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Geology and Copper Sulfide Occurrences of the Numedal Region, Norway

1975 Annual Report

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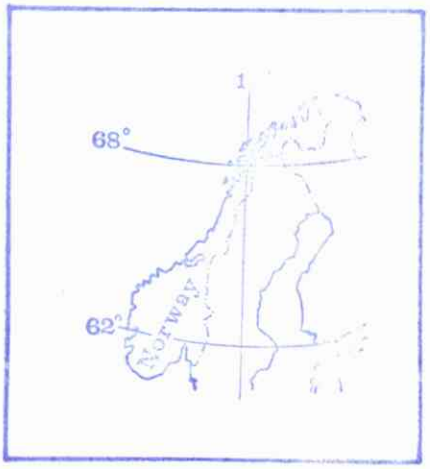


Report No. 375/75/15

Geology and Copper Sulfide Occurrences of the Numedal Region, Norway

1975 Annual Report

M. P. Annis

Contents

This report describes the geology of the upper Numedal region and several sulfide mineral occurrences located there. It incorporates the new results from field work during 1975, presents a new, and more complete geologic map of the region from Slettestøl to Nore, and describes the Duses, and Lauvaasen - Brennebekk occurrences in some detail. The study region includes most of the Skjønne map sheet and extends onto the Nore map sheet to the south as far as Nore (AMS series 711, 1615 I & II map sheets, respectively; 1:50,000).

Little was known about the regional geology when the project began, and no thorough study of the mineralization and its origin has been written previously. 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 deposits localities for southern Norway (Foslie, 1925) shows the Numedal localities plot along a linear trend which may be extended 80 km southwards to intersect the sulfide occurrences at Hovin.

Due to the lack of regional, district-wide geologic studies, the aim of this study has been to first 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 18 weeks, consisting of 3 weeks in the Numedal area during the summers of 1972, 1973, and 1974; 6 weeks during 1975; and 3 weeks in the Hovin area in summer 1974. Air photographs were used for base maps in the field, and the data was then transferred to the rather poor quality topographic map sheets. The initial reconnaissance geologic map provided a base for more precise mapping in key areas during subsequent field work.

Important new points resulting from the 1975 field work include a thoroughly revised stratigraphy and structure for the region, and site descriptions for the Duses and Lauvaasen - Brennebekk occurrences.

This investigation is part of the NumHov Project established by Professor F. M. Vokes to study the mineralization of the district. His encouragement, support and discussions have helped to increase the value of this contribution. Amanuensis S. Bergstøl has studied a number of the sulfide occurrences and conducted field studies in selected parts of the region as part of the project study (Bergstøl, 1973). Discussions with him

during the course of field work have been of immediate benefit. A field tour was held on September 3-4, 1974 with Professor G. O. Allard, Professor Vokes, and Mr. Tore Vrålstad. This contribution to the project study has also benefitted from discussions with Professor Allard and other members of staff at the Department of Geology, University of Georgia. Norsk Hydro A/S provided a magnetometer on loan during parts of the 1974 and 1975 field seasons.

Geologic Setting.

Figure 1 shows the regional geologic provinces, and the location of the study area, at Rødberg, in the late Precambrian Telemark Formation supracrustal rocks. This formation has been divided into three lithologic groups as shown in Table 1.

The Numedal area is considered to be a northeastern arm of the Telemark Formation, with lithologic equivalence as listed in Table 1. While the comparison is excellent at the formation/group scale, more detailed stratigraphic sequences, and the interfingering Haglebu formation - Quartzite formation contact contrast with the regional relationships. The structure of the study area is dominated by an isoclinal fold whose axial surface passes through the greenstone formation.

Stratigraphic Units.

The oldest formation in the area is the Haglebu formation, named after Haglebu campground. It is overlain by the Quartzite formation, which, in turn is unconformably overlain by the Greenstone formation as listed in Table 1.

The Haglebu formation occupies a large area in the eastern part of the map area and may continue several kilometers to the north and east into Hallingdal. The rock is uniformly pink to gray hornblende-biotite-alkali feldspar-quartz schist with accessory magnetite. Color index is about 15. White spots, 3 to 5 mm, are aggregates of tiny quartz and feldspar(?) grains. The texture is inequigranular, ranging from less than 1 mm quartz grains to 2 mm hornblende prisms. The foliation is due to aligned black minerals, black mineral streaks and the long dimension of the white spots. It is well developed in most outcrops. Thin (1 cm) quartz veins are present at many localities.

Infrequent outcrops of black amphibolite and biotite-hornblende schist north of Økteren lakes appear to represent a mafic sill parallel to foliation

