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A Reconnaissance Exploration of the Area North-East of Gaizervatn, in the Grong District, of Norway

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Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

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

På grunnlag av feltobservasjonene beskrives den geologiske historie, plate tektonikken ogmiljømessige rekonstruksjoner. Mineraliseringene er sammenlignet med andre mineraliseringer. Ikke noen kopper/molybden forekomst er funnet og stocverket og disseminneringen er spredt over et stort område.
det er funnet Cu/Mo på 3 lokaliteter. det foreslås røsking og boring som oppfølging

PORTSMOUTH POLYTECHNIC

DEPARTMENT OF GEOLOGY

A RECONNAISSANCE EXPLORATION OF THE AREA NORTH-EAST OF GAIZERVATN, IN THE GRONG DISTRICT OF NORWAY.

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Year: III (1983)

A reconnaissance exploration of the area North-East of Gaizervatn, in the Grong District of Norway

by

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1983

ACKNOWLEDGEMENTS

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ABSTRACT

This project was undertaken as part of a regional study into molybdenite mineralization within the Grong District.

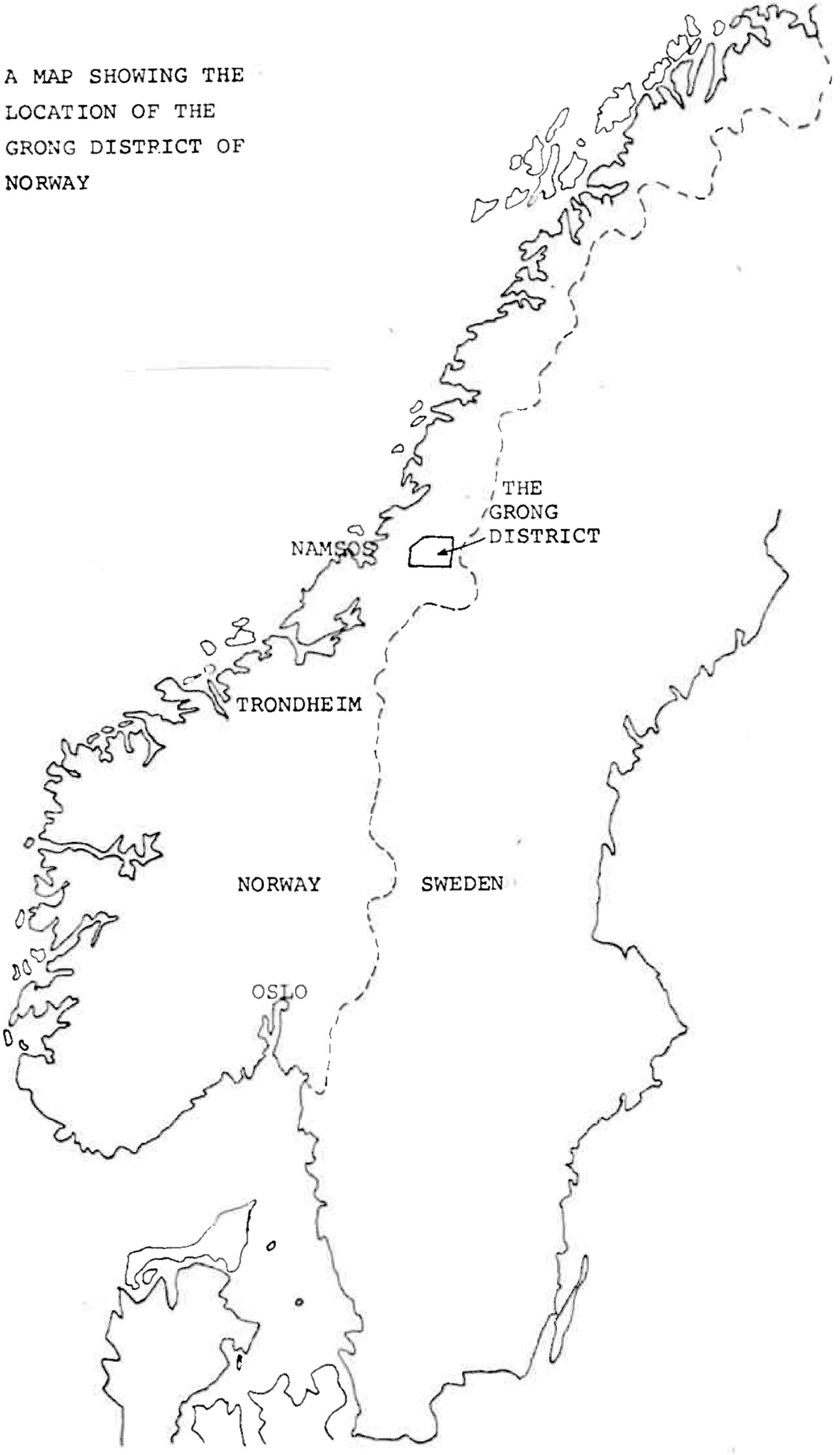
The introduction describes, very briefly, the geography of the Grong District, which is followed by an outline of the Norwegian Caledonides in general. The following section concentrates, in more detail, on the Grong Caledonides describing the three main tectonostratigraphic units as defined by S Kollung 1979. This is followed by details of the observations taken both in the field and from thin section work in the laboratory.

From the observations the geological history of the area, including plate tectonic theories and environmental reconstructions, is discussed, and the mineralization is compared with other mineralized areas and with models of disseminated porphyry deposits.

Concluding the report, suggestions of further work are put forward, which in my mind should be carried out before any economic viability decisions are made in respect to the mineralization.

INTRODUCTION

A MAP SHOWING THE LOCATION OF THE GRONG DISTRICT OF NORWAY



THE OBJECTIVES OF THE EXPEDITION

This expedition was undertaken in conjunction with Grong Gruber A/S as part of their prospecting programme. The aim of the survey was to produce a detailed geological map showing the major lithologies and structures, with a view to assess the extent of the copper-molybdenum mineralization shown on anomaly maps produced by Grong Gruber A/S and Norges Geologiske Undersøkelse.

THE GEOGRAPHICAL LOCATION AND ACCESS TO THE AREA

The region in which the survey was undertaken is covered by the Skorovatn sheet, no. 1824, 11, of the Norway 1:50,000 series. The mapping area consisted of the strip of land approximately 5 kms long by 1 km in width between the mountain Blåmuren (GR 127589) and the lakes of Gaizervatn and Pervatn (GR 100597 and 120613 respectively).

Access to the area is best attempted from the North, where vehicles can be left at the Skorovas mine (GR 095695), and a poor footpath leads South to a small fishing hut on the shores of Pervatn

THE GEOGRAPHICAL DISCRIPTION

The topography of this part of Norway is that of a post glacial landscape, where deeply dissected mountain areas are separated by large 'U'-shaped valleys eg. The Namsen Valley (GR 940780). In the mapping area itself however, the relief varies from 651 ms up to 778 ms in altitude, considerably less than elsewhere.

The drainage in the area tends to follow the geological grain of the country, thus flowing in a North-East to South-West direction, between narrow elongate ridges of the more resistant rocks. However, the lakes such as Gaizervatn and Pervatn form the head-waters to tributaries of the Namsen in the North-West, and therefore as the streams mature they begin to cut across the geological grain with overflow channels such as at (GR 099604 and GR 107611).

The vegetation of the region can be divided into two zones, that of the valleys and that of the upland areas. In the valleys the vegetation is primarily in the form of extensive coniferous forests, whilst above the tree line, in the uplands, tundra type vegetation is dominant. One important plant species of these upland areas is Lychinis Alpina, which thrives on cuperiferous soils thus indicating copper rich bed rocks.

