Bergvesenet

Postboks 3021, N-7441 Trondheim

Rapportarkivet

Bergvesenet rapport nr	Intern Journal nr	Internt arkiv nr	Rapport lokalisering	Gradering
4790	0103/02			**Fortrolig**
Kommer fra ..arkiv	Ekstern rapport nr	Oversendt fra	Fortrolig pga	Fortrolig fra dato:
	NGU 2001.051	MoMin AS	Leieavtale 2001	

Tittel
Ore mineralogical investigation of the Mofjell deposit (Mo i Rana, Nordland, Norway) with ephasis on the gold and silver distribution.

Forfatter	Dato År	Bedrift (Oppdragsgiver og/eller oppdragstaker)
Cook, N. J.	01.07 2001	MoMin AS NGU Norges geologiske undersøkelse

Kommune	Fylke	Bergdistrikt	1: 50 000 kartblad	1: 250 000 kartblad
Rana	Nordland		19271	Mo i Rana

Fagområde	Dokument type	Forekomster (forekomst, gruvefelt, undersøkelsesfelt)
Geologi		Mofjellet
Råstoffgruppe	Råstofftype	
Malm/metall	Au Ag	

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

The presence of gold has been proven in the Mofjell ores, with 49 grains having been indentified in seven polished sections. Gold ocur as electrum (both Au and Ag-rich warities. The grain size is typically <10my.

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

GEOLOGY FOR SOCIETY

NGU Report 2001.051

Ore mineralogical investigation of the Mofjell deposit (Mo i Rana, Nordland, Norway) with emphasis on gold and silver distribution

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

Geological Survey of Norway
N-7441 Trondheim, Norway
Tel.: 47 73 90 40 00
Telefax 47 73 92 16 20

REPORT

Report no.: 2001.051	ISSN 0800-3416	Grading: Confidential until 2008

Title:
Ore mineralogical investigation of the Mofjell deposit (Mo i Rana, Nordland, Norway) with emphasis on gold and silver distribution

Authors: N.J. Cook		Client: MoMin AS	
County: Nordland		Commune: Norway	
Map-sheet name (M=1:250.000) Mo i Rana		Map-sheet no. and -name (M=1:50.000) 1927- I Mo i Rana	
Deposit name and grid-reference: Mofjellet Deposit - UTM 462200 7354100		Number of pages: 31 Map enclosures: None	Price (NOK): -
Fieldwork carried out: None	Date of report: June 1st, 2001	Project no.: 291800	Person responsible: [signature]

Summary:

The presence of gold has been proven in the Mofjell ores, with 49 gold grains having been identified in seven polished sections. Gold occurs as electrum (both Au- and Ag-rich varieties). The grain size is typically < 10 µm. This must be borne in mind when considering alternatives for processing the ore. Fine grinding will be essential for optimum recovery. Gold is chiefly associated with Sb-rich mobilsates. Associated minerals are tetrahedrite and other Sb-sulphosalts, galena, chalcopyrite, pyrite and quartz. Gold is not associated with sphalerite and Zn-rich samples are typically gold poor. Future exploitation of the Mofjell ore would need to carefully consider the implications of the fact that gold is locked within several different sulphides (chalcopyrite, galena, tetrahedrite), causing it to report to both Pb- and Cu-concentrates. Some gold is also present within the silicate matrix.

Silver is chiefly hosted within galena and argentian tetrahedrite. Minor amounts may be present in electrum, dyscrasite and Ag-Sb sulphosalts.

The occurrence of both gold and silver in the Mofjell deposit is consistent with other metamorphosed sulphide deposits (amphibolite grade) elsewhere in the Norwegian Caledonides (e.g., Bleikvassli, Sulitjelma). The mineralogy of the Mofjell deposit has been shown to be complex and further work will be necessary to confirm the conclusions of this report. This is especially true in the case of silver, for which a detailed and representative assessment of the silver distribution needs to be carried out prior to any test mining.

Keywords: Mofjell	Nordland	Sulphide
Mineralogy	Gold	Silver

CONTENTS

FIGURES

PLATES

TABLES

1. INTRODUCTION

This report is designed to complement the report of Bjerkgård et al. (2001; NGU report 2000.050), in which details of geology, structure and gold distribution in the Mofjell deposit are given. The reader is referred to that report for details of location of material studied and reported here.

The main opaque minerals in the Mofjell ores are, in order of abundance, pyrite (FeS_2), sphalerite (ZnS), galena (PbS), chalcopyrite ($CuFeS_2$), monoclinic pyrrhotite ($Fe_{1-x}S$), magnetite (Fe_3O_4), ilmenite ($FeTiO_3$), rutile (TiO_2), hematite (Fe_2O_3) and arsenopyrite (FeAsS). Gangue minerals include garnet, quartz, albite, hornblende, biotite, calcite, diopside, epidote, barite and staurolite. The gangue minerals have not been studied in the present investigation.

2. PREVIOUS MINERALOGICAL INVESTIGATIONS OF MOFJELL ORES

Saager (1966; 1967) made numerous valuable observations on the mineralogy of the Mofjell deposit, and was the first to recognize the complexity of many of the mineral assemblages. In the main Mofjell ores, he was able to recognize numerous ore trace minerals alongside the above-mentioned phases (hereafter, the 'common sulphides'). Stannite (Cu_2FeSnS_4)[1], cubanite ($CuFe_2S_3$), "valleriite"[2], ullmannite (NiSbS), various compositions within the tetrahedrite-tennantite solid solution series ($(Cu,Ag)_{10}(Fe,Zn)_2(Sb,As)_4S_{13}$), jamesonite ($Pb_4FeSb_6S_{14}$), gudmundite (FeSbS), molybdenite (MoS_2), breihauptite (NiSb), "white breithauptite"[3], hessite (Ag_2Te) and dyscrasite (Ag_3Sb). Gold was recognized as disseminations within the silicate matrix, as inclusions within pyrite and mostly, associated with chalcopyrite. Some gold grains had characteristic Ag-enriched rims. A good correlation between the occurrence of gold and chalcopyrite was noted, with the mineral commonly occurring at grain boundaries between chalcopyrite and galena, pyrrhotite or tetrahedrite, and commonly associated with that mineral. The size of the coarsest gold grain was given as 50 µm. Saager recognized that the Sb-sulphosalt minerals were locally abundant and also that these were enriched in the Hauknestind, Umskaret and Rostafjell deposits, compared to the Mofjell deposit itself. In Hauknestind ores, several additional minerals were recognized, including bournonite ($CuPbSbS_3$), boulangerite ($Pb_5Sb_4S_{11}$), pyrargyrite (Ag_3SbS_3), native bismuth (Bi) and a rare Bi-sulphosalt, cosalite[4]. Saager (1966) presented some microanalytical data for tetrahedrite-tennantite, showing that some varieties of tetrahedrite are Ag-bearing and that there is a positive correlation between Ag and Fe content. He further remarks on an additional "Ag-Te-sulphosalt", that occurs as micro-scale inclusions within tetrahedrite[5].

Schulze (1975) studied ores from Hauknestind and included microprobe analyses to corroborate some of the above identifications and identifying mackinawite ($(Fe,Ni)_9S_8$).

---

[1] The present author believes that most of what has been called stannite is actually members of the stannite-kësterite solid solution series with a wide range of compositions (Cu_2FeSnS_4-Cu_2ZnSnS_4).

[2] Shown by Schulze (1975) to be mackinawite.

[3] "White breithauptite" is almost certainly nisbite, another Ni-Sb compound. The two are both known from other Caledonide sulphide deposits, e.g. Sulitjelma.

[4] The present author believes this is, in all likelihood, not cosalite, but other Bi-sulphosalts, probably lillianite. The optical properties are near identical.

[5] The present author believes, based on the description and qualitative analysis presented by Saager, that this is most probably cervelleite, Ag_4TeS, a rare telluride known from just 7 deposits worldwide.

Lind (1980) undertook a detailed study of the Mofjell ores collected from underground localities. As was the case for Saager's study, most of the identifications were made based on microscopic observations, not on the basis of electron probe microanalysis[6]. Lind recognized a similar range of minerals as Saager. Additionally, she recognized minor amounts of bornite (Cu_5FeS_4), marcasite (FeS_2) and covellite (CuS) and a further Pb-Sb-sulphoslt phase, occurring as inclusions in galena, and referred to as 'schulzite'. Lind did not document gold in the ores. The generally Fe-rich tetrahedrite from lens 0 was shown to be richest in Ag, followed by lens 2. Tetrahedrite from lenses 1 and 3 contained lesser amounts of Ag, and were richer in Zn. Lind also discussed the mineralogy of several smaller showings in the Mofjell area. A similar range of minerals were found in these, but also seligmannite ($CuPbAsS_3$), geocronite ($Pb_{14}(Sb,As)_6S_{23}$), altaite (PbTe) and the rare telluride rucklidgeite, $(Bi,Pb)_3Te_4$[7].

Eidsmo et al. (1985), in their survey of silver distributions in various Caledonide sulphide deposits remark briefly upon the likely hosts for Ag in the deposit, even though their work did not include any quantitative data for Mofjell. In particular, they note how little Ag reported to the Zn-concentrate, inferring galena and tetrahedrite-tennantite to be the principal Ag-carriers in the ore.

Karlstrøm (1990) noted the good correlation between Ag and Sb in the Mofjellet ores. Karlstrøm included Te in his suite of analysed elements. All samples were below the detection limit of 0.1 ppm, suggesting tellurides to be a very minor component.

Nixon & Rui (1988) examined 31 polished sections (from drillholes 1321, 1323 and 1326) and identified gold minerals in 11 of these. Gold was seen as tiny grains (given in abstract as 'less than 1 μm'[8]), chiefly associated with silicates in fractures and on grain boundaries. They, interestingly, did not observe inclusions of gold in the common sulphides (pyrite, galena, sphalerite, chalcopyrite), but noted that some of the gold grains were associated with tetrahedrite-tennantite (*'fahlerts'*) and, in general, with fine-grained sulphide disseminations in silicate gangue.

As noted by Craig & Vokes (1992), Mofjell is, along with Bleikvassli and some deposits of the Sulijelma district (e.g. Jakobsbakken), one of those deposits with the most complex mineralogy within the Appalachian-Caledonide stratabound sulphide deposits. This is partly a result of the high metamorphic grade and resultant extensive sulphide remobilisation identified in these deposits, partly also a reflection of the more Pb- and Ag-rich character of these deposits (these elements characteristically form a number of trace minerals), but also a reflection that these deposits are among those which have been most carefully and thoroughly investigated.

3. THE PRESENT SAMPLE SUITE - ORE TYPES AND LOCATION

The suite of samples studied consist of 23 polished specimens, 1 inch in diameter prepared from the Ag- and Au-rich intersections in seven drillholes (Table 1). A further 46 samples were collected from drillcore intersections in the east of the deposit. However, it was decided not to proceed with the preparation of sections for these samples because of the low to very low gold assays.

---

[6] Some compositional data for tetrahedrite-tennantite minerals was shown as plots in a later publication (Lind & Makovicky 1982). Silver concentrations range from virtually zero up to about 20 wt. %, corresponding to a formula of $Cu_6Ag_4(Fe,Zn)_2(Sb,As)_4S_{13}$.

[7] Lind gives microprobe data supporting the identification of rucklidgeite.

[8] This is not consistent with their description, in which one of the grains is said to be <0.02 mm (i.e <20μm).

Each polished section has been investigated in reflected light at magnifications of 40X and 100X. Gold grains have been identified in seven of these samples (shown in bold in Table 1).

Table 1 Index of studied polished sections

Sample no.	Intersection	Description
Mo 1	DH 1321 1.42 m	Disseminated pyrite, sphalerite & galena in biotite-quartz gneiss.
Mo 2 & Mo 2a	DH 1321 4.30-4.32 m	Semi-massive pyrite-galena-sphalerite ore.
Mo 3	DH 1321 8.45 m	Disseminations of chalcopyrite & galena in biotite gneiss.
Mo 4	DH 1323 13.50-13.53 m	Pyrite & chalcopyrite disseminations along the schistosity planes of phyllosilicates .
Mo 5	DH 1323 13.36 m	Coarse-grained sphalerite in biotite gneiss.
Mo 6	DH 1323 11.12-11.15 m	Disseminated pyrite in biotite-quartz gneiss
Mo 7	DH 1323 17.9 m	Quartz rich ore carrying galena & sulphosalts
Mo 8	DH 1323 6.50 m	Finely disseminated chalcopyrite in gneiss.
Mo 9	DH 1324 12.05 m	Finely disseminated chalcopyrite in gneiss.
Mo 10 & **Mo 10a**	DH 1324 14.85-14.95 m	Coarse porphyroblastic pyrite carrying galena, sphalerite & some sulphosalts in fracture fillings.
Mo 11	DH 1326 2.14 m	Massive pyrite from micro-shear. Galena & chalcopyrite fill fractures in the pyrite.
Mo 12	DH 1326 1.28 m	Semi-massive dissemination of chalcopyrite & galena in biotite gneiss.
Mo 13	DH 1327 3.07 m	Semi-massive dissemination of chalcopyrite & galena in biotite gneiss.
Mo 14	DH 8004 278.7 m	Massive quartz carrying pyrite & sphalerite adjacent to vein.
Mo 15 & Mo 15a	DbH 8004 279.3 m	Disseminations of chalcopyrite & galena in biotite gneiss. Narrow veinlets.
Mo 16	DbH 1327 2.78 m	Disseminations of prite in quartz-rich gneiss.
Mo 17 & **Mo 17a**	DbH 1327 1.74 m	Disseminations of chalcopyrite & galena in biotite gneiss. Narrow veinlets.
Mo 18 & Mo 18a	DbH 1328 1.5-1.6 m	Semi-massive ore with pyrite. galena & chalcopyrite. Some sulphosalts.

4. MICROSCOPY OF GOLD ORES: CONSTRAINTS AND LIMITATIONS

In most sulphide ores like Mofjell, gold is present in concentrations of a few g/t at most. For this reason, a mineralogical study looking for gold in polished sections will be constrained by a number of difficulties, which should be anticipated before starting the study. Success, i.e. locating gold particles and accounting, mineralogically, for gold as has been measured by assay, is not always guaranteed.

There are several reasons for not encountering gold during a mineralogical study

- Poor selection of samples – are they truly representative of the gold-bearing intervals? A single one-inch polished block cannot necessarily duplicate the gold assayed over a 1 m section of drillcore – especially if the gold is concentrated within a small segment of that core.

- Poor polishing causing small gold particles to be lost from the polished surface. This can be a particularly serious problem in quartz-rich ores where too heavy a weight is placed on the specimen during polishing.
- The size of gold grains is sufficiently coarse that the nugget effect is observed, with gold inhomogeneously distributed between samples.
- Gold is present as 'invisible gold' locked within the lattice of sulphide minerals and cannot be seen during microscopic study.
- (Part of the) gold is present as other gold minerals, e.g. tellurides, which by virtue of their inconspicuous appearance are not readily noted during microscopic study.

As a result, certain precautions need to be taken in mind during the microscopic work and in interpretation of the results. See relevant publications on investigation of gold-bearing samples (Gasparrini 1983; Cook 1990; Harris 1990), sample preparation and polishing (Stanley & Laflamme 1998) and problems associated with the nugget effect (Dominy et al. 2000).

5. MAIN SULPHIDE MINERALS, ORE TEXTURES AND FABRICS

The ore mineralogy of the Mofjell deposit is that of typical metamorphosed sulphide deposits of VMS or SEDEX type. The common sulphides, sphalerite, galena, pyrite, pyrrhotite and chalcopyrite occur as fine grained disseminated grains, rarely exceeding 2 mm in diameter, within the silicate matrix. Sulphides follow the foliation of the rock and are commonly aligned parallel with the elongation of blades of biotite. Sulphides also occur as irregular aggregates within quartz and in garnet, and filling fractures and micro-shears (chalcopyrite and galena, in particular) within the silicates.

Isolated porphyroblasts of sphalerite, pyrite and galena occur disseminated throughout the ore. In most of the samples studied, pyrite was dominant over pyrrhotite. All the common sulphides are intimately intergrown with one another, especially chalcopyrite, pyrrhotite and galena. Magnetite occurs as relict grains, overgrown or replaced by pyrrhotite or chalcopyrite. Arsenopyrite and tetrahedrite-tennantite are abundant minor minerals. Both occur intergrown with chalcopyrite and galena. Grain size of both minerals rarely exceeds 100 µm in size. Cubanite is very abundant, as often spectacular, exsolution lamellae within chalcopyrite. Several sections (Drillholes 8004 and 1328) contained abundant molybdenite, as lath-shaped grains 100-200 µm in size. The large number of trace minerals recognised in this study are discussed in more detail below. All of these are small and occur as sub-50 µm grains intergrown with the common sulphides.