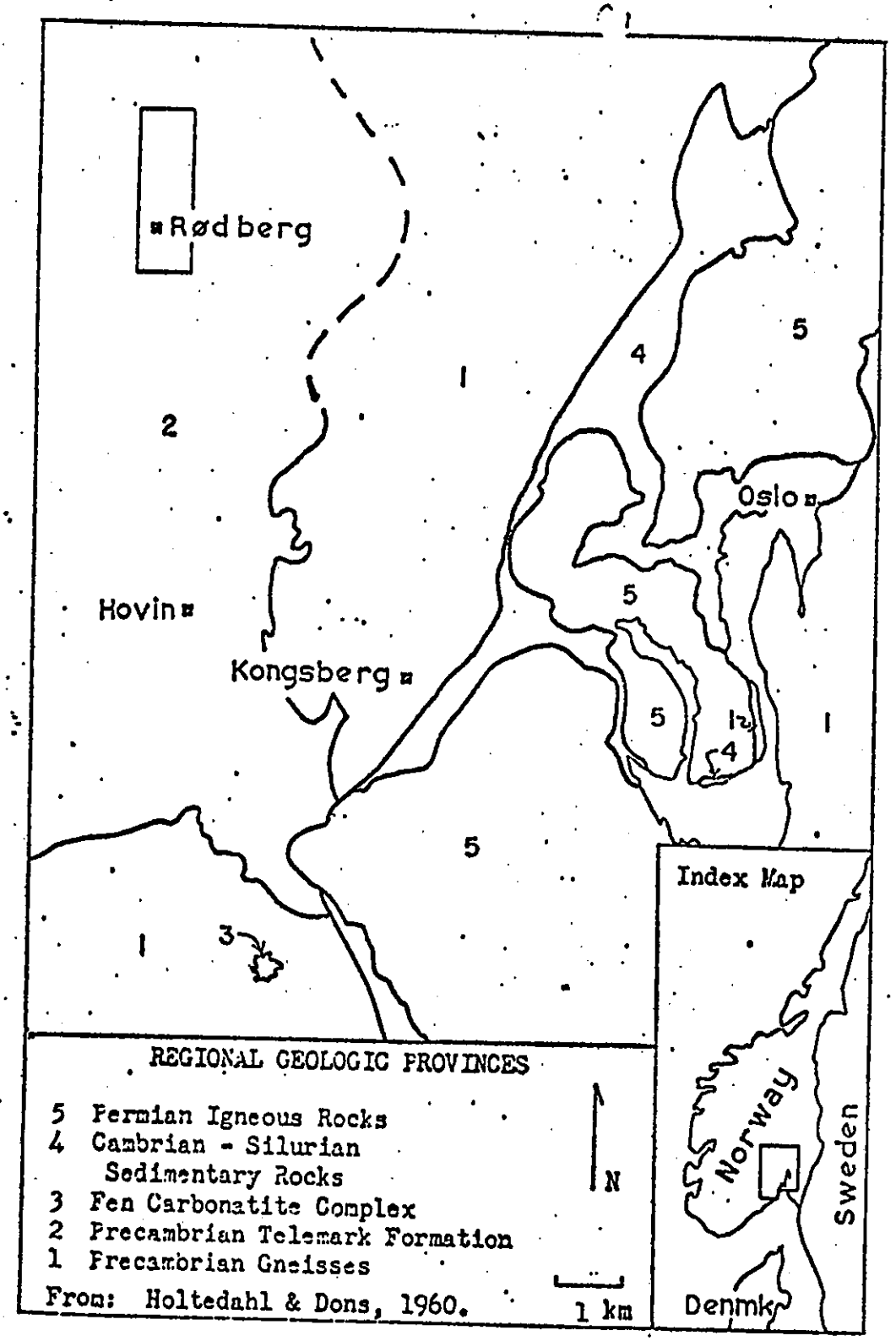


Fig. 1. Index map and distribution of geologic provinces.

Table 1. Comparison of stratigraphic units in the Numedal region with the supracrustal Telemark Formation.

Telemark Formation (Dons, 1960, pp. 49-55)	Stratigraphic units in the Numedal region.
Bandak Group. (acid and basic volcanics, and quartz-rich sediments).	
8. Quartz schist with conglomerate.	
7. Marble (present locally).	
6. Green lava; includes one layer of sandstone containing fossil algae(?).	
5. Porphyry (acid volcanic rock), (locally missing).	Greenstone formation. fine-grained greenschists, amphibolite, meta-basalt, greenstone, meta-tuff, quartz schist (in part conglomeratic), phyllite; pillow structures locally; Cu - Mo mineralization.
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 nr. 3 forms the base(?).	
Unconformity	Unconformity
Seljord Group. (quartzites, conglomerates, schists). cross beds and oscillation ripple marks are common; basic sills are common.	Quartzite formation. metamorphosed pure orthoquartzite with cross beds and oscillation ripple marks; muscovite quartz schist, in part conglomeratic; mafic sills; at least one meta-basalt layer.
Unconformity	interfingering contact
Rjukan Group. Vemork formation. basic volcanic rocks, sediments. Tuddal formation. acid volcanic rocks (flows and tuffs).	Haglebu formation. hornblende-biotite-alkali feldspar-quartz schist.

of the enclosing Haglebu schist. The sill approaches the top of the formation, and appears to lie along the contact with overlying quartz schist northwest of Økteren lakes.

The Quartzite formation includes two units, described separately in previous reports as the Rødberg Quartzite and the muscovite-quartz schist. Field work in the northeastern part of the map area this summer revealed that these units intertongue along strike, and that the dark sills, commonly present in the quartzite, continue into the quartz schist in this northeastern area.

The distinctive, pure orthoquartzite, now metamorphosed, is exposed along the entire western border of the study area, and in the northeast, as just mentioned. The rock is a hard, white muscovite-bearing quartzite, with about 95% quartz. Muscovite, the only major accessory mineral, occurs along bedding planes and imparts the dominant foliation. A few oblique muscovite plates indicate that an incipient crenulation foliation has developed. Cross beds and oscillatory ripple marks are common in the western outcrop belt, where they consistently indicate an eastward younging direction.

Muscovite-quartz schists crop out over much of the eastern part of the area, and are situated between the greenstone formation and the Haglebu formation. To the north along strike it is in contact with the quartzite member. Typical hand specimens are light gray, fine-grained muscovite-quartz schist. Minor biotite and chlorite are present locally. Biotite is evenly distributed in some samples, and forms dark spots, a few mm across, in others. A thin section of the latter type gives an estimated mode of 75% quartz, 10% albite, 5% muscovite, 5% epidote, 3% biotite, 1% calcite and traces of Fe-Ti oxide. The rock has an irregular texture of fine groundmass quartz and albite, with aggregates of coarser grained quartz. These aggregates may be metamorphosed chert fragments. The muscovite, biotite and epidote tend to be concentrated along foliation surfaces which enclose lozenge-shaped areas of colorless minerals. Additional fine muscovite needles without apparent preferred orientation cut across all other minerals. This schist member varies markedly across the area. Near its contact with the greenstone formation the biotite content increases locally and becomes as abundant, even slightly more abundant, than muscovite. A large portion of the formation is conglomeratic, especially in the eastern and northern part of the outcrop belt. The large clasts are rounded and flattened pebbles and cobbles that make up as much as 30% of the rock. These clasts are composed of very fine-grained quartz, and

quite possibly originated as chert. A small number of the clasts are colored green by epidote. The flattened clasts are parallel to one another, and at least locally, have their maximum dimensions preferrentially aligned. A different conglomeratic quartz schist has been exposed in road cuts along the east side of Numedal. It contains flattened cobbles of several rock types, including gneiss and dark gray, fine-grained amphibolite(?). Rarely, the muscovite-quartz schist can be seen to be highly deformed into tight, isoclinal mesoscopic folds not seen in other formations in the region.

Several dark mafic sills of amphibolite, and one meta-basalt flow are present in the Quartzite formation. The sills are found in both the eastern and western outcrop belts. Most are between 1/2 and 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 sills are dense, fine-grained black amphibolite with infrequent traces of pyrite. Contacts with both quartzite and quartz schist are sharp, rarely with a small apophysis extending into the quartzite. Finer grained borders, suggestive of chilled margins,are present at a few localities.

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

The Greenstone formation is made up of greenschists, greenstones, meta-tuff and meta-sedimentary rocks. It forms a north-south-trending belt along the synclinal trough. It appears to thin in the south near Nore. As shown on the geologic map (fig. 2), all copper-sulfide occurrences in this region are situated in this formation.

The succession of lithologies observed along the highway from near Skjønne Kapel (003803 map grid coordinates) to Rødberg (Table 2) indicates the stratified and complex nature of the formation. Metamorphosed clastic sedimentary rocks with preserved graded bedding and mud cracks are exposed locally elsewhere. A few members of the formation are shown on the geologic map. Contacts between the various lithologies are well defined.

Original textures frequently are preserved in thin section even though the rocks have undergone greenschist facies metamorphism. A thin section

Table 2. Lithologic sequence in the Greenstone formation from Rødberg to Skjønne Kapel.

