Tittel

Geology and copper sulfide occurrences of the Numedal - Hovin region.

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Råstofftype	Emneord
Malm/metall	Cu

Sammendrag

Denne har vi to eksemplarer av.

FOR FALCONBRIDGE NIKKELVERK A/S

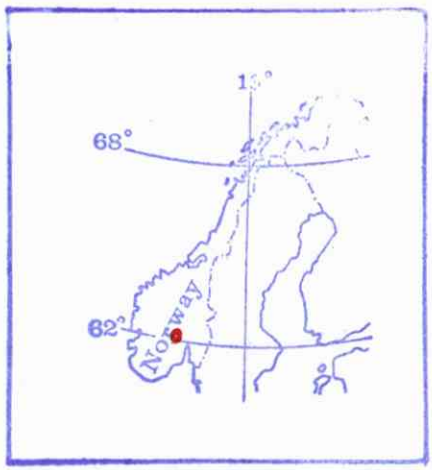
A/S SULFIDMALM

PROJECT 905-15

GEOLOGY AND COPPER SULFIDE OCCURENCES OF THE NUMEDAL-HOVIN REGION, NORWAY.

BY

M. ANNIS



Report Nr. 338/74/15

Contents

Introduction

This report describes the geology of the Numedal-Hovin region and several of the copper sulfide occurences found there. Most of the sulfide occurences are located in either the Numedal area or near Hovin. These two areas have been mapped in reconnaissance.

Very little was known about the regional geology when the project began, and no thorough study of the sulfide occurences and their origin has been written. The Geological Map of Norway (Holtedahl and Dons, 1960) indicates Precambrian supracrustal rocks of the Telemark Formation occur in this region, with basement gneisses exposed to the east and west of the area. The map of mine and ore deposit localities for southern Norway (Foslie, 1925) shows the Numedal localities plot along a linear trend which may be extended 80 km southwards where it intersects the Hovin occurences.

In view of the lack of regional, or district-wide, geologic studies, the aim of this study is to map and describe the geologic setting in which the sulfide minerals occur, and to provide an applicable geologic description of how they formed. Most of the information presented here is based on field observations. Field work to date totals about 12 weeks, consisting of about 3 weeks in the Numedal

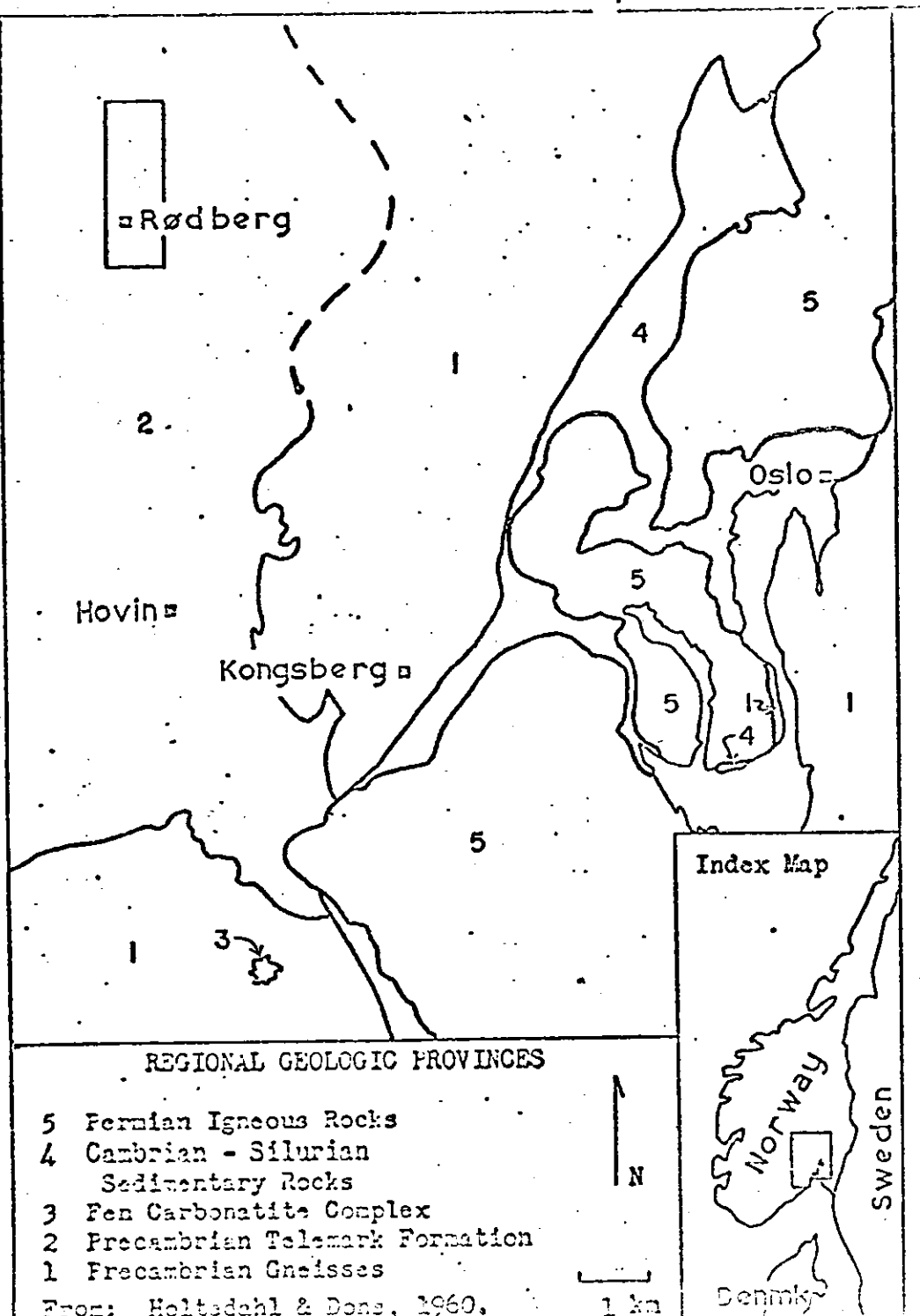
area during the summers of 1972, 1973, and 1974; and 3 weeks in the Hovin area in summer 1974. Map data has been plotted on air photographs (1:35000 and 1:50000 scales) in the field and subsequently transferred to the rather poor quality 1:50000 topographic map sheets. The resulting, largely reconnaissance geologic map has been improved by more precise mapping in key areas.

