of the mineralized area, occur felsic agglomeratic facies in a rock consisting of alternating light green and grey bands. This rock unit is largely silicified, especially the grey felsic bands. Felsic fragments are usually tectonically flattened and contorted (fig. 4). Reliable observations are often difficult to make in this area due to the heavy alteration of these rocks. Locally, however, mainly undeformed felsic fragments up to a dm in size can be observed (fig. 5). Layers, up to one metre thick, of quartz-feldspar porphyries and fine grained rhyolites can be observed within this rock unit.

Gabbro is present, apparently in the form of a layer, beneath the meta-volcanites. In the northern part of the area, where this gabbro is in contact with the mainly basic volcanic rocks, the thickness of the gabbro layer is between 100 and 200 m. In the southern part it is less than 5 m thick.

The trondhjemite has intruded the overlying gabbro and meta-volcanites in a complex manner, giving a very complicated geological picture (fig. 6 and 7). In this, generally lens-like bodies of the overlying rocks occur as roof pendants in trondhjemite in a zone close to the boundary, while dykes of trondhjemite occur in the overlying volcanites further away from the boundary.

A red, potash feldspar bearing aplite occurs cutting the earlier crystallized trondhjemite as E-W trending, sheet-like bodies, a decimetre or so in thickness.

A very distinctive, 1-8 m thick, porphyritic dyke crosses the trondhjemite and acid metavolcanites. The matrix is black and fine grained and the phenocrysts are white basic plagioclase up to 0.5 cm in size. Locally this dyke is altered to a green coloured rock carrying phenocrysts of actinolite.

Dolerite dykes cut all the previously mentioned rock types in the area, including the mineralization. They are dark green, fine grained and locally porphyritic.

Local small bodies of conglomerate can be found in contact with trondhjemite or greenstone. This rock is composed of boulders, cobbles and pebbles derived locally from the underlying rocks of the eruptive complex (Halls et al. 1977). The type of clast present is largely determined by the bedrock at the immediate locality. A clast showing a quartz-molybdenite vein crosscutting trondhjemite has been found in this conglomerate.

Petrography

The gabbros of the area are mainly composed of plagioclase, pyroxene and hornblende, with biotite, apatite, sphene and iron oxides as minor phases. They vary in composition from pyroxenite, through hornblendite and cumulate gabbro to hornblende gabbro (Elamin 1984). Both clino- and orthopyroxene are present, but clinopyroxene predominates. Pyroxenes are often uralitized and partially or completely replaced by hornblende, actinolite or chlorite. Brown hornblende is most commom in the hornblende gabbro. Calcic plagioclase is present in amounts varying from 10 modal percent in the pyroxenite to 60 modal percent in the massive gabbro (Elamin, op cit).

The basic volcanites have undergone metamorphism to greenschist facies; the dominating minerals are chlorite, epidote, amphibole, plagioclase and minor amounts of quartz, sericite and pyrite.

The felsic bands consist mainly of an intergrowth of quartz and chessboard-albite.

The trondhjemite is dominated by plagioclase crystals with quartz as interstitial material. Euhedral grains of sphene are often observed. Hornblende and biotite are normally replaced by chlorite and muscovite. Accessory minerals are pyrite, magnetite, apatite and zircon.

Aplite consists mainly of fine grained quartz and plagioclase. Sericitic alteration of the feldspar is common. Epidote, sphene, amphibole and pyrite/chalcopyrite are accessory minerals.

The late dark porphyritic dyke has a matrix that consists mainly of partly chloritized amphibole. The phenocrysts are strongly saussuritized feldspars.

The metadolerite is a fine grained, pale green rock showing a recrystallised texture and a mineralogy indicating greenschist facies metamorphism: epidote, chlorite, sericite and minor amounts of feldspar and quartz.

Mineralization

The centre of the mineralization consists of a well-developed stockwork of quartz-veins with fine grained molybdenite, often associated with pyrite and, rarely, chalcopyrite. This central, intense, stockwork (fig. 8) has an extension of 200x50 m (fig. 3) on the surface with the longest axis trending ESE-WNW. Around this central area there is a discontinuous, less intense stockwork. The veins occur in three main directions, (see below) the frequency of the veining being relatively high in the central part of the stockwork (around 30 veins/pr. m), and the thickness of the veins about 1/2-1 cm.

The stockwork lies in the southeasternmost part of the trondhjemite, and continues eastwards into the overlying gabbro/greenstone complex.

Quartz-molybdenite veins can be observed over a large area outside the central stockwork. These veins are often subparallel and show an E-W strike direction, dipping steeply northwards.

Molybdenite occurs also in several other types of paragenesis in addition to the quartz-veins:

- in "dry" veins
- in veins associated with quartz-pyrite
- in veins associated with epidote
- in fine grained strongly silicified zones

Detailed studies show that quartz veins rimmed with reddish potash feldspar and albite were deposited first. Quartz-molybdenite veins crosscut and displace the early quartz-alkalifeldspar veins. Even later quartz-molybdenite-pyrite ± chalcopyrite veins crosscut and displace the earlier veins. Quartz veins associated with chalcopyrite show crosscutting relations to all the earlier described mineralized veins.

The amount of molybdenite is greatest in the central part of the stockwork and the copper content seems to be high outside the central Mo-rich parts (fig. 9 and 10). This cannot be observed in the field. Towards east the amount of molybdenite decreases, so that only barren quartz veins occur in the easternmost part of the stockwork.

The three main strike directions of the molybdenite bearing veins in the central part of the stockwork are N40-60°E, N80-100°E and N120-140°E; all veins seem to dip relatively steeply towards the north.

There is a less distinct stockwork at Smalvann (fig. 2 and 3). Here the three main directions are more parallel, apparently due to late tectonic deformation: N60-75°, N85-100° and N110°, all dipping 50-80° northwards.

Wall-rock alteration

It is difficult to map out distict alteration zones, because a late albite/epidote alteration seems to overprint a large area. However, several types of alteration paragenesis can be observed. A weak potash feldspar alteration in the central part of the mineralized area expresses itself in partial potash feldspar replacement of plagioclase (fig. 11 and 12). One can observe a disappearence of albite-twins in parts of the plagioclase grains where the newly formed K-feldspar occurs.

Potash feldspar is also observed as mm thin fringes to quartz-veins and as red, mm-cm thick, discrete veins. This potash feldspar alteration is only observed in trondhjemite and aplite; not in the greenstones.

Quartz-sericite alteration is more widespread and occurs in erratic zones over a large, ill-defined, area (fig. 3). Locally these alteration zones are pervasive and can be from a few mm up to 2-3 meters wide. In these zones the typical porphyritic trondhjemite changes to a fine grained, grey-green rock. Generally the alteration is rather weak and the sericite often replaces only up to about 50% of the plagioclase grains. Pyrite often occurs as disseminated grains in the quartz-sericite alteration zones.

Albite alteration is very extensive around the mineralized area, and expresses itself as red to pink grains, often as phenocrysts. It is difficult in the field to distinguish between albite and potash feldspar alteration because they both have a reddish colour. In the microscope the hydrothermal albite occurs as chessboard albite and it is often associated with light green epidote and dark green chlorite.

Extensive epidote alteration can be observed over a very large area. In the central part of the mineralized area, cm-wide massive epidote veins cut through all the earlier alteration zones, including earlier, massive albite/epidote alteration. A general epidotisation of the plagioclase is observed over a large part of the trondhjemite, for several km beyond the hydrothermally mineralized zone.

A weak epidotisation of the trondhjemite leads to a drastic change in the rock texture, and makes it difficult to map out the various porphyritic trondhjemite intrusions in the heavily mineralized area.

A late overprinting of quartz-calcite veins is observed over a large area. Veins with quartz, anhydrite and, locally, chalcopyrite are observed in the central part of the stockwork. These veins seem to be rather late in the mineralization sequence and cross cut sericitic and feldspathic alteration. Locally cm-thick magnetite-veins can be observed in the volcanites and in strongly epidotised trondhjemite.

North of Pistoltjern, on the boundary between gabbro and trondhjemite, there is a little magnetite showing that consists of two 0.50 m thick and 2 m long rounded magnetite lenses, sourrounded by pervasive epidote alteration. The magnetite fills a breccia in earlier deposited massive pyrite.

Fluid inclusion study

About 30 thin sections of mineralized material were studied and from these, 15 samples were selected and prepared for heating- and freezing-stage work. All the samples came from quartz-rich parageneses:

- a, Quartz-molybdenite ± pyrite ± chalcopyrite veins; some folded and mylonitized
- b, Quartz-pyrite veins
- c, Quartz-sericite alteration
- d, Quartz-alkalifeldspar veins
- e, Quartz veins
- f, Quartz-chlorite veins
- g, Quartz-anhydrite veins
- h, Quartz-actinolite veins

Microthermometry was carried out on a Linkam T_H 600 heating and freezing stage. Most of the fluid inclusion study is based on fine grained, equigranular quartz with triple junction borders. These grains form a matrix in which 2-3 mm large, unevenly shaped, quartz-grains with lamellar strain shadows occur.

Types and setting of fluid inclusions

The large quartz-grains contain many healed fractures with fluid inclusions, while the fine grained quartz generally shows very few inclusions, both isolated and in healed fractures.