Rødberg.	
	quartzite of the Quartzite formation.
unconformity	
0– 700m	Meta-tuff(?). Gray to purple gray, very fine grained with 2– to 3–mm quartz or feldspar crystals.
700–3000	Actinolite-hornblende schist. Dark green to gray, fine grained, with traces of epidote.
3000–3300	Muscovite-quartz meta-tuff(?). Light pinkish gray, fine grained, with traces of magnetite, rounded, deformed chert(?) pebbles; a few calcite-bearing quartz veins and pods, with traces of chalcocite, rarely chalcopyrite; in lower 20m unit is medium grained, with biotite and blue quartz.
3300–3338	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.
3430–3472	not exposed.
3472–3487	Actinolite-hornblende-plagioclase schist. Dark green, fine grained except for a few local medium-grained zones.
3487–3490	Felsic rock. Light gray, very fine grained, flinty, with traces of biotite. Quartz veins at contacts.
3490–3498	Actinolite-hornblende-plagioclase schist. Same as 3472–3487.
3498–3510	Quartz schist(?). Gray, very fine grained, dense, with traces of calcite, similar to 0–700 meta-tuff.
3510–3642	not exposed.
3642–3673	Actinolite-hornblende-plagiocalse schist. Same as 3472–3487.
3673–3678	Muscovite-biotite-quartz-feldspar schist. Medium gray, fine grained, with traces of epidote, calcite, magnetite, & bornite, calcite-bearing quartz veins 1/2 to 3 cm thick.
3678–3760	Chlorite-actinolite-plagioclase schist. Dark green, fine grained, with traces of epidote.
Skjønne Kapel	

of greenstone has an estimated mode of 59% albite, 32% epidote, 5% Fe-Ti Oxide, 3% chlorite, and 1% or less calcite. Albite occurs as 0.25-0.5 mm laths that preserve the diabasic texture. Occasional ovoids, rich in epidote, calcite and chlorite, may represent former vesicles. This greenstone is considered to be meta-basalt.

The meta-tuff near Kisgang (976894) is in part a crystal meta-tuff. The crystal-tuff texture is well preserved by euhedral albite crystals and glomerocrystalline aggregates of albite set in a cryptocrystalline groundmass. Small amounts of included calcite and muscovite suggest that the crystals are now more sodic than originally. Calcite and muscovite display a random texture not related to the overall rock texture, and are thought to be the only completely metamorphic textural elements in this section. Fe-Ti oxide occurs in irregular grains which include small silicate grains and traces of apatite. It is also present as fine specks in the groundmass. Euhedral zircon is present in trace amounts, and offers an opportunity to assess the age of igneous activity. Another sample, from close by one of the Kisgang veins, contains more quartz and sufficient magnetite to attract a pencil magnet. The original texture is less well preserved, and distinct foliation is developed by muscovite. Euhedral magnetite, with cubic outlines, cuts across and interrupts individual foliation planes.

The base of the greenstone formation is in contact with the Quartzite formation along an unconformity of slight angular discordance. The meta-tuff host rock at Groven rests directly on the quartzite south of Groven, but is separated from it by greenstones north of Groven, so that the occurrence appears to be situated at the base of the basin flank. Locally, small lenses of breccia composed of quartzite blocks immediately overlie the unconformity, most notably at Kisgang. An apparent topographic high of quartzite (at 967925) has greenschist at the base of its flanksbeneath the meta-tuff bed; and interrupts the meta-tuff bed.

Structure.

North-south trending folds dominate the structural patterns in the region, modified by interference at the south end of lake Reinsjø (060950).

A regional unconformity is present along the base of the Greenstone formation as described on the preceeding page. However, this contact may be conformable north of Slettehollenseter (004979). The Haglebu schist and Quartzite formation interfinger north of lake Reinsjø (040000), in contrast to the regional unconformity located at this horizon elsewhere in the Telemark Formation (Dons, 1960). Both of these formational boundaries have been folded. A small number of faults which offset contacts a few tens to hundreds of meters are present in the western area. The zone of sheared rock at Duses will be described with the Duses occurrence description.

Folds.

The isoclinal syncline at Slettestøl (928982) has a steep axial surface which trends north-south through the Greenstone formation. The mineral occurrences, as well as lithologic units are distributed on both limbs.

Complex fold patterns south of lake Reinsjø (060950) are thought to result from a north-south oriented open anticline interfering with a northeast-southwest trending synclinal feature.

Faults.

Infrequent faults along the west flank of the Slettestøl syncline offset the base of the Greenstone formation. These have apparent offsets ranging from less than 100 meters to about 500 meters. Both sinistral and dextral faults are present. Another fault, of undetermined displacement, occurs 1 km northwest of Tunnhovd dam (at 954878) in the Quartzite formation.

Copper-sulfide Occurrences.

Seven former prospects and mines, and smaller yet similar mineral localities occur in the lower part of the Greenstone formation. The seven are Duses, Kisgang, Hytte, Groven, Knutstøl, Lauvaasen, and Brennebekk. Sulfide-bearing quartz veins at these localities are irregular, seldom more than 25 cm thick, and seldom extend more than 100 meters in length. They cut across foliation and occasionally include fragments of the metamorphic wall rock. The wall rock has been altered, and partially replaced at some

Table 3. The seven copper-sulfide occurrences: location, host rock, type of occurrence and minerals present.

Occurrence	Coordinates	Formation	Host rock	Magnetite in wall rock	Type of mineralization	Minerals present (+) or absent (-)									
						Quartz	Feldspar	Calcite (siderite)	Chalcopyrite	Bornite	Digenite	Chalcocite	Molybdenite	Pyrite	Hematite
Brennebekk	008836	GSF	GYS	+	VR	+	+	+	-	+	+	-	+	+	-
Duses	967946	GSF	GS	+	V	+	?	+	-	+	+	+	-	-	-
Groven	994741	GSF	MT	+	V	+	+	+	-	+	+	-	-	-	+
Hytta	977850	GSF	MT	+	V	+	+	+	+	+	-	-	-	-	-
Kisgang	976894	GSF	MT	+	V	+	+	+	+	-	-	-	-	-	-
Knutstøl	993944	GSF	GS	+	VR	+	+	+	+	?	?	?	-	-	-
Lauvaasen	008845	GSF	P	+	VR	+	+	+	-	+	+	-	+	-	-

GSF = Greenstone formation, GYS = gray schist, GS = greenschist
MT = meta-tuff, P = phyllite, V = vein, R = replacement

occurrences, but not at others. Magnetite is disseminated in wall rocks at each locality. Pyrite is generally lacking. These features indicate that the veins formed after the regional metamorphic recrystallization and schistosity. Yet confinement of the quartz veins to areas where light, or siliceous, rocks are present; and variation in mineralogy according to host rock lithology indicate that 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. Table 3 summarizes the above data individually, and gives the grid coordinates of the occurrences. Each occurrence has several unique characteristics that serve to distinguish it from others in the district. These are reviewed below, in alphabetical

order, except that Lauvaasen and Brennebekk are described together. Mining activity in the district had ceased by 1794, according to Mr. Loftsgård, Nore County Historian (personal communication).