Important new points resulting from the summer 1974 field work discussed here include all the Hovin area work, with resulting extension of the regional stratigraphy. Refinements in the stratigraphy and structure of the Numedal area suggest a possible eastward extension of the supracrustal belt, and any accompanying sulfide occurences, into the Hallingdal drainage basin.

This study is part of the NumHov Projekt established by Professor F. M. Vokes, Norges Tekniske Høgskole. His encouragement, support and discussions have helped to increase the value of this study. Amanuensis S. Bergstøl, also at NTH, has studied a number of the sulfide occurences and conducted field studies in selected parts of the region as part of the project effort (see Bergstøl, 1973). Discussions with him during the course of field work have been most helpful. A brief, informal field tour was held on September 3 & 4, 1974 for Professor G. O. Allard, University of Georgia, Professor Vokes, and Mr. Tore Vraalstad, Norsk Hydro.

Regional Geology

Figure 1 shows the regional geologic provinces.


Rødberg
Hovin
Kongsberg
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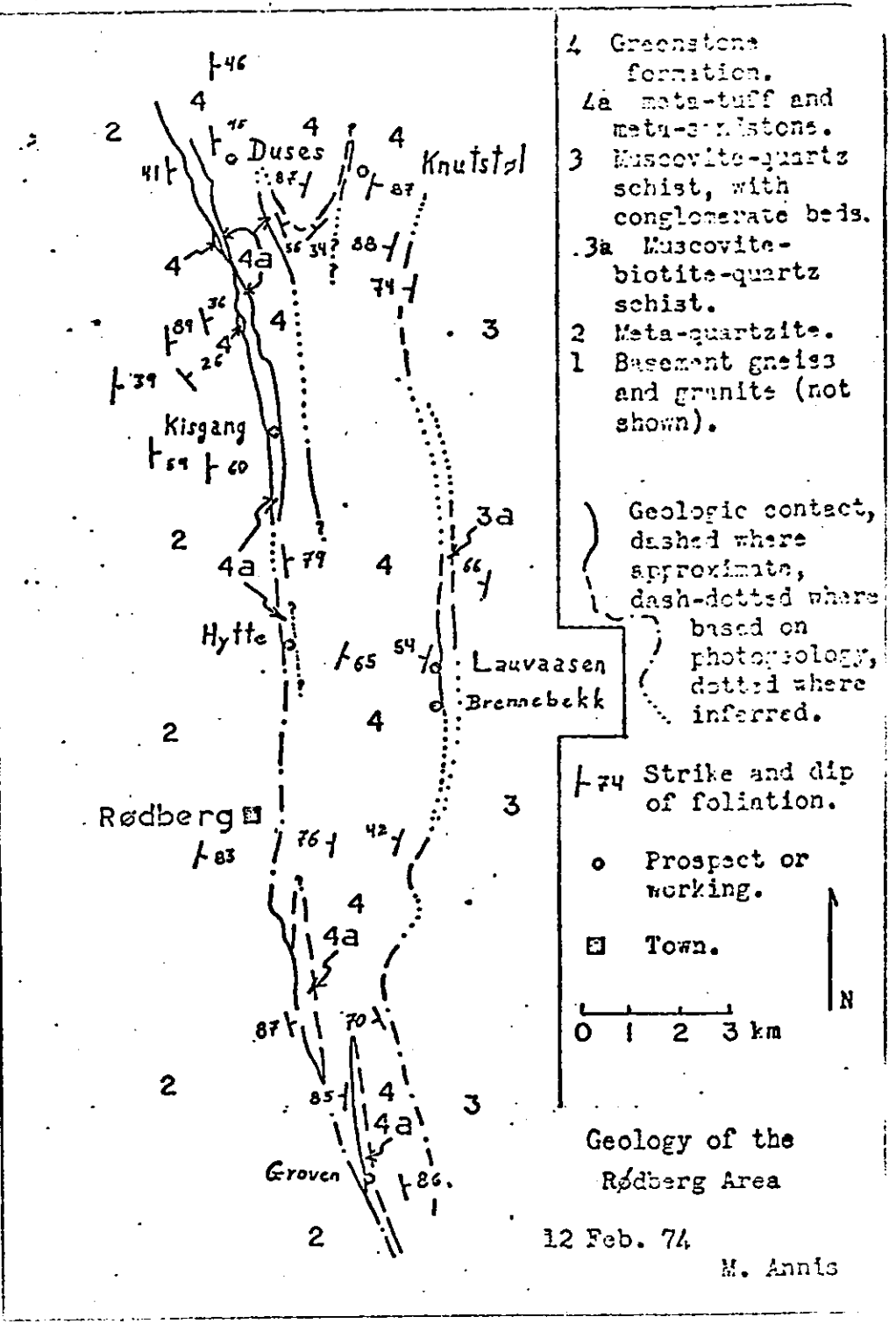
Index Map
Norway
Sweden
Denmk
REGIONAL GEOLOGIC PROVINCES
5 Permian Igneous Rocks
4 Cambrian - Silurian Sedimentary Rocks
3 Fen Carbonatite Complex
2 Precambrian Telemark Formation
1 Precambrian Gneisses
From: Holtedahl & Dons, 1960.
N
1 km


Duses
Knutstøl
Kisgang
Hytte
Lauvaasen
Brennebekk
Rødberg
Groven
4 Greenstone formation.
4a meta-tuff and meta-sandstone.
3 Muscovite-quartz schist, with conglomerate beds.
3a Muscovite-biotite-quartz schist.
2 Meta-quartzite.
1 Basement gneiss and granite (not shown).
Geologic contact, dashed where approximate, dash-dotted where based on photogeology, dotted where inferred.
Strike and dip of foliation.
Prospect or working.
Town.
N
0 1 2 3 km
Geology of the Rødberg Area
12 Feb. 74
M. Annis

The supracrustal rocks in the Numedal-Hovin region are quartzite, greenstone, porphyritic schist ("porphyry"), and muscovite-quartz schists. These are thought to be equivalent to members of the Telemark Formation established elsewhere in the manner listed in the stratigraphic comparison (Table 1). Dips are generally steep, except in the southern part of the Hovin area. Folding in the region is not yet well understood even though at least two important fold structures appear to be present in the Numedal area, and a third may occur near the southern limit of the Hovin area.