Exclusivly aqueous inclusions are found in the quartz. They usually contain 1-5 volume% vapour, in extreme cases up to 10%. The inclusions are generally rounded in shape, and their diameters are less than 5µm. No daughter minerals were found in them.

Heating and freezing studies

The inclusions were found to show a range of salinities from 0 to 16 equivalent weight % NaCl (fig. 13), deduced from temperatures of the final melting of ice formed during cooling.

There seem to be two closely spaced peaks in the temperature frequency distribution; one around 7 and one around 10 equivalent weight % NaCl. The temperatures of the first observable melting of the ice were around 20°C. This indicates that only NaCl was present in the inclusions.

Homogenization temperatures are shown in fig. 14. There were no distinct differences in homogenization temperatures between isolated inclusions and inclusions along fractures. The highest homogenization temperatures were measured in the quartz stockwork close to the border between trondhjemite and overlying gabbro/-greenstone.

Discussion

The scattering of homogenization temperatures may have three causes: 1, necking down (that is the dividing of one original inclusion with a certain composition into several smaller inclusions with a variety of compositions); 2, trapping at decreasing temperature; 3, variation in fluids trapped. Inclusions suspected of having necked down have been purposely avoided in these measurements. The scatter of salinities may, however, indicate that some inclusions which have undergone necking down have been included in some of the measurements.

Fig. 15 shows the relationship between temperature and salinity. The sharp drop in temperature at almost constant salinity has been interpreted by Shepard et al. (1985) as a simple cooling of a hydrothermal solution. A hydrothermal solution within the trondhjemite escaped by following fractures created in the roof zone. The original hydrothermal solution had a low salinity (5 eq.wt.% NaCl) and a moderate temperature (300°C; not corrected for pressure). This solution was rapidly cooled down to around 150°C, and then mixed with a fluid having low temperature and moderately salinity (15 eq.wt.% NaCl). This might be due to influx of a saline brine, or to later overprinting by a metamorphic fluid causing lower greenschist facies metamorphism. This mixing caused the metals to precipitate and crystallize as ore minerals. A later overprint of a cool, low saline solution is represented by quartz-chlorite-epidote alteration.

In zones where the mineralized stockwork is mylonitized there are very few inclusions. The homogenization temperatures for these inclusions are around 150°C. This indicates a dry deformation with recrystallization of quartz at a relativly low temperature.

Fig. 16 seems to indicate a pressure around 300-400 bars for the formation and trapping of the low density and high temperature inclusions.

The increase of NaCl in the metamorphic solution can be caused by two things:

1) Liberation of Na^+ following breakdown of albite to chlorite
$NaAlSi_3O_8 + 3Mg^{2+} + 2Fe^{2+} + Al(OH)_4^- + 6H_2O \longrightarrow$
$Mg_3Fe_2Al_2Si_3O_{10}(OH_8) + Na^+ + 8H^+$

2) Chloride increase following on from rock hydration involving formation of hydrous metamorphic minerals like chlorite, actinolite and epidote (Michard et al. 1984).

The pressure correction for the trapped high temperature inclusions will be very small; around +20°C. However the pressure correction of the temperatures for inclusions trapped at low temperatures will be slightly under +100°C (Roedder 1984). This indicates that the real formation temperature is around 250°C which indicate a low greenschist metamorphism temperature.

GEOCHEMISTRY

The available data included whole rock geochemical analyses from earlier, unpublished, work of Elamin (1983) and Reinsbakken (written com., 1979), and analyses of samples collected by the author.

Some elements show a good correlation with SiO_2 content and can indicate a continous evolution from gabbro to trondhjemite (fig. 17).

CIPW-norms were used in calculating the content of albite (Ab), orthoclase (Or) and anorthite (An). The analyses were plotted in an Ab-Or-An triangle with an overlay of the classification after O'Connor (1965). Most of the rock samples fall within the tonalite and trondhjemite fields (fig. 18).

Plotted on a AFM-diagram two trends can be observed; one aborted tholeiitic trend of basalt and gabbro, and one calc-alkaline trend ending in the low temperature end of a gabbro-trondhjemite suite (Barker and Arth 1976) which is a sub-trend of the more general calc-alkaline suite of Green & Ringwood (1968).

Plotting of the samples in a chemical-mineralogical diagram (fig. 19) (Debon and Le Fort 1982) also shows that there are two trends, one tholeiitic and one calc-alkaline. The diagram permits recognition of the mineralogical significance of chemical variations. Quartz is represented by $Q = Si/3-(K+Na+2Ca/3)$ and the feldspar type by $P = [K-(Na+Ca)]$ where Si, K, Na and Ca represent gram-atoms of the different elements. The values are calculated by dividing the oxide-content (e.g.: Na_2O) by the molecular weight of the oxide and multiplying by the number of atoms of the actual element. The tholeiitic trend ranges from gabbro through diorite and trondhjemite to end in quartz-diorite. The calc-alkaline trend ranges from gabbro through diorite/-granodiorite to trondhjemite and ends up in granitic and altered rocks. The granitic samples and samples with potash feldspar and sericite alteration fall in the same area; mainly adamelite/-granite field, and show a great resemblance to each other. Albite altered samples fall on the plagioclase side of the figure.

The relatively big spread in results can be a result of varying degrees of alteration of the rock samples.

Conclusion

There seem to be two suites of rocks in the area; one with tholeiitic and one with a calc-alkaline trend. The latter seems to be related to the mineralization.

The trondhjemite intruded the gabbro-greenstone belt in the east. A porphyritic border facies was created and this porphyritic rock acted as a impermeable roof, beneath which highly differentiated fluids were trapped.

Such fluids will break through the roof if the pressure inside is high enough or if tectonic movements give rise to structures leading to the surface. The fluids will migrate upwards until they meet a more saline, cooler, fluid and this sudden interaction will create an intense stockwork and alteration.

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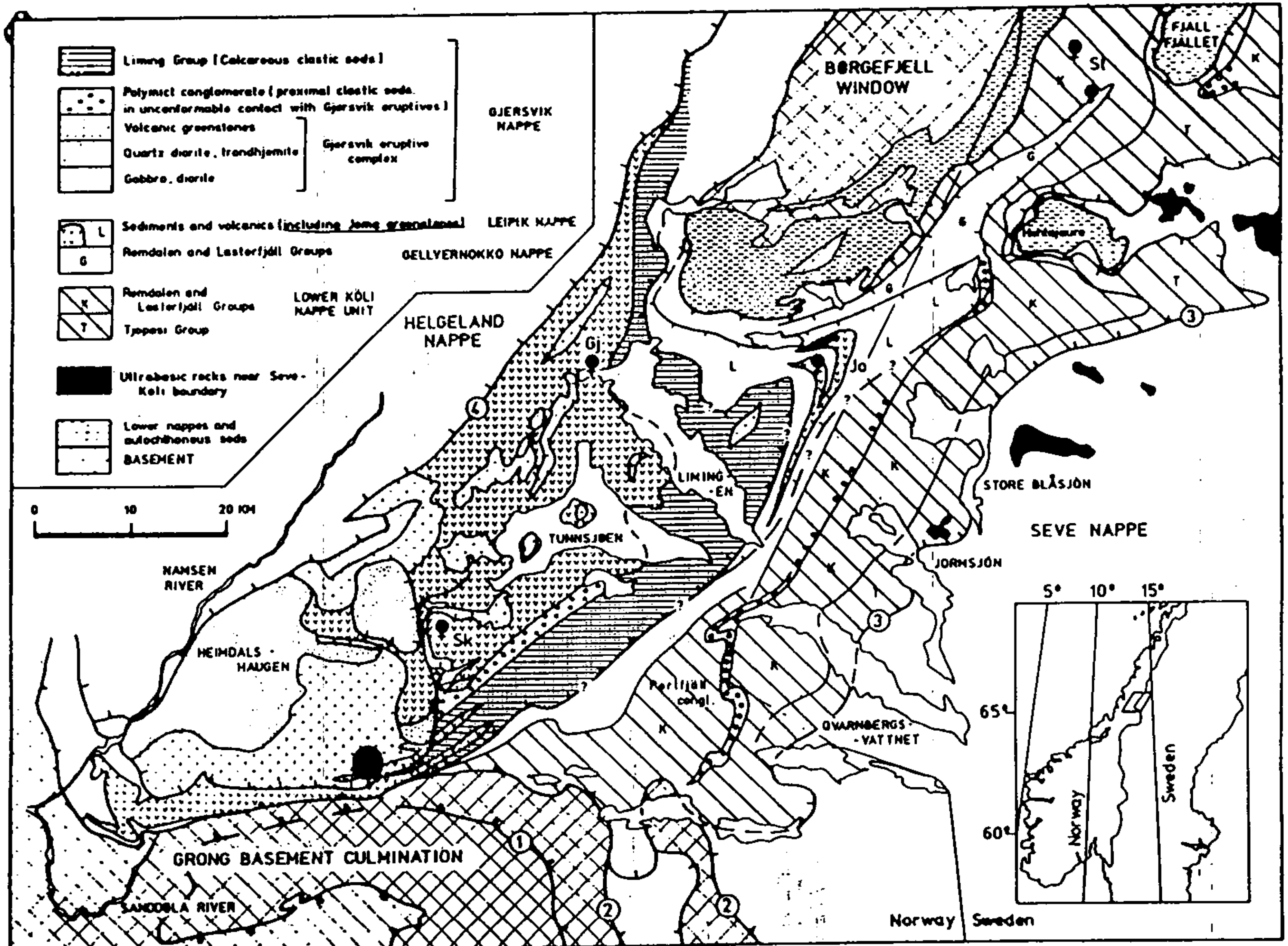


Fremstfjell

FIG:1. Map showing location of main ore deposits in Grong–Stekenjokk district (Sk, Skorovas, Gj, Gjersvik, Jo, Joma and St. Stekenjokk) and main structural and stratigraphic units that can be distinguished within Köli Nappe. (1) Thrust at base of Olden basement nappe; (2) thrust at base of Seve–Köli Nappe; (3) thrust separating Seve and Köli sequences within Seve–Köli Nappe Complex; (4) thrust separating Gjersvik Nappe at top of Köli Nappe sequence from high-grade metamorphic rocks of Helgeland Nappe Complex. Boundaries based on geological infc rmation from Foslie, Oftedahl, Zachrisson, Gee and Gustavson (after Halls et al. 1977).