Duses.

The Duses occurrence is located in the northwest part of the area, on the west limb of the Slettestøl syncline. Access to Duses is by footpath. A private road leads from Thnnhovdfjord to Slaattelihaugen, about 2 km southwest of Duses. A footpath leads around the south tip of Dusetjörn to Duses. It is also possible to drive to Slettestøl, southeast of Duses and follow the footpath from there. (Neither of these roads are shown on the topographic map, but can be seen on the air photographs and the better highway maps.)

The main workings follow a zone of sheared rock and calcite veins in greenstone. A small working, located 500 meters to the southeast, is in greenschist that is less obviously sheared. Here the veins cut across foliation. The main workings (fig. 3a) consist of a trench excavated along the vein and shear system for a length of 55 meters, and underground workings with the entry at the south end of the trench. The mine is completely flooded.

Exposure in the immediate vicinity is limited to the area about the trench and infrequent outcrops as shown on fig. 3a. Greenstone is present at the trench and in exposures west of the trench. Coarser, more distinctly foliated greenschist is exposed in the outcrop located east of the trench. Foliation in the greenschist and the shear planes essentially parallel one another. This, together with the absence of measurable criteria of displacement, leaves the question as to the nature of this zone of sheared rock and calcite veins unresolved. Calcite veins vary from a few cm to 2 m thick along the zone. They are broken by shear planes and locally fill thin oblique tension fractures in greenstone. Parallel greenstone slivers are frequently interleaved in the calcite veins. The veins generally contain small but variable amounts of bornite. Digenite, chalcopyrite, molybdenite and quartz are also present.

Magnetite crystals are disseminated in the greenstone, especially west of the shear - vein system. A magnetic survey in the vicinity of the workings

indicates low magnetic susceptibilities at the trench and a linear positive apparent anomaly about 25 meters to the west. Fig. 3b is a contour map of the uncorrected field values, and fig. 3c combines this data with the general map of the occurrence.

In summary, magnetite-bearing greenstone is present west of the trench, whereas limited evidence suggests more distinctly foliated greenschist is present east of the trench. The calcite veins and sheared rocks are closely associated at the trench. At least the sheared vein material is older than the shearing, while the tension gash filling suggests some degree of carbonate mobility during shearing. It seems possible that the shear zone represents slip along foliation during folding, and that it might have been localized along a carbonate zone.

Groven.

Groven is the southernmost occurrence, and is situated in meta-tuff near the flank of the depositional basin. Several openings here are located on quartz veins in schistose meta-tuff. A few veins have been deformed along with enclosing schist, and are partially rolled into -shaped cross sections.

Hytta.

Hytta is partially covered by a large dump from a nearby hydro-electric tunnel excavation. It occurs in the gray schistose meta-tuff, about 4 km south of Kisgang. Cu-sulfide minerals and calcite are present in the quartz veins here.

Kisgang.

Chalcopyrite is the only important copper sulfide at Kisgang. Calcite is essentially absent, although siderite is present. Kisgang is located in schistose meta-tuff a few meters above the unconformable contact with the Quartzite formation. Irregular quartz veins, about 25 cm thick, contain the chalcopyrite and siderite. The meta-tuff host contains disseminated magnetite, and is discolored to a lighter gray at the vein walls.

Knutstøl.

Knutstøl occurs on the east limb of the Slettestøl syncline where greenschist and greenstone layers meet. The greenstone contains magnetite at the occurrence and for distances up to 200 m to the southeast. A ground

magnetic survey has not been undertaken. N. G. U. Bergarkiv 668 reports that small amounts of silver and gold are present here, in addition to copper. The sulfides occur in quartz veins which range from less the 1 cm to 25 cm thick. Although irregular, they generally strike along the foliation of the host rock and dip moderately to the east. Most veins contain small amounts of copper sulfides. Wall rocks are often discolored to dark pink within 10 to 15 cm of the veins. The veins are largely, but not entirely, confined to the more massive dark greenstone.

Lauvaasen & Brennebekk.

The similarities between Lauvaasen and Brennebekk have been noted in my previous annual reports. Three tape and compass traverses were made during summer, 1975; one near Lauvaasen, one near Brennebekk, 1 km to the south, and one across an anomalous bend in the river Borgaai, about half way between the other two. Each was oriented approximately perpendicular to the regional strike. The results are plotted on fig. 4, on which the contacts have been connected from one traverse to the next. Access to these occurrences is good via the Borgagrend road from Numedal. The connecting road to Lauvaasen farm passes over the dump at Lauvaasen. Although abandoned, the connecting road to Brennebekk might still be suitable for tractor use. (These roads are not shown on the topographic maps, but can be seen on air photographs and the better road maps, except for the road to Brennebekk.) Although mining activity ceased long ago, exploration adits were driven beneath the Brennebekk trench during a recent period of activity, reportedly during the 1940s. The decaying headframe at Lauvaasen may also date from this period, and indicate that some activity went on here at this time too.

Both Lauvaasen and Brennebekk are in the Greenstone formation, 300 and 260 meters, respectively, from the contact with the Quartzite formation, on the east limb of the Slettestøl syncline. West of this contact, the Greenstone formation here consists of a sequence of three greenschist units separated by two felsic beds. Their individual characteristics are noted on the map, fig. 4. Relict pillow structures in greenschists have been observed in the riverbed on the Lauvaasen and Riverbend traverses, and where noted on the map between these traverses. The foliation in this area dips moderately to

the west, and mineral lineations plunge along the foliation in a WNW direction. At Lauvaasen, the shaft and most of the access trench is flooded. The limited accessible exposures are of phyllite, cut by a few thin quartz veins with small amounts of sulfide minerals. Blocks on the dump reveal that molybdenite is present as well as copper sulfides, feldspar and calcite. Alteration and replacement of the phyllite host is demonstrated in other blocks on the dump. Brennebekk is located in very fine-grained, gray felsic schist. The old, surface trench follows a zone of quartz veins which range from 1 to 15 cm thick, and approximately parallel the host rock foliation. The rock forming the east slope of the trench contains chlorite and locally has been altered to a dark red color. The features of mineralization here are very similar to Lauvaasen, with significant molybdenite showings, copper sulfides present in the quartz veins, and discoloration and replacement of wall rocks at least locally developed. The main exploration adit penetrates very fine-grained light gray phyllite and fine-grained greenschists. Calcite-bearing quartz veins occur in both lithologies and are generally parallel to foliation. About 40 m underground drifts extend out along strike where malachite stains a few joint surfaces. Blocks on the dump show quartz veins with calcite, epidote, and bornite. Rarely, a pyrite grain is present in a vein block. Calcite is frequently concentrated along vein borders. Other blocks have molybdenite on joint surfaces. Although disseminated magnetite is present, no ground magnetic survey has been undertaken in conjunction with these traverses, as the magnetometer was not available at this time.