The greenstone formation is the host rock for the Cu-sulfide occurences in Numedal, but not at Hovin where it is absent. At Hovin, the country rock is muscovite-quartz schist for all but one occurrence.

Stratigraphy

Each of the three lithologic groups of the Telemark Formation are thought to be represented in the expanded study region which includes the Hovin area. The inferred psoition of the muscovite-quartz schist has been changed so that it now overlies the greenstone formation in Table 1.

Comparison with the Telemark Formation succession shown in Table 1 is excellent at the group level, but several differences show up within the important Bandak group. These are attributed to geographic-geologic variations within individual Bandak basins. The discrepancy with the Bandak group succession increases northward into the Numedal arm of the Telemark Formation.

Table 1. Comparison of Stratigraphic Units in the Numedal-Hovin Region with the Telemark Formation.

Stratigraphic Units in the Numedal-Hovin Region.	Telemark Formation Units (Dons, 1960, pp. 49-55.)
	Bandak Group (acid and basic volcanics quartz-rich sediments).
Muscovite-quartz schist with deformed meta-conglomerate and calcareous facies.	8. Quartz schist with conglomerate. 7. Marble (locally present). 6. Green lava; includes one layer of sandstone containing fossil algae(?).
Greenstone formation fine-grained greenschist, amphibolite, meta-basalt, siliceous greenstone, porphyritic schist ("porphyry"), meta-sandstone, Cu - Mo mineralization.	5. Porphyry (acid volcanic rock) (locally missing). 4. Green volcanic rock with conglomerate, beds of quartzite with conglomerate, minor quartz schist. Pillow(?) structures; Cu - Ag mineralization. Possible unconformity. 3. Quartzite, with conglomerate. 2. Porphyry (acid volcanic rock) variable thickness, locally missing). 1. Basal conglomerate and quartzite, Thickness decreasing eastward to zero, where no. 3 forms the base(?).
	Unconformity
	Seljord Group (quartzites, conglomerates, schists).
Quartzite metamorp osed pure orthoquartzite with cross beds and oscillation ripple marks; basic sills present, in part layered.	Cross beds and oscillation ripple marks are common; basic sills are common.
	Unconformity
	Rjukan Group
Medium gray to dark gray porphyritic schist.	Vemork formation basic volcanic rocks, sedimemts. Tuddal formation acid volcanic rocks (flows and tuffs).

Rjukan group

Porphyritic schist in the extreme northwest corner of the Hovin area is thought to be equivalent to the Rjukan group exposed across Tinnsjø. The porphyritic schist is medium to dark gray and very fine grained, with colorless, 1- to 3-mm phenocrystal grains. A medium gray, fine-grained chlorite-biotite-felsic minerals schist with crude layered structure occurs nearby, but its stratigraphic relation is unclear. It may belong to the Rjukan group, or it might be part of the layered sill immediately to the east. The Rjukan rocks here are in contact with a layered sill which is part of the overlying quartzite formation.

Quartzite at Rødberg

Distinctive, pure orthoquartzite, now metamorphosed, is exposed along the western edge of the study areas from the northernmost point in the Numedal area to the southernmost point south of Tinnoset. The rock is a hard, white muscovite-bearing quartzite. It consists of about 95% or more quartz, with muscovite as the only major accessory mineral. The muscovite occurs along bedding planes and imparts the dominant foliation. A few oblique muscovite plates indicate an incipient crenulation foliation has developed.

Cross beds and oscillatory ripple marks abound in the Numedal area, and have been observed south of Tinnoset. These preserved sedimentary structures consistently indicate younger rocks lie to the east.

Several dark mafic sills, and one meta-basalt flow are present in the quartzite unit. The mafic sills are found in both areas. Most in the Numedal area are ½ to 3 meters thick, and extend from 1 to several kilometers along strike. One unusually thick sill exposed in a road cut near the east end of lake Fönnebö is indistinctly layered. Most of the Numedal sills are dense, fine-grained black amphibolite with traces of pyrite. Contacts with quartzite are sharp, rarely with a small apophysey extending into the quartzite. Finer grained borders suggestive of chilled margins are present at a few localities.

A second unusually thick layered sill occurs in the Hovin area. It is exposed in roadcuts at reference point 995419, and extends at least 4 km to the south. Neither its northern continuation, nor its possible presence along the shore of Tinnsjø have been determined. The sill is a dark greenish black, medium- to coarse-grained, actinolite-hornblende-plagioclase amphibolite with traces of pyrite. Differences in color, grain size and color index impart the layered structure, each layer having a massive texture. It is cut by 5 sets of joints and fractures, 2 of which contain drusy quartz fillings.

Tunnhovd dam is founded on meta-basalt which is situated about 700 m below the top of the quartzite formation. It is a biotite-ilmenite(?)-quartz-clinozoisite-plagioclase metamorphite with relict volcanic texture dominated by plagioclase laths.

The quartzite is separated from overlying formations by an unconformity having slight angular discordance.