THE REGIONAL GEOLOGY AND STRATIGRAPHY

The Caledonides of Norway (General)

The Caledonian rocks of Norway occur as a belt of sediments, volcanics and intrusions, which stretch for almost the full length of the country, some 1700 kms. Only a small area in southern Norway lacks these rocks, consisting solely of Precambrian basement.

The Cambrian, Ordovician and Silurian sediments show great variations in facies throughout different parts of the orogen and its foreland. An eastern and a western facies have been distinguished corresponding to miogeosynclinal and eugeosynclinal facies respectively. The eastern facies outcrops North of Oslo as a highly fossiliferous sequence, and also beneath the nappes of southern Central Norway, as pelitic sediments. The autochthonous deposits along the Caledonian margin in the southern and northern parts of the country are also thought to belong to the eastern facies. The western eugeosynclinal sediments have been divided by T Strand and O Kulling into a Trondheim facies type and a Nordland facies type. The Trondheim facies is characterized by the abundance of basic volcanic rocks and by sediments of greywacke type, whilst the Nordland facies is typified by thick limestones, dolomites and ferruginous sediments of more stable environments.

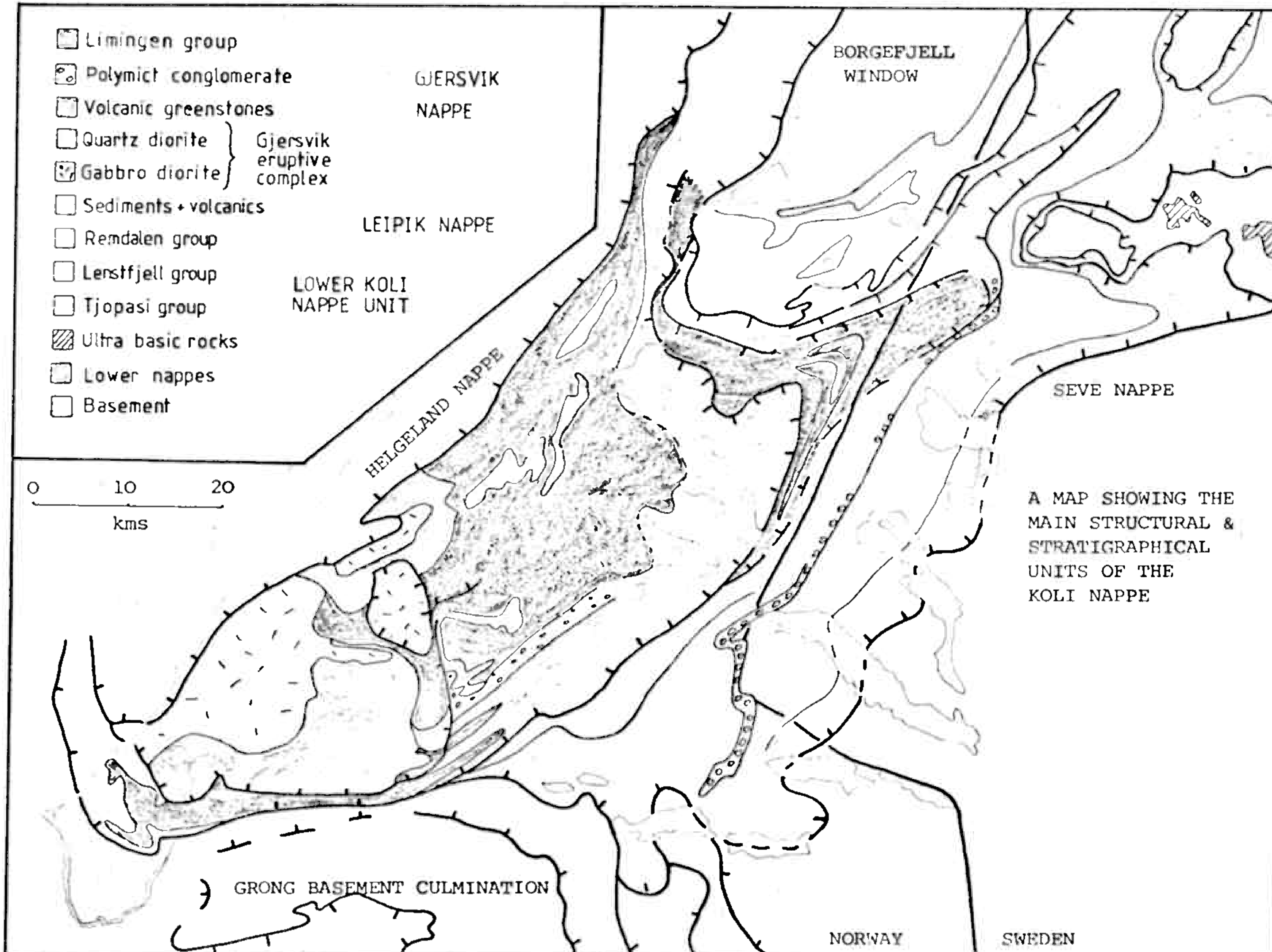
The Caledonides first appear in the South-East and East as autochthonous Cambrian sediments, which rest on a peneplained Precambrian surface. These sediments are generally thin as it seems that all but the lower units have been sheared off by overriding thrust sheets.

The eastern edge of the Caledonides occurs where the Cambrian sediments rest on the peneplained basement of the Baltic Shield without any intervening fore-deep deposits.

This suggests that nappe movements along horizontal thrust planes and over long distances have occurred, the orogen, on the whole, being made up of such nappes.

These nappes can be divided into three groups, the lower, the middle and the upper. The lower nappes consist of unmetamorphosed sediments of facies corresponding to the autochthonous deposits represented by the Vemdal Nappe of Eocambrian sandstones in South Norway and by the unmetamorphosed allochthonous sandstones and dolomites of the Finmark sequence in the North. The middle nappes consist of miogeosynclinal deposits characterized by the allochthonous Sparagmite deposits of the South. The upper nappes consist of eugeosynclinal facies with underlying basement rocks, including all the sediments in the Trondheim region, and in North Norway, the Seve Nappe Complex.

A distinct angular unconformity marks the end of the main Caledonian deformation, of which there were three or four phases of major, large scale folding, faulting and magmatic injection.



A MAP SHOWING THE MAIN STRUCTURAL & STRATIGRAPHICAL UNITS OF THE KOLI NAPPE

MAJOR STRATIGRAPHIC AND TECTONIC UNITS OF THE GRONG DISTRICT CALEDONIDES

TABLE 1

WESTERN COMPLEX	HELGELAND NAPPE	NAMSEN GROUP
WESTERN COMPLEX	LIMINGEN NAPPE	GJERSVIK GROUP
WESTERN COMPLEX	LIMINGEN NAPPE	LIMINGEN GROUP
CENTRAL COMPLEX	RANTSER NAPPE	RØYRVIK GROUP
CENTRAL COMPLEX	RANTSER NAPPE	HUDDINGSDALEN GROUP
EASTERN COMPLEX	LOWER KØLI NAPPE	RENSELVANN GROUP
EASTERN COMPLEX	LOWER KØLI NAPPE	NORDLI GROUP
EASTERN COMPLEX	SEVE NAPPE	HARTKJØLEN GROUP
EASTERN COMPLEX	SEVE NAPPE	DAERGAFJELL GROUP

After S Kollung - N.G.U. V. 354 p.6

STRATIGRAPHY OF THE WESTERN COMPLEX

TABLE 2

8) Calcareous phyllite - sandstone (conglomeratic) 7) Polymict greenstone conglomerate 6) Banded calcareous phyllite/ sandstone 5) Highly calcareous arkose (conglomerate) 4) Arkose conglomerate 3) Calcareous phyllite/sandstone (banded) - local greenstone/ schist 2) Highly calcareous conglomerate 1) Polymict conglomerate Local limestone	LIMINGEN GROUP MIDDLE? AND UPPER? ORDOVICIAN
6) Younger greenstones. Mostly Ma/Ca rich lavas - Minor tuffs and agglomerates 5) Middle greenstone. Mostly Fe rich lavas. Minor tuffs and aglomerates. Kerotophyres 4) Older greenstone. Amphibolitic towards the South. Mostly tuffs. Minor lavas, local agglomerates. 3) Homogeneous amphibolitic greenstone. 2) Banded amphibolite 1) Banded hornblende gneiss	GJERSVIC GROUP LOWER? ORDOVICIAN

After S Kollung - N.G.U. Vol 354 p 20

The Caledonides of the Grong District

The Grong District consists of great thicknesses of allochthonous eugeosynclinal deposits within a large depression, delimited to the South by the Grong Culmination, and to the North by the Borgefjell Massif, both of Precambrian age. According to Kolling (1979), these deposits can be divided into three major units, the Eastern Complex, the Central Complex and the Western Complex, as shown in Table 1.