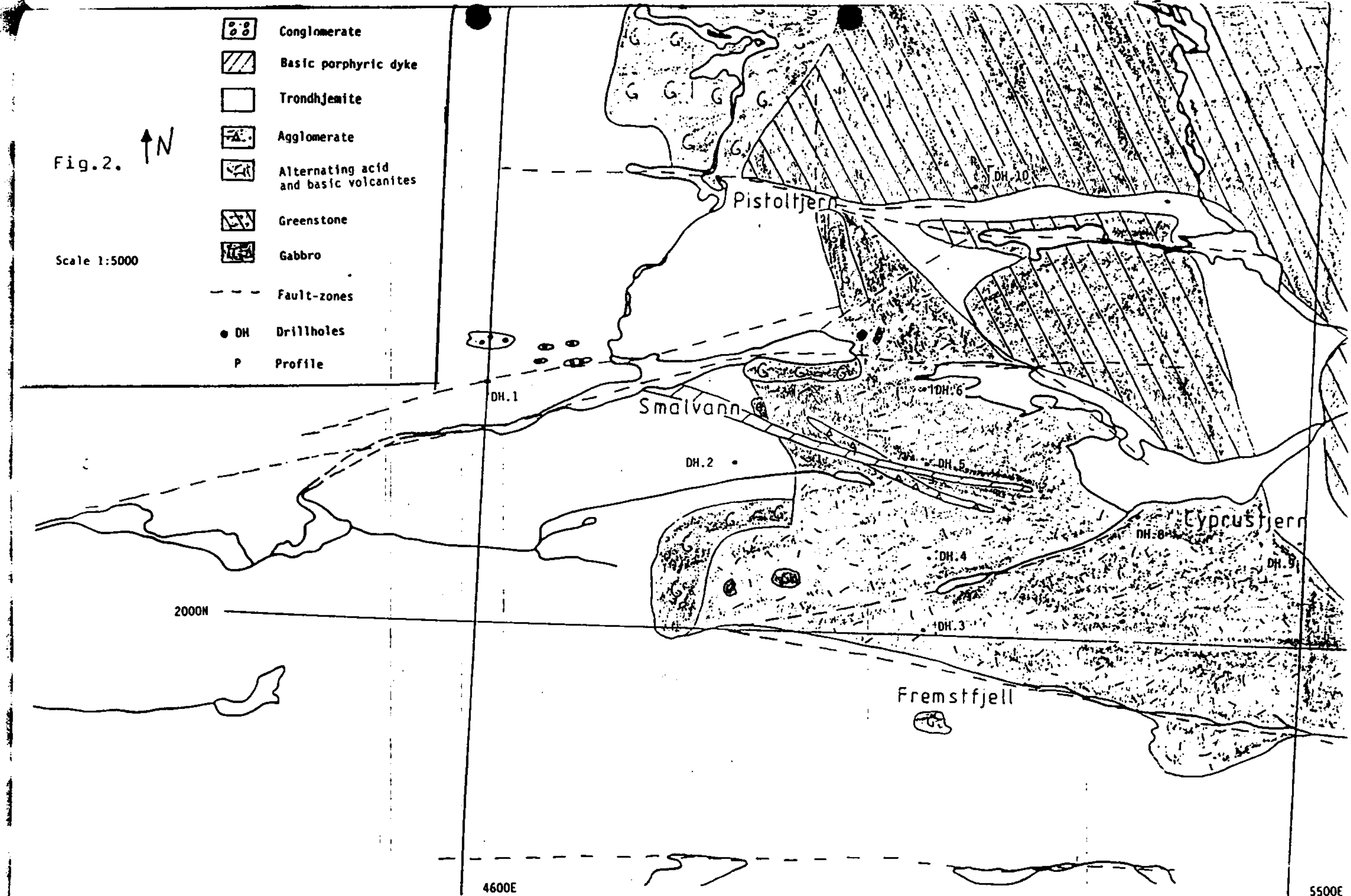


Fig.2.
N
Scale 1:5000
Conglomerate
Basic porphyric dyke
Trondhjemite
Agglomerate
Alternating acid and basic volcanites
Greenstone
Gabbro
Fault-zones
DH Drillholes
P Profile
Pistoltjern
DH.10
DH.1
Smalvann
DH.6
DH.2
DH.5
Cyprustjern
DH.8
DH.4
DH.9
DH.3
2000N
Fremstfjell
4600E
5500E

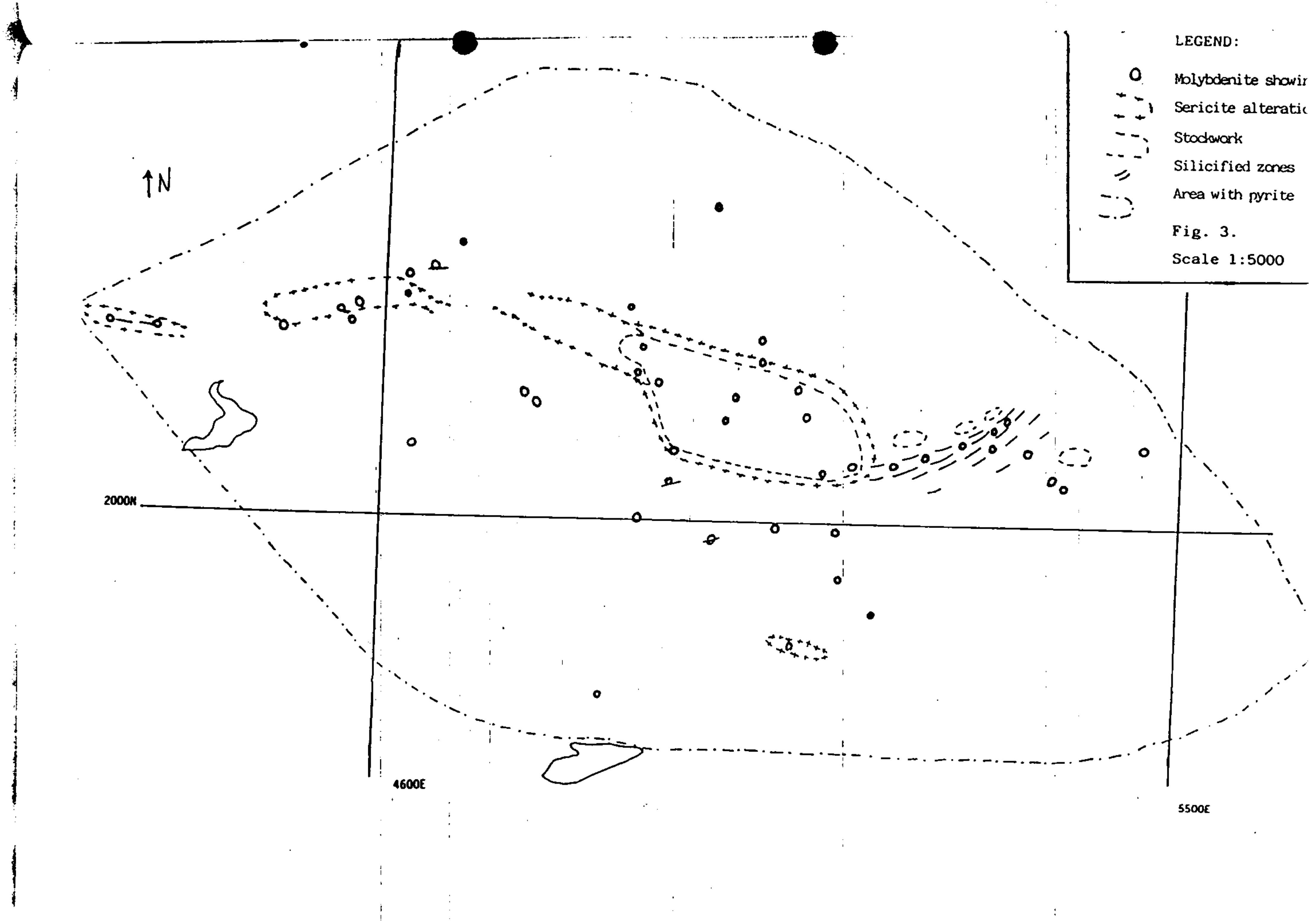


Fig. 3.