Greenstone formation of Vadsetvann

This complex formation includes greenstones and greenschists, porphyritic schists, and metamorphosed clastic sediments. It forms a north-south-trending belt through the Numedal area. To the south, it appears to thin near Nore, and is not present in the Hovin area. All the Cu-sulfide occurrences in the Numedal area lie within this belt.

Table 2 presents one succession of litho-stratigraphic members of the formation. Internal members have not been mapped in detail, except for selected lithologies that are especially relevant to the mineral occurrences or to features of the regional geology. Contacts between the members are well defined at the map scale.

The unconformable contact with underlying quartzite is sharply defined, and marked by quartzite breccia locally deposited at the base of the formation. The upper contact of the greenstone formation with overlying muscovite-quartz schist is distinguished by biotite-muscovite-quartz schist adjacent to greenstone. In the northernmost part of the area, the contact is somewhat gradational over about 10 m. Here the outcrop surfaces of dark green fine-grained massive greenstone become lumpy, with development of epidote nodules and seams. Siliceous clasts of meta-chert(?) appear and the matrix changes to fine-grained epidote-quartz schist. The matrix then changes to muscovite-quartz schist. Several meters of deformed cobble and pebble conglomerate with muscovite-quartz-schist matrix overlie the contact zone.

Table 2. Litho-stratigraphic Succession of the Greenstone Formation, Skjønne Kapel to Rødberg.

3678-3760m	Chlorite-actinolite-plagioclase schist. Dark green, fine grained, with epidote traces.
3673-3678	Muscovite-biotite-quartz-feldspar schist. Medium gray, fine grained, with traces of epidote, calcite, magnetite, and bornite; ½ to 3 cm thick, calcite-bearing quartz veins parallel foliation.
3642-3673	Actinolite -hornblende-plagioclase schist. Dark green, fine grained except for a few local medium grained zones.
3510-3642	not exposed
3498-3510	Quartz schist(?). Gray, very fine grained, dense, with calcite traces; similar to porphyritic schist formation.
3490-3498	Actinolite-hornblende-plagioclase schist. Same as 3642-3673.
3487-3490	Felsic rock. Light gray, very fine grained, flinty, with traces of biotite. Quartz veins at contacts
3472-3487	Actinolite-hornblende-plagioclase schist. Same as 3642-3673.
3430-3472	not exposed
3338-3430	Actinolite-hornblende-plagioclase schist. Dark green, fine to medium grained; with epidote ovoids, foliation diverges about the ovoids; pyrite and magnetite at 3396.
3300-3338	not exposed
3000-3300	Muscovite-quartz meta-tuff(?). Light pinkish gray, fine grained; with magnetite traces, rounded, deformed chert(?) pebbles; a few calcite-bearing quartz veins and pods, with traces of chalcocite, rarely chalcopyrite; medium grained, with biotite and blue quartz in lower 20 m.
700-3000	Actinolite-hornblende schist. Dark green to gray, fine grained, with traces of epidote.
0- 700	Porphyritic schist. Gray to purple gray, very fine grained with 2- to 3-mm quartz or feldspar crystals.
unconformity	

Muscovite quartz schist of Vetterhusgrend

Muscovite-quartz schists crop out over the eastern part of the Numedal area, and forms the central formation in the Hovin area. Dark lenses and other dark rocks included in the formation in the Hovin area contain most of the Cu-sulfide occurrences in this area. The muscovite-quartz schist evidently overlies the greenstone formation, and comes into direct contact with the quartzite to the south where the greenstone formation is missing.

Typical hand specimens are light gray, fine-grained muscovite-quartz schist±biotite, with traces of magnetite and chlorite common. Quartz makes up about 80 to 85%, the remainder being mica. The rock has low density, and contains too little magnetite to attract a pencil magnet. Near the contact with greenstones in the Numedal area, biotite content increases until it becomes as abundant as muscovite, or slightly more abundant.

A large portion of this formation is conglomeratic, especially in the eastern and northern part of the Numedal area. This variant contains up to 30% rounded and flattened pebbles and cobbles. The vast majority of these clasts are very fine-grained quartz, quite possibly having originated as chert. A small number of clasts are colored green by epidote. The flattened clasts lie parallel, and at least locally have their long axes perferentially aligned. A similar conglomeratic quartz schist exposed in road cuts along the east side of Numedal differs in having flattened cobbles of several lithologies, including gneiss, and dark gray

fine-grained amphibolite(?).

In the Hovin area, the typical fine-grained muscovite-quartz schist also forms a major part of the formation. Eastwards, however, it contains calcite and epidote in variable amounts. A thin (50 cm thick) calc-silicate zone or series of lenses, marks the beginning of this calcareous facies. Bergstøl (1973) first located and mapped this zone. It consists of medium-grained, actinolite-chlorite-epidote-quartz-calcite marble. This zone, with the succeeding calcareous muscovite-quartz schist facies eastwards, may form a suitable marker horizon within the formation. Immediately west of Blefjell Campground, the cal-silicate zone lies within 15 m of the upper contact of the formation. To the north a thick section of epidote- and calcite-bearing muscovite-quartz schist overlies the calc-silicate zone. An occasional bed, or lense of porphyritic schist occurs interbedded in this part of the section.

A number of lense- or dike-like bodies of dark rocks occur in the lower, muscovite-quartz schist part of the formation. These are the locus of the Cu-sulfide occurrences in the Hovin area. Their contrasting lithologies are cited below as part of the locality descriptions. Coarse, pegmatitic calcite-bearing quartz veins fill joints in the quartz schist formation, and are especially well developed in biotite-rich zones of the schist. Most are 20 cm thick and parallel to slightly oblique to foliation. Sulfides are rarely present, and then in only trace amounts.

The muscovite-quartz schist formation is highly deformed by tight, isoclinal mesoscopic folds not seen in other formations in the region. The fold axes parallel regional foliation, and plunge gently (10-15°) north and south.

The eastern contact with porphyritic schist in the Hovin area appears to be conformable, even though its map trace is slightly oblique to the strike of regional foliation.