Malachite stains and chalcopyrite are locally present on joint surfaces in dark gray felsic schist near the eastern limit of the muscovite-quartz phyllite bed on the Riverbend traverse. Furthermore it is possible to follow the felsic zone northwards to the diversion dam, about 1 km north of Lauvaasen at coordinates 005865, where blasting to excavate the dam foundation exposed quartz veins which contain bornite, a little pyrite, and havesome open space. The host rock of blastoporphyritic muscovite-feldspar-quartz schist with traces of magnetite is 15 m thick, with greenschist on either side.

In summary, Lauvaasen and Brennebekk are located in felsic rocks which form a zone within the Greenstone formation, and extends for at least 2 km.

Copper sulfides are present in at least two additional localities along the zone, one where the rock is freshly blasted and one where the river flows across the strike of the beds.

Summary and general conclusions.

A northeastern are of the Telemark formation extends through the upper Numedal region, where the Bandak-equivalent Greenstone formation is preserved in the core of an isoclinal fold. Seven formerly worked sulfide occurrences in the region invariably are quartz or calcite vein mineralization with no, to moderate, wall-rock discoloration and replacement. In contrast to these epigenetic hydrothermal vein features, the veins are confined to the lower part of the greenstone formation and are situated in felsic beds, except for Duses and Knutstøl. It is also noteworthy that some of the occurrences may be paired about the isoclinal fold. Duses and Knutstøl are located at about the same latitude, and approximately the same distance above the folded base of the formation. These two are located in greenstone rather than meta-tuff. Similarly, Hytta and Lauvaasen are located at about the same latitude, and approximately the same distance above the folded base of the formation.

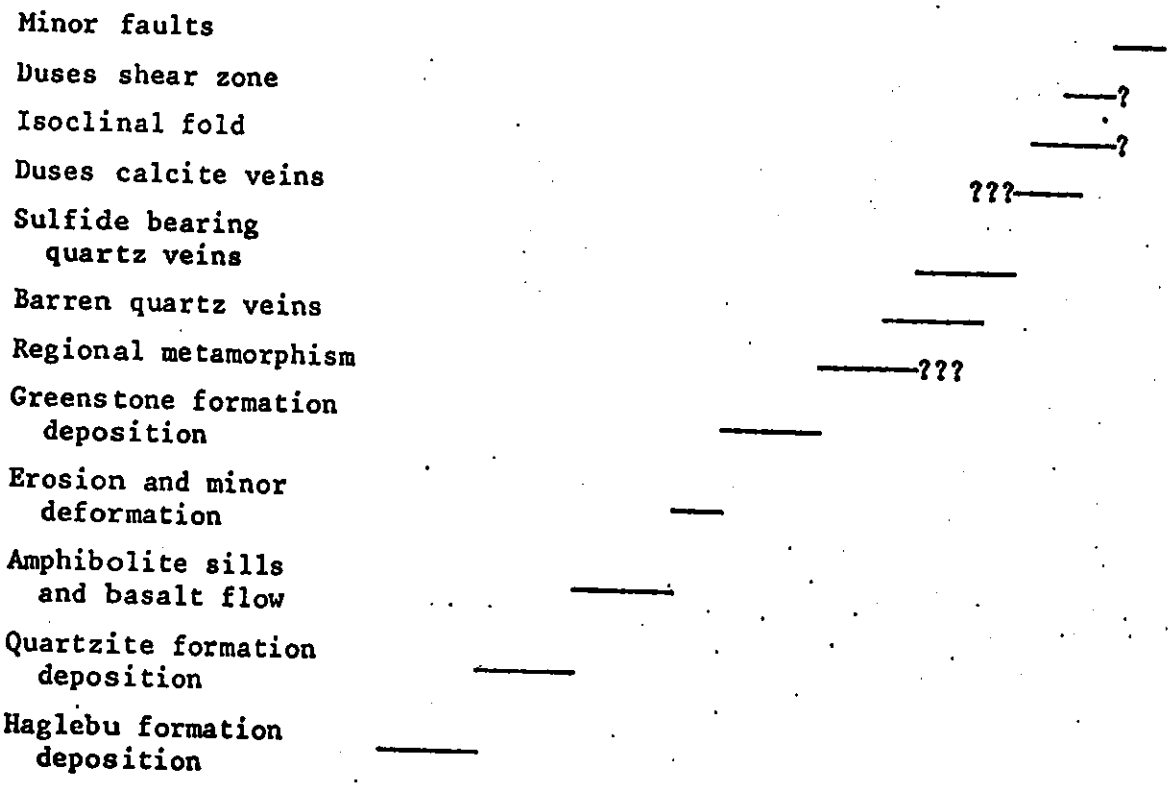
Aeromagnetic information.

Aeromagnetic maps covering the 4 map sheets of the project area (1615 I & II, 1614 I & II) were scheduled to be completed in December, 1975. Anomalously high magnetic values occur in the vicinity of the Vasstveit mine in the Hovin area, and another anomaly reportedly is present at the Duses occurrence. (Bergstøl, personal communication).

Geologic history.

The following time sequence chart is based on information already stated in this report, except that the amphibolite sills in both the Haglebu and Quartzite formations are assigned the same temporal position here and associated with the meta-basalt at Tunnhovd dam. 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.

Table 4. Time sequence chart.



Recommendations.

1. All aeromagnetic anomalies in the Greenstone formation should be visited to determine their cause, and the possibility of associated mineralization. (It is possible that when my copy of the aeromagnetic maps arrive I will already have field observations on some anomalies, and be able to say something more definite about them.)

2. The shear zone at Duses, and its possible continuation along the western slope of the ridge from Langaasen, south of Duses, to hill 1071, north of Duses, should be thoroughly prospected along its entire length, ie - from coordinate locality 977910 northwards as far as 965965, with special emphasis on the break in slope visible on air photographs, but not distinguished on the topographic map.

3. The felsic rock zone through Lauvaasen and Brennebekk should be examined more completely. Especially if an aeromagnetic anomalie is coincident with the zone, ground magnetic surveys might help locate more concentrated mineralization. The repeated showings of copper sulfides in favorable outcrops suggests that geochemical surveys designed to identify anomalous metal concentrations in the area might also pinpoint more concentrated mineralization. It is doubtful that cursory or widespread stream sediment sampling will prove to be suitable. However sediment sampling along small drainage tributaries, or samples of the lower soil horizons might succeed.

4. The chemical characteristics of the Greenstone formation, and laboratory studies of the possible role of metamorphism in the mineralization history are to be undertaken (as part of my studies here).

5. Long-range studies of the mineralization - metal content patterns of the Bandak Group; and of the formation and metamorphic history of the Telemark Formation in relation to mineralization might profitably follow the items above.