All the units in the field area occur within the Western Complex, which is further subdivided into the Limingen Nappe and the Helgeland Nappe. In this region the highly metamorphosed Helgeland Nappe complex tectonically overlies the Limingen Nappe complex towards the North-West due to the presence of a well defined thrust plane at its base, which separates the Namsen Group from the Gjersvik and Limingen groups.

The limestones and schists of the Namsen Group have undergone amphibolite facies metamorphism from which the grade increases towards the South, resulting in the gneissic rocks of the Tromsfjell area. These rocks have also been heavily intruded by granodiorites, which in places account for over fifty percent of the rock mass, and numerous pegmatite veins and feldspar rich bands can be seen within the country rock.

The underlying Gjersvik Group consists of six separate units as shown in Table 2.

The Banded Hornblende Gneiss (1)

The origin of these rocks is uncertain, but their strongly banded character suggests that they were originally volcanic tuffs. The foliation is well developed with bands of dark amphibolitic composition alternating with bands of light coloured quartz dioritc composition. These gneisses occur between Tromsvann and Grondolen.

The Banded Amphibolites (2)

These too have the same type of banding as the unit above, though the quartz diorite is usually much coarser and forms schlieren or lenses within the rock mass. Also numerous light coloured keratophyric bands occur within this unit.

The Homogeneous Amphibolite Greenstones (3)

This unit is a dark green to black, fine grained schist which together with unit 2, above, has been folded into large isoclinal folds. The contact between the banded amphibolites and the greenstones is very sharp and abrupt but the contact with the overlying greenstones is often transitional.

The Older Greenstones (4)

This unit is quite extensive, occurring between Tromsfjell and Grondolen, and between Moblevann and Grong. It is made up of banded greenstones with thin streaks of lighter and darker green material, the main amphibole being actinolite. Towards the South West this banding becomes stronger as the metamorphic grade increases and the actinolite is replaced by dark hornblende. It is likely that these rocks were originally tuffs where the banding has become more apparent due to metamorphic segregation. Acid volcanics and kerotophyres are also abundant in this unit.

The Middle Greenstones (5)

The type outcrop for this unit occurs in the North West extending Southwards to the upper part of the Nesådolen where it is intruded by large trondhjemites. Three greenstone units in the Limingen Group of deposits are thought to correlate, with this unit occurring between Borvann and Ingulsvann, Gaizervann and Skarfjell and from Blåmuren to the Grong area.

Massive to moderately schistose, fine grained, dark green andesitic-basaltic lavas are the main components of the unit some of which show amygdaloidal textures with epidote as the main mineral. It is thought that some of the larger segregations of epidote, especially in the Skarovas area represent deformed pillow structures.

In the mapping area - between Gaizervann and Blåmuren, according to Gale (1975) volcanic tuffs are the main constituents. The main minerals present are plagioclase (as secondary albite) chlorite, epidote, +/- amphibole (actinolite) +/- quartz, +/- stilpnomelane, +/- calcite, and a fairly high content of pyrite and magnetite.

The Younger Greenstones (6)

In general, this is typically lighter in colour and coarser grained than the middle greenstones, and has more calcite and less magnetite and pyrite. Quartz and stilpnomelane are usually absent or occur in very small amounts. Acid igneous rocks are abundant, some of the keratophyres probably originating as tuffs. In some places they penetrate adjacent rocks and are clearly intrusive. Intercalated with these acid rocks, thin agglomerates and layers of magnetite - quartz bearing cherts or jasper occur.

The Intrusives

The above volcanics of the Gjersvik Group have been heavily intruded by acid and basic intrusive rocks which are almost as widely distributed as the rocks into which they are emplaced. These intrusives can be divided into three provinces, the North Western, the North Eastern and the Southern.

The North Western Province

The intrusives of this province occur in units 1 - 4 and are mainly medium to fine grained granodiorites and metagabbros. Due to the presence of microcline the granodiorites are usually pink in colour. They are younger than the metagabbros as in places they can be seen to cut across the latter.

The North Eastern Province

These intrusions occur within units 4 - 6, consisting of trondhjemites and metagabbros, which form large plates subconcordant with the enclosing rocks.

The trondhjemites, in general, are light grey and medium grained containing quartz aggregates. The metagabbros are fine grained and often difficult to differentiate from the greenstones of which large rafts or inclusions can often be seen in the intrusive bodies.

The Southern Province

This province is made up of two massifs, The Gróndalsfjell massif and a large massif in the South. Both intrusions contain layered gabbros, which according to Halls et al (1977) varies in composition from Olivine gabbro to hypersthene gabbro.

The Structures of the Grong Caledonides

The Caledonides of the Grong District have been affected by numerous phases of deformation such that the later deformations have eradicated many of the effects of the earlier phases. However, the general strike over the region is from NE to SW. The main schistosity was imprinted onto the rocks at one of the early phases, but this itself has been deformed by later movements.

Due to several periods of thrusting, tectonic and stratigraphic boundaries are very scarce. The last phase of deformation however was rather more brittle than previous ones and resulted in very high angle faults with movements varying from 3 feet to 500 metres.

Burde vært mer spesifikk om
typen deformasjon

MAP AND AERIAL PHOTOGRAPH INTERPRETATION

Field Methods

The methods used to compile the map in the field were those known as outcrop mapping. This involved visiting each exposure of rock and the identification of all the lithologies which were recorded both on the field map and in the note book. The area of outcrop was also marked on the map showing their orientations, size and general shape. Measurements such as the dip and strike of bedding and cleavage were recorded and brief descriptions of new rock types made.

Any obvious concentrations of mineral deposits were noted as were the occurrence of any rusty coloured outcrops. Samples of the major lithological units were also obtained and carefully located before being brought back to England for further laboratory analysis.

The Map Analysis

The rocks of this area comprise a series of granodiorites, leucogranites,and greenstones which occur in an elongate North-East to South-West trending belt. This is bordered on each side by meta-sediments which include thick sequences of conglomerates and arkoses.

The northern contact between the greenstone belt and the meta-sediments is a faulted one with a major steeply dipping fault trending North-East to South-West along the lengths of Gaizervann and Pervatn. The southern margin of the belt is marked by the outcrop of another conglomerate-arkose sequence which can be seen to overstep the greenstones (GR 110050) indicating that an unconformable relationship exists between the greenstone belt rocks and the meta-sediments.