Scale 1:5000

Fig. 4. Folded and contorted mafic and felsic volcanites.

Fig. 5. Undeformed felsic fragments in a chlorite-rich matrix.

Legend for fig. 6 and 7.

P (diagonal hatching)	Basic porphyritic dyke
(blank box)	Trondhjemite
(patterned box)	Quartz-diorite
(patterned box)	Greenstone
(patterned box)	Gabbro
-·-·-	Fault-zones
D	Metadolerite

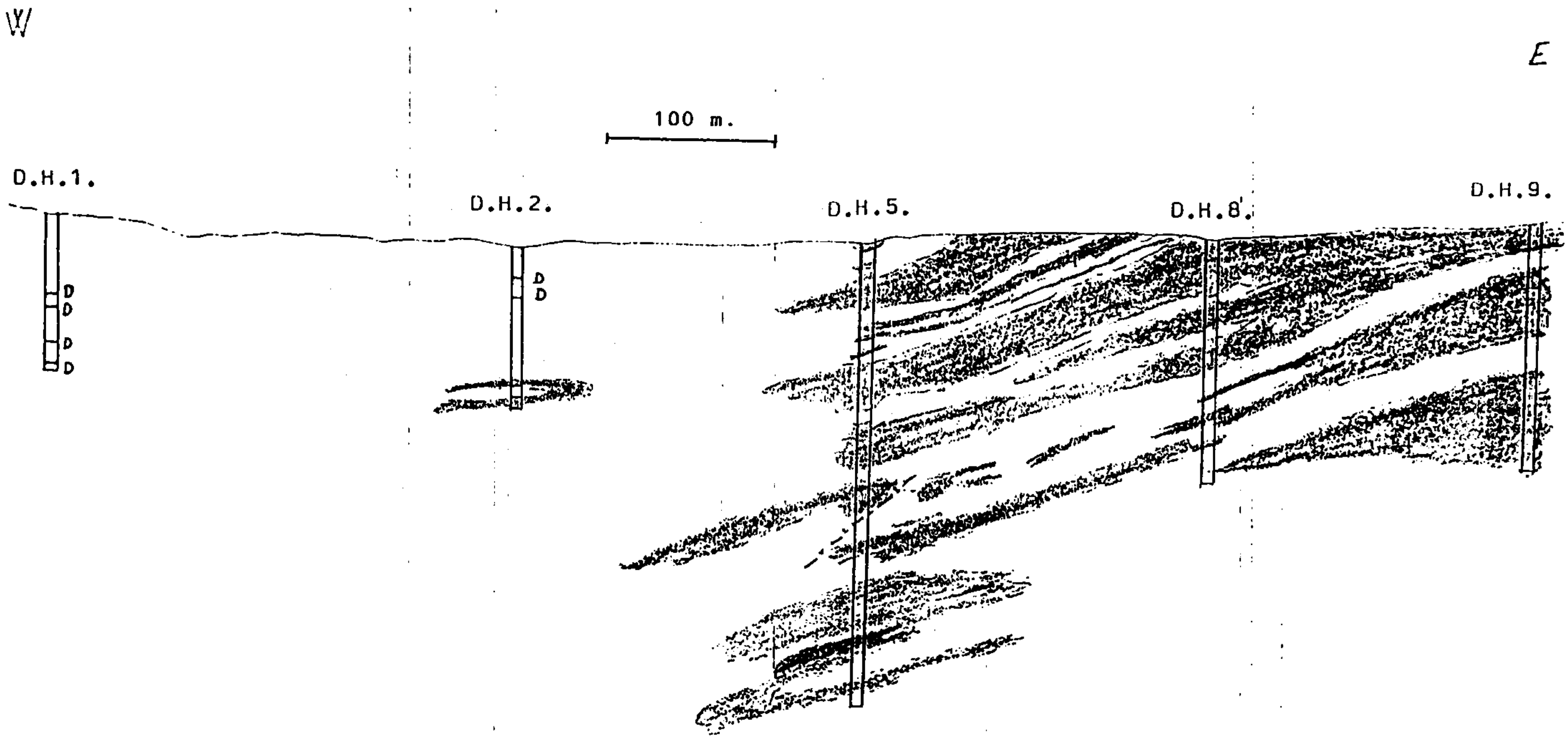


Fig. 6. E-W vertical interpretation of geology based on drillholes(d.H.) and surface geology.

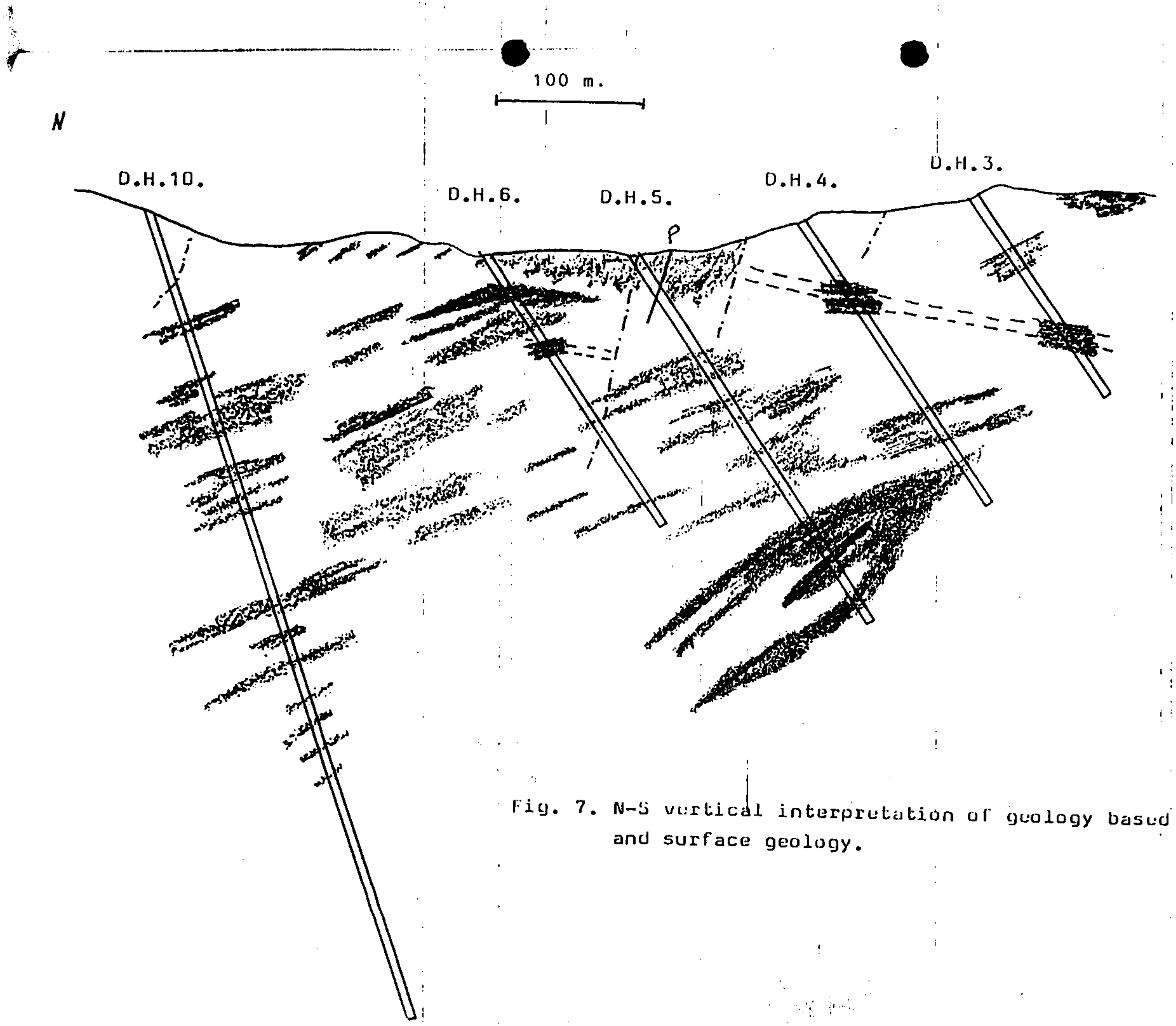


Fig. 7. N-S vertical interpretation of geology based on drillholes(D.H.) and surface geology.

Fig. 8. Intense stockwork of quartz-veins mineralized with molybdenite, chalcopyrite and pyrite.