The ores display abundant evidence of extensive remobilisation, in which sulphides, including the precious metals, have been released from sulphide ore during metamorphic recrystallisation and subsequently re-concentrated within veinlets, deformed quartz-rich masses and as fracture fillings in pyrite and garnet. Several types of remobilisates are recognised in the sample suite, each reflecting discrete stages of the metamorphic cycle. Of relevance to the genetic history of the deposit is the observation of tetrahedrite-chalcopyrite-galena-bournonite inclusions within the cores of garnet porphyroblasts, with a later generation of mobilised minerals infilling fractures in the same garnet.

6. GOLD MINERALOGY

Before discussing the gold mineralogy in the studied sections, some background information is briefly presented.

Gold distribution in metamorphosed sulphide deposits – an introduction

Although some 31 gold minerals are known (Table X.2), the majority of these are exceptionally rare and will generally not be encountered in metamorphosed sulphide deposits.

In gold deposits, gold is typically distributed between:

- Native gold, electrum (Ag,Au) and more rarely, alloys with Hg (Au,Ag,Hg) (i.e. visible gold)
- Other Au-bearing minerals, particularly Au- and Ag-Au tellurides (calaverite, krennerite, sylvanite, petzite etc.), but also other compounds (e.g. maldonide, auripigment, aurostibite etc.; see Table 2)
- "Invisible gold" – that is gold within the common sulphides, either as sub-microscopic (< 1 µm) particles not observable using a reflected light microscope at 50 or 100x magnification, or within the crystal lattice of the sulphides. Arsenopyrite and pyrite are both important hosts of invisible gold in a variety of deposit types (Cook & Chryssoulis 1990; Cabri 1992). Other As-bearing minerals, e.g. löllingite, enargite, tennantite, may, if present in the ore, also contain some invisible gold.

In ore deposits regionally metamorphosed at amphibolite grade or above, gold is normally present as native gold or electrum. Although instances of invisible gold are known from metamorphosed sulphide ores, the higher the metamorphic grade, the less likely it is that invisible gold plays a significant role. This is because invisible gold, if any is present, will generally be released from the lattice of the common sulphides (chiefly pyrite and arsenopyrite) during syn-metamorphic recrystallisation (Larocque et al. 1993; 1995; Neumayr et al. 1993). That gold released from pyrite may be remobilised to form concentrations outside of the massive ore, commonly in zones of structural weakness within adjacent wallrock.

Although gold is commonly coarser in ores that have recrystallised at high metamorphic grade, the combination of major sulphide and gangue minerals and the ore fabric will impact on grain size, such that fine to very fine grain size is also observed in some metamorphosed ores.

Other gold minerals (e.g. tellurides, compounds with Sb or Bi) are typically exceptionally rare in metamorphosed massive sulphide deposits. Even though a number of other Au-bearing minerals have been recorded in Caledonide deposits (e.g. aurostibite at Sulitjelma), these are no more than a minor curiosity.

Table 2. Known gold minerals

Mineral Name	Chemical Formula	Au %	Rarity
Anyuiite	$Au(Pb,Sb)_2$	34.64	RRR
Auricupride	Cu_3Au	50.82	RR
Auroantimonate *	$AuSbO_3$	53.71	RRR
Aurostibite	$AuSb_2$	44.72	R
Bezsmertnovite	$Au_4Cu(Te,Pb)$	78.56	RRR
Bilibinskite	$Au_3Cu_2PbTe_2$	50.06	RRR
Bogdanovite	$(Au,Te,Pb)_3(Cu,Fe)$	33.23	RRR
Buckhornite	$AuPb_2BiTe_2S_3$	16.81	RRR
Calaverite	$AuTe_2$	43.56	R (T)
Criddleite	$TlAg_2Au_3Sb_{10}S_{10}$	23.18	RRR
Electrum	(Ag,Au)	15-85	C
Fischesserite	Ag_3AuSe_2	29.03	RRR
Gold	Au	100	C
Goldamalgam *	(Au,Ag)Hg	39.36	R
Hunchunite	$(Au,Ag)_2Pb$	53.08	RRR
Kostovite	$CuAuTe_4$	25.55	RRR
Krennerite	$AuTe_2$	43.56	R (T)
Kurilite *	$(Ag,Au)_2(Te,Se,S)$	27.08	RRR
Maldonite	Au_2Bi	65.34	R
Montbrayite	$(Au,Sb)_2Te_3$	39.97	RR (T)
Muthmannite	(Ag,Au)Te	29.06	RRR
Nagyagite	$AuPb(Sb,Bi)Te_{2-3}S_6$	18.60	R (T)
Penzhinite	$(Ag,Cu)_4Au(S,Se)_4$	25.94	RRR
Petrovskaite	AuAg(S,Se)	58.06	RRR
Petzite	Ag_3AuTe_2	29.49	R (T)
Sylvanite	$(Au,Ag)_2Te_4$	34.36	R (T)
Tetra-auricupride	AuCu	75.61	RR
Uytenbogaardtite	Ag_3AuS_2	33.69	RRR
Weishanite	$(Au,Ag)_3Hg_2$	47.90	RRR
Yuanjiangite	AuSn	62.40	RRR
Zvyagintsevite	$(Pd,Pt,Au)_3(Pb,Sn)$	9.67	RRR

C = common, R = rare, RR = very rare, RRR = exceptionally rare, (T) = important in gold-telluride deposits

7. MINERALOGY OF GOLD IN THE MOFJELL SUITE

Gold has been confirmed in the samples. Forty-one gold/electrum grains are identified in a total of seven polished sections. Each of these is tabulated in Table 3, with grain size and association. Each identified gold grain is shown in Plates 1 and 2. No other Au-bearing minerals have been observed in the samples.

As can be seen from the table, gold chiefly occurs as small grains, sub-10 µm in diameter. The size distribution is shown in Fig. 1, showing a normal distribution and an average grain diameter of 6 µm.

Gold is chiefly associated with chalcopyrite (15 grains), followed by tetrahedrite-tennantite (13 grains) and galena (8 grains). More rarely, gold is seen as inclusions within the quartz-silicate matrix (5 grains) or within pyrite (1 grain). This information is, however, somewhat subjective, however, since most gold grains occur at the mineral boundaries rather than as inclusions in a single mineral.

Conspicuously, gold is not seen associated with sphalerite, and indeed, those samples containing gold generally contained little sphalerite. Assemblages containing gold commonly also contain a range of Sb-sulphosalts, tetrahedrite being the most abundant of these. Many grains occur as very thin rims to tetrahedrite grains. Those samples containing gold grains were also those samples containing the greatest abundance of Sb-sulphosalts (tetrahedrite, bornite etc.). Pyrrhotite is commonly present as an associated mineral of those gold grains observed in chalcopyrite. Gold was not observed showing any association with arsenopyrite.

Based on their optical properties, the grains have a wide range of compositions. The majority were golden yellow in colour, suggesting fineness in excess of .750. Some however, appeared much more silver-rich. These are marked with * on Table 3. Four of the grains were checked by electron microprobe and showed compositional variation from 47.55 to 62.26 wt. % Au (Table 4). Other coarser, golden-yellow grains are approximately 80-85 wt. % Au. Small amounts (1.3-2.6 wt. % Hg) were noted in all grains – a common feature of gold grains from metamorphosed sulphide ores.

Based on these observations and knowledge on the gold distribution on other comparable deposits, it can be concluded that:

- ★ Invisible gold is unlikely to play a role in the Mofjell ores.
- ★ Gold occurs only in the form of native gold and alloys with silver (electrum), covering a relatively broad compositional range.
- ★ The observed gold is typically very fine-grained. A nugget effect, with a relatively small number of coarse grains erratically distributed within the gold-enriched ores, is considered as unlikely but cannot be ruled out.
- ★ Future exploitation of the Mofjell ore would need to carefully consider the implications of the fine average grain size of gold and the fact that it is locked within several different sulphides (chalcopyrite, galena, tetrahedrite), causing it to report to both the Pb- and Cu-concentrates. A significant proportion is also present within the silicate matrix[9], even if the present study did, unlike that of Nixon & Rui, indicate that the majority of gold grains are associated with sulphides rather than silicate matrix.

[9] The relatively high proportion of Mofjell gold lost to tailings (33%) was noted in a 1971 report (rapp. 'Gull i råmalm og konsentrater'; BV 3214)

Table 3 Gold grains identified in this study. The consecutive "grain number" given (first column indexes grains to Plates 1 and 2. Grain sizes are given as the diameter if the grain.

Grain	Sample	ID #	Size (µm)	Location & mineral association
1	Mo 3	1	30	In silicate matrix, associated with galena
2	"	2	2	In silicate matrix, associated with galena
3	"	3	2	On margin of galena grain
4	"	4	3	On margin of galena grain
5	"	5	14	On margin of galena grain
6	"	6	4	On margin of galena grain
7	"	7	11	On margin of galena grain
8	"	8*	3	Filling fracture in galena, associated with tetrahedrite
9	"	9	18	In quartz matrix, associated with galena
10	"	10	15	On margin of chalcopyrite grain
11	"	11*	3	On margins of tetrahedrite grain
12	"	12*	2	On margins of tetrahedrite grain
13	"	13*	10 x 1	On margins of tetrahedrite grain
14	"	14	7	In quartz matrix, associated with galena & chalcopyrite
15	"	15*	6	On margins of tetrahedrite grain
16	"	16*	5	On margins of tetrahedrite grain
17	"	17*	3	On margins of tetrahedrite grain
18	"	18*	60 x 1	On margins of tetrahedrite grain, some chalcopyrite
19	"	19*	3	On margins of tetrahedrite grain
20	"	20	3	In quartz, associated with galena & tetrahedrite
21	"	13*	8	On margins of tetrahedrite grain
22	"	14	5	Enclosed in tetrahedrite
23	"	15*	4	On margins of tetrahedrite grain
24	"	16	19	On margin if chalcopyrite, associated with tetrahedrite
25	"	17	5	In quartz, associated with galena
26	"	18	3	Enclosed in tetrahedrite
27	Mo 7	1	10	In silicate matrix, associated with chalcopyrite
28	Mo 10A	1	15	At margin of chalcopyrite
29	"	2	15	At margin of chalcopyrite
30	"	3	5	With chalcopyrite, filling fracture in pyrite
31	"	4	4	With chalcopyrite, filling fracture in pyrite
32	Mo 12	1	3	Inclusion in galena
33	"	2	1	At boundary between chalcopyrite and pyrrhotite
34	"	3	3	Within fracture in chalcopyrite
35	"	4	8	At margin of chalcopyrite, assoc. with tetrahedrite
36	"	5*	6	On margin of galena
37	Mo 13	1	3	At boundary of chalcopyrite and tetrahedrite
38	"	2	1	At margin between galena and tetrahedrite
39	"	3	1	At margin between galena, tetrahedrite and bournonite
40	"	4	2	Inclusion in galena
41	"	5	2	Inclusion in galena
42	"	6	5	At margin between galena and tetrahedrite
43	Mo 17A	1	2	Inclusion in chalcopyrite
44	Mo 18	1	1	Inclusion in chalcopyrite, itself within pyrite
45	"	2	22	Inclusion in pyrite
46	"	3	10	Inclusion in chalcopyrite-pyrrhotite, itself within pyrite
47	"	4	8	Inclusion in chalcopyrite-pyrrhotite, itself within pyrite
48	"	5	8	Inclusion in chalcopyrite-pyrrhotite, itself within pyrite
49	"	6	1	Inclusion in chalcopyrite-pyrrhotite, itself within pyrite

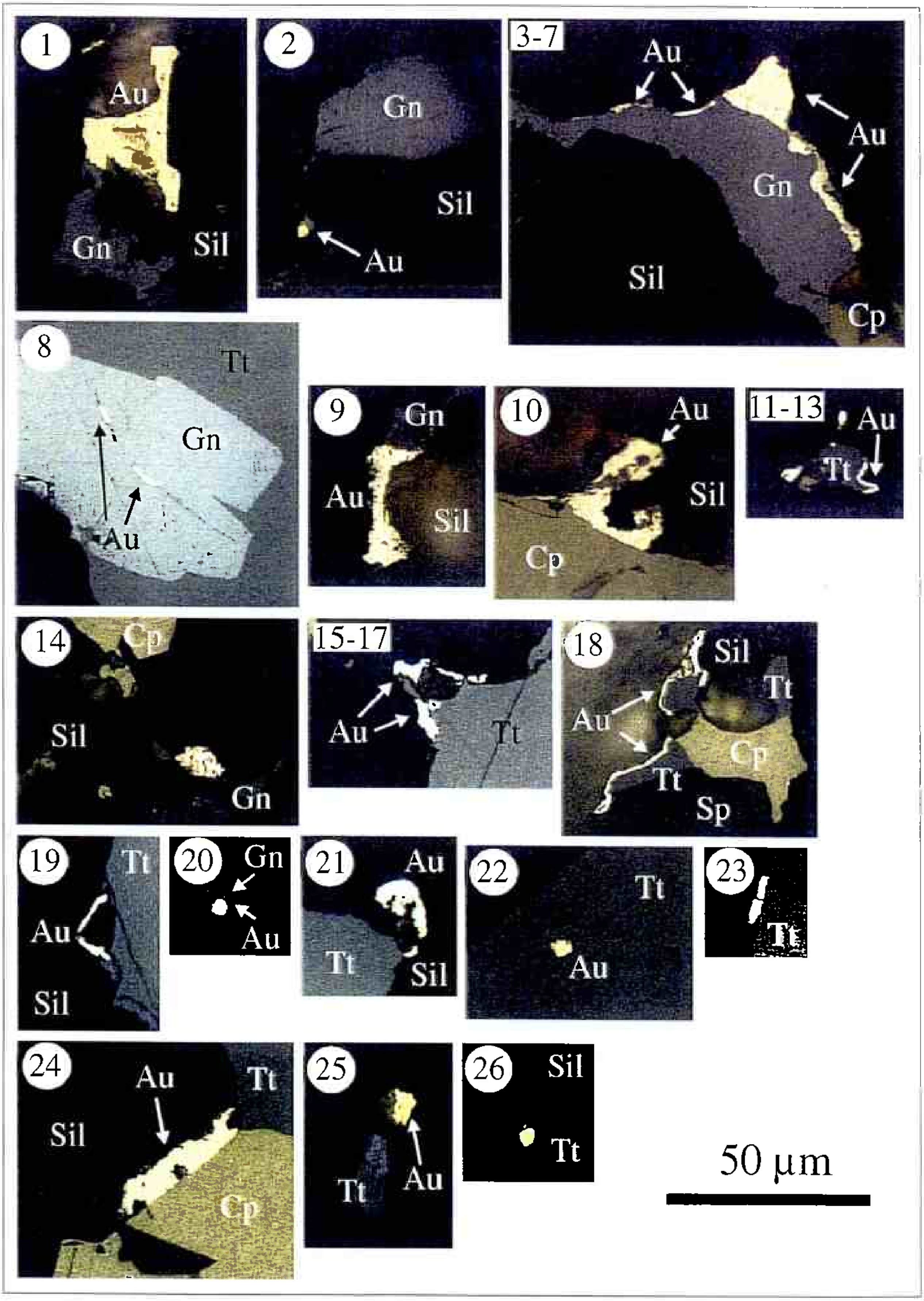


Plate 1 Gold grains observed in sample Mo 3. Abbreviations are Au: gold, Cp: chalcopyrite, Gn: galena, Tt: tetrahedrite, Sp: sphalerite, Sil: silicate. All images are shown at the same scale.