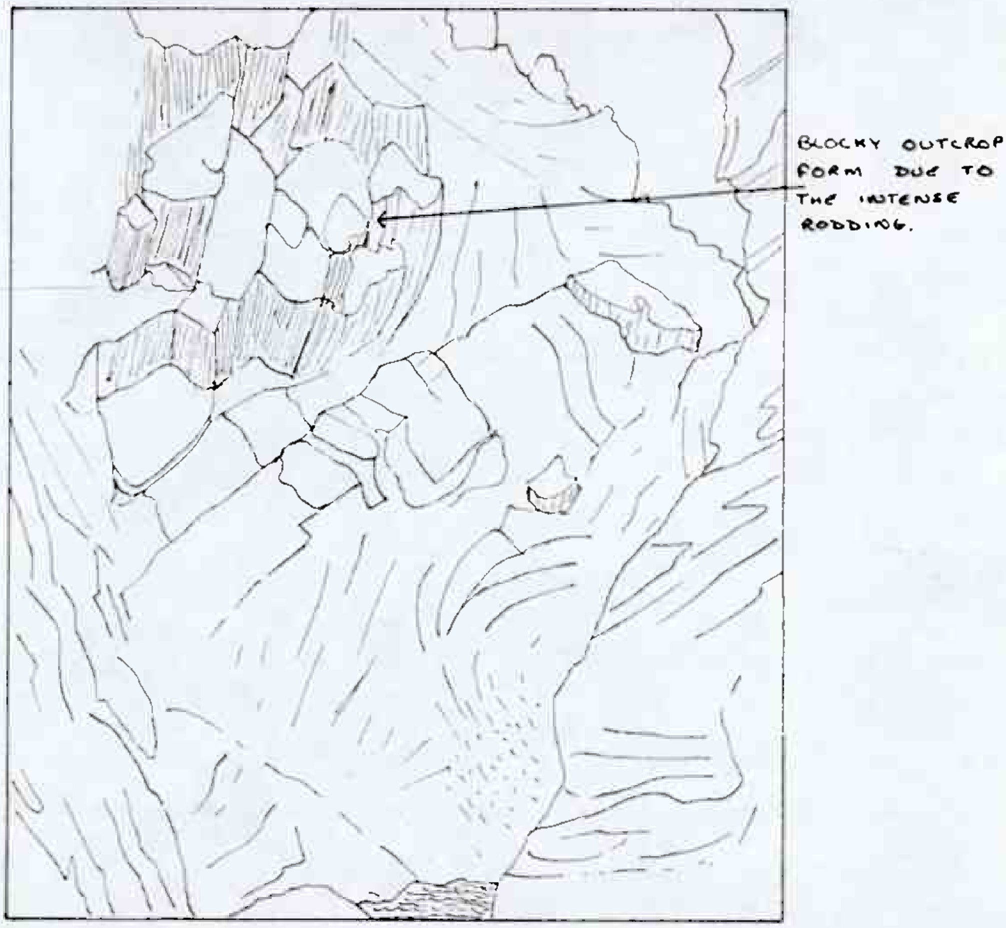
The Meta-Sediments

These rocks occur in well bedded units where the lithologies vary from massive conglomerates to thinly bedded, cross laminated, and vaguely graded arkoses. The beds are usually very continuous with an average strike of about 045° and dip steeply to the South. The cleavage direction also follow the trends of the bedding and in some cases have almost obliterated the original sedimentary structures. From the cross laminations and graded bedding it is possible to determine that the beds are the correct way up, though in the units South-West of Gaizjavre Nordre (GR 340380) some of the thinner arkose beds have been severely folded and crumpled between the thicker conglomerates so that they are locally overturned.

Evidence for other internal deformations occurs in the form of rodding which possibly indicate zones of shearing. These rods show the present orientation of the stretching lineation that effected the rocks, on average trending at 060° and plunging at 8°.

PLATE 1

INTENSE RODDING IN SILICIFIED GREENSTONES



The greenstones

Lack of visible bedding in the greenstones has caused the immediate identification of any structures impossible. This is further hindered by the fact that the greenstones have been severely dissected by granodioritic and leuco-granite intrusions, leaving very discontinuous outcrops with which to work.

The cleavage in the greenstones shows a regional strike of about 045° throughout the whole belt. Towards the South of the area the cleavages tend to dip in a northerly direction at angles of between 20 and 85°, whilst in the North-East the cleavages generally dip southwards at angles varying from 30° to 86°.

Rodding is also present in the greenstones, again representing possible shear zones. In the South West these plunge at between 12° and 22° towards 060 whilst in the North-East the rocks plunge at angles varying from 4° to 15° towards 060 suggesting that lateral movement was greater in the North-East. (see Plate 1)

Occasionally small outcrops of very pyritiferous cherts occur, completely enclosed within the greenstones. The largest of these is at (GR 090050) and occurs as an 80 m lense trending NE-SW along the regional strike.

The outcrop pattern of the greenstones, inferred from the exposures observed, show that they occur in narrow North-East to South-West elongate lenses and belts separated by large masses of intrusives. Towards the North-East as the extent of the intrusive rocks decrease the greenstones become more abundant and continuous over a wider area.

The Granodiorites and Leucogranites

These lithologies consist of over fifty percent of the rock mass, especially in the South-West where they occur very extensively with relatively small outcrops of greenstones. In the North East the occurrence of these intrusives diminishes becoming isolated North-East - South-West trending lenses separated by the more extensive greenstones. This suggests that the centre of intrusive activity was to the South West around Gaizervann.

The contact between the granodiorites/leucogranites and the greenstones was very rarely seen because the two lithologies tend to grade into each other. Also associated with the contacts in some places eg (GR 050050) the foliation or schistosity showed a greater degree of development and it was frequently found that large rafts of the greenstone had become separated from the main greenstone masses forming isolated blocks in the granites of the transition zone.

The cleavage in the granodiorites/leucogranites follow the same trends as that of the greenstones, as do the rodding lineations. This suggests that both lithologies were affected by the phase of deformation which resulted in the formation of these features.

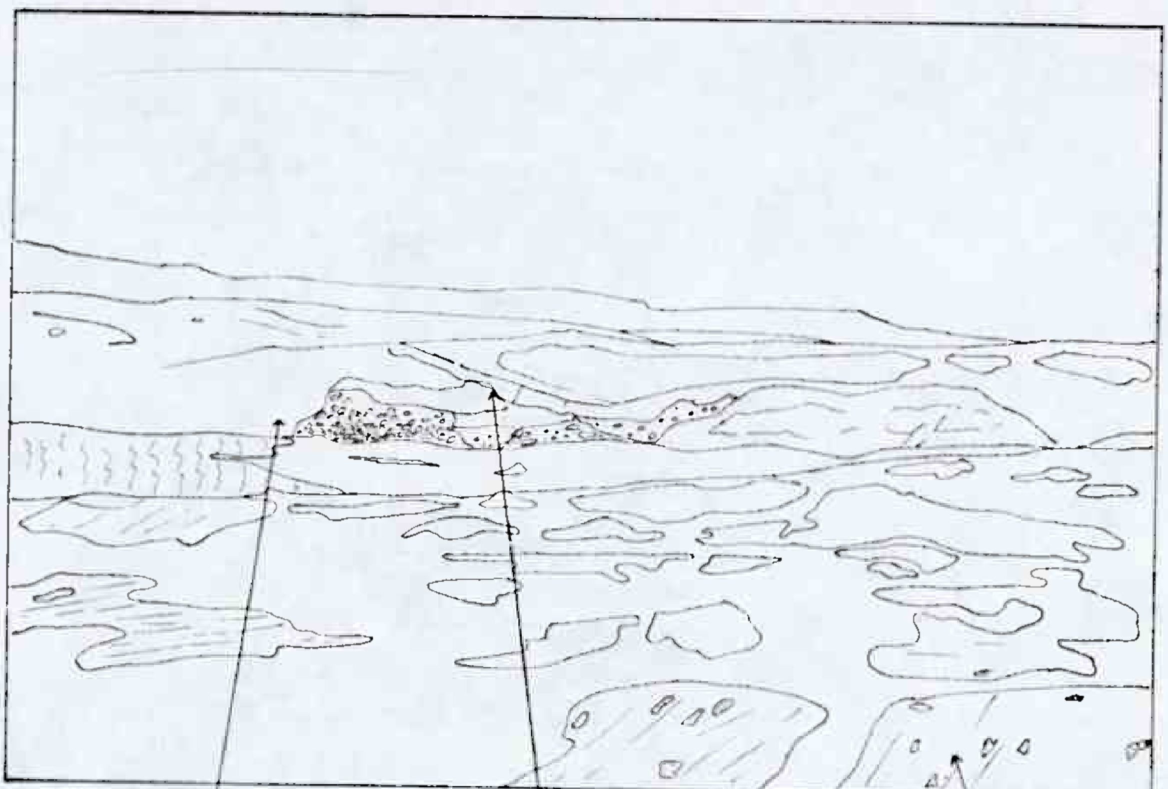
Besides occurring as large intrusive bodies, the granodiorite/leucogranite was also observed to form small dyke like features which cut the greenstones in a NE-SW orientation usually being approximately 20 cms to 1 m in thickness. An example of such can be seen on the small islands in Pervatn (GR 250250).