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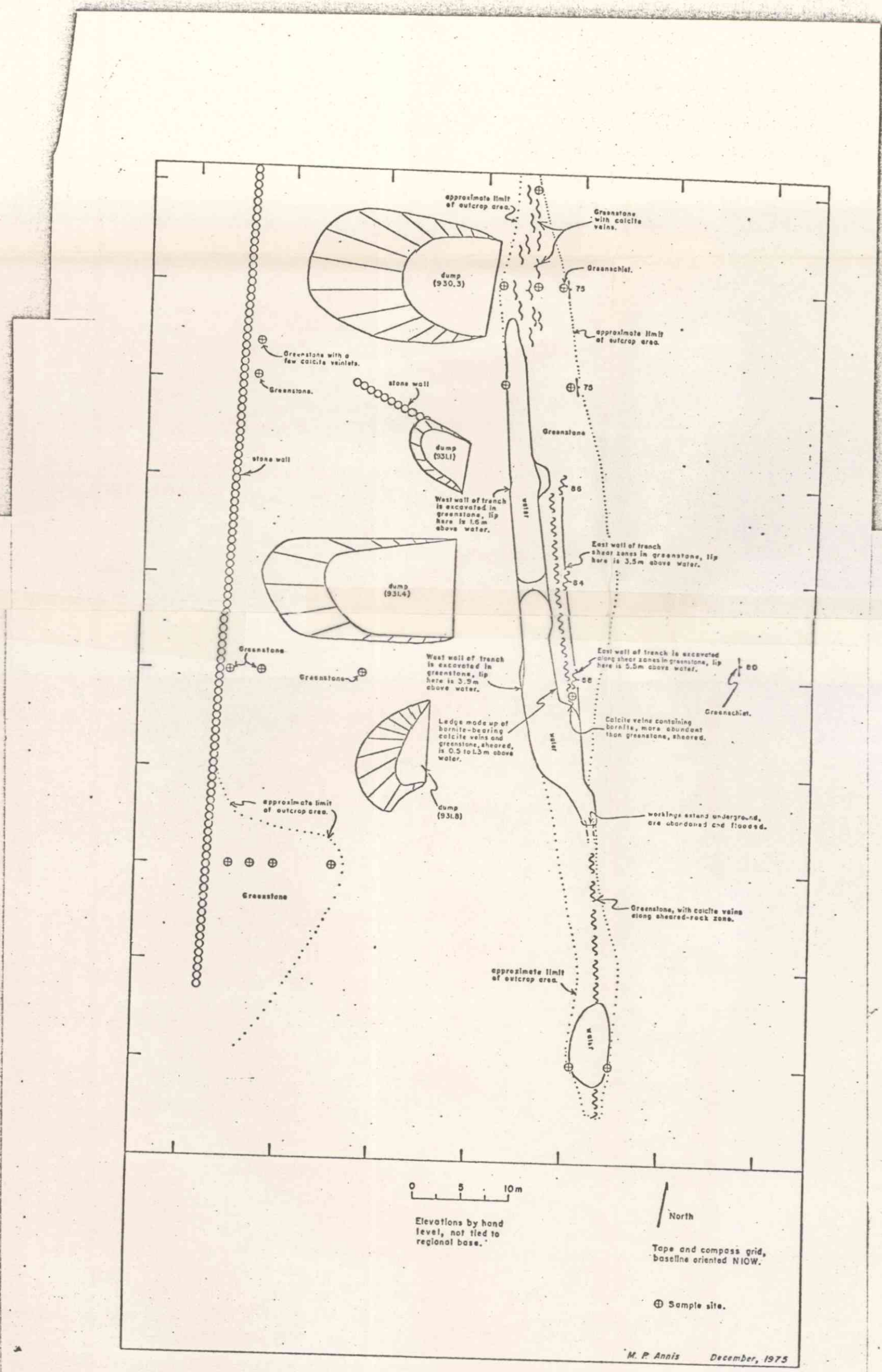


Fig. 3a DUSES OCCURRENCE, Geology and Plan.

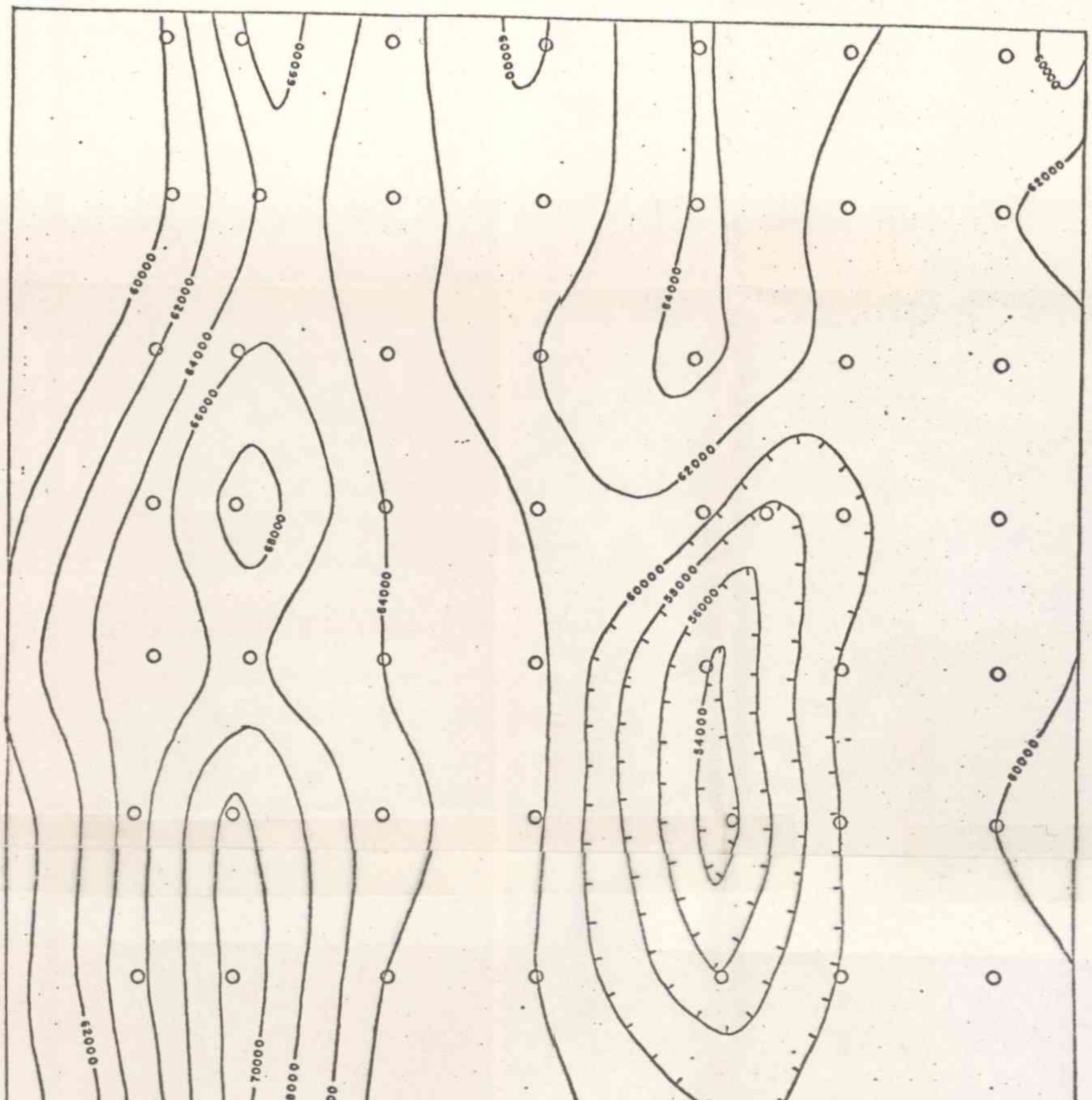


Fig.3b DUSES OCCURRENCE, Magnetic vertical intensity, uncorrected.