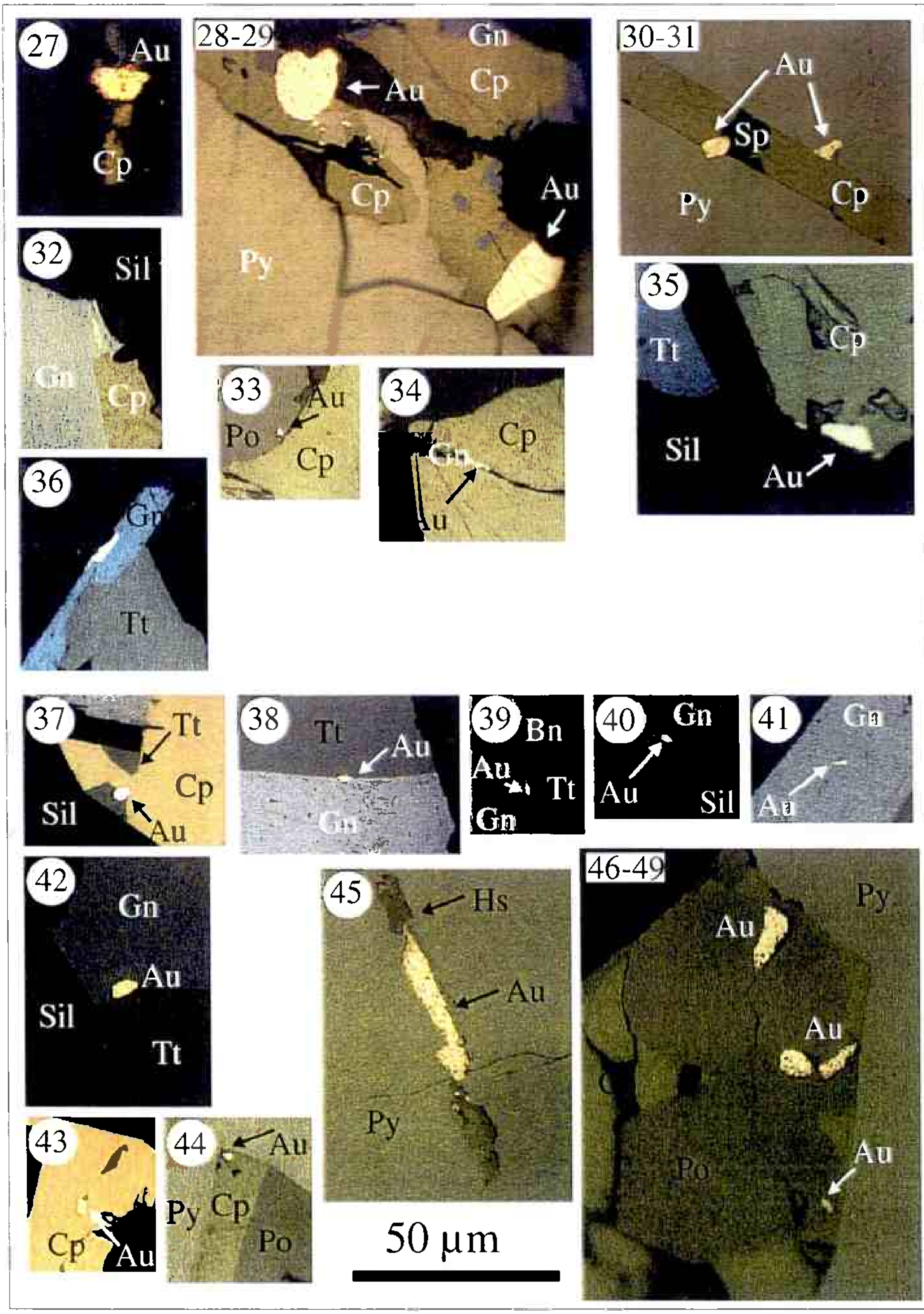
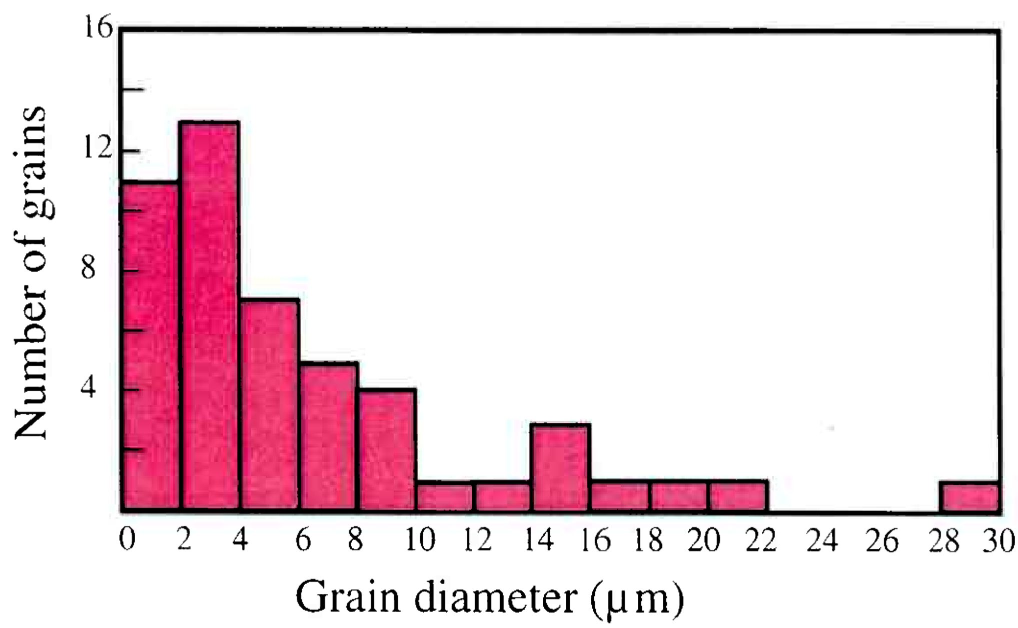


Plate 2 Gold grains observed in samples Mo 7, -10A, -12, -13, -17A and -18. Abbreviations are Au: gold, Cp: chalcopyrite, Gn: galena, Tt: tetrahedrite, Sp: sphalerite, Py: pyrite, Po: pyrrhotite, Hs: hessite, Sil: silicate. All images are shown at the same scale.

Table 4 Electron probe microanalyses of electrum grains, normalized to 100 wt. %

Wt. %	Grain 33	Grain 32	Grain 35	Grain 34
Ag	47.55	51.04	54.16	62.26
Au	48.80	46.55	41.64	35.61
Hg	1.31	1.83	2.57	1.88
Cu	1.94	0.33	-	0.13
Sb	0.40	0.25	1.64	0.17

Fig. 1 Grain size distribution among the 49 identified gold grains. Diameter is measured as an approximate mean of the longest and shortest dimensions of each grain.



8. SILVER MINERALOGY

Silver, like gold, is a valuable minor component of various types of sulphide Cu-Zn-Pb ore deposits. The mineralogical distribution of silver depends upon the main sulphide minerals present, the concentrations of Sb and other minor elements in the deposit, with which Ag may form compounds, the grade of metamorphism, speed of re-equilibration and speed of cooling. Silver is typically distributed between:

- Galena (the major sulphide host) as a coupled substitution with Bi in the lattice ($2Pb^{2+} \Leftrightarrow Bi^{3+} + Ag^{+}$) or as impurities of sub-microscopic silver minerals)
- Minerals of the tetrahedrite-tennantite-freibergite family (freibergite, argentian tetrahedrite) and more rarely, also argentian tennantite.
- Native silver and alloyed with gold in electrum
- Other Ag-bearing minerals (argentite-acanthite, various Ag-Sb sulphosalts, Ag-Pb-Bi sulphosalts, selenides, tellurides and many others; see Table 5).
- As lattice-bound silver in other common sulphides. Pyrite, arsenopyrite, chalcopyrite, sphalerite and pyrrhotite have all been shown to take Ag into their structures at concentrations below the minimum detection limit of the electron microprobe, but sufficiently high to account for a significant proportion of the total Ag in the deposit (Berubé et al. 1985; Chryssoulis et al. 1986; Chryssoulis & Surges 1988; Cabri 1992; Petruk & Wilson 1993; Huston et al. 1995; Larocque et al. 1995; Cook & Chryssoulis 1999). This applies to all types of deposit, including metamorphosed sulphide ores, but cases in which lattice bound Ag is more important than the other mineralogical hosts tends to be the exception rather than the rule, even though among the exceptions are a number of major deposits, e.g. Brunswick no. 12 (N.B. Canada), where sphalerite is the major Ag-carrier (Chryssoulis et al. 1986) or Izok Lake, where chalcopyrite is the major Ag-carrier (Harris et al. 1984).

The recovery of silver from the ores is dependant on a variety of factors, of which mineralogy is most important, but also textural association of the silver-bearing minerals with base metal sulphides and grain size (Gasparrini 1984). The considerable advances in microanalytical capability over the past decade, notably the facility to analyse Ag and other trace elements at ppm levels in sulphide minerals, have led to a much improved understanding of the mineralogical distribution of Ag in sulphide ores and thus the relative importance of key minerals as hosts for silver.

The mineralogy of Ag in sulphide ores, particularly those belonging to the VMS-SEDEX continuum is typically dominated by galena (with concentrations of typically some hundreds of ppm) and subordinately, in tetrahedrite-tennantite. The regional metamorphism of the ores is an agent for the redistribution of Ag, since the element is easily remobilised into the wallrock. In mobilised ores, other Ag-minerals (e.g. native silver or dyscrasite Ag_3Sb) may be important, at least locally. Metamorphic recrystallisation of the common sulphides generally tends to reduce the concentration of impurities, including Ag, in the lattice to very low levels, such that these minerals only contribute a couple of % to the total silver balance. In a recent study of an ore comparable to Mofjell, Cook & Chryssoulis (1999) estimated that less than 5% of the total Ag was locked in the common sulphides other than galena.

Table 5 Silver minerals

Mineral Name	Chemical Formula	Ag %	Rarity
Acanthite	Ag_2S	87.06	R
Aguilarite	Ag_4SeS	79.53	RR
Allargentum	$Ag_{1-x}Sb_{x(x=0.009-0.16)}$	98.87	R
Amalgam *	Ag_2Hg_3	26.39	R
Andorite	$PbAgSb_3S_6$	12.36	RR
Antimonpearceite	$(Ag,Cu)_{16}(Sb,As)_2S_{11}$	61.02	R
Aramayoite	$Ag(Sb,Bi)S_2$	34.18	RRR
Arcubisite	Ag_6CuBiS_4	61.76	RRR
Argentite *	Ag_2S	87.06	R
Argentojarosite	$AgFe^{+++}{}_3(SO_4)_2(OH)_6$	18.94	RR
Argentopentlandite	$Ag(Fe,Ni)_8S_8$	13.21	RR
Argentopyrite	$AgFe_2S_3$	34.16	RR
Argentotennantite	$(Ag,Cu)_{10}Fe_2As_4S_{13}$	43.56	R
Argyrodite	Ag_8GeS_6	76.51	RR
Arsenpolybasite	$(Ag,Cu)_{16}(As,Sb)_2S_{11}$	62.39	R
Aurorite	$(Mn,Ag,Ca)Mn_3O_7\ 3(H_2O)$	8.12	RR
Balkanite	$Cu_9Ag_5HgS_8$	34.39	RRR
Benjaminite	$(Ag,Cu)_3(Bi,Pb)_7S_{12}$	11.37	RRR
Benleonardite	$Ag_8(Sb,As)Te_2S_3$	65.74	RRR
Berryite	$Pb_3(Ag,Cu)_5Bi_7S_{16}$	8.91	RR
Bideauxite	$Pb_2AgCl_3(F,OH)_2$	16.21	RRR
Billingsleyite	Ag_7AsS_6	73.85	RR
Bohdanowiczite	$AgBiSe_2$	22.72	RR
Boleite	$Pb_{26}Ag_{10}Cu_{24}Cl_{62}(OH)_{48}\ 3(H_2O)$	9.75	RR
Borodaevite	$Ag_5(Bi,Sb)_9S_{16}$	19.71	RRR
Bromargyrite	$AgBr$	57.45	RR
Cameronite	$AgCu_7Te_{10}$	5.90	RRR
Canfieldite	Ag_8SnS_6	73.50	RR
Capgaronnite	$HgAg(Cl,Br,I)S$	27.07	RRR
Cervelleite	Ag_4TeS	72.99	RR
Chlorargyrite	$AgCl$	75.26	RR
Chrisstanleyite !	$Ag_2Pd_3Se_4$	25.36	RRR
Cocinerite *	Cu_4AgS	27.37	RRR
Criddleite	$TlAg_2Au_3Sb_{10}S_{10}$	8.46	RRR
Crookesite	$Cu_7(Tl,Ag)Se_4$	2.87	RRR
Cuboargyrite !	$AgSbS$	41.22	RRR
Cupropavonite	$AgPbCu_2Bi_5S_{10}$	5.97	RRR
Danielsite	$(Cu,Ag)_{14}HgS_8$	28.31	RRR
Dervillite	Ag_2AsS_2	60.81	RRR
Diaphorite	$Pb_2Ag_3Sb_3S_8$	23.80	RR
Dyscrasite	Ag_3Sb	72.66	R
Embolite *	$Ag(Br,Cl)$	69.85	RR
Empressite	$AgTe$	45.8	RR
Eskimoite	$Ag_7Pb_{10}Bi_{15}S_{36}$	10.61	RRR
Eucairite	$CuAgSe$	43.08	RRR
Eugenite	Ag_9Hg_2	70.76	RRR
Fettelite	$Ag_{24}HgAs_5S_{20}$	68.03	RRR
Fischesserite	Ag_3AuSe_2	47.69	RRR
Fizelyite	$Pb_{14}Ag_5Sb_{21}S_{48}(?)$	7.16	RR
Freibergite	$(Ag,Cu,Fe)_{12}Sb_4S_{13}$	40.25	R
Freieslebenite	$AgPbSbS_3$	20.24	RR
Furutobeite	$(Cu,Ag)_6PbS_4$	14.17	RRR
Geffroyite	$(Ag,Cu,Fe)_9(Se,S)_8$	43.40	RRR
Giraudite	$(Cu,Zn,Ag)_{12}As_4Se_{13}$	6.34	RRR
Goldamalgam *	$(Au,Ag)Hg$	7.19	R
Gustavite	$PbAgBi_3S_6$	9.51	RR
Hatchite	$(Pb,Tl)_2AgAs_2S_5$	12.9	RRR
Henryite	$Cu_4Ag_3Te_4$	29.74	RRR
Hessite	Ag_2Te	45.81	R
Heyrovskyite	$Pb_{10}AgBi_5S_{18}$	2.84	RR
Hocartite	Ag_2FeSnS_4	41.60	RRR
Hunchunite	$(Au,Ag)_2Pb$	9.69	RRR
Iltisite	$HgSAg(Cl,Br)$	27.87	RR
Imiterite	Ag_2HgS_2	44.90	RRR
Iodargyrite	AgI	45.95	RR
Jalpaite	Ag_3CuS_2	71.71	RR
Kitaibelite*	$15Bi_2S_3\ 5Ag_2S\ PbS$	11.74	RRR
Kurilite *	$(Ag,Au)_2(Te,Se,S)$	44.48	RRR
Kutinaite	Cu_2AgAs	34.81	RRR
Laffittite	$AgHgAsS_3$	22.49	RRR
Laforetite	$AgInS_2$	37.61	RRR
Larosite	$(Cu,Ag)_{21}(Pb,Bi)_2S_{13}$	9.56	RRR
Lenaite	$AgFeS_2$	47.34	RRR
Lengenbachite	$Pb_6(Ag,Cu)_2As_4S_{13}$	7.51	RR
Luanheite	Ag3Hg	61.73	RRR
Makovickyite	$Ag_{1.5}Bi_{5.5}S_9$	10.11	RR
Marrite	$PbAgAsS_3$	22.19	RRR
Matildite	$AgBiS_2$	28.31	R
Mckinstryite	$(Ag,Cu)_2S$	71.71	R
Miargyrite	$AgSbS_2$	36.72	R
Miersite	$(Ag,Cu)I$	36.17	RRR
Moschellandsbergite	Ag_2Hg_3	26.39	RRR
Mummeite	$Ag_{2-3}Cu_{1-2}PbBi_6S_{13}$	14.29	RRR
Muthmannite	$(Ag,Au)Te$	23.87	RRR
Naumannite	Ag_2Se	73.21	RR
Neyite	$Pb_7(Cu,Ag)_2Bi_6S_{17}$	1.59	RRR
Novakite	$(Cu,Ag)_{21}As_{10}$	9.93	RRR
Ourayite	$Pb_4Ag_3Bi_5S_{13}$	12.96	RRR
Owyheeite	$Pb_7Ag_2(Sb,Bi)_8S_{20}$	6.24	RR
Paderaite	$AgPb_2Cu_6Bi_{11}S_{22}$	2.76	RRR
Paraschachnerite	Ag_3Hg_2	44.65	RRR
Pavonite	$(Ag,Cu)(Bi,Pb)_3S_5$	9.16	RR
Pearceite	$Ag_{16}As_2S_{11}$	77.45	R
Penzhinite	$(Ag,Cu)_4Au(S,Se)_4$	42.62	RRR
Perroudite	$Hg_{5-x}Ag_{4+x}S_{5-x}(Cl,I,Br)_{4+x}$		27.45
Petrovskaite	$AuAg(S,Se)$	31.80	RR
Petzite	Ag_3AuTe_2	32.30	R (T)
Pirquitasite	Ag_2ZnSnS_4	40.85	RRR
Polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$	60.35	C
Proustite	Ag_3AsS_3	65.41	C
Pyrargyrite	Ag_3SbS_3	59.75	C
Pyrostilpnite	Ag_3SbS_3	59.75	RR
Quadratite !	$Ag(Cd,Pb)AsS_3$	26.29	RRR
Ramdohrite	$Ag_3Pb_6Sb_{11}S_{24}$	8.80	RR
Rayite	$(Ag,Tl)_2Pb_8Sb_8S_{21}$	4.53	RRR
Roshchinite	$Ag_{19}Pb_{10}Sb_{51}S_{96}$	15.28	RRR
Samsonite	$Ag_4MnSb_2S_6$	46.78	RRR
Schachnerite	$Ag_{1.1}Hg_{0.9}$	39.66	RRR
Schapbachite*	$AgBiS_2$	28.31	R
Schirmerite	$Ag_3Pb_3Bi_9S_{18}$	10.84	RR
Selenostephanite	$Ag_5Sb(Se,S)_4$	57.99	RRR
Silver	Ag	100	C
Smithite	$AgAsS_2$	43.69	RRR
Sopcheite	$Ag_4Pd_3Te_4$	34.21	RRR
Stephanite	Ag_5SbS_4	68.33	R
Sternbergite	$AgFe_2S_3$	34.16	RR
Sterryite	$Ag_2Pb_{10}(Sb,As)_{12}S_{29}$	4.75	RRR
Stetefeldtite	$Ag_2Sb_2(O,OH)_7(?)$	37.65	RRR
Stromeyerite	$AgCuS$	53.01	R
Stutzite	Ag_7Te_4	59.67	R
Sylvanite	$(Au,Ag)_2Te_4$	6.27	R (T)
Telargpalite	$(Pd,Ag)_3Te$	4.82	RRR
Tocornalite	$(Ag,Hg)I(?)$	31.36	RRR
Toyohaite	$Ag_2FeSn_3S_8$	24.40	RRR
Treasurite	$Ag_7Pb_6Bi_{15}S_{32}$	12.26	R
Trechmannite	$AgAsS_2$	43.69	RRR
Tsnigriite	$Ag_9SbTe_3(S,Se)_3$	60.87	RRR
Uchucchacuaite	$AgPb_3MnSb_5S_{12}$	6.07	RRR
Uytenbogaardtite	Ag_3AuS_2	55.35	RRR
Vikingite	$Ag_5Pb_8Bi_{13}S_{30}$	9.18	RRR
Volynskite	$AgBiTe_2$	18.86	RR
Wallisite	$PbTl(Cu,Ag)As_2S_5$	3.39	RRR
Weishanite	$(Au,Ag)_3Hg_2$	8.74	RRR
Xanthoconite	Ag_3AsS_3	65.41	RRR
Zoubekite	$AgPb_4Sb_4S_{10}$	6.18	RRR