Mineralization

The main area of mineralization is at the locality known as 'Rusty Cliff' (GR 100090) where silicified and sericitized granodiorites host relatively high percentages of

PLATE 2

A VIEW OF THE RUSTY CLIFF LOCALITY



WHITE QUARTZ MOLYBDENUM VEIN

3-4 m LAYERS OF RUSTY GRANODIORITE DIPPING N.E.

DEFORMED CONGLOMERATE

disseminated pyrite. These tend to occur in separate rusty layers of about three to four metres in thickness and dipping towards the North-East at about 30° to 40°. (see Plate 2).

Molybdenite, chalcopyrite and pyrite were observed in some of the quartz veins which are present in the granodiorites. These were usually rusty on weathered surfaces, but the fresh surfaces usually showed a blue grey colour, reflecting the presence of disseminated Molybdenite. One such vein is at (GR 120090) half way up 'Rusty Cliff' occurring as a 40 - 50 cm thick unit running in a North-West to South-East direction. In this case epidote was also found within the quartz.

By far the largest quartz/Molybdenite vein in the area is located at the South West end of 'Rusty Cliff'. It was first seen as large $13/_4$ m loose blocks in the valley below. In situ it occurs as a very discontinuous unit, pinching and swelling from 30 cms up to 2 m, but could only be traced for about 20 m. This quartz-molybdenite vein is unusual in that the quartz is white in colour as the molybdenite occurs in distinct pockets or lenses in the form of coarse, visible grains. Also the pyrite content is comparatively low and traces of other minerals, such as ilsemannite (as ink splashes), and secondary alteration products of molybdenite may be present.

Towards the South-West by about 100 m, quartz, molybdenite, chalcopyrite, and pyrite were found in veins of between 5 and 30 cms in thickness. Three such veins were observed along the coastal section between (GR 090070) and (GR 040050), trending approximately East to West, but these could not be traced inland. Also in this area, small quartz veinlets were in abundance throughout the host granodiorite most of these containing pyrite. In one locality (GR 070070) secondary copper as well as pyrite was found in a small 15 mm thick veinlet which cut through a very rusty outcrop of granodiorite. No molybdenite or chalcopyrite was observed in these small 2 to 15 mm veinlets.

Throughout the remainder of the mapping area pyrite occurred in abundance, disseminated within both the greenstones and the granodiorites as well as in veins and veinlets. Concentrations vary from one or two percent up to twenty-five or thirty percent in very rusty outcrops.

In the area South-West of, and including the coast between (GR 200200) and (GR 260180) the occurrence of secondary copper and chalcopyrite in veins increased . The copper usually occurred as the bright green secondary product in thin films along fractures within the quartz veins. Maximum concentrations were less than one percent. Chalcopyrite, though more abundant than the traces of copper also have concentrations no greater than one percent and usually occurred along the margins of the quartz veins with the cubes of pyrite.

Further North-East the occurrence of chalcopyrite and copper decreases with the exception of three localities at (GR 240220), (GR 230230) as chalcopyrite and at (GR290240) as secondary copper. However, North-East of lake 664 chalcopyrite again becomes more abundant though no secondary copper was seen in this area.

The only other location where molybdenite was found other than the areas already mentioned is at (GR 380260), where molybdenite occurs as thin films down the margins of small veinlets of about 3 mm in thickness. These veins also contain pockets of pyrite and chalcopyrite and run through a spotted greenstone which originally was probably a dioritic intrusive body, about 2 to 4 m thick (GR 380270). This is also intruded by a leucogranitic dyke or vein throughout its length which is about 20 - 30 cm thick.

Photographic Interpretation

A series of aerial photographs covering the area within which the mineral anomalies occur was available. From these photographs it is possible to observe any outstanding geological features such as faults and sedimentary bedding.

To the South and North of the greenstone belt distinct linear features can be seen running in a North-East to South-West direction and being very continuous. These features probably represent the bedding planes of the steeply dipping sediments which enclose the greenstones and at least ten such features can be recognised. Some of these features to the North can be seen to bend round and turn back on themselves, indicating the presence of a major fold which closes and probably plunges as an anticline towards the South-West.

The southern boundary between the greenstones and the sediments can be seen on the photograph as another distinct linear feature trending North-East to South-West, which at the time the photograph was taken contained patches of snow. However, this feature has been truncated by an East-West trending fault which results in the feature known as 'Rusty Cliff'. To the South-East of this feature the boundary between the greenstones and the sediments is no longer represented by this linear feature. It is here that the conglomerates were observed to overstep the greenstones with an unconformable relationship.

If the linear feature of 'Rusty Cliff' and that separating the greenstones from the sediments are taken to represent faults then the 'Rusty Cliff' feature is the youngest of the two, and must have accommodated the movement between the sediments and greenstones in the North-East as there is no evidence for faulting in the South-West.

The rocks of the greenstone belt are impossible to differentiate as on the photographs the granodiorites, leucogranites and greenstones show the same shades of grey, and there are no outstanding topographic features associated with the lithologies.

The northern contact between the greenstone belt and the sediments is probably faulted, but most of its length is covered by the lakes Gaizervann and Pervatn.

FIELD AND LABORATORY OBSERVATIONS

OUTCROP DESCRIPTIONS

The Conglomerates: (Polymict)

This lithology occurs as two massive suites, on either side of the greenstone belt, which dip steeply towards the South. Differences between the two conglomerates are apparent in that the thickness of the unit in the North-East is at least 50 m and contains well rounded phenocrysts of up to 50 cm in diameter, whilst the unit in the South-West is between 20 - 30 m thick and contains lensoid, angular phenoclasts of about 2 to 20 cm in length. However, the phenoclasts of the North eastern unit do become smaller in size towards the greenstone belt and are then comparable in shape and dimensions to those of the other conglomerate.

In both cases the clasts are predominantly, granodioritic and leucogranitic in character though clasts of basic epidote rich volcanics were also present. This suggests that the source area may have been within the greenstone belt where these lithologies occur in situ. The quartzite matrix or groundmass of the conglomerates, is fine grained and green in colour, possibly indicating the presence of chlorite and evidence of calcareous weathering suggests that calcite may also be present in some areas.