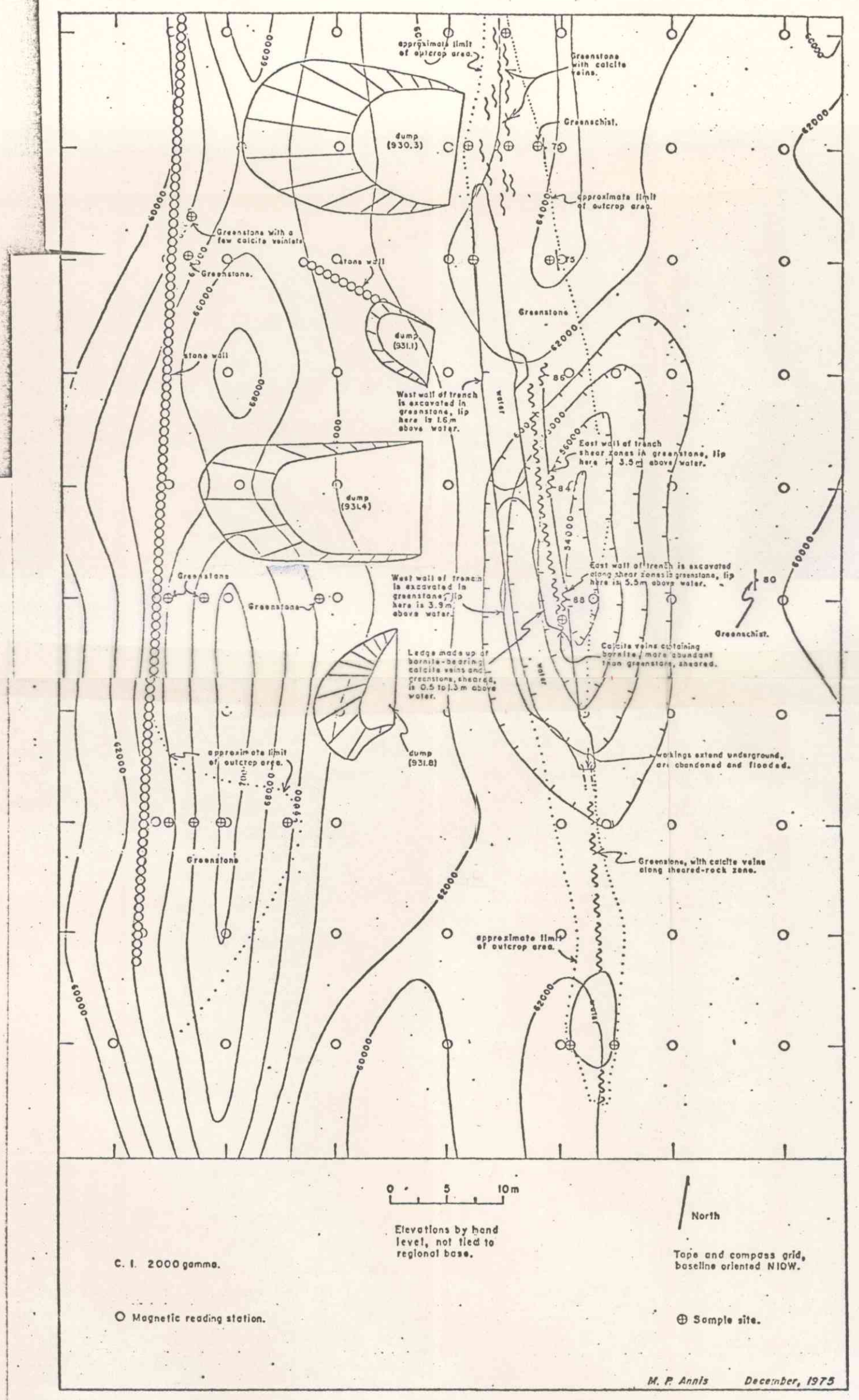


Fig. DUSES OCCURRENCE, Geology and Plan.
Fig 3c DUSES OCCURRENCE, Magnetic vertical intensity, uncorrected.