C = common. R = rare. RR = very rare. RRR = exceptionally rare.
(T) = important in gold-telluride deposits

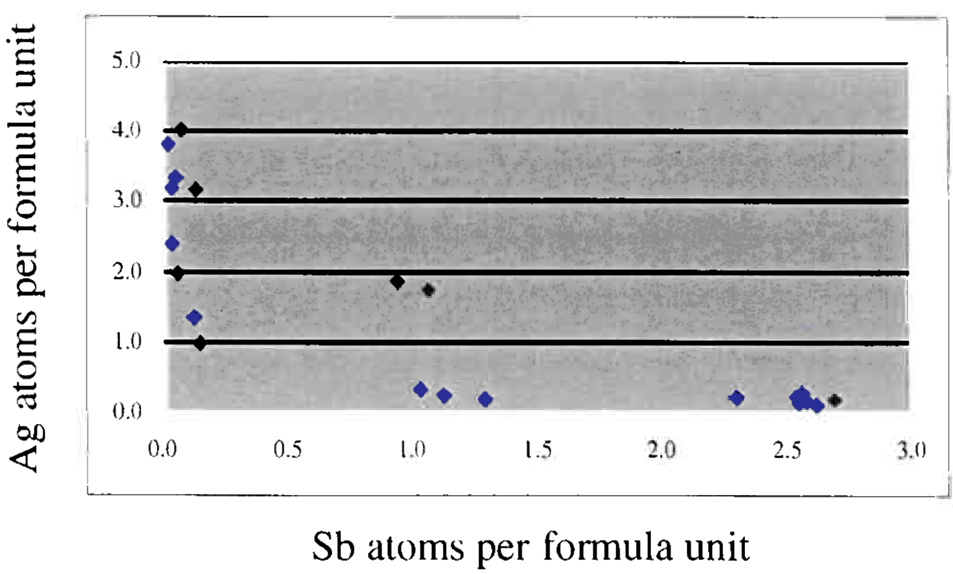
9. MINERALOGY OF SILVER IN THE MOFJELL SUITE

The silver mineralogy of the samples appears to be distributed between galena and tetrahedrite-tennantite, $(Cu,Ag)_{12}(Fe,Zn)_2(Sb,As)_4S_{13}$, with minor amounts of silver present as native silver/electrum and as discrete Ag-minerals.

Galena is a major mineral in the ores and therefore may be expected to play a significant role as a Ag-carrier, not least because of the strong positive correlation seen between Ag and Pb in bulk samples. However, quantitative data for the Ag content of galena is lacking. The concentration of Ag in galena lies under the detection limit of conventional electron microprobe techniques (ca. 300-1000 ppm). None of the 12 galena grains analysed in this study contained Ag at measurable concentrations.

Tetrahedrite-tennantite is shown to be a widespread mineral, especially in the most strongly mobilised ores. Optical properties and microprobe analyses have shown that a broad range of composition is present among the grains, including Ag-rich and Ag-poor tetrahedrite and also compositions closer to tennantite (Table 6; Fig. 2). There appears to be no correlation between the concentration of Ag present in the mineral and either the size of the grain or its habit (symplectitic intergrowth with galena, sulphosalts, or as inclusions in galena or chalcopyrite. Tetrahedrite is most commonly present as symplectitic intergrowths with galena, bournonite or meneghinite, but analyses of these grains have indicated both Ag-rich and Ag-poor varieties to be present, sometimes with two compositional varieties present within a single grain aggregate.

Fig. 2 Compositions of tetrahedrite-tennantite minerals. Note strong correlation between Ag and Sb contents.



Three grains of **native silver**, all < 5 μm, have been observed. Native silver therefore only plays a minor role in the ores. Some of the Ag (probably about 5%) is hosted within electrum, since probe analyses have shown the electrum to commonly be silver-rich.

Table 6 Microprobe analyses of tetrahedrite-tennantite minerals.

Element wt. %	13 25.2	13 25.3	13 25.4	13 25.5	13 22a.5	12 13.3	12 7a.1	12 7a.4	12 4.2	12 4.3	13 17.1	13 17.2	13 16.1	13 16.2	13 26.3	13 25a.2	13 11.1	13 22.2	13 24.1	13 26a.1	13 26a.2
Ag	1.33	0.57	1.04	0.82	5.51	17.79	18.33	17.88	21.86	21.53	11.12	10.72	1.41	1.57	0.97	1.96	11.41	7.99	13.70	1.14	1.37
Cu	33.94	40.31	34.31	40.01	29.80	23.01	20.18	20.75	18.20	19.34	26.71	28.38	38.31	33.51	39.28	33.60	25.05	28.05	25.49	36.26	37.04
Fe	5.89	7.73	6.31	8.95	3.11	5.74	5.30	5.31	4.82	5.05	5.88	5.86	6.91	6.11	7.80	6.08	5.42	3.89	4.35	7.29	6.87
Zn	0.31	0.00	1.06	0.00	1.93	0.00	0.00	0.44	0.00	0.00	0.00	0.27	0.16	1.58	0.00	0.25	1.23	2.65	1.48	0.13	0.00
Cd	0.23	0.03	0.00	0.00	0.00	0.65	0.49	0.92	2.08	1.17	0.29	0.95	0.00	0.00	0.20	0.21	0.05	0.00	1.06	0.07	0.01
Pb	0.00	0.83	0.00	0.57	1.72	0.30	1.35	0.32	0.65	0.46	0.31	0.73	0.25	0.12	0.16	0.84	0.32	0.00	0.36	0.77	1.10
Sb	24.33	9.39	24.16	8.95	31.19	29.36	28.85	30.90	29.88	30.86	23.18	22.73	12.34	10.96	10.12	25.46	32.28	31.52	28.57	11.17	11.24
Bi	0.89	0.00	0.44	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	1.42	0.33	0.42	0.54	0.45	0.00
As	4.55	12.52	5.82	12.50	0.60	0.52	0.22	0.15	0.30	0.10	3.95	4.60	10.67	10.49	12.71	4.61	0.26	0.52	0.17	11.98	11.74
S	20.02	26.30	24.75	27.22	20.67	20.27	20.67	20.56	19.70	21.05	23.63	23.53	25.80	21.18	28.25	24.91	21.33	23.05	21.14	24.08	25.70
Se	0.26	0.16	0.77	0.34	0.47	0.15	0.22	0.36	0.29	0.10	0.24	0.40	0.39	0.60	0.12	0.11	0.22	0.24	0.10	0.11	0.49
Te	0.00	0.00	0.00	0.00	0.17	0.47	0.00	0.56	0.53	0.00	0.23	0.90	0.00	1.01	0.36	0.00	0.00	0.00	0.00	0.00	0.72
Total	91.75	97.84	98.66	99.36	95.17	98.26	96.02	98.15	98.31	99.66	95.85	99.07	96.24	87.13	99.97	99.45	97.90	98.33	96.96	93.45	96.28
Formula																					
Ag	1.23	0.53	0.96	0.76	5.11	16.49	16.99	16.58	20.27	19.96	10.31	9.94	1.31	1.46	0.90	1.82	10.58	7.41	12.70	1.06	1.27
Cu	53.41	63.43	53.99	62.96	46.89	36.21	31.75	32.65	28.64	30.43	42.03	44.66	60.28	52.73	61.81	52.87	39.42	44.14	40.11	57.06	58.28
Fe	10.55	13.84	11.30	16.03	5.57	10.28	9.49	9.51	8.63	9.04	10.53	10.49	12.37	10.94	13.97	10.89	9.71	6.97	7.79	13.05	12.30
Zn	0.47	0.00	1.62	0.00	2.95	0.00	0.00	0.67	0.00	0.00	0.00	0.41	0.24	2.42	0.00	0.38	1.88	4.05	2.26	0.20	0.00
Cd	0.20	0.03	0.00	0.00	0.00	0.58	0.44	0.82	1.85	1.04	0.26	0.85	0.00	0.00	0.18	0.19	0.04	0.00	0.94	0.06	0.01
Pb	0.00	0.40	0.00	0.28	0.83	0.14	0.65	0.15	0.31	0.22	0.15	0.35	0.12	0.06	0.08	0.41	0.15	0.00	0.17	0.37	0.53
Sb	19.98	7.71	19.84	7.35	25.62	24.11	23.70	25.38	24.54	25.35	19.04	18.67	10.14	9.00	8.31	20.91	26.51	25.89	23.47	9.17	9.23
Bi	0.43	0.00	0.21	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.68	0.16	0.20	0.26	0.22	0.00
As	6.07	16.71	7.77	16.68	0.80	0.69	0.29	0.20	0.40	0.13	5.27	6.14	14.24	14.00	16.96	6.15	0.35	0.69	0.23	15.99	15.67
S	62.45	82.03	77.20	84.90	64.47	63.23	64.47	64.13	61.45	65.66	73.71	73.39	80.47	66.06	88.12	77.70	66.53	71.90	65.94	75.11	80.16
Se	0.33	0.20	0.98	0.43	0.60	0.19	0.28	0.46	0.37	0.13	0.30	0.51	0.49	0.76	0.15	0.14	0.28	0.30	0.13	0.14	0.62
Te	0.00	0.00	0.00	0.00	0.13	0.37	0.00	0.44	0.42	0.00	0.18	0.71	0.00	0.79	0.28	0.00	0.00	0.00	0.00	0.00	0.56
Total	155.12	184.89	173.87	189.39	152.97	152.29	148.26	150.99	146.87	151.96	161.92	166.11	179.67	158.22	190.76	172.13	155.61	161.55	154.00	172.43	178.64
Formula	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29	to 29
Ag	0.231	0.083	0.161	0.116	0.968	3.140	3.324	3.184	4.001	3.809	1.846	1.735	0.211	0.267	0.137	0.306	1.971	1.330	2.392	0.178	0.206
Cu	9.984	9.949	9.005	9.640	8.890	6.895	6.211	6.271	5.655	5.808	7.527	7.796	9.730	9.665	9.397	8.908	7.346	7.923	7.553	9.596	9.462
A Total	**10.215**	**10.032**	**9.166**	**9.757**	**9.858**	**10.035**	**9.535**	**9.455**	**9.656**	**9.617**	**9.374**	**9.531**	**9.941**	**9.932**	**9.533**	**9.214**	**9.317**	**9.253**	**9.945**	**9.774**	**9.668**
Fe	1.972	2.171	1.885	2.454	1.056	1.957	1.856	1.826	1.704	1.726	1.886	1.832	1.997	2.005	2.123	1.834	1.809	1.250	1.467	2.195	1.997
Zn	0.089	0.000	0.270	0.000	0.560	0.000	0.000	0.129	0.000	0.000	0.000	0.072	0.040	0.443	0.000	0.064	0.351	0.728	0.426	0.033	0.000
Cd	0.038	0.004	0.000	0.000	0.000	0.110	0.085	0.157	0.365	0.199	0.046	0.148	0.000	0.000	0.027	0.031	0.008	0.000	0.178	0.010	0.001
B Total	**2.099**	**2.175**	**2.155**	**2.454**	**1.615**	**2.067**	**1.942**	**2.113**	**2.070**	**1.924**	**1.932**	**2.052**	**2.037**	**2.448**	**2.150**	**1.930**	**2.168**	**1.978**	**2.071**	**2.239**	**1.998**
A+B Total	**12.313**	**12.207**	**11.321**	**12.211**	**11.473**	**12.102**	**11.476**	**11.568**	**11.726**	**11.541**	**11.306**	**11.583**	**11.977**	**12.380**	**11.684**	**11.144**	**11.485**	**11.231**	**12.016**	**12.013**	**11.666**
Pb	0.000	0.063	0.000	0.042	0.157	0.028	0.127	0.030	0.062	0.042	0.027	0.062	0.019	0.011	0.012	0.068	0.029	0.000	0.033	0.063	0.086
Sb	3.736	1.210	3.310	1.126	4.857	4.592	4.635	4.875	4.846	4.837	3.410	3.259	1.636	1.650	1.264	3.523	4.941	4.647	4.419	1.543	1.499
Bi	0.080	0.000	0.035	0.000	0.000	0.000	0.038	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.114	0.029	0.036	0.049	0.036	0.000
As	1.135	2.621	1.296	2.555	0.152	0.132	0.057	0.038	0.079	0.025	0.944	1.072	2.299	2.566	2.579	1.037	0.065	0.125	0.043	2.689	2.544
C Total																					
C Total	**4.951**	**3.894**	**4.641**	**3.723**	**5.166**	**4.752**	**4.858**	**4.943**	**4.987**	**4.905**	**4.407**	**4.393**	**3.954**	**4.227**	**3.854**	**4.743**	**5.064**	**4.808**	**4.543**	**4.331**	**4.129**
S	11.674	12.867	12.876	13.001	12.223	12.039	12.611	12.317	12.133	12.530	13.200	12.813	12.989	12.109	13.396	13.090	12.399	12.906	12.417	12.632	13.013
Se	0.062	0.032	0.163	0.066	0.113	0.036	0.054	0.088	0.073	0.024	0.054	0.088	0.080	0.139	0.023	0.023	0.052	0.055	0.024	0.023	0.101
Te	0.000	0.000	0.000	0.000	0.025	0.070	0.000	0.084	0.082	0.000	0.032	0.123	0.000	0.145	0.043	0.000	0.000	0.000	0.000	0.000	0.092
D Total	**11.736**	**12.899**	**13.039**	**13.067**	**12.361**	**12.146**	**12.665**	**12.489**	**12.287**	**12.554**	**13.287**	**13.025**	**13.069**	**12.393**	**13.462**	**13.114**	**12.451**	**12.961**	**12.441**	**12.656**	**13.205**

Microprobe analysis has revealed minor amounts of two other Ag-bearing phases, **ramdohrite** and **diaphorite** (Table 7), both as fine exsolutions within galena. Neither of these minerals had been previously recognised in the Mofjell ores. In addition, **dyscrasite**, Ag_3Sb, has been confirmed by electron probe microanalysis. A single grain of hessite, Ag_2Te, was observed. Conspicuously, no pyrargyrite was observed in the present study. None of the other Sb-sulphosalts (bournonite, boulangerite, meneghinite) was found to contain silver. All of these other Ag-minerals are very minor constituents of the ore and play only very insignificant roles as Ag-carriers.