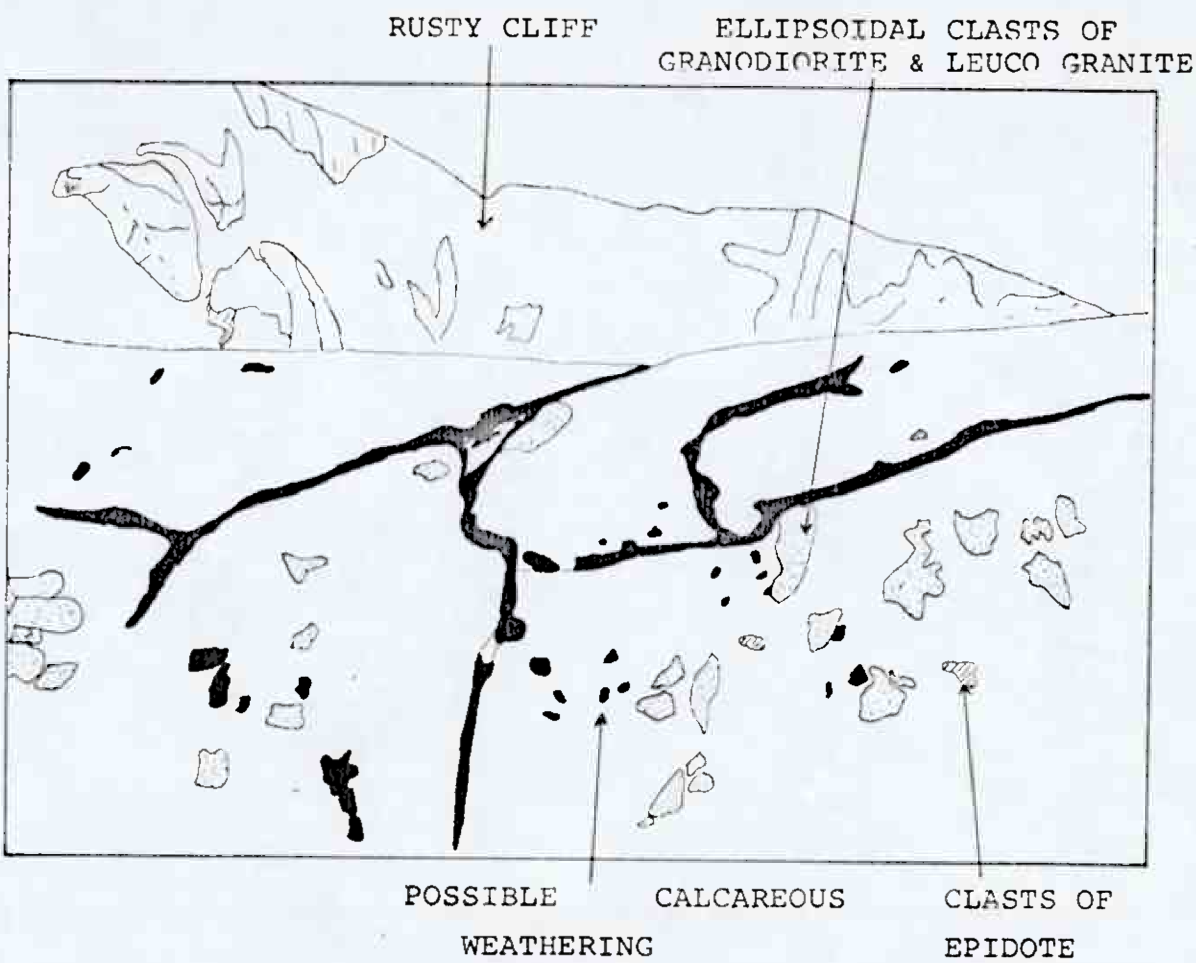
Foliation and lineation in these conglomerates is very well developed, in that the elipsoidal clasts are orientated so that their elongate axis is parallel to the trend of cleavage, ie. ← 062^{o} →. (see Plate 3).

The Arkoses

These occur in beds ranging in thickness from 0.5 m up to 10 m. Grain size is generally fine to medium grained with varying amounts of quartz in a green/grey cement. Some of the beds show cross bedding structures but these are poorly

PLATE 3

A LARGE OUTCROP FO THE DEFORMED CONGLOMERATE S.W. OF THE RUSTY CLIFF AREA.



preserved due to the development of a strong foliation parallel to bedding. The bedding planes are usually clearly defined being picked out by weathering processes as parallel and very continuous features.

The Greenstones

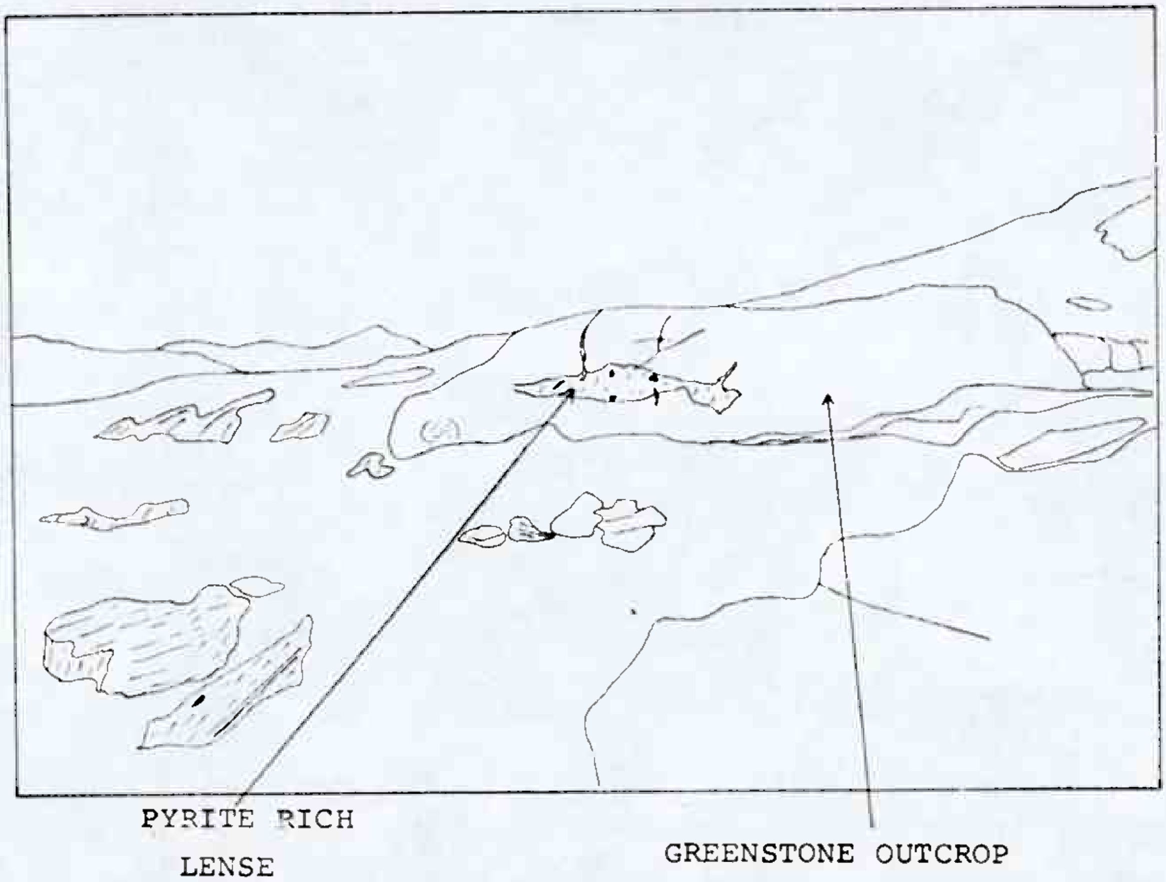
This lithology generally occurs in large, massive outcrops, which can be poorly to moderately foliated. These outcrops vary in colour, from light grey-greens, to very dark greens, but on the weathered surfaces rusting of any disseminated pyrite may also give pyritiferous outcrops a brown colour.