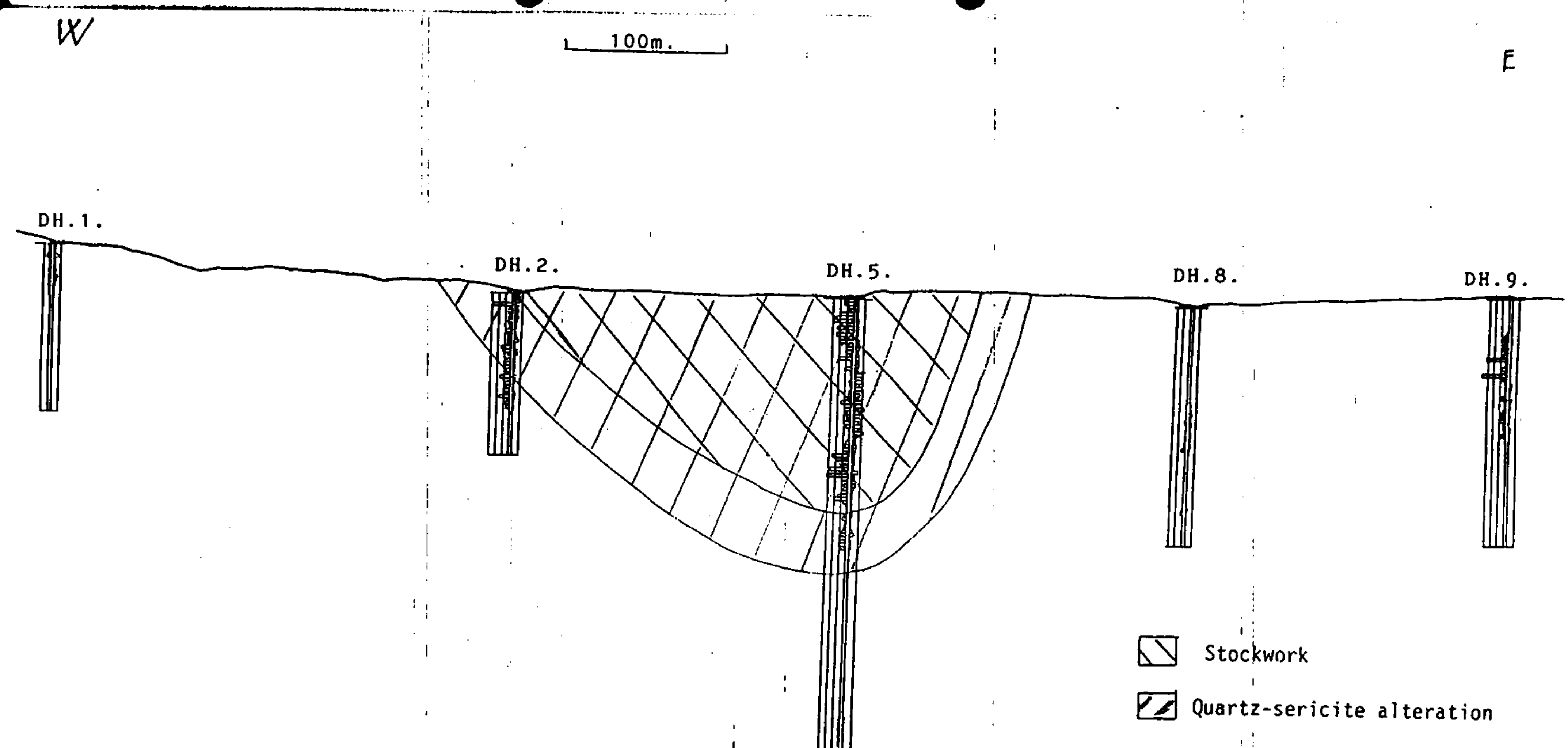


Fig. 9. Drillholes showing contents of Cu and Mo. Cu to the left; each vertical line represents 1000 ppm. Mo to the right with the same scale as Cu.

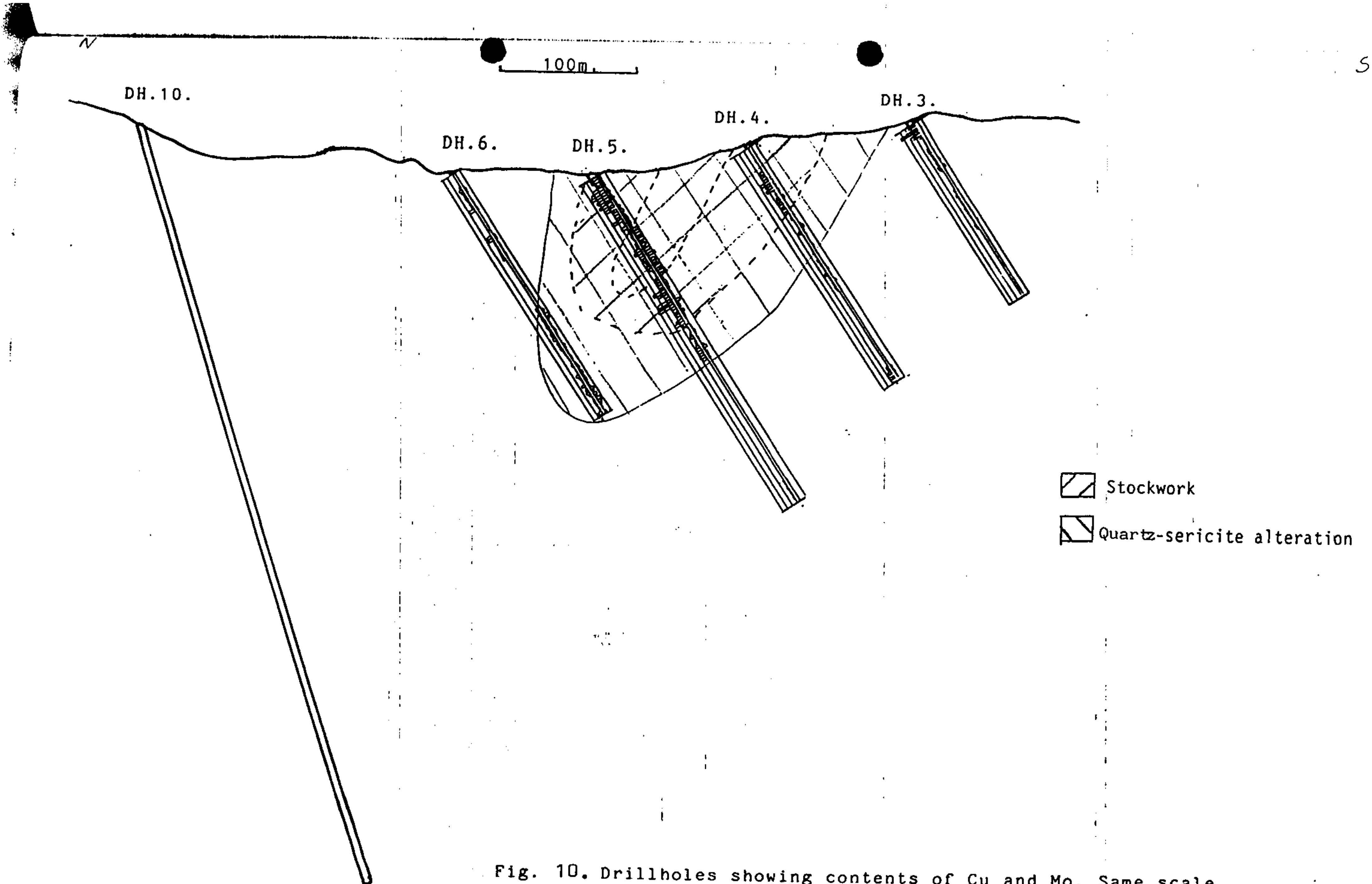


Fig. 10. Drillholes showing contents of Cu and Mo. Same scale as fig. 9.

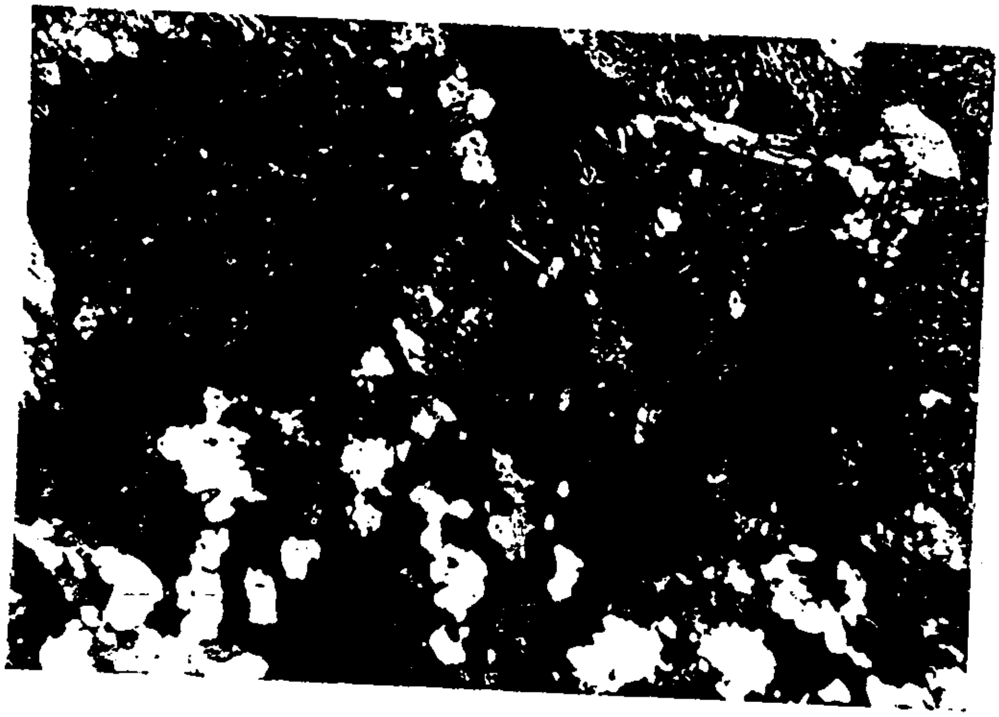


Fig. 11. Plagioclase with weak sericitization replaced by late hydrothermal potash feldspar (area without sericite).