Porphyritic schist at Blefjell Campground

Porphyritic schist, colloquially called 'porphyry', is a common lithology in the region as thin beds and lenses in the greenstone formation and the muscovite-quartz schist. It is sufficiently extensive along the eastern margin of the Hovin area to be recognized as a formation.

The rock is light pinkish to purplish gray, very fine-grained felsic schist composed of muscovite, quartz, and feldspar. 3- to 4-mm quartz crystals impart the porphyritic texture at some localities, whereas feldspar crystals produce the porphyritic texture at other localities. Although a homogeneous formation, it has 5 lithologic variants of note. Immediately east of the calcareous muscovite-quartz schist facies just described, the porphyritic schist commonly carries epidote and calcite. At one locality south of Reisjaavann, trace amounts of tourmaline are present. About 1 km east of Ormemyr, the porphyritic schist contains many fine milky quartz veinlets and siliceous seams, and numerous, distinctive euhedral pyrite cubes up to 5 mm.

It was not possible to map this zone more than a few hundred meters to the north, where it terminated against an intersecting fault. Near Venelund, a dark gray rock body in the schist forms the host rock at the Venelund prospect. Two mafic sills 2 m thick, and mafic rocks elsewhere in the southern part of the area cut the schist. These bodies are biotite-actinolite-hornblende schist with traces of sulfides, mostly pyrite. Biotite and epidote prevail at their margins.

Coarse, calcite-bearing quartz veins similar to those found in the muscovite-quartz schist are rarely present in the porphyritic schist. They are about 25 cm thick, contain small amounts of mica, alkali feldspar and bornite, have an occasional drusy cavity, and tend to have mica concentrations along their borders. A few of these veins cut across foliation, contain rotated fragments of wall rock, and are bordered by more intensely colored wall rock up to several decameters from the vein.

Gray schist at Økteren lakes

This formation is present at the Økteren lakes in the Numedal area, and appears to occupy the core of a major antiform. The schist is a fine-grained, magnetite-bearing biotite-feldspar-quartz schist ± hornblende. Schistosity is not sufficiently well developed for the rock to be fissile. Thin, 1-cm-thick quartz veins are common in trace amounts throughout. Although gray on fresh surfaces, the rock weathers pink. The contact relations of this unit have not yet been observed.

Structure

An unconformity separates the quartzite from younger rocks to the east. Foliation strikes north-south and dips steeply over most of the region except at Øksteren lakes and in the southern part of the Hovin area. The divergent foliation at these localities are thought to reflect large scale folds. Another important fold occurs at Slettestøl in the Numedal area. Faults have not yet been shown to play a major role in the regional structure; yet some possibility that faults oriented parallel to the strike of foliation are present remains. Minor cross faults offset the muscovite-quartz schist, porphyritic schist contact. Zones of sheared rock are present at Duses, near Venelund, and at the northern termination of the pyrite zone in the porphyritic schist.

Unconformity

The unconformity along the top of the quartzite is marked by slight angular discordance in the southern part of the Numedal area, and locally by minor quartzite breccia at the base of the overlying unit. Evidently a topographic high persisted in the southern part of the Numedal area, with a basin to the north. Lenses of porphyritic schist here rest on the quartzite along the flank of the high, and extend out into the basin where they rest on earlier layers.

Fold at Øksteren lakes

Striking geomorphic features visible on air photographs

suggest a major antiform occurs at Økteren lakes and northwards. A gently north-plunging antiform is inferred to be present at the lakes. Its plunge is thought to form a saddle about 7 or 8 km north of the lakes, and emerge as a gently south-plunging antiform farther north. This interpretation is supported by the pattern of strike and dip readings about the lakes, and the atypical failure of the Økteren schist to continue northwards. If this inferred antiform is of regional extent, it is quite possible for the greenstone formation to recur to the east, towards Hallingdal.

Fold at Slettestøl

This is a syncline with steep axial plane approximately parallel to the regional foliation. The axis appears to plunge gently to the north.

Fold near Ormemyr

Unusually shallow dips near Ormemyr at the southeastern part of the Hovin area are interpreted to reflect a large fold structure. Arcuate linear topographic features support this inference, and raise the possibility that the muscovite-quartz schist formation curves around the porphyritic schist to the south.

Faults and sheared-rock zones

A set of faults with sinistral apparent offset of a few tens of meters cuts the muscovite-quartz schist-porphyritic schist contact in the Hovin area. Although none of the faults

appear to be a major tectonic feature, the set is consistent over this part of the area. Two additional possible members of the set occur at Venelund and at the northern exposed limit of the pyrite zone. The pyrite zone appears to be cut off by a fault at the northern limit of exposure, and its continuation displaced from view.

Joints

No detailed joint studies have been undertaken due to time restrictions. Their orientations relative to fold structures, coupled with selective presence of vein filling, may warrant study as part of future, more detailed mapping in critical, or target, areas.

Copper-sulfide occurrences

The Cu-sulfide occurrences are located in the first major formation above the quartzite, that is, above the unconformity, except Venelund. The Numedal occurrences are confined to the greenstone formation, are vein deposits, are frequently located in siliceous members of the formation, and have magnetite disseminated in wall rocks. In contrast, the Hovin occurrences have Cu-sulfide minerals both in quartz veins, and disseminated in the host rock. Host rocks are dark gray to black, and enclosed in distinctly siliceous country rocks. No associated magnetite disseminations were observed in this area. Table 3 summarizes the mineralogy, type, and host rock lithologies of the occurrences.

Table 3. Mineralogy, host rocks and country rocks of the Numedal-Hovin Prospects and Workings.