The hardness of the greenstones also varies depending on the degree of silicification. Where there is much secondary quartz the greenstones are very hard, almost cherty whilst in areas where silicification is not evident the greenstones can be scratched with finger nail and are thus very soft.

The mineralogy of these greenstones is primarily Actinolite, chlorite, quartz and albite which make up the fine grained units. Epidote is also an important mineral, occurring in clots or lenses and in veins running through the greenstones. This could indicate that the process of epidotization was important as well as silicification. The light green clots or lenses of epidote occur on the surface of the outcrops with sizes ranging from 4 cm to 20 or 30 cm in diameter. These are often elongate in the direction of foliation and grade into the greenstone rocks. It is thought that these clots may represent the central complexes of very deformed pillow structures and therefore suggests that some of the greenstones originated, possibly, as basaltic lavas erupted into a marine environment. These epidote clots, however, are not always present and in some outcrops very small rock fragments were observed, indicating that some of the greenstones are tuffaceous in origin.

PLATE 4

THE RUSTY BROWN PYRITE RICH LENSE WITHIN THE GREENSTONES AT (GR 350 320)



Another important mineral contained within the greenstones is that of sericite which is especially abundant in the more schistoze greenstones. This indicates the importance of another alteration process which has effected the rocks of the greenstone belt, that of sericitization.

Within the greenstones at (GR 350320) a rusty brown soft, pyrite rich lense was observed. This lense had dimensions of about 8 - 10 m in length and 1.5 m in thickness. Further up the stream outcrop other lenses such as this were seen and seemed to be closely associated with a series of thrust zones. (see Plate 4).

The Cherts

These small outcrops are always contained within the greenstones and can occur as dark grey/black or light grey lenses. The largest outcrop is located in the South-West of the area (GR 090050) and associated with this one body is a magnetite-pyrite rock which occurs along its western margin as a narrow band. mm scale quartz-pyrite bands or veins are interbanded with the black magnetite rich rock. This quartz, pyrite, magnetite rich rock probably originated as a volcanic exhalative, as did the cherts but this is the only locality where the magnetite bands occur.

The Acid Intrusives

These lithologies outcrop over quite extensive areas as moderately to well foliated acidic rocks. The well foliated areas are generally medium grained and contain more coloured minerals than those areas where the foliation is less well developed. In this case individual feldspar and quartz crystals tend to stand proud of the surface due to differential erosion. The amount of coloured minerals is also less.

The mineralogy on the whole consists of quartz, white feldspar (probably Oligoclase) some green and pink feldspars, and varying percentages of accessories such as biotite and hornblende. In many cases the hornblende and biotite is partially replaced by chlorite. Alteration minerals are also present in the form of epidote veinlets, excessive silica, mainly as quartz and also potassium feldspar.

Distinguishing between the leucogranites and granodiorites is very difficult in this area because there were many intermediate types of acid intrusive present which could have been put in each category. Only in some areas could a true leuco-granite, (being very pale in colour and containing biotite as the only coloured mineral if any present) be differentiated from the surrounding granodiorite eg Rusty Cliff area. Leucogranites, however, were also observed in the form of 10 to 30 cm thick dykes. One such dyke can be seen emplaced into the Dioritic intrusion at (GR 380270) trending NE-SW. This intrusive body is in the form of a fine grained light green rock which contains sphericle spots of feldspathic material which grades into the groundmass. This body is poorly foliated and its outcrop takes on a blocky appearance due to the preferential weathering of small veinlets containing quartz pyrite, molybdenite and chalcopyrite.

<u>The Greenstones: Hand Specimen</u>

The two examples of this rock type included within the report represent probable end members of this lithology. The darker coloured greenstone is much softer and more homogeneous than the other, which contains greater percentages of quartz and epidote.

The mineralogy of the darker greenstone is set out in the list below.

CHLORITE	40%
ACTINOLITE	35%
EPIDOTE	15%
QUARTZ	10%

These occur in a very fine-grained schistose rocks, which shows very limited amounts of mineralization, a fact possibly related to the lack of secondary quartz. Only a very small amount of fine, disseminated pyrite is evident.

The mineralogy of the lighter greenstone differs mainly in the percentage of secondary quartz present, and an increase in the amount of epidote, which appears as visible, but discontinuous veins. The list below shows the mineralogy.

QUARTZ	60%
EPIDOTE	20%
CHLORITE	10%
SERICITE	6%
CALCITE	4%

This mineralogy is probably a result of the alteration processes of silicification, epidotization and sericitization having acted to a much greater extent in the locality where the lighter greenstone was collected. Mineralization within this specimen is much more evident with pyrite content being up to 2% in both the disseminated form and in pockets or concentrations within quartz veins.

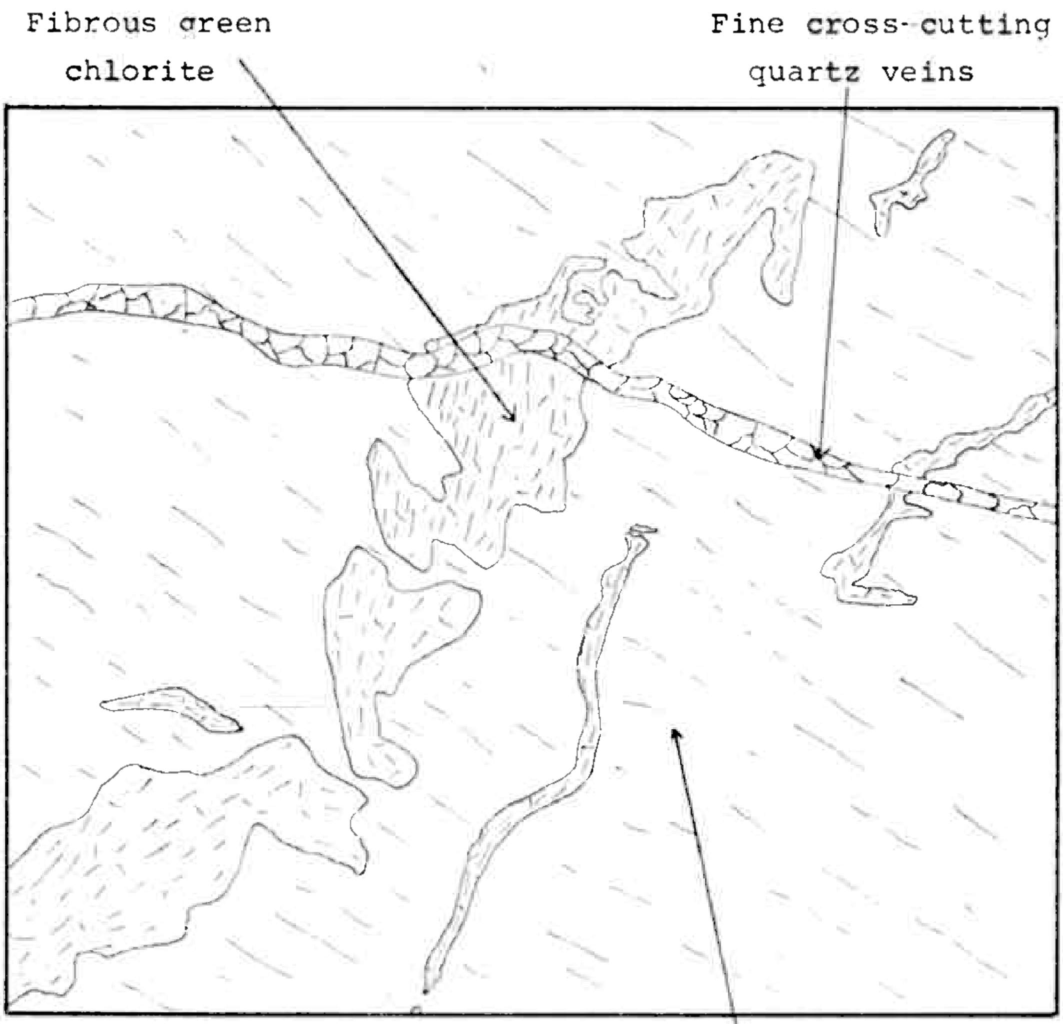
Thin Section:

Under thin section the darker greenstone can be seen to have been cross-cut by very narrow < 1 mm wide quartz veinlets. These veinlets also cut through larger discontinuous pockets or veins of chlorite, which occur in a very fine groundmass of epidote and and hornblende (Diagram 1).