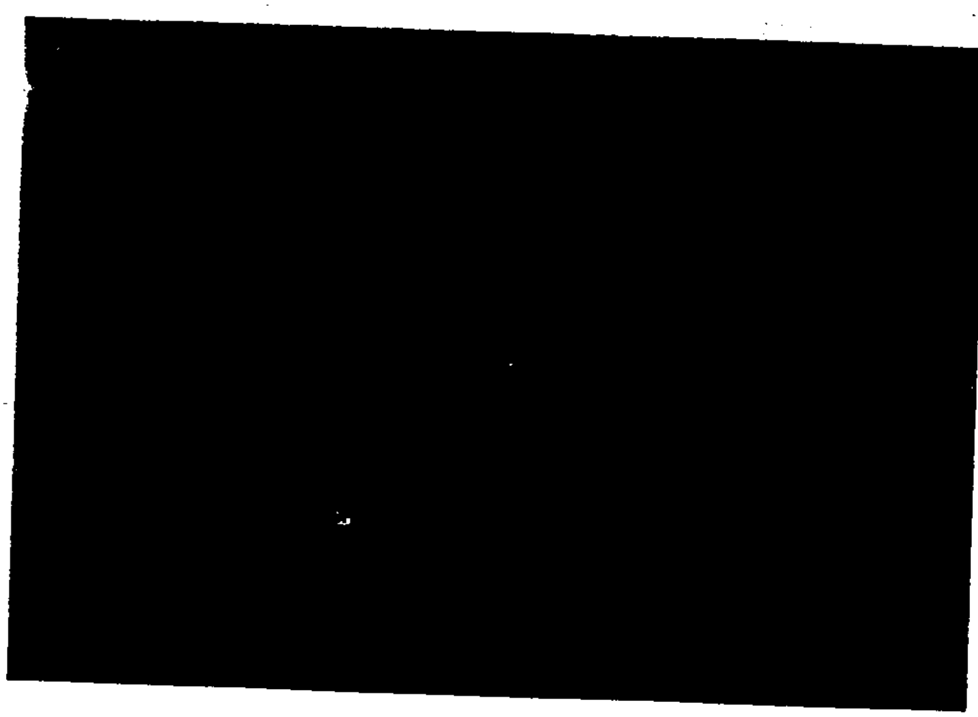


Fig. 12. Same picture as above without crossed nichols. The thin section is stained and the weak brown colour represents potash feldspar.

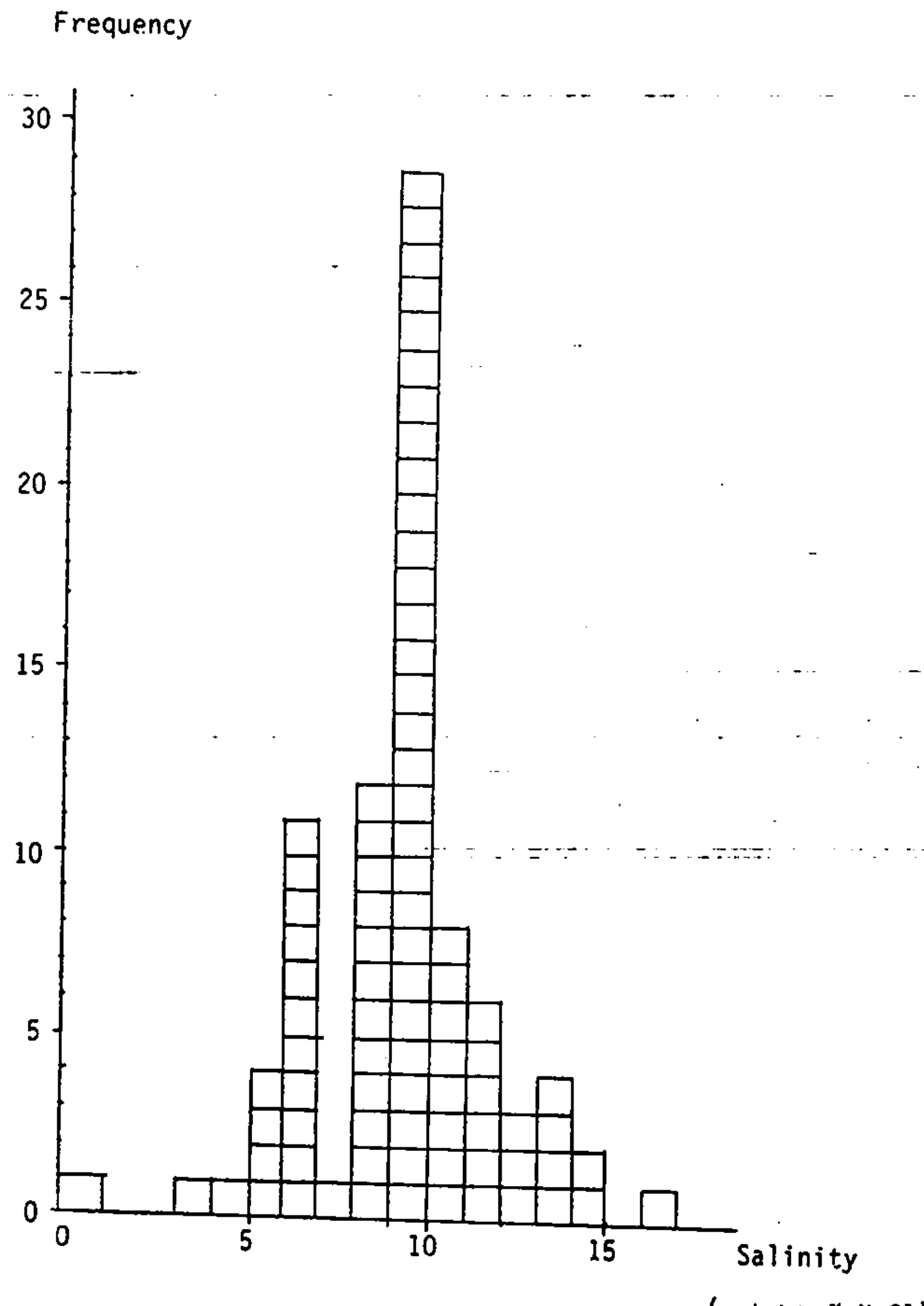


Fig. 13. Frequency distribution of salinity in fluid inclusions from quartz veins.