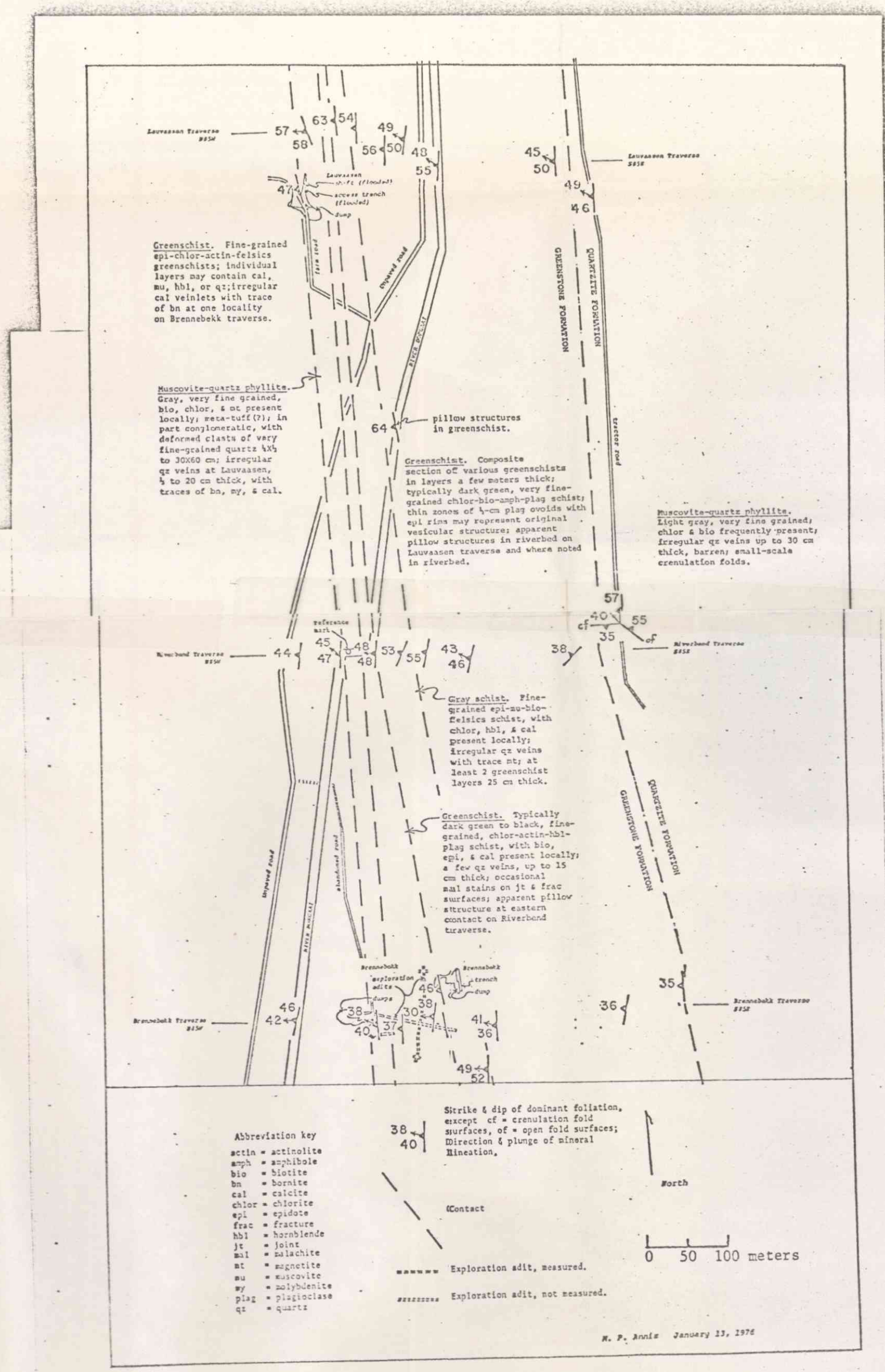


FIG. 4. THREE TRAVERSES ACROSS THE LAUVAASEN - BRENNEBEKK AREA.

GEOLOGY OF THE SLETTESTØL–NORE REGION.

Legend

LITHOLOGIC UNITS (Telemark Fm. equivalent)

GREENSTONE FORMATION. (Bandak Group)

Gp — phyllite.
Gqs — quartz schist, in part conglomeratic.
Ga — greenschist.
Gmt — meta-tuff.

QUARTZITE FORMATION. (Seljord Group)

Qmb — meta-basalt.
Qa — amphibolite, as sills, many not shown.
Qmqs — muscovite-quartz schist, in part conglomeratic.
Qq — quartzite.

HAGLEBU FORMATION. (Rjukan Group)

Ha — amphibolite, as sill.
Hbtqs — biotite–alkali feldspar–quartz schist.

Lithologic contact, dashed where approximate, dotted where inferred.

Axial surface of fold, dashed where approximate, dotted where inferred.

Fault.

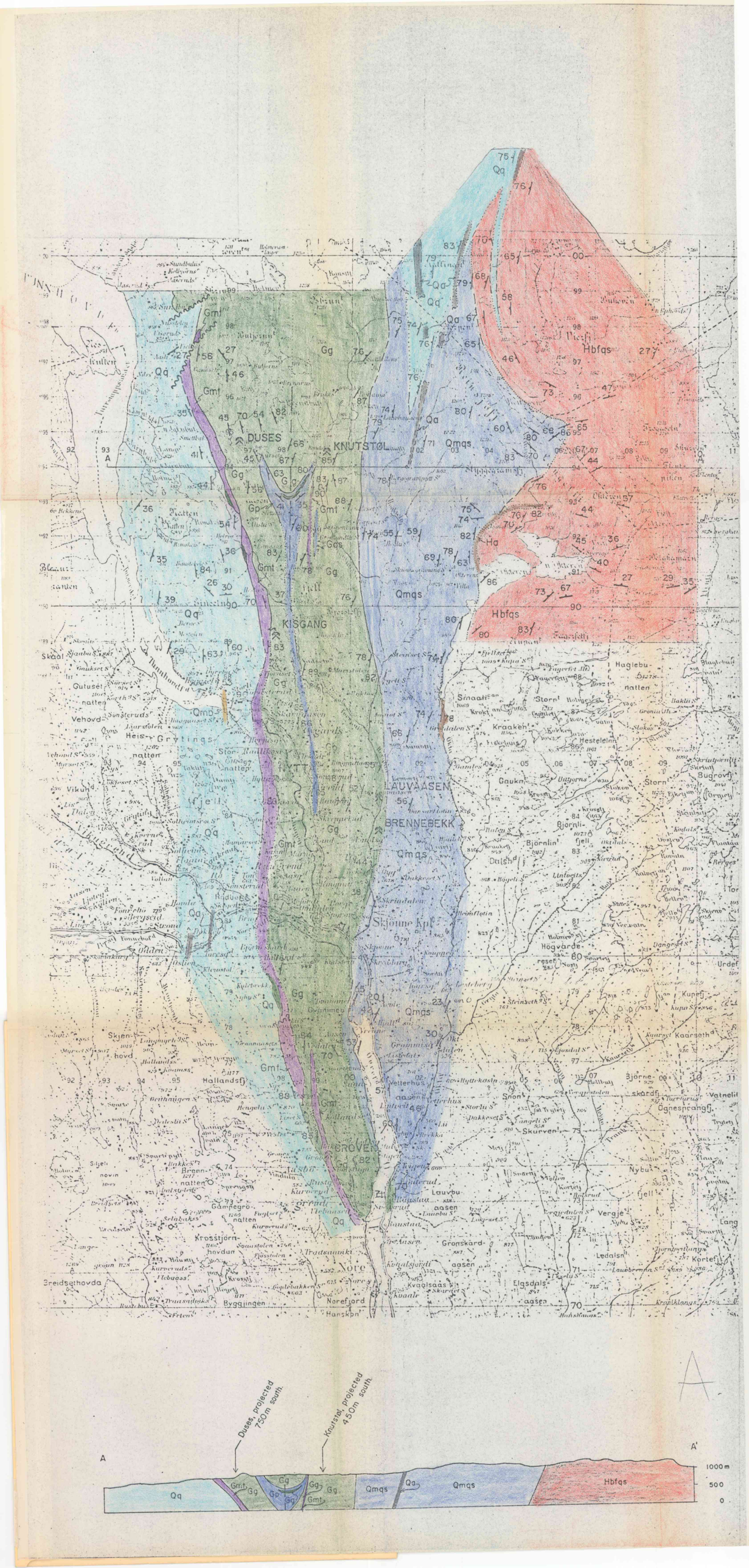
76/90 — Strike and dip of foliation.

Copper-sulfide occurrence.

0 1 2 km

N

M. P. Annis Jan 8, 1976


DUSES
KNUTSTØL
KISGANG
LAUVÅSEN
BRENNEBEKK
SKJØNE
Qa
Qq
Qmqs
Hbfqs
Gmt
Gg
Gp
Ha
Qmb
A
A'
Duses, projected 750m south.
Knutstøl projected 450m south.
1000m
500
0