Table 7 Microprobe analyses of ramdohrite (columns 1-5) and diaphorite (columns 6-8).

	1	2	3	4	5	6	7	8
Element wt. %	12 12.1	12 12.2	12 12.3	12 15.1	12 15.2	12 15.3	12 15a.1	12 15a.2
Ag	6.15	6.46	4.88	3.19	4.79	21.54	23.33	23.93
Cu	0.36	0.98	0.3	0	0.79	0.79	0.24	0
Fe	0.45	0.14	0	0.24	0.28	0.02	0.45	0
Zn	0	0	0.49	0.2	0	0	0	0.37
Cd	0.25	0.43	0.24	0.42	0.7	0.55	1.08	1.6
Pb	40.06	41.62	41.99	48.42	46.57	31.55	25.69	24.81
Sb	31.51	31.38	31.54	29.33	28.56	26.9	29.46	29.24
Bi	2.41	1.59	2.69	0.00	0	1.29	1.76	1.71
As	0.03	0	0	0	0	0	0.19	0
S	16.9	16.16	15.94	16.3	16.97	15.60	16.23	17.03
Se	0.16	0.00	0.34	0.18	0.12	0.16	0.00	0
Te	0	0.75	0.43	0.44	0	0.73	0.64	0.00
Total	98.28	99.51	98.84	98.72	98.78	99.13	99.07	98.69
Formula								
Ag	5.70	5.99	4.52	2.96	4.44	19.97	21.63	22.18
Cu	0.57	1.54	0.47	0.00	1.24	1.24	0.38	0.00
Fe	0.81	0.25	0.00	0.43	0.50	0.04	0.81	0.00
Zn	0.00	0.00	0.75	0.31	0.00	0.00	0.00	0.57
Cd	0.22	0.38	0.21	0.37	0.62	0.49	0.96	1.42
Pb	19.33	20.09	20.27	23.37	22.48	15.23	12.40	11.97
Sb	25.88	25.77	25.91	24.09	23.46	22.09	24.20	24.02
Bi	1.15	0.76	1.29	0.00	0.00	0.62	0.84	0.82
As	0.04	0.00	0.00	0.00	0.00	0.00	0.25	0.00
S	52.71	50.41	49.72	50.84	52.93	48.66	50.62	53.12
Se	0.20	0.00	0.43	0.23	0.15	0.20	0.00	0.00
Te	0.00	0.59	0.34	0.34	0.00	0.57	0.50	0.00
Total	106.62	105.78	103.91	102.94	105.83	109.11	112.59	114.10
Formula	to 44	to 44	to 44	to 44	to 44	to 6	to 6	to 6
Ag	2.353	2.491	1.916	1.264	1.846	2.562	2.689	2.722
Cu	0.234	0.641	0.200	0.000	0.517	0.160	0.047	0.000
A Total	2.587	3.132	2.116	1.264	2.363	2.722	2.736	2.722
Fe	0.333	0.104	0.000	0.184	0.208	0.005	0.100	0.000
Zn	0.000	0.000	0.317	0.131	0.000	0.000	0.000	0.069
Cd	0.092	0.159	0.090	0.160	0.259	0.063	0.119	0.175
B Total	0.424	0.263	0.408	0.474	0.467	0.067	0.220	0.244
A+B Total	**3.011**	**3.396**	**2.523**	**1.738**	**2.831**	**2.789**	**2.956**	**2.966**
Pb	**7.979**	**8.356**	**8.582**	**9.989**	**9.345**	**1.954**	**1.542**	**1.469**
Sb	10.680	10.721	10.970	10.297	9.753	2.835	3.009	2.947
Bi	0.476	0.316	0.545	0.000	0.000	0.079	0.105	0.100
As	0.017	0.000	0.000	0.000	0.000	0.000	0.032	0.000
C Total	**11.173**	**11.037**	**11.515**	**10.297**	**9.753**	**2.914**	**3.145**	**3.047**
C Total								
S	21.754	20.967	21.054	21.731	22.008	6.243	6.295	6.518
Se	0.084	0.000	0.182	0.097	0.063	0.026	0.000	0.000
Te	0.000	0.244	0.143	0.147	0.000	0.073	0.062	0.000
D Total	**21.837**	**21.211**	**21.379**	**21.976**	**22.071**	**6.343**	**6.357**	**6.518**

10. OTHER MINERALOGICAL OBSERVATIONS

Minerals identified in the mineralogical study are summarised in Table 8. Microprobe analysis was carried out in some cases to confirm the optical interpretation, indicated with * on the table. Probe analyses for these other minerals are given in Table 9 (bournonite, boulangerite), Table 10 (meneghinite) and 11 (dyscrasite, ullmannite, native-Sb, arsenopyrite, gudmundite). Typical associations of these minerals are shown in the images on Plates 3-7. Back-scattered electron images are shown in Plate 8.

Table 8 Minerals identified in the present study

*Arsenopyrite	$FeAsS$	*Meneghinite	$Pb_{13}CuSb_7S_{24}$
*Boulangerite	$Pb_5Sb_4S_{11}$	Molybdenite	MoS_2
*Bournonite	$CuPbSbS_3$	*Native Sb	(Sb,As)
Cubanite	$CuFe_2S_3$	Pyrite	FeS_2
*Diaphorite	$Pb_2Ag_3SbS_8$	Pyrrhotite	$Fe_{1-x}S$
*Dyscrasite	Ag_3Sb	*Ramdohrite	$Ag_3Pb_6Sb_{11}S_{24}$
*Galena	PbS	Sphalerite	ZnS
*Gold/electrum	(Au,Ag)	Stannite	Cu_2FeSnS_4
*Gudmundite	FeSbS	*Tennantite	$Cu_{10}(Fe,Zn)_2(As,Sb)_4S_{13}$
Hessite	Ag_2Te	*Tetrahedrite	$(Cu,Ag)_{10}(Fe,Zn)_2(Sb,As)_4S_{13}$
Mackinawite	$(Ni,Fe)_9S_8$	*Ullmannite	NiSbS

Meneghinite, not previously recognised in Mofjell, was found to be very abundant in the studied samples, occurring in symplectitic intergrowths with both galena and bournonite and also a common accessory mineral in tetrahedrite-bearing assemblages. **Native antimony** was confirmed, as small, bright grains exsolved on the margins of Sb-sulphosalts. Microanalysis showed that these grains also contain appreciable As. We did not find native Bi or the Bi-sulphosalts mentioned by Saager (1966). A single grain of what is suspected as a Bi-telluride (tsumoite, BiTe or hedleyite, Bi_7Te_3) was noted.

11. METAMORPHIC SULPHIDE REMOBILISATION - BACKGROUND & IMPLICATIONS

Remobilisation has long been recognised as a feature of many of the Norwegian deposits; the first contributions on remobilised assemblages appearing more than 60 years ago (Ramdohr, 1938). Remobilisation phenomena, in which ore components have been transported and re-concentrated have now been documented from most major metamorphosed deposits in the Scandinavian Caledonides (e.g. Sulitjelma; Cook 1992; 1994; 1996; Bleikvassli; Cook et al. 1998; Moralev et al. under review) as well as from smaller, yet often spectacularly illustrative deposits such as Gressli (Vokes & Craig 1993). In the past decade there has been a growing understanding of the principles behind, and processes involved in remobilisation. The reader is referred to the following publications on the subject: Cox et al. (1987), Gilligan & Marshall (1987), Marshall & Gilligan (1987, 1993), Marshall & Spry (2000) and Marshall et al. (2000).

Generally speaking, remobilisation can be divided into 'internal' and 'external' remobilisation. In internal remobilisation, ore components are redistributed, either in the solid- or fluid-phase, within the massive ore itself. A good example is the filling of fractures in deformed pyrite porphyroblasts by chalcopyrite. External remobilisation, on the other hand, means that ore components are reconcentrated outside of the massive ore, within wallrock. Typically these will occur as small (cm-scale or less) veinlets and pods, displaying local structural control, emplaced in zones of relative weakness, such as pressure shadows. Mobilisates are commonly associated with quartz. The scale of external remobilisation is rarely more than a few metres, in rare cases a few tens of metres.

Table 9 Microprobe analyses of bournonite and boulangerite (last column to the right).

Element wt. %	13 27.3	13 26.1	13 25a.1	13 11.2	13 25.1	13 22.1	13 22.3	13 22a.2	13 22b.1	13.24.3
Ag	0.00	0.00	0.19	0.00	0.00	0.07	0.16	0.48	0.18	0.05
Cu	10.60	11.44	10.30	12.35	10.66	10.54	12.15	10.82	11.78	0.78
Fe	0.00	0.16	0.22	0.00	0.17	0.15	0.11	0.00	0.12	0.00
Zn	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	1.08	1.67
Cd	0.21	0.25	1.24	0.39	0.27	0.39	0.04	0.58	0.24	0.29
Pb	40.34	43.95	40.77	38.30	40.90	39.91	38.33	41.65	42.45	52.97
Sb	27.55	25.05	27.97	26.29	28.95	26.79	27.65	27.45	22.13	28.13
Bi	2.45	0.00	1.46	3.41	0.95	2.61	2.83	1.07	1.88	0.00
As	0.08	0.28	0.67	0.19	0.00	0.08	0.00	0.24	2.71	0.00
S	16.83	17.20	14.70	17.96	16.93	17.11	17.65	15.85	18.88	16.29
Se	0.16	0.23	0.00	0.27	0.05	0.07	0.00	0.56	0.31	0.16
Te	0.00	0.00	0.00	0.00	0.62	0.00	0.47	0.82	0.02	0.19
Total	98.22	99.23	97.52	99.16	99.50	97.72	99.39	99.52	101.78	100.53
Formula										
Ag	0.00	0.00	0.18	0.00	0.00	0.06	0.15	0.44	0.17	0.05
Cu	16.68	18.00	16.21	19.43	16.77	16.59	19.12	17.03	18.54	1.23
Fe	0.00	0.29	0.39	0.00	0.30	0.27	0.20	0.00	0.21	0.00
Zn	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.00	1.65	2.55
Cd	0.19	0.22	1.10	0.35	0.24	0.35	0.04	0.52	0.21	0.26
Pb	19.47	21.21	19.68	18.49	19.74	19.26	18.50	20.10	20.49	25.57
Sb	22.63	20.57	22.97	21.59	23.78	22.00	22.71	22.55	18.18	23.10
Bi	1.17	0.00	0.70	1.63	0.45	1.25	1.35	0.51	0.90	0.00
As	0.11	0.37	0.89	0.25	0.00	0.11	0.00	0.32	3.62	0.00
S	52.50	53.65	45.85	56.02	52.81	53.37	55.05	49.44	58.89	50.81
Se	0.20	0.29	0.00	0.34	0.06	0.09	0.00	0.71	0.39	0.20
Te	0.00	0.00	0.00	0.00	0.49	0.00	0.37	0.64	0.02	0.15
Total	112.94	115.64	107.98	118.11	114.65	113.35	117.49	112.26	123.26	103.92
Formula	to 6	to 6	to 6	to 6	to 6	to 6	to 6	to 6	to 6	to 6
Ag	0.000	0.000	0.010	0.000	0.000	0.003	0.008	0.024	0.008	0.009
Cu	0.886	0.934	0.901	0.987	0.878	0.878	0.976	0.910	0.902	0.236
A Total	0.886	0.934	0.910	0.987	0.878	0.881	0.984	0.934	0.910	0.245
Fe	0.000	0.015	0.022	0.000	0.016	0.014	0.010	0.000	0.010	0.000
Zn	0.000	0.053	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.492
Cd	0.010	0.012	0.061	0.018	0.013	0.018	0.002	0.028	0.010	0.050
B Total	0.010	0.080	0.083	0.018	0.029	0.033	0.012	0.028	0.101	0.541
A+B Total	**0.896**	**1.014**	**0.994**	**1.005**	**0.906**	**0.914**	**0.996**	**0.961**	**1.012**	**0.786**
Pb	**1.034**	**1.101**	**1.093**	**0.939**	**1.033**	**1.020**	**0.945**	**1.074**	**0.997**	**4.920**
Sb	1.202	1.068	1.277	1.097	1.244	1.165	1.160	1.205	0.885	4.447
Bi	0.062	0.000	0.039	0.083	0.024	0.066	0.069	0.027	0.044	0.000
As	0.006	0.019	0.050	0.013	0.000	0.006	0.000	0.017	0.176	0.000
C Total	**1.270**	**1.087**	**1.365**	**1.193**	**1.268**	**1.237**	**1.229**	**1.250**	**1.105**	**4.447**
C Total										
S	2.789	2.784	2.548	2.846	2.764	2.825	2.812	2.642	2.867	9.779
Se	0.011	0.015	0.000	0.017	0.003	0.005	0.000	0.038	0.019	0.039
Te	0.000	0.000	0.000	0.000	0.025	0.000	0.019	0.034	0.001	0.029
D Total	**2.800**	**2.799**	**2.548**	**2.863**	**2.792**	**2.830**	**2.830**	**2.715**	**2.886**	**9.847**

Since some metals are more readily mobilised than others, mobilisates will have a characteristic mineralogy. Generally, copper is enriched and Pb to a subordinate degree. The precious metals (Au, Ag) are easily mobilised and together with other highly mobile trace elements (Sb, As) are strongly enriched in external mobilisates.
Remobilisation has the affect of actually diluting the grade of an ore deposit in total, since the same amount of metals are concentrated into a greater volume of rock. At the same time, however, the process may actually significantly upgrade portions of the deposit to make them economically viable for exploitation (Marshall et al. 2000).

An understanding of remobilisation at Mofjell can be grained by drawing a direct analogy with the Bleikvassli deposit. The mineralisation of that deposit has been relatively well studied and the constraints on mineralisation and remobilisation are partially understood. At Bleikvassli, rocks adjacent to the massive ore (particularly those in the hanging wall) contain abundant sulphides, the 'wall-rock mineralisation' of Vokes (1963). Irregular patches, veins and disseminations of sulphides, commonly together with quartz, are characterised by an abundance of arsenopyrite, tetrahedrite, a range of Pb-Sb and Pb-As sulphosalts and minerals containing both Ag and Au (Vokes 1963, Moralev et al. 1995, Cook et al. 1998). The distribution of precious metals at Bleikvassli appears closely related to such irregular patches and to disseminated sulphide mineralisations hosted by quartz ± feldspar veins, quartzose rocks, and muscovite schists within the wall-rock to the massive ore. All these wall-rock mineralisations are ascribed to localised ore remobilisation accompanying regional metamorphism and deformation, but at different stages of the metamorphic cycle.

Table 10 Microprobe analyses of meneghinite.