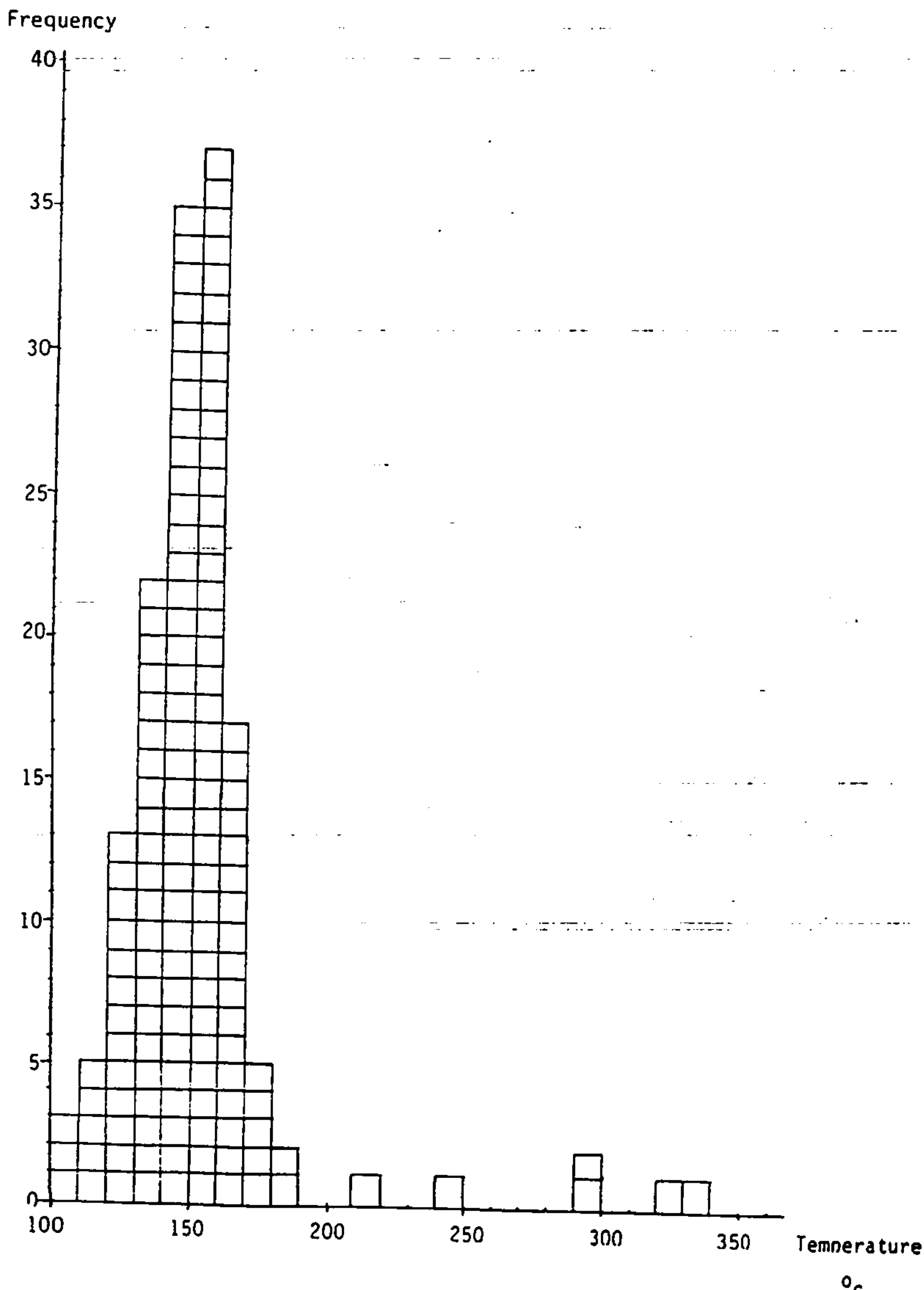


Fig. 14. Frequency distribution of homogenisation temperatures in fluid inclusions from quartz veins.

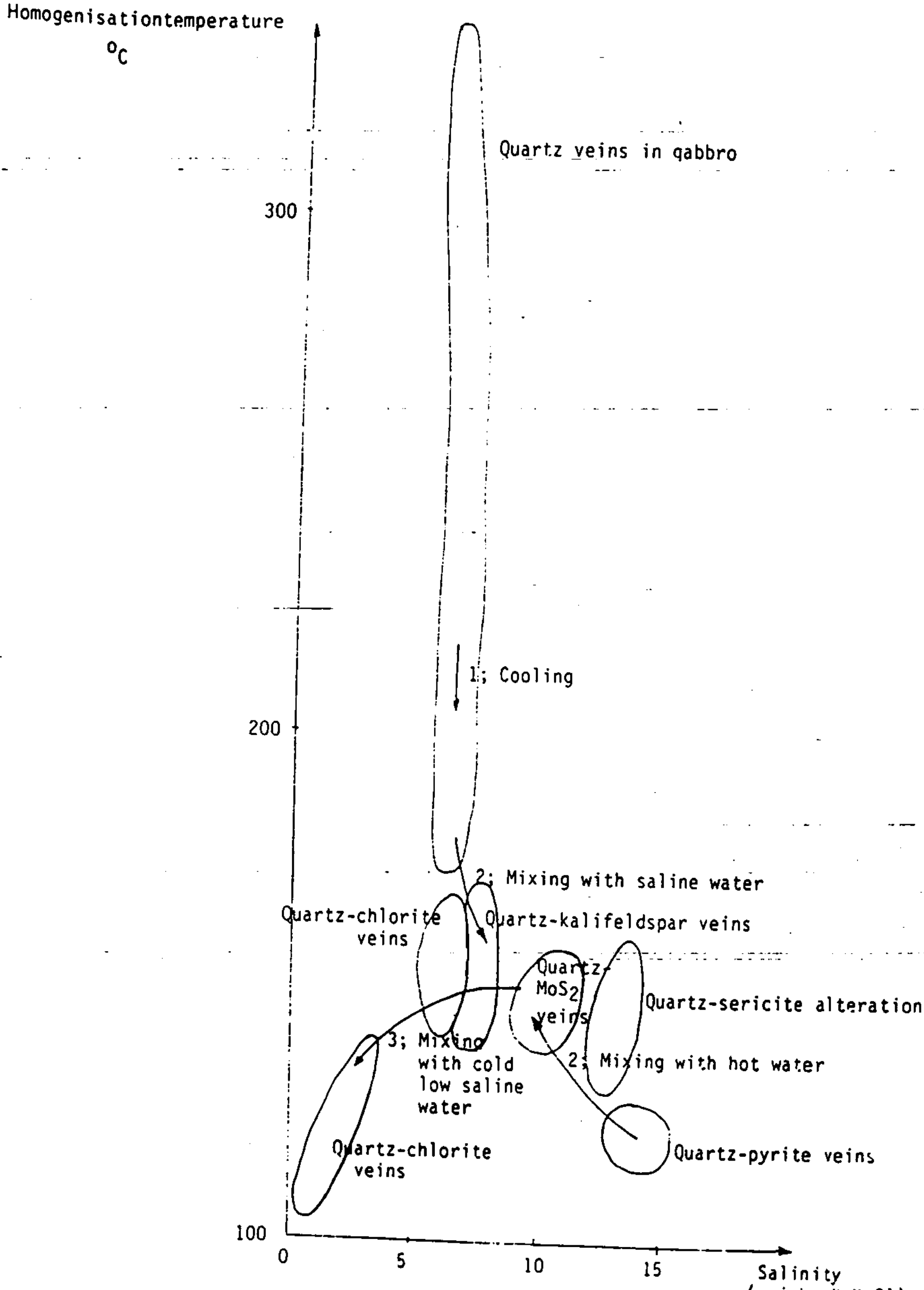
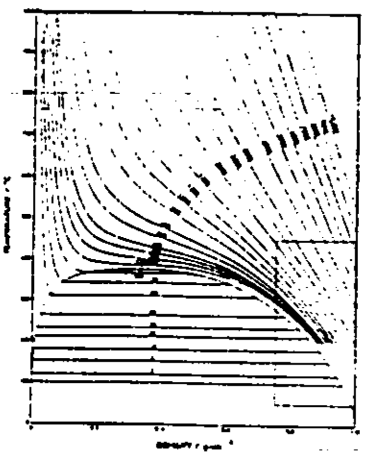


Fig. 15. Homogenisation temperature plotted against salinity. The domains mark measurements in quartz from different mineral assemblages. The numbers and comments represent genetic interpretation.



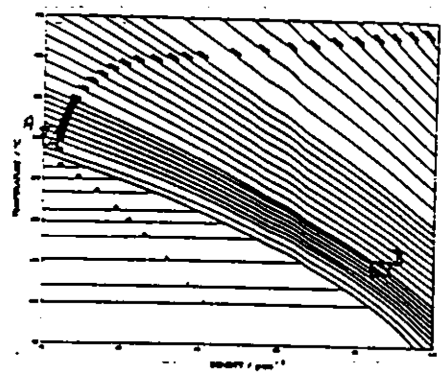


Fig. 16. This diagram shows the relation between temperature, density and pressure in the inclusions.
Area A represents low density and high temperature inclusions, and indicates a pressure of around 300-400 bars.
Area B represents moderately saline and low temperature inclusions, and indicates 500-1000 bars. (see text).