Locality	Coordinates	Country rock	Host rock	Magnetite abundant	Feature	Quartz	Feldspar	Calcite	Chalcopyrite	Bornite	Digenite	Chalcocite	Molybdenite	Pyrite	Hematite
Duses	967946	GSF	GS	+	V	+	?	+	-	+	+	+	+	-	-
Kisgang	976994	GSF	PS	+ + +	V	+ +	+	-	+	-	-	-	-	-	-
Hytte	977850	GSF	PS	+ + +	V	+ +	+	+	+	+	-	-	-	-	-
Groven	994741	GSF	PS	+ + +	V	+ +	+	+	-	+ +	+ +	+	-	-	+
Knutstøl	993944	GSF	GS	+ +	VR	+ +	+	+	+	?	?	?	-	-	-
Lauvaasen	008945	GSF	SG	+ +	VR	+ +	+	+	-	+ +	+ +	-	+ +	-	-
Brenebekk	008836	GSF	SG	+	VR	+ +	+	+	-	+ +	+ +	-	+ +	-	-
Bakke	033378	MQS	DS	-	VD	+									
Vasstveit	014333	MQS	DR	-	VD	+		+		+			+		
Skivdalen	032347	MQS	DS	-	VD	+				+					
Damstøl	034243	MQS	DR	-	VD	+									
Venelund	067269	PS	HS	-	VD	+				+					

GSF = Greenstone formation GS = Greenstone
MQS = Muscovite-quartz schist PS = Porphyritic schist
SG = siliceous greenstone DS = dark schist
DR = dark rock HS = Hornblende schist
V = vein R = replacement D = disseminations

Numedal area

The Cu-sulfide occurrences in the Numedal area consist of quartz vein networks within particular lithologies of the greenstone formation. The mineralogy of the veins and extent of replacement vary according to wall rock lithology.

Seven prospects and former mines, plus smaller, similar mineral localities are included in the study area. The seven are Duses, Kisgang, Hytte, Groven, Knutstøl, Lauvaasen, and Brennebekk. Quartz veins at these localities are irregular, seldom more that 25 cm thick, and seldom extend more than 100 meters. They cut across foliation and occasionally include fragments of the metamorphic wall rock. The wall rock has been altered, and partially replaced at some occurences, but not at others. Magnetite is disseminated in wall rocks at each locality. Pyrite is lacking. These features indicate the veins formed after the regional metamorphic recrystallization and its associated schistosity developed. Confinement of the quartz veins to areas where light, or siliceous, rocks are present; and variation in mineralogy according to host rock lithology indicates the wall rocks had a marked control over localization and mineralogy at some point in the history of these rocks. It is possible that the greenstone formation provided at least some of the vein-forming components.

Each deposit has several unique characteristics that serve to distinguish it from others in the district. Duses occurs along a zone of sheared rock in schistose

greenstone. The quartz veins carry abundant calcite, and calcite also fills oblique fractures. Bergarkiv 668 reports this occurrence carries silver and gold in trace amounts. Professor Allard was particularly interested in the possible continuation of the shear zone, and recommended it be mapped and examined in detail.

At Kisgang, chalcopyrite is the only important copper sulfide. Calcite is essentially absent, although some siderite is present. It is located in porphyritic schist only a few meters above the unconformable contact with the quartzite formation. The chalcopyrite is in a network of irregular quartz veins about 25 cm thick. The porphyritic schist nearby contains disseminated magnetite, and close by the veins is lighter gray and slightly altered.

Hytte is partially covered by a large dump from nearby tunnel excavation. It occurs in gray porphyritic schist. The quartz veins carry calcite as well as Cu-sulfides, in contrast to Kisgang.

There are several workings at Groven. All are located on quartz veins in porphyritic schist. Some of the veins have been deformed along with enclosing schist, and are partially rolled into ζ shaped cross sections.

Knutstøl occurs within the greenstones at an internal contact between greenschist and siliceous greenstone. The siliceous greenstone contains magnetite at the deposit, and for distances up to 200 m to the southeast. Bergarkiv 668 reports small amounts of silver and gold are present here too.

Lauvaasen and Brennebekk are quite similar. They are situated in the same siliceous bed in the greenstone formation. This is a purple-gray finely liminated bed. Molybdenite is a significant ore mineral in these deposits as well as bornite and digenite. In addition to irregular quartz veins, wall rock alteration and replacement is important here. This is shown by samples on the dumps, but could not be evaluated in situ because the mines are now closed and flooded. The altered wall rock is cream to pink colored, and contains Cu-sulfides along former foliation planes and cross fractures.

Malachite is present at each deposit, and elsewhere marks outcrops in the greenstone formation which contain a few grains of Cu-sulfide minerals.

Most of these occurrences lie along two north-south zones. Duses, Kisgang, Hytte and Groven make up the western zone. Lauvaasen and Brennebekk form the eastern zone. Knutstøl lies between the projected zones to the north.

Hovin area

Most of the 3 weeks spent in the Hovin area was devoted to reconnaisance mapping. For this reason, and because other current work by Bergstøl and others, together with old Bergarkiv reports, partially describe the Cu-sulfide localities, the following comments are far from complete, and no large scale maps have been prepared. With the availability of larger scale (1:35000) air photographs, and complete stereographic coverage, photographed this summer, more precise

locations of the occurrences should become a simple matter. More thorough descriptions of selected occurrences should follow.

The Hovin occurrences contrast sharply with those at Numedal. All but one occurs in dark rocks in the muscovite-quartz schist. Venelund differs only in that the dark rock is enclosed in porphyritic schist. Disseminated Cu-sulfides in the dark rock are important in addition to Cu-sulfide bearing quartz veins. Discoloration of the dark rock at Vasstveit may be an indication of an epigenetic origin. The distinct magnetite disseminations found associated with the Numedal occurrences is essentially absent at the Hovin localities. Pyrite is lacking at the occurrences here too.

The Bakke locality consists of several small surficial diggings near Bakken farm. Here the muscovite-quartz schist contains more irregular quartz veins and streaks than usual. Dark muscovite-epidote-biotite-feldspar schist ± hornblende ± quartz forms a 2 m wide zone which appears in every way other than mineralogy to be a part of the muscovite-quartz schist lithology, including presence of quartz veins. Within the dark schist, the veins carry Cu-sulfides. Minor amounts of Cu-sulfides are disseminated in the dark schist as well.