Element wt. %	13 24.2	12 13.1	12 13.2	12 4.1	12 7.1	12 7.3	13 17.3	13 17.4	13 17a.1	13 17a.2
Ag	0.02	0.56	0.35	0.31	0.06	0.41	0	0.32	0	0.44
Cu	1.31	0.20	1.04	1.03	1.36	0.76	0.66	1.29	1.75	0.73
Fe	0.00	0.67	0	0.05	0.03	0.03	0.12	0.13	0	0
Zn	0.00	0.00	1.47	0	0.41	0.08	0.36	0.18	0.88	0
Cd	0.10	0.10	0.12	0.62	0.12	0.6	0.13	0.46	0	0
Pb	59.96	64.79	54.76	59.61	59.49	55.65	55.47	58.74	57.77	60.26
Sb	22.75	16.08	20.78	21.59	22.21	21.99	22.1	22.27	20.61	22.65
Bi	0.00	0	3.83	0	0	0	0.34	0	0	0
As	0.00	0.45	0	0	0	0	0	0	0	0
S	14.75	14.00	15.15	15.48	15.43	13.69	13.41	15.15	17.21	15.64
Se	0.00	0.12	0.2	0	0.25	0	0	0	0.16	0
Te	0.67	0.00	0.17	0.37	0	0.21	0.64	0	0	0.23
Total	99.56	96.97	97.87	99.06	99.36	93.42	93.23	98.54	98.38	99.95
Formula										
Ag	0.02	0.52	0.32	0.29	0.06	0.38	0.00	0.30	0.00	0.41
Cu	2.06	0.31	1.64	1.62	2.14	1.20	1.04	2.03	2.75	1.15
Fe	0.00	1.20	0.00	0.09	0.05	0.05	0.21	0.23	0.00	0.00
Zn	0.00	0.00	2.25	0.00	0.63	0.12	0.55	0.28	1.35	0.00
Cd	0.27	0.27	0.73	0.55	0.11	0.53	0.12	0.41	0.00	0.00
Pb	28.94	31.27	26.43	28.77	28.71	26.86	26.77	28.35	27.88	29.08
Sb	18.69	13.21	17.07	17.73	18.24	18.06	18.15	18.29	16.93	18.60
Bi	0.00	0.00	1.83	0.00	0.00	0.00	0.16	0.00	0.00	0.00
As	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S	46.01	43.67	47.26	48.28	48.13	42.70	41.83	47.26	53.68	48.78
Se	0.00	0.15	0.25	0.00	0.32	0.00	0.00	0.00	0.20	0.00
Te	0.53	0.00	0.13	0.29	0.00	0.16	0.50	0.00	0.00	0.18
Total	96.51	91.20	97.91	97.63	98.38	90.07	89.34	97.14	102.79	98.21
Formula	to 45	to 45	to 45	to 45	to 45	to 45	to 45	to 45	to 45	to 45
Ag	0.009	0.256	0.149	0.132	0.025	0.190	0.000	0.137	0.000	0.187
Cu	0.961	0.155	0.752	0.747	0.979	0.597	0.523	0.940	1.206	0.526
A Total	0.970	0.411	0.901	0.880	1.004	0.787	0.523	1.078	1.206	0.713
Fe	0.000	0.592	0.000	0.041	0.025	0.027	0.108	0.108	0.000	0.000
Zn	0.000	0.000	1.034	0.000	0.287	0.061	0.277	0.128	0.589	0.000
Cd	0.126	0.133	0.336	0.254	0.049	0.267	0.058	0.190	0.000	0.000
B Total	0.126	0.725	1.369	0.296	0.360	0.355	0.444	0.425	0.589	0.000
A+B Total	**1.096**	**1.137**	**2.270**	**1.175**	**1.365**	**1.142**	**0.967**	**1.503**	**1.795**	**0.713**
Pb	**13.494**	**15.429**	**12.147**	**13.261**	**13.133**	**13.419**	**13.486**	**13.133**	**12.206**	**13.327**
Sb	8.713	6.517	7.844	8.174	8.344	9.024	9.143	8.473	7.411	8.524
Bi	0.000	0.000	0.842	0.000	0.000	0.000	0.082	0.000	0.000	0.000
As	0.000	0.296	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C Total	**8.713**	**6.813**	**8.687**	**8.174**	**8.344**	**9.024**	**9.225**	**8.473**	**7.411**	**8.524**
C Total										
S	21.453	21.546	21.718	22.256	22.014	21.333	21.069	21.891	23.500	22.353
Se	0.000	0.075	0.116	0.000	0.145	0.000	0.000	0.000	0.089	0.000
Te	0.245	0.000	0.061	0.134	0.000	0.082	0.253	0.000	0.000	0.083
D Total	**21.697**	**21.621**	**21.896**	**22.390**	**22.158**	**21.416**	**21.322**	**21.891**	**23.588**	**22.436**

Table 11 Microprobe analyses of arsenopyrite (column 1), gudmundite (columns 2-3), native bismuth-arsenic (columns 4-6), dyscrasite (columns 7-8) and ullmannite (columns 9-11).

	1	2	3	4	5	6	7	8
Element wt. %	13 27.1	13 14.1	13 14.2	12 16.1	12 16.2	13 11.1	13.11.2	13 11.3
Ag	0.00	0.11	0.00	70.86	66.77	0.00	0.00	0.00
Cu	0.90	0.43	0.12	0.40	0.37	0.36	0.07	0.00
Fe	33.58	21.62	23.16	0.10	0.00	0.36	0.03	0.26
Zn	0.32	1.00	0.30	0.54	0.96	0.21	0.52	0.00
Cd	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Pb	1.80	0.85	0.45	0.00	0.37	0.74	0.88	1.68
Sb	0.62	57.52	59.23	25.88	27.98	79.25	73.30	72.94
Bi	0.45	0.00	0.51	0.02	0.00	0.00	0.21	4.72
As	37.44	0.00	0.16	0.00	0.00	16.09	22.08	17.66
S	16.65	10.86	10.98	0.16	0.00	0.10	0.09	0.00
Se	0.61	0.19	0.13	0.00	0.00	0.45	0.84	0.00
Te	0.40	0.00	0.00	0.00	0.68	0.78	0.00	0.26
Total	92.77	92.62	95.04	97.96	97.13	98.34	98.02	97.52
Formula								
Ag	0.00	0.10	0.00	65.69	61.90	0.00	0.00	0.00
Cu	1.42	0.68	0.19	0.63	0.58	0.57	0.11	0.00
Fe	60.13	38.71	41.47	0.18	0.00	0.64	0.05	0.47
Zn	0.49	1.53	0.46	0.83	1.47	0.32	0.80	0.00
Cd	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Pb	0.87	0.41	0.22	0.00	0.18	0.36	0.42	0.81
Sb	0.51	47.24	48.65	21.26	22.98	65.09	60.21	59.91
Bi	0.22	0.00	0.24	0.01	0.00	0.00	0.10	2.26
As	49.97	0.00	0.21	0.00	0.00	21.48	29.47	23.57
S	51.93	33.87	34.25	0.50	0.00	0.31	0.28	0.00
Se	0.77	0.24	0.16	0.00	0.00	0.57	1.06	0.00
Te	0.31	0.00	0.00	0.00	0.53	0.61	0.00	0.20
Total	166.62	122.83	125.85	89.09	87.64	89.95	92.51	87.22
Formula	to 3	to 3	to 3	to 4	to 4	to 1	to 1	to 1
Ag	0.000	0.002	0.000	2.949	2.825	0.000	0.000	0.000
Cu	0.025	0.017	0.005	0.028	0.027	0.006	0.001	0.000
A Total	0.025	0.019	0.005	2.978	2.852	0.006	0.001	0.000
Fe	1.083	0.946	0.989	0.008	0.000	0.007	0.001	0.005
Zn	0.009	0.037	0.011	0.037	0.067	0.004	0.009	0.000
Cd	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
B Total	1.091	0.984	0.999	0.045	0.067	0.011	0.009	0.005
A+B Total	**1.117**	**1.003**	**1.004**	**3.023**	**2.919**	0.017	0.010	0.005
Pb	**0.016**	**0.010**	**0.005**	**0.000**	**0.008**	0.004	0.005	0.009
Sb	0.009	1.154	1.160	0.954	1.049	**0.724**	**0.651**	**0.687**
Bi	0.004	0.000	0.006	0.000	0.000	**0.000**	**0.001**	**0.026**
As	0.900	0.000	0.005	0.000	0.000	**0.239**	**0.319**	**0.270**
C Total	**0.913**	**1.154**	**1.171**	**0.955**	**1.049**	0.962	0.971	0.983
C Total								
S	0.935	0.827	0.816	0.022	0.000	0.003	0.003	0.000
Se	0.014	0.006	0.004	0.000	0.000	0.006	0.012	0.000
Te	0.006	0.000	0.000	0.000	0.024	0.007	0.000	0.002
D Total	**0.955**	**0.833**	**0.820**	**0.022**	**0.024**	0.017	0.015	0.002

	9	10	11
Element wt. %	12 9.1	12 9.2	12 9.3
Ag	0	0	0.24
Cu	0.73	0.31	0.06
Ni	23.35	24.33	22.75
Fe	0.48	0.19	0.51
Zn	0.15	0	0.29
Cd	0.00	0.24	0
Pb	0.98	1.33	0.75
Sb	60.25	60.38	59.71
Bi	0	0	0
As	0.08	0	0.3
S	13.55	12.62	12.93
Se	0.13	0.06	0.32
Te	0.13	0	1.15
Total	99.83	99.46	99.01
Formula			
Ag	0.00	0.00	0.22
Cu	1.15	0.49	0.09
Ni	39.77	41.44	38.75
Fe	0.86	0.34	0.91
Zn	0.23	0.00	0.44
Cd	0.00	0.21	0.00
Pb	0.47	0.64	0.36
Sb	49.49	49.59	49.04
Bi	0.00	0.00	0.00
As	0.11	0.00	0.40
S	42.26	39.36	40.33
Se	0.16	0.08	0.41
Te	0.10	0.00	0.90
Total	134.61	132.16	131.87
Formula	to 3	to 3	to 3
Ag	0.000	0.000	0.005
Cu	0.077	0.033	0.006
Ni	0.886	0.941	0.882
Fe	0.019	0.008	0.021
Zn	0.005	0.000	0.010
Cd	0.000	0.005	0.000
A Total	**0.987**	**0.987**	**0.924**
Pb	0.011	0.015	0.008
Sb	1.103	1.126	1.116
Bi	0.000	0.000	0.000
As	0.002	0.000	0.009
C Total	**1.116**	**1.140**	**1.133**
S	0.942	0.894	0.918
Se	0.004	0.002	0.009
Te	0.002	0.000	0.021
D Total	**0.948**	**0.895**	**0.947**

The mineralogy of mobilised ores from Mofjell strongly resembles those from Bleikvassli. However, remobilisates at Mofjell only have rather minor amounts of arsenopyrite, and the size of the mobilisate aggregates is generally much lower – a few mm, instead of several cm as in Bleikvassli . However, the mobilisates contain the same minerals (e.g. Ag-tetrahedrite, bournonite, meneghinite, arsenopyrite, gudmundite and native antimony[10]) and are just as rich in gold – and possibly richer in silver and are in all respects very reminiscent of such assemblages in remobilised ores within the Bleikvassli deposit, which are also enriched in gold. Additionally, other trace minerals identified in the Bleikvassli deposit (e.g. stannite) have also been identified in the Mofjell samples.

[10] Jordanite, a very abundant sulphosalt in Bleikvassli has, conspicuously, not been observed in Mofjell.

12. CONCLUSIONS

1. The presence of gold is proven in the Mofjell ores
2. Gold occurs as electrum (both Au- and Ag-rich varieties)
3. Grain size is typically < 10 µm. This must be borne in mind when considering alternatives for processing the ore. Fine grinding will be essential for optimum recovery.
4. Gold is chiefly associated with Sb-rich mobilsates. Associated minerals are tetrahedrite and other Sb-sulphosalts, galena, chalcopyrite, pyrite and quartz. Gold is not associated with sphalerite and Zn-rich samples are typically gold poor.
5. The occurrence of gold in the Mofjell deposit is consistent with other metamorphosed sulphide deposits (amphibolite grade) elsewhere in the Norwegian Caledonides (e.g., Bleikvassli, Sulitjelma).
6. Silver is chiefly hosted within galena and tetrahedrite. Minor amounts may be present in electrum, dyscrasite and Ag-Sb sulphosalts.

13. RECOMMENDATIONS

1. The mineralogy of the Mofjell deposit is undeniably complex and further work is necessary to corroborate the findings of this study. The author believes that additional work on relevant material from other parts of the deposit will reveal still more complex mineral intergrowths and microscopic amounts of unusual minerals, which although not affecting the overall findings, may have some implications for the global gold and silver distribution in the deposit.
2. A detailed and representative assessment of the silver distribution must be carried out prior to any test mining, to allow planning of an appropriate processing flowsheet.

ACKNOWLEDGEMENTS

Tom Jakobsen (NGU) is gratefully acknowledged for producing polished sections of excellent quality. Cristiana Ciobanu is gratefully acknowledged for operation of the microprobe and also assisted greatly with compilation of the photomicrographs. Reidar Bøe (SINTEF Petroleum Research, Trondheim) assisted with SEM operation and microprobe analysis. Iain Henderson (NGU) kindly read the report and made a number of valuable observations.

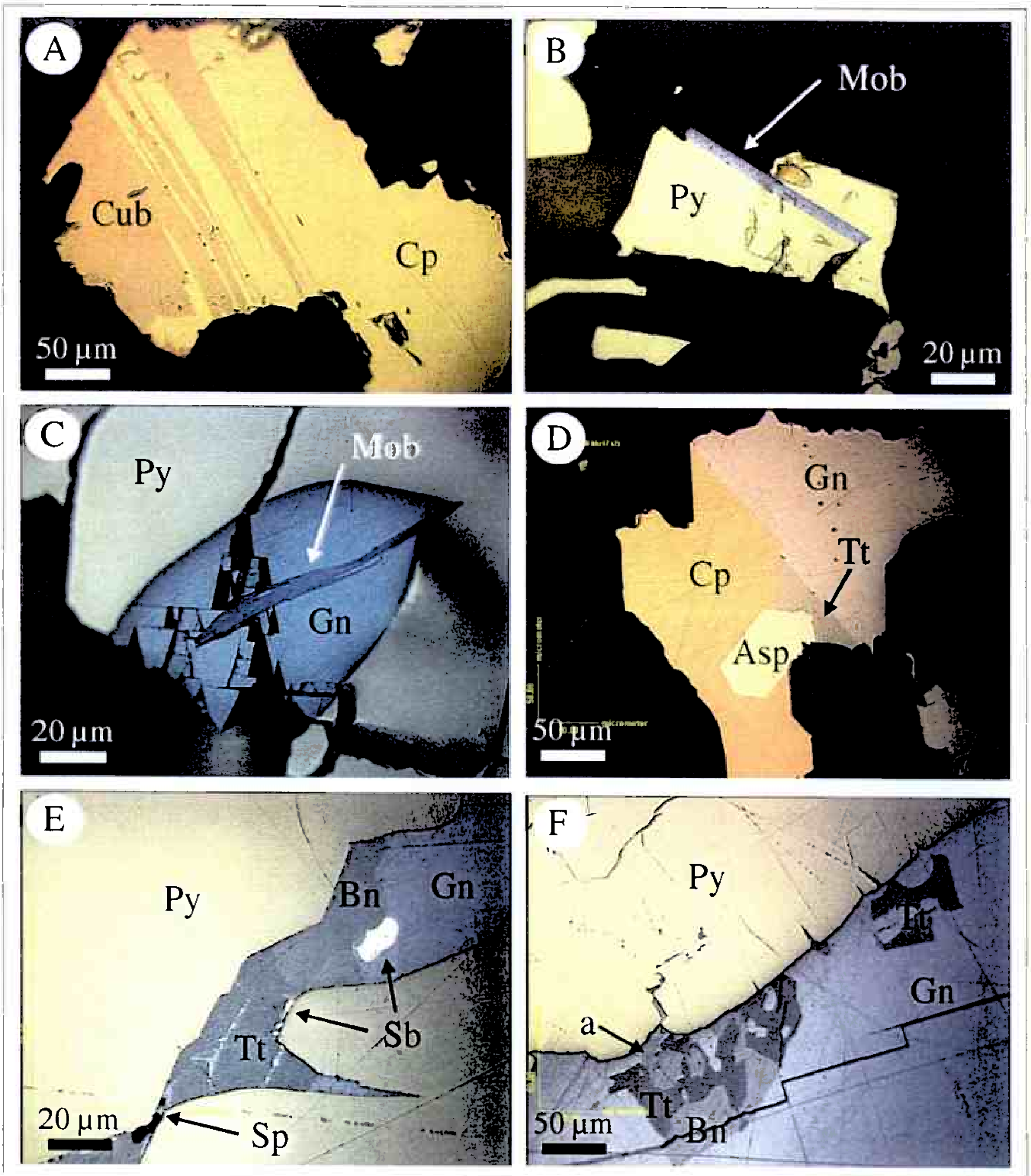


Plate 3 A. Lamellae of cubanite (Cub) exsolved in chalcopyrite (Cp). SampleMo 10. B. Lath of molybdenite (Mob)within pyrite (Py).Gold grains observed in samples Sample Mo 18. C. Molybdenite (Mob) associated with galena (Gn) and pyrite (Py). Sample Mo 18A. D. Rhomb-shaped grain of arsenopyrite (Asp) within chalcopyrite (Cp) in association with tetrahedrite (Tt) and galena (Gn). Sample Mo 17. E. Assemblages containing Sb-minerals are commonly found in fractures within pyrite (Py). Here, tetrahedrite (Tt) and bournonite (Bn) are associated with galena (Gn) and minor sphalerite (Sp). Native antimony (Sb, bright white) has exsolved from the sulphosalts. Sample Mo 11. F. Assemblage of tetrahedrite (Tt) and bournonite at the margin of a coarse pyrite porphyroblast (Py). Gn: galena. An additional Sb-sulphosalt, possibly jordanite, is indicated by 'a'. Sample Mo 11.