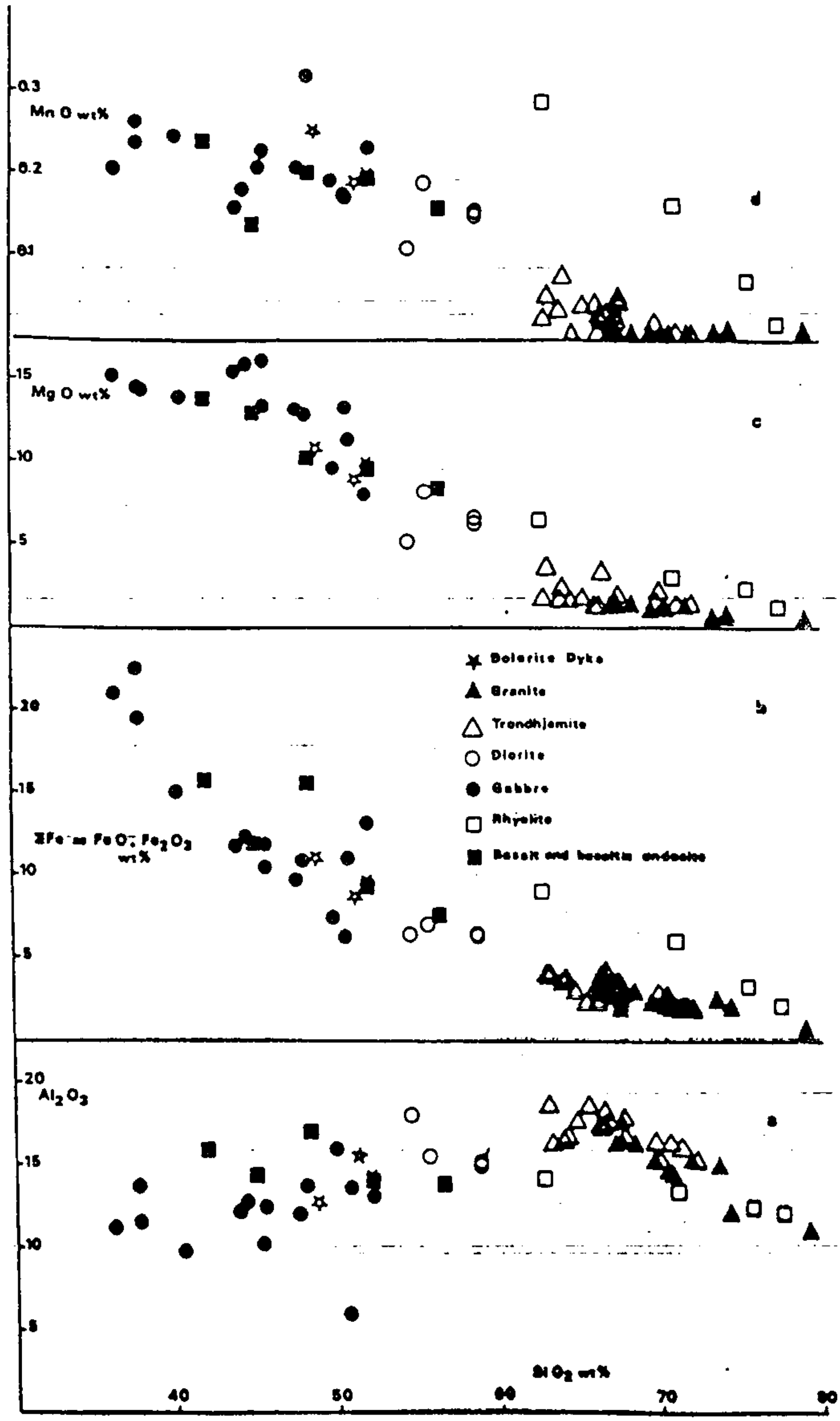


Fig. 17. Harker diagram from Elamin (1984).

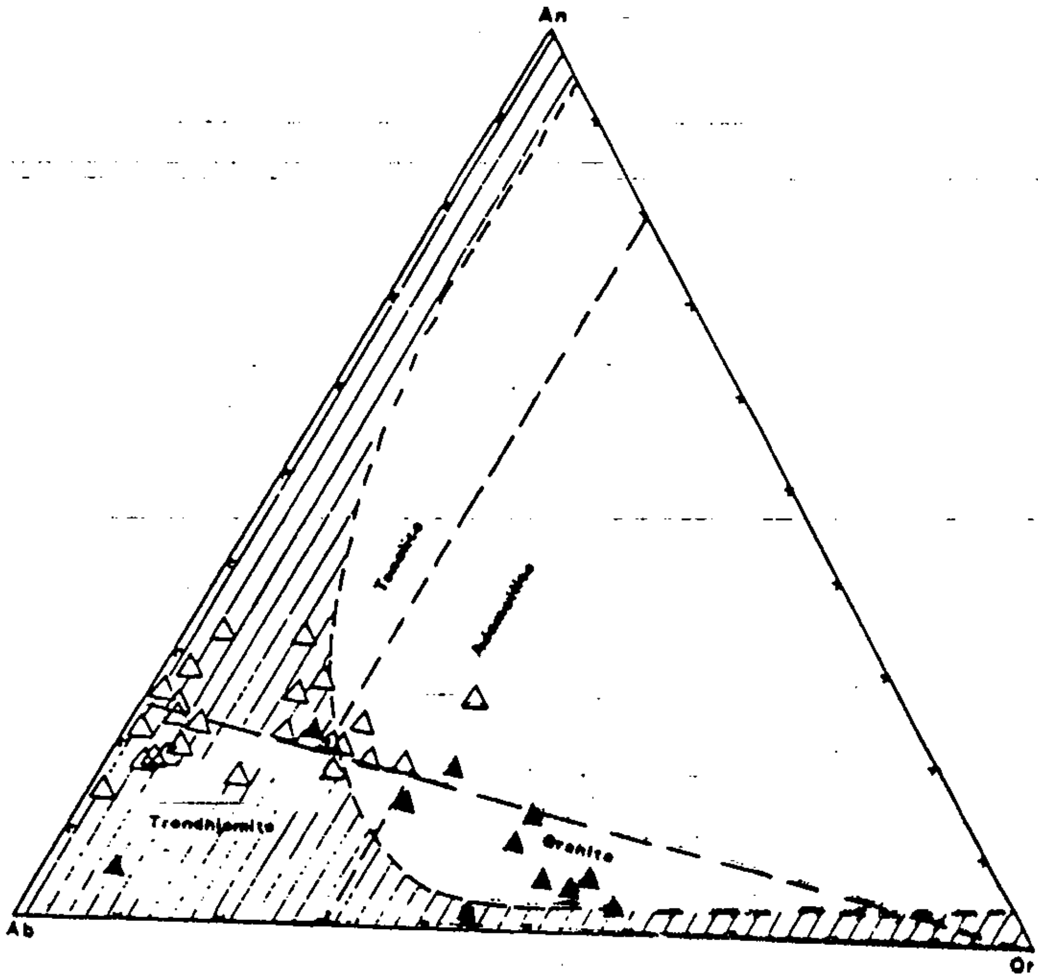


Fig. 18. Normative feldspar diagram for trondhjemite and granite.

Fields: Trondhjemite, granite, adamellite and tonalite after O'Connor (1965) and the shaded area is the low pressure feldspar stability field (< 5 kb) after Coleman and Peterman (1975).

Symbols as fig. 17.

(after Elamin 1984).

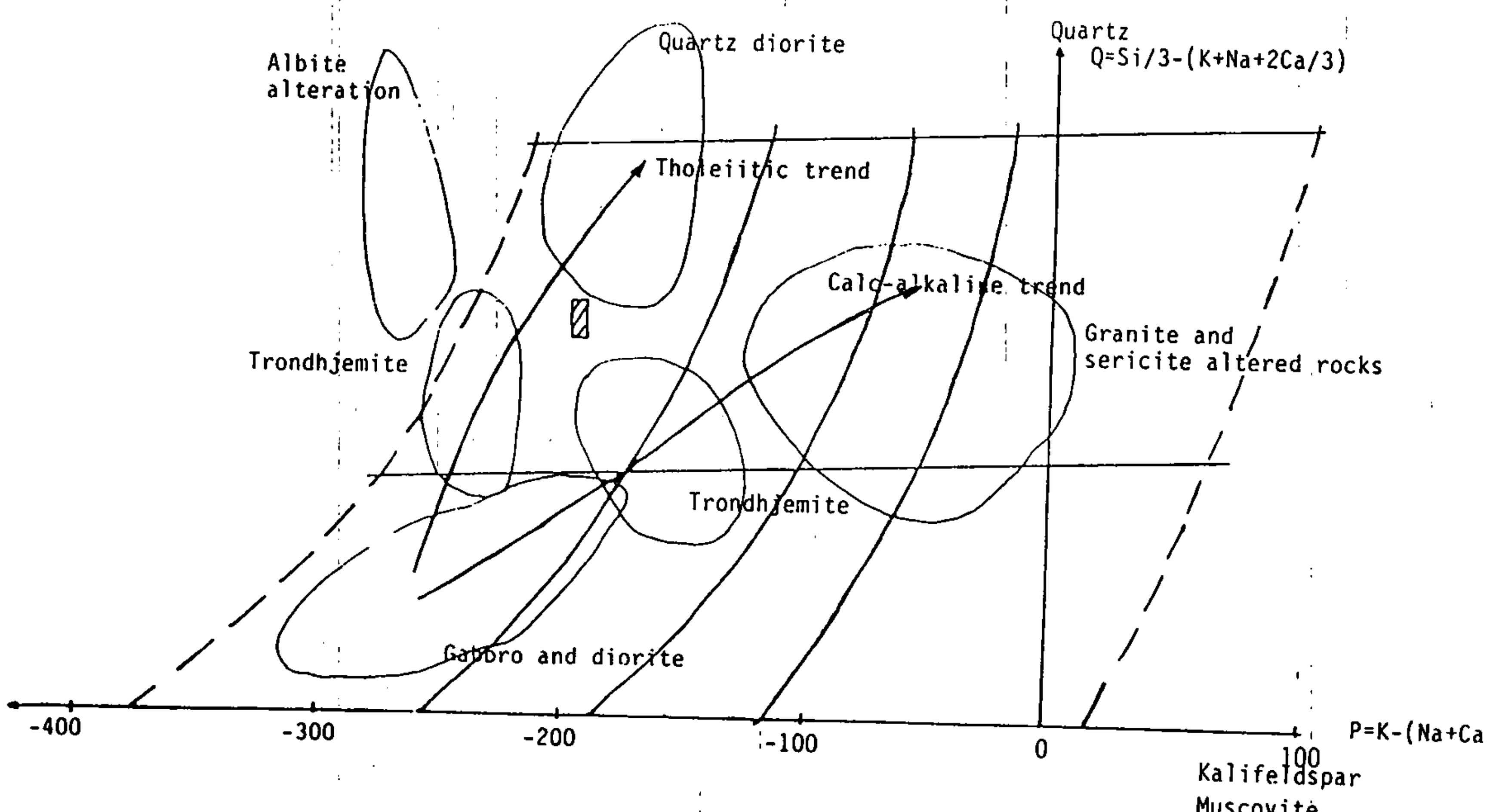


Fig. 19. Geological interpretation from geological samples of Elamin (1984), Reinsbakken (1986, pers.com.) and author. Classification after Debon and LeFort (1982).