Vasstveit is the largest mine in the Numedal-Hovin region. The main stall is located in a rather variable dark rock, several tens of meters thick, enclosed by muscovite-quartz schist. At the entrance, and immediately outside, it is dark, fine-grained massive amphibolite with visible magnetite. Discoloration near bornite-bearing calcite veins near the entrance suggest an epigenetic

origin for at least this part of the deposit. Most of the walls in the stall, however, expose dark fine-grained schist composed of biotite and felsic minerals ± magnetite. Where the schist contains disseminated traces of Cu-sulfides, chiefly bornite, it is purple colored. Discontinuous bornite coatings are present on some joint surfaces in the south wall. A breccia of purple, bornite-bearing rock, and crystalline calcite in a biotite-rich matrix is exposed at the base of the southeast wall. Minor molybdenite is present in loose blocks and in samples on the dump.

Efforts to map the dark host rock at Vasstveit were frustrated as much by inadequate control as by heavy vegetation. Hopefully, stereographic coverage by air photographs at 1:35000 scale will suffice for future mapping of the host rock.

The old Skivdalen mine opening is now covered by a large rock and the workings are inaccessible. The country rock is the ordinary muscovite-quartz schist with the usual coarse quartz veins, which here contain significant quantities of Cu-sulfides, mostly bornite. Orientation of foliation in the schist varies considerably at the mine locality. Most specimens on the dump are dark, biotite-rich schist, frequently with traces of Cu-sulfides. A few quartz-vein samples with bornite and other Cu-sulfides are also present, so that it isn't known if the mine was based on vein ore, or disseminated ore, or both. A dike-like body of dark black schist exposed a few meters above the opening, and elsewhere nearby contains visible chalcopyrite. Both grade and volume

of this dark schist appears too low to be worked economically. At least 2 outcrops less than 1 km east of the mine contain Cu-sulfides. These are in dark gray to black schist enclosed by muscovite-quartz schist.

Damstøl is a small working situated high on a steep hillside in the southern part of the area. The dark gray host rock is about 3 meters across and encosed by muscovite-quartz schist. Host rock and regional foliation dip steeply and are conformable. The working extends about 14 m along the dark rock. Quartz veins are present and might have been the basis for mining. Yet Cu-sulfide disseminations in the dark rock might better explain excavation along the host rock.

Venelund is an underground working, unique in having porphyritic schist for country rock. However, the deposit itself is located in a variable, dark, medium-grained hornblende schist enclosed in the country rock. It contains traces of magnetite and minor Cu-sulfides, chiefly bornite. Quartz veins cross cut foliation. Pure quartzite is present about 100 m to the east, separated from the porphyritic schist by a small sharp valley thought to mark a fault. A dark sill is present in the quartzite at this locality.

Magnetic information

Because magnetite is commonly associated with the Numedal occurrences, I previously suggested magnetic surveys might prove interesting. Aeromagnetic maps for the southern 3 of the 4 map sheets which cover the project area (that is

sheets 1615 II, 1614 I and 1614 II) demonstrate the generally even magnetic values obtained at the widely spaced network flown. A magnetic high is present near the Vasstveit mine.

Spot readings at outcrops during the latter part of the field season served to confirm the generally even magnetic attraction of the country rocks. Few spot readings near the Cu-sulfide occurrences in the Hovin area were enormously higher than country rock values. However, distinctly higher values were obtained at the Numedal occurrences visited. (Unfortunately, these are in the northern map sheet (1615 I) for which no aeromagnetic map is available.)

The ground magnetometer studies carried out by Bergstøl during July in the Hovin area may further clarify the general weakness of magnetic anomalies associable with the occurrences here. A comparable study of the Numedal area would delimit the magnitude and extent of the anomalies there, and might prove to be a useful prospecting tool for this area.

Summary and problems remaining

A single, regional stratigraphy characterizes the study areas. Metamorphosed volcanic, volcaniclastic, and clastic rocks form the bulk of the lithologic units overlying the quartzite, and host all the Cu-sulfide occurrences. The greenstone formation occupies a former topographic low in the Numedal area and may pinch out to the south. The muscovite-quartz schist has a conglomeratic facies in the Numedal area

and a calcareous upper member, or facies, in the Hovin area. Steep dips prevail, yet major folds remain to be mapped. They appear to be present near the borders of the mapped areas. They might bring about a repetition of the Cu-sulfide-bearing strata in adjacent areas, such as Hallingdal. This, in turn, would provide better insight into the extent of mineralization, its nature, and possible genetic relation to the host rock/country rock associations. Presumably this would also present an expanded comprehensive perspective of possible target areas over the entire region.

The role of metamorphism and its timing relative to original Cu-sulfide fixation in these rocks remains a major problem to understanding ore genesis, and to exploration potential in this region.

Proposals for future work

Several questions and incomplete statements made above must be satisfied in the field. Others lack the benefit of laboratory studies. Chief among the field related problems at the regional scale, are the fold structures and the extent of Cu-sulfide mineralization in this arm of the Telemark Formation. More specifically, siliceous members of the greenstone formation should be mapped carefully. Likewise dark rocks in the muscovite-quartz schist merit more complete study.

Several sulfide occurrences deserve close scrutiny. Detailed mapping of the Lauvaasen-Brennebekk area, Duses,

Kisgang, Grovenaas, Vasstveit, and Venelund should be undertaken. (A detailed map of Kisgang is already underway.) The zone of sheared rock at Duses should be explored along its length by various means. Magnetic anomalies should be sought in the greenstone formation and carefully evaluated.

Laboratory study of samples collected during the 1974 field season is hampered at the moment by delays in shipment. They are expected to arrive within a few days.