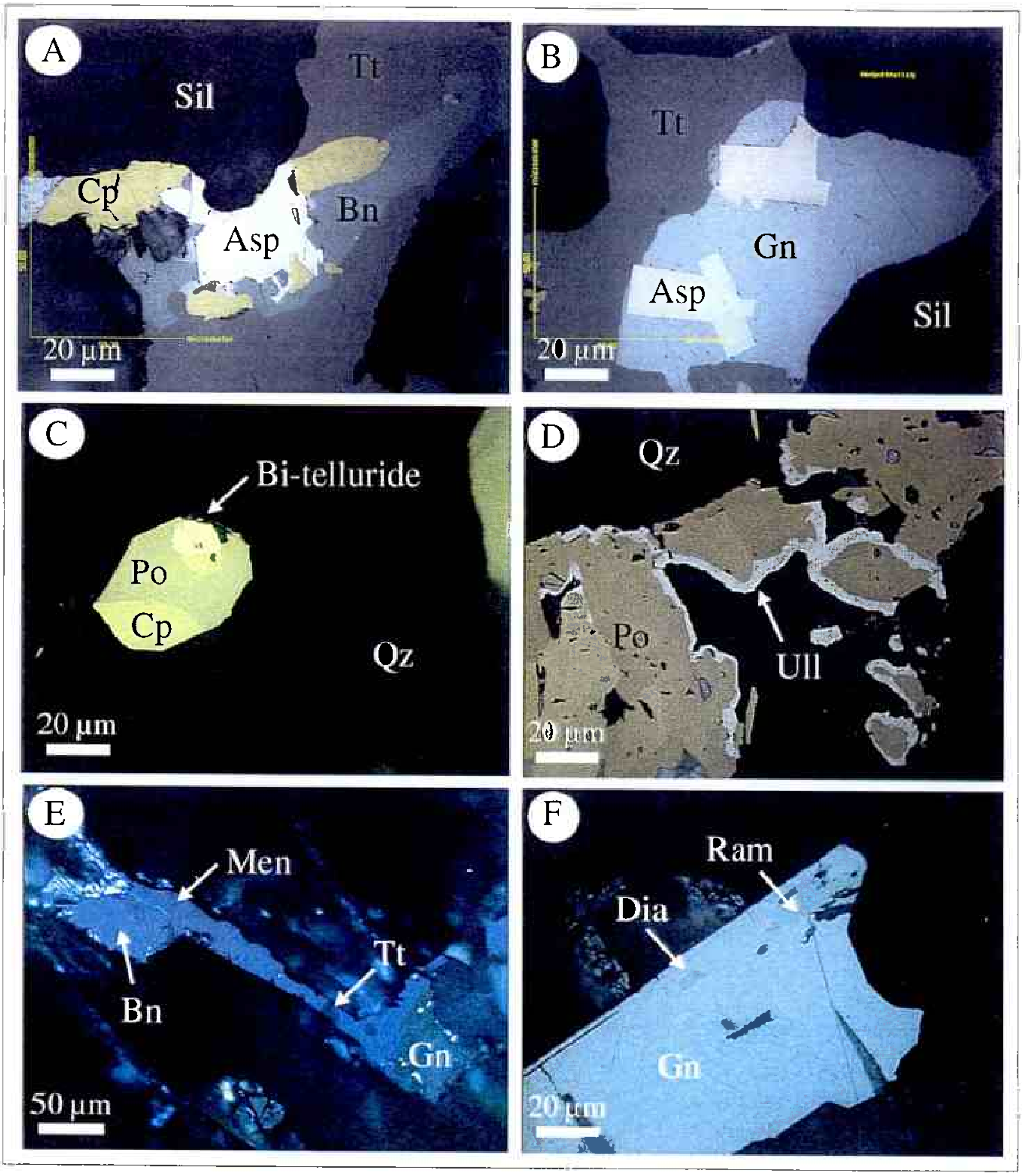


Plate 4 A. Assemblage of arsenopyrite (Asp), bournonite (Bn), tetrahedrite (Tt) and chalcopyrite /Cp). Sil: silicate matrix. Sample Mo 13. B. Twinned crystals of arsenopyrite (Asp) within galena (Gn). Dark grey: argentian tetrahedrite (Tt), silicate matrix is quartz (Sil). Sample Mo 13. C. Inclusion of chalcopyrite (Cp) and pyrrhotite (Po) within quartz (Qz) hosting a small bright grain identified as a Bi-telluride, possibly rucklidgeite. Sample Mo 8. D.Coarse-grained pyrrhotite (Po) surrounded by a rim of ullmannite (Ull). Sample Mo 12. E Aggregate grains consisting of meneghinite (Men), bournonite (Bn), tetrahedrite (Tt) and galena (Gn). The minerals are hosted within a quartz matrix. The photograph, taken under half-crossed nicols shows the strong anisotropy of meneghinite. Sample Mo 12. F Inclusions of Ag-Sb sulphosalts in galena (Gn). Ram: ramdohrite, Dia: diaphorite.

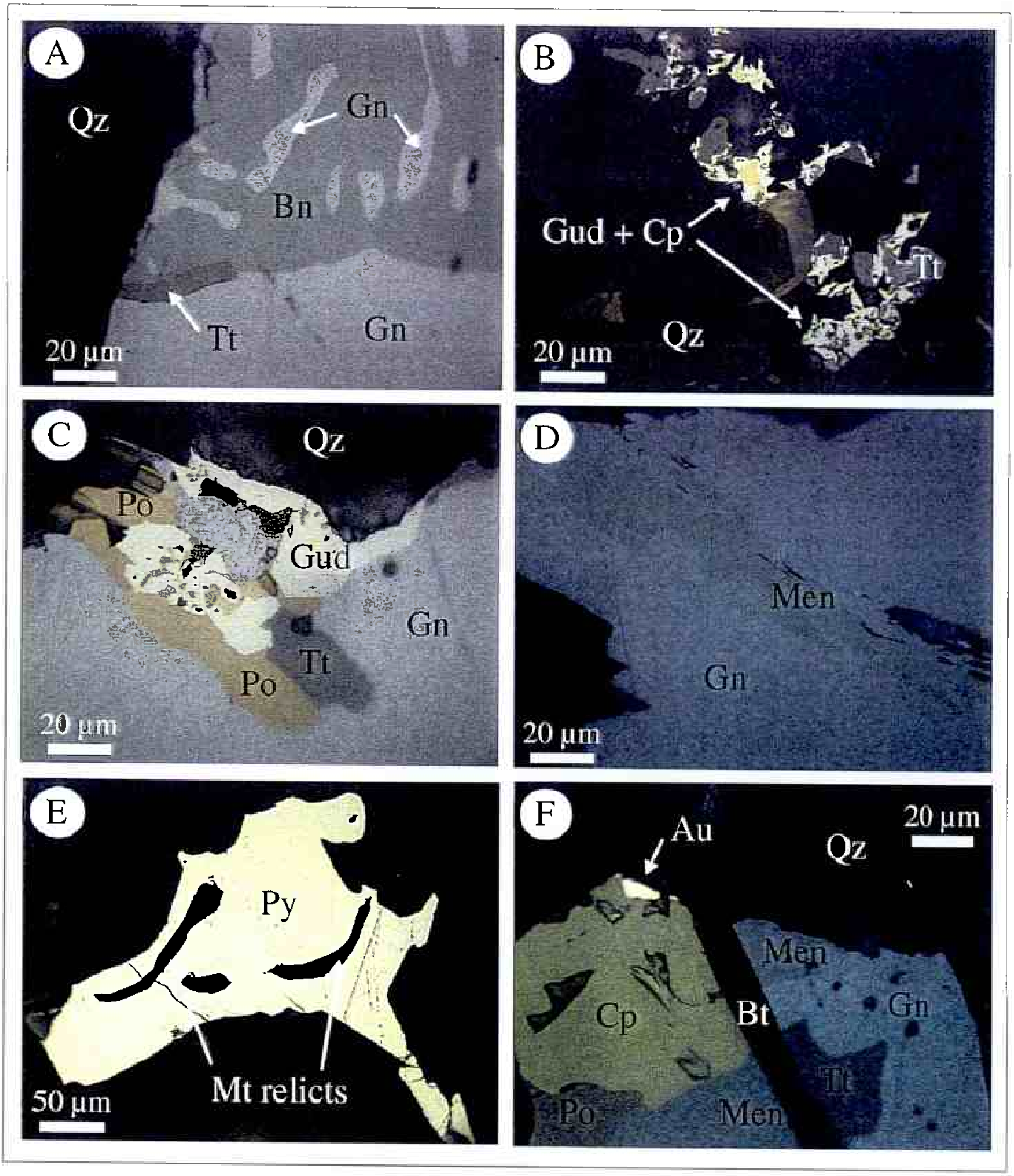


Plate 5 A. Myrmekitic intergrowth of galena (Gn) and bournonite (Bn), within quartz (Qz), with small grain of tetrahedrite (Tt) at margin to coarse galena. Sample Mo 13. B. Fine-grained skeletal aggregate of gudmundite (Gud) and chalcopyrite (Cp) formed by decomposition of tetrahedrite (Tt). Sample Mo 13. C. Assemblage of pyrrhotite (Po), gudmundite (Gud), tetrahedrite (Tt) and galena (Gn). Sample Mo 12. D. Exsolution of greenish-grey meneghinite (Men) within galena (Gn). Sample Mo 12. E. Relicts of magnetite (Mt) in pyrite (Py). Sample Mo 12. F. Gold-bearing assemblage, consisting of native gold (Au), meneghinite (Men), tetrahedrite (Tt), galena (Gn) and pyrrhotite (Po). Bt: biotite, Qz: quartz. Sample Mo 12.

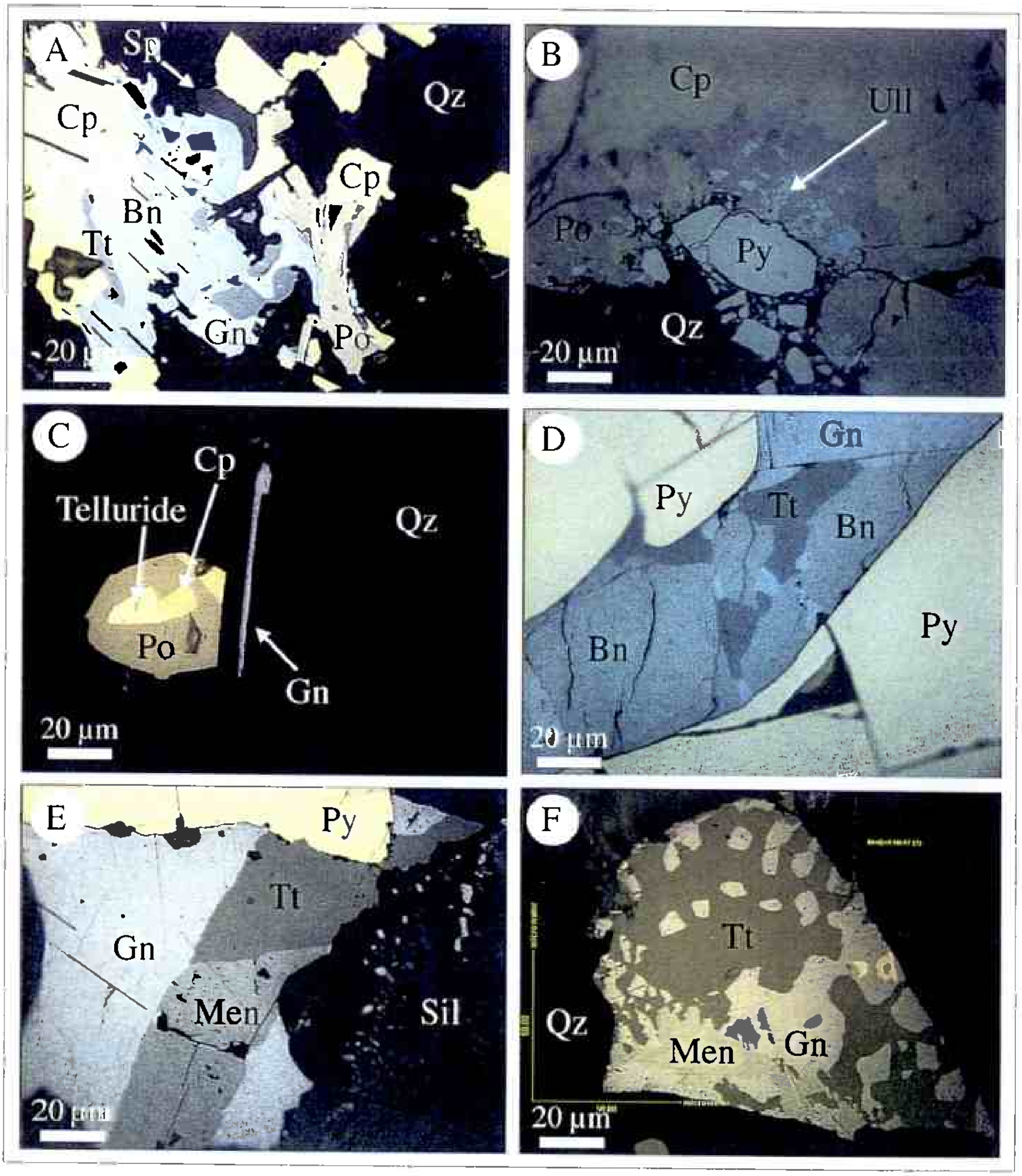


Plate 6 A. Complex assemblage of bournonite (Bn), tetrahedrite (Tt), pyrrhotite (Po) and galena (Gn) associated with chalcopyrite (Cp) within quartz (Qz). Note the characteristic grain shape of the monoclinic pyrrhotite. Sample Mo 13. B. Fine-grained exsolutions (?) of ullmannite(Ull) within pyrrhotite (Po) at the margin of coarse chalcopyrite (Cp). Note small, new-formed pyrite grains. This assemblage appears to have resulted from decomposition of a higher temperature mineral. Sample Mo 13 C. Small grain of pyrrhotite (Po) in quartz (Qz) with exsolved chalcopyrite (Cp) and an unknown telluride phase.Gn: galena. Sample Mo 8. D. Intergrowth of bournonite (Bn) with galena (Gn) and tetrahedrite (Tt). Sample Mo 11. E. Equilibrium crystallisation of galena (Gn), tetrahedrite (Tt) and meneghinite (Men) with characteristic 120 degree triple junction between the grains. Py: pyrite. Sample Mo 12. F. Semi-symplectitiic intergrowth of tetrahedrite (Tt) and galena (Gn), also with exsolved meneghinite (Men). Sample Mo 17.

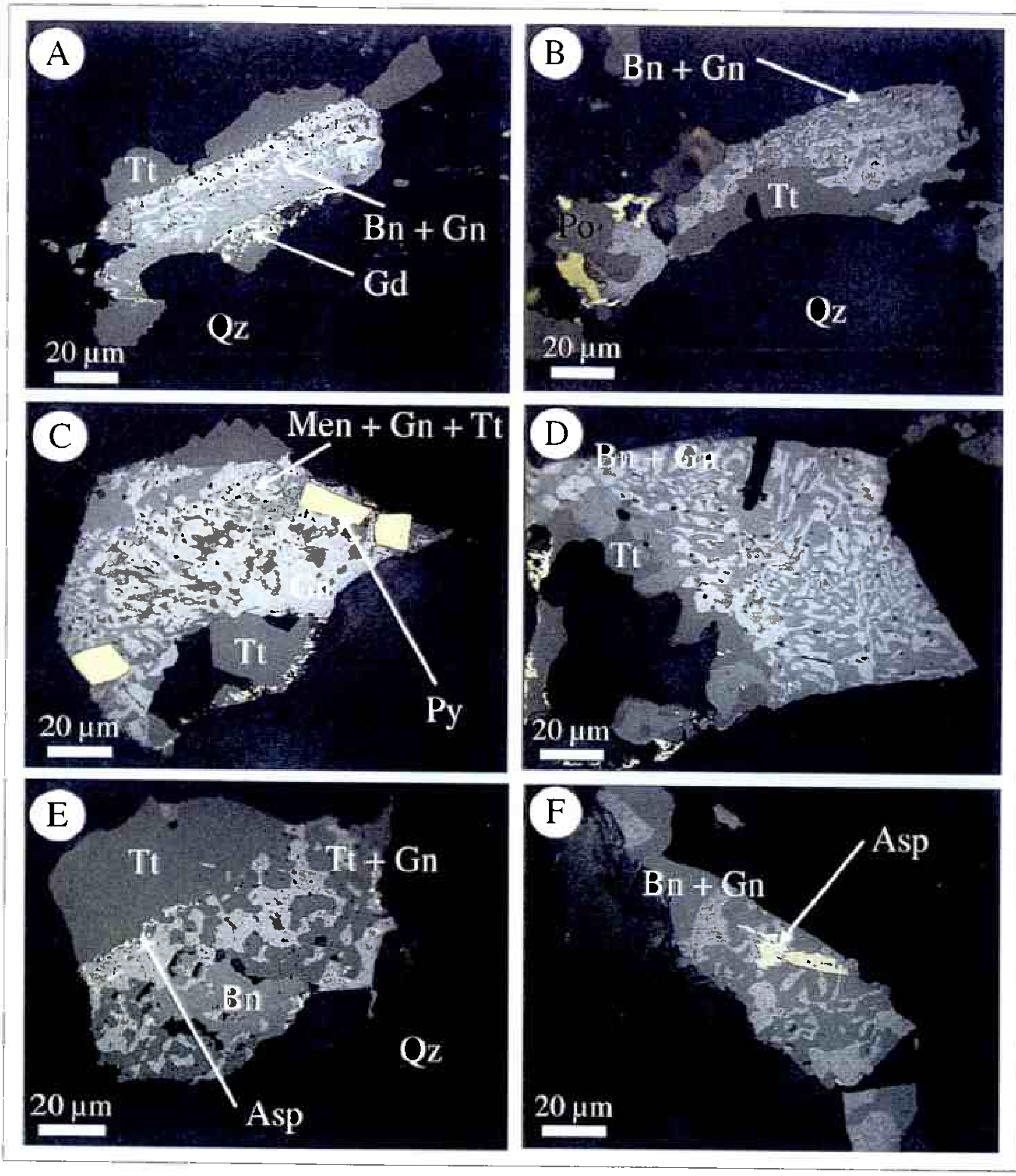


Plate 7 Series of photomicrographs illustrating the complex symplectitic intergrowths of Sb-sulphosalt minerals in the Mofjellet ore. A. Symplectite of bournonite and galena (Bn + Gn), with marginal tetrahedrite (Tt) and small bodies of exsolved gudmundite (Gd). Sample Mo 13. B..Similar symplectite as in A. Sample Mo 13. C.Complex ternary symplectite of meneghinite, galena and tetrahedrite (Men + Gn + Tt), with inclusions of pyrite (Py). Sample Mo 13. D.Symplectite of bournonite and galena (Bn + Gn). Sample Mo 13. E. Symplectite of tetrahedrite and galena (Tt + Gn) and larger body of bournonite (Bn). Small grains of arsenopyrite (Asp) at margin of symplectite with tetrahedrite. Sample Mo 13. F. Symplectite of bournonite and galena (Bn + Gn), and coarser bodies of exsolved arsenopyrite. Sample Mo 13.

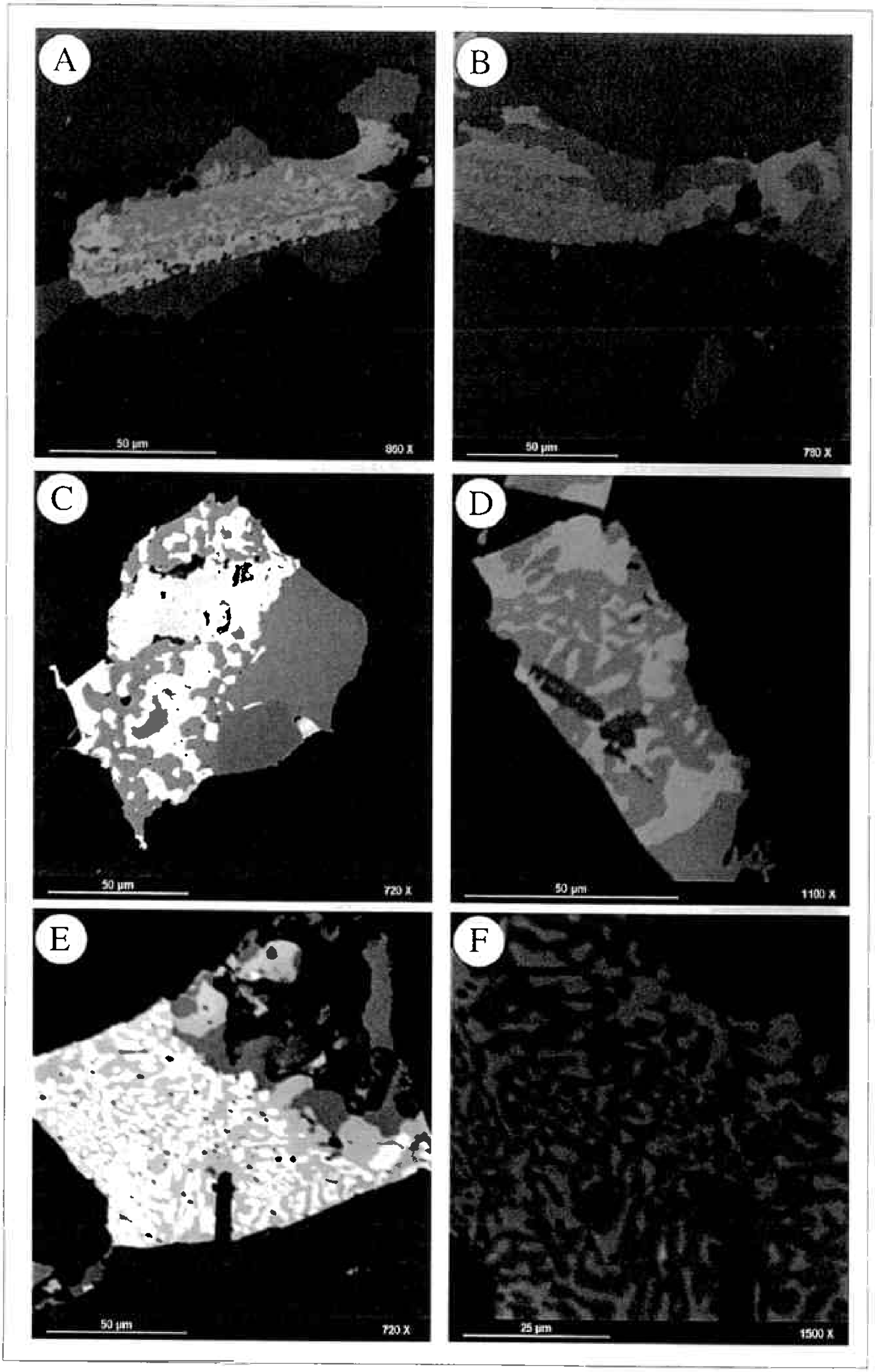


Plate 8 Series of back-scattered electron images showing the complex symplectitic intergrowths from Plate 7. Minerals with higher (total) atomic weights appear as brighter colours, those with lower mean atomic weights, as darker areas.

14. REFERENCES

Berubé, M.A., Bernard, D. & Lacat, J. (1985): Distribution mineralogique de l'argent dans les rejets de la mine Calumet, Québec. Can Mineral 23: 635-641.

Cabri, L.J. (1992): The distribution of trace precious metals in minerals and mineral products. Mineral. Mag. 56: 289-308.

Chryssoulis, S.L. & Surges, L.J. (1988): Behaviour of tetrahedrite in mill circuits of Brunswick Mining and Smelting Corporation Ltd. In: Silver Exploration. Inst. Min. Metall. London: 205-216.

Chryssoulis, S.L., Chauvin, W.J. & Surges, L.J. (1986): Trace element analysis by secondary ion mass spectrometry with particular reference to silver in the Brunswick sphalerite. Can. Metall. Quarterly 25: 233-239.

Cook, N.J. (1990): Mineralogical examination of gold-bearing samples. CIM Bulletin 83 (no. 944): 51-55.

Cook, N.J. (1992): Antimony-rich mineral parageneses and their association with Au minerals within massive sulphide deposits at Sulitjelma, Norway. Neues Jahrb. Mineral. Monatsh.: 97-106.

Cook, N.J. (1994): Post-recrystallisation phenomena in metamorphosed stratabound sulphide ores: a comment. Mineral. Mag. 58: 482-486.

Cook, N.J. (1996): Mineralogy of the sulphide deposits at Sulitjelma, northern Norway. Ore Geol. Rev. 11: 303-338.

Cook, N.J. & Chryssoulis, S.L. (1990): Concentrations of "invisible gold" in the common sulphides. Canadian Mineralogist 28: 1-16.

Cook, N.J. & Chryssoulis, S.L. (1999): Determination of sub-microscopic gold and silver in Romanian base metal ores by secondary ion mass spectroscopy. Rom. J. Mineral. 79: 113-122.

Cook, N.J., Spry, P.G. & Vokes, F.M. (1999): Mineralogy and textural relationships among sulphosalts and related minerals in the Bleikvassli Zn-Pb-(Cu) deposit, Nordland, Norway. Mineralium Deposita 34: 19-34.

Craig, J.R. & Vokes, F.M. (1992): Ore mineralogy of the Appalachian-Caledonian stratabound sulfide deposits. Ore Geol. Rev. 7: 77-123.

Dominy, S.C., Annels, A.E., Johansen, G.F. & Cuffley, B.W. (2000): General considerations of sampling and assaying in a coarse gold environment. Trans. Inst. Min. Metall. B109: 145-167.

Eidsmo, O., Foslie, G., Malvik, T. & Vokes, F.M. (1985): The mineralogy and recovery of silver in some Norwegian base-metal sulphide deposits. In: Applied Mineralogy (W.C. Park, D.M. Hausen & R.D. Hagni eds.) Trans AIME: 891-910.

Gasparrini, C. (1983): The mineralogy of gold and its significance in metal extraction. CIM Bulletin 76 (no. 851): 144-153.

Gasparrini, C. (1984): the mineralogy of silver and its significance in metal extraction. CIM Bulletin 77 (no. 866): 99-110.

Gilligan, L.B. & Marshall, B. (1987): Textural evidence for remobilisation in metamorphic environments. Ore Geol. Rev. 2: 205-230.

Harris, D.C. (1990): The mineralogy of gold and its relevance to gold recoveries. In: Gold '89 in Europe. Mineralium Deposita 25 (Suppl.): 3-7.

Harris, D.C., Cabri, L.J. & Nobiling, R. (1984): Silver-bearing chalcopyrite, a principal source of silver in the Izok Lake massive sulfide deposit: Confirmation of electron- and proton-microprobe analyses. Can. Mineral. 22: 493-498.

Huston, D.L., Sie, S.H., Suter, G.F., Cooke, D.R. & Both, R.A. (1995): Trace elements in sulfide minerals from Eastern Australia volcanic-hosted massive sulfide deposits: Part I. Proton microprobe analyses of pyrite, chalcopyrite, and sphalerite, and Part II. Selenium levels in pyrite: Comparison with $d^{34}S$ values and implications for the source of sulfur in volcanogenic hydrothermal systems. Econ. Geol. 90: 1167-1196.

Karlstrom, H.J. (1990): Edelmetaller i Norske Kaledonske Sulfidforekomster. BVLI Teknisk rapport nr. 77.

Larocque, A.C.L., Hodgson, C.J. & Lafleur, P-J. (1993): Gold distribution in the Mobrun volcanic-associated massive sulfide deposit, Noranda, Quebec: A preliminary evaluation of the role of metamorphic remobilization. Econ Geol 88: 1443-1459.

Larocque, A.C.L., Hodgson, C.J., Cabri, L.J. & Jackman, J.A. (1995): Ion microprobe analysis of pyrite, chalcopyrite and pyrrhotite from the Mobrun VMS deposit in northwestern Quebec: Evidence for metamorphic remobilisation of gold. Can. Mineral. 33: 373-388.

Lind, I.L. (1980): Studier i Sulfosalte af Kobber: Faseforhold i Systemet Cu-Sb-S ved 220 °C og 1000 kg/cm^2. Tetrahedrite-tennantite fra Mofjell området, Nordland, norge. Unpubl. M.Sc. thesis, University of Copenhagen, Denmark.

Lind, I.L. & Makovicky, E. (1982): Phase relations in the system Cu-Sb-S at 200 °C, 108 Pa by hydrothermal synthesis. Microprobe analyses of tetrahedrite – a warning. Neues Jahrb. Miner. Abh. 145: 134-156.

Marshall, B. & Gilligan, L.B. (1987): An introduction to remobilisation: Information from orebody geometry and experimental considerations. Ore Geol. Rev. 2: 87-132.

Marshall, B. & Gilligan, L.B. (1993): Remobilisation, syn-tectonic processes and massive sulfide deposits. Ore Geol. Rev. 8: 39-64.

Marshall, B. & Spry, P.G. (2000): Discriminating Between Regional Metamorphic Remobilization and Syn-Tectonic Emplacement in the Genesis of Massive Sulfide Ores. Reviews in Economic Geology, 11.

Marshall, B., Vokes, F.M. & Larocque, A.C.L. (2000): Regional metamorphic remobilization: upgrading and formation of ore deposits. Reviews in Economic Geology, 11.

Moralev, G.V., Larsen, R.B. & Bjerkgård, T. (1995): Distribution of precious metals in the Bleikvassli Zn-Pb Sedex type deposit, Nordland, Norway. Open Report, Norges Geol. Unders. 95.154: 120 pp.

Moralev, G.V., Larsen, R.B., Bjerkgård, T. & Laputina, I.P. (under review): Distribution, speciation and genesis of gold and silver occurrences in the Bleikvassli Zn-Pb deposit, Nordland, Norway. Economic Geology.

Neumayr, P., Cabri, L.J., Groves, D.I., Mikucki, E.J. & Jackman, J.A. (1993): The mineralogical distribution of gold and relative timing of gold mineralisation in two Archean settings of high metamorphic grade in Australia. Can. Mineral. 31: 711-725.

Nixon, F. & Rui I.J. (1988): Gull i Mofjellet-utvidet mikroskopering. Unpubl. Report, A/S Prospektering, 8pp.

Petruk, W. & Wilson, J.M. (1993): Silver and gold in some Canadian volcanogenic deposits. In: Proc. 8th quadrennial IAGOD symposium (Y.T. Maurice ed.), Schweizerbart'sche, Stuttgart: 105-117.

Ramdohr, P. (1938): Antimonreiche Paragenesen von Jackbsbakken bei Sulitjelma. Nrosk geol. Tiddskr. 18: 275-289.

Saager, R. (1966): Erzgeologische Untersuchungen an kaledonischen Blei, Zink und Kupfer führenden Kieslagerstätten im Nord-Rana-Distrikt, Nord-Norwegen mit besonderer Berucksichtigung der Mofjell-Grube bei Mo-i-Rana. Unpubl. Dissertation, ETH Zürich.

Saager, R. (1967): Drei typen von Kieslagerstätten im Mofjell-Gebiet, Nordland, und ein neuer Vorschlag zur Gliederung der kaledonischen Kieslager Norwegens. Norsk Geol Tidsskr. 47: 333-358.

Schulze (1975): Sulfidvererzungen am Hauknestind (Rana, Nord-Norwegen): Prospektion und lagerstättenkundliche Untersuchungen. Unpubl. Diss., ETH Zürich.

Stanley, C.J. & Laflamme, J.H.G. (1998): Preparation of specimens for advanced ore-mineral and environmental studies. In: Modern approaches to ore and environmental mineralogy (L.J. Cabri & D.J. Vaughan eds.), Mineral. Assoc. Canada Short Course Vol. 27: 111-121.

Vokes, F.M. (1963): Geological studies on the Caledonian pyritic zinc-lead orebody at Bleikvassli, Nordland, Norway. Norges Geol. Unders. 222: 1-126.

Vokes, F.M. & Craig, J.R. (1993): Post-recrystallisation phenomena in metamorphosed stratabound sulphide ores. Mineral. Mag. 57: 19-28.