I would like to continue field work in summer, 1975 in order to study the importance of regional folding and possible eastern extension of the district in the north; examine the occurrences named above in the greenstone formation by means of larger scale mapping; and to continue to take spot magnetometer readings during the course of field work. The Hovin area warrents similar continued study which I would like to pursue, time permitting. Finally, it would be worthwhile to trace the unconformity along the top of the quartzite from Numedal to Hovin while paying particular attention to the lithologies immediately overlying it.

Petrographic and other laboratory study, coupled with library research prior to the field season should help clarify the origin of questionable rocks such as the muscovite-quartz schist and the porphyritic schist; the mineralogy and texture of the Cu-sulfides; and the rock alteration where present.

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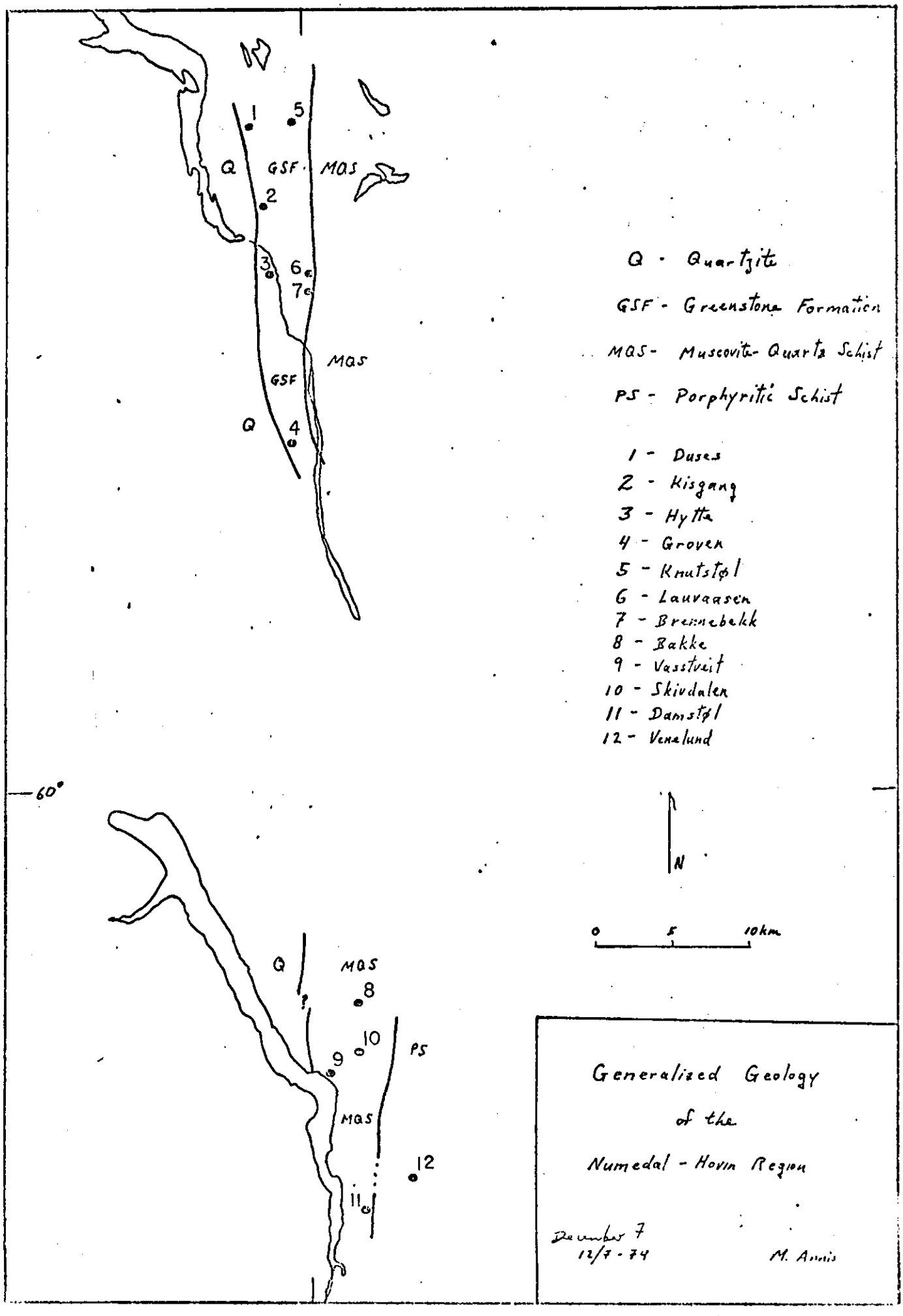
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PS
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Q - Quartzite
GSF - Greenstone Formation
MQS - Muscovite-Quartz Schist
PS - Porphyritic Schist
1 - Duses
2 - Kisgang
3 - Hytta
4 - Groven
5 - Knutstøl
6 - Lauvaasen
7 - Brennebekk
8 - Bakke
9 - Vasstveit
10 - Skivdalen
11 - Damstøl
12 - Venalund
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Generalized Geology
of the
Numedal - Hovin Region
December 7
12/7-74
M. Annis

A/S SULFIDMALM

INTER-OFFICE MEMORANDUM

Date: 26th February, 1975

To: Falconbridge Nikkelverk A/S

cc: W. D. Harrison, H. T. Berry, F. Nixon

From: J. B. Gammon

Subject:

905-15. Field work at Numedal-Hovin. Report No. 338/74/15.

Please find attached a report by Annis on his work in the Numedal-Hovin area during 1974. This area is the third joint venture region that we have with the Norsk Hydro company. Neither company prioritises activity here which mainly consists of an academic study being undertaken by Annis from the University of Georgia under the direction of Professor G. O. Allard. Annis's expenses are covered by Norsk Hydro. Sulfidmalm's only expenses currently are maintaining tittle to the main showings which have been optioned from the state.

As a quick study of Annis's report will reveal he is only just getting to detailed grips with the problem and future action on our part will await his findings.

J. B. Gammon