DIAGRAM 1

- P.P.L. at x 4 magnification

The Darker Greenstone



The diagram shows pockets and veins of chlorite within a fine matrix of hornblende and epidote. Cutting through the chlorite and groundmass occurs thin 1 mm quartz veins.

The lighter coloured greenstone under thin section shows that epidote veins have been folded and fractured evidently sometimes under compressional force and at others under tensional forces. The margins of many of these epidote veins are embayed which suggests that they became unstable with their environment.

Two types of quartz masses can be identified, a coarser variety 2-3 mm and a finer variety < 1 mm. The coarser quartz occurs in the voids left when an epidote vein is pulled apart (Diagram 2a), in the elbows of folds in the epidote veins (Diagram 2b) and in quartz veins (Diagram 2c). The latter tend to cut through the finer quartzite material but do not cut through all epidote veins. In general this coarser variety lacks any desseminated pyrite, whilst the finer quartz contains up to 5% pyrite.

Within both types of quartz, and cutting across the boundary, are traces of chlorite (Diagrams 2b and 2c) which suggests that these are possibly the youngest fraction of the rock. However in Diagram 2c a chlorite grain can be seen to be truncated up against an epidote vein suggesting that the epidote was even later in development. This however conflicts with the view that the coarser quartz is found in the gap where an epidote has been fractured (Diagram 2a).

Epidote also occurs in the finer quartz as disseminated grains.

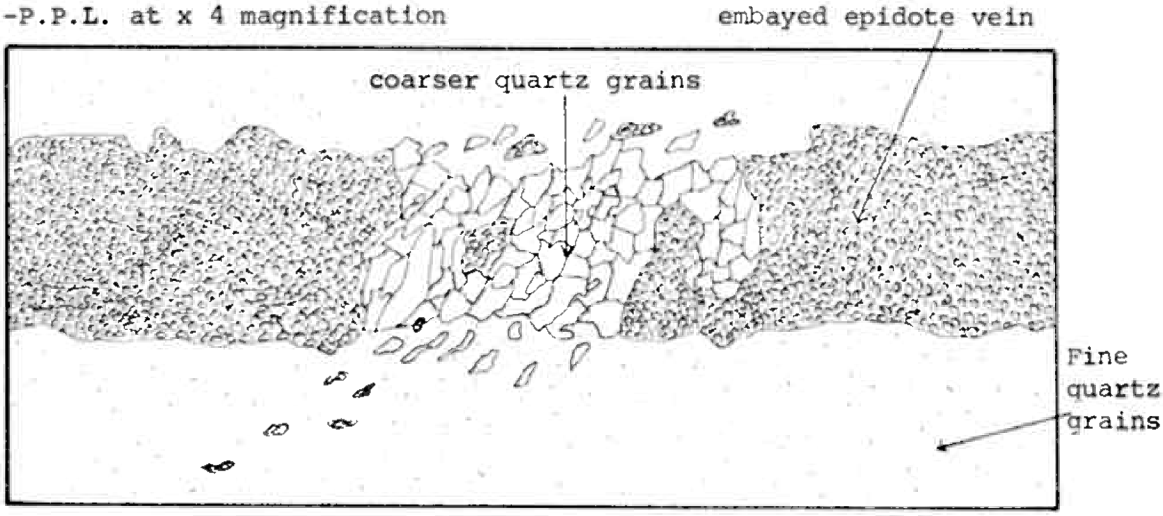
<u>The Chert: Hand Specimen:</u>

This lithology occurs as mainly homogeneous, dark grey-black, cryptocrystalline masses. Within the sample collected, however, very small veins < 1 mm in thickness run parallel to each other through the rock. These quartz veins contain very fine pyrite and in some places can be seen to bifurcate.

DIAGRAM 2

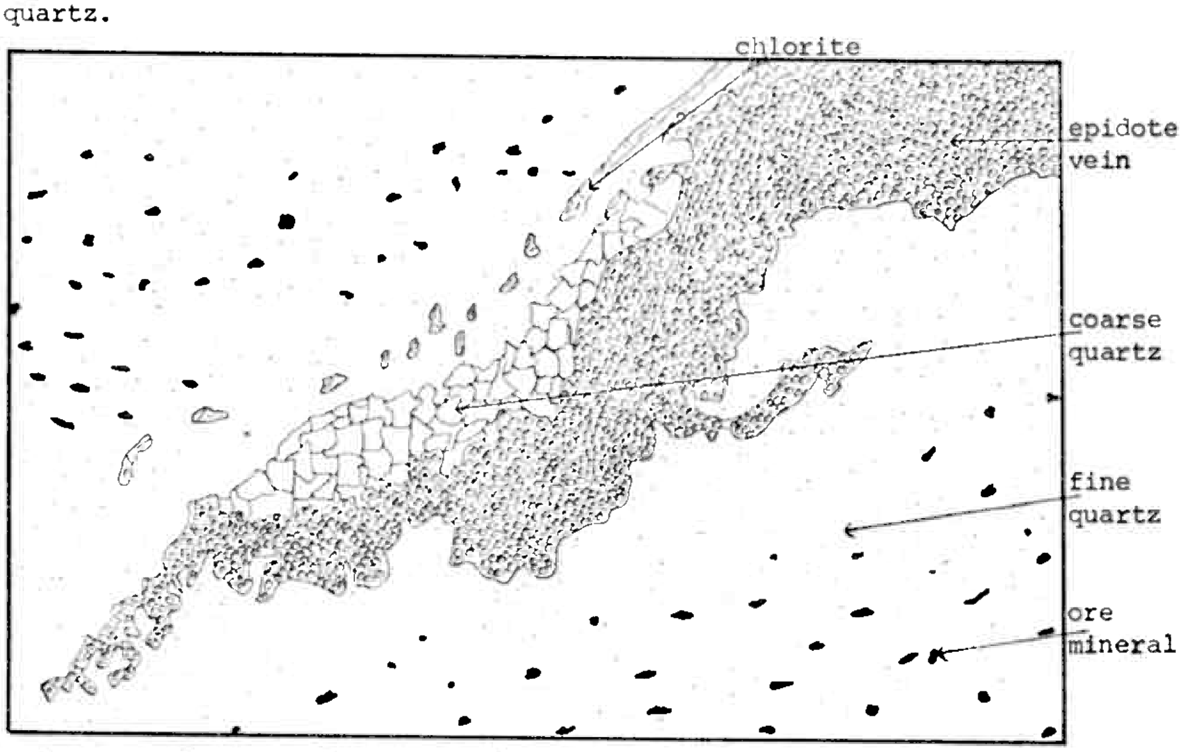
-P.P.L. at x 4 magnification

a)



The above diagram shows an epidote vein which has been pulled apart by tensional forces. The void has been infilled with coarse secondary quartz.

b)



The above diagram shows a deeply embayed epidote vein which has been folded with secondary quartz development in the elbow of the fold.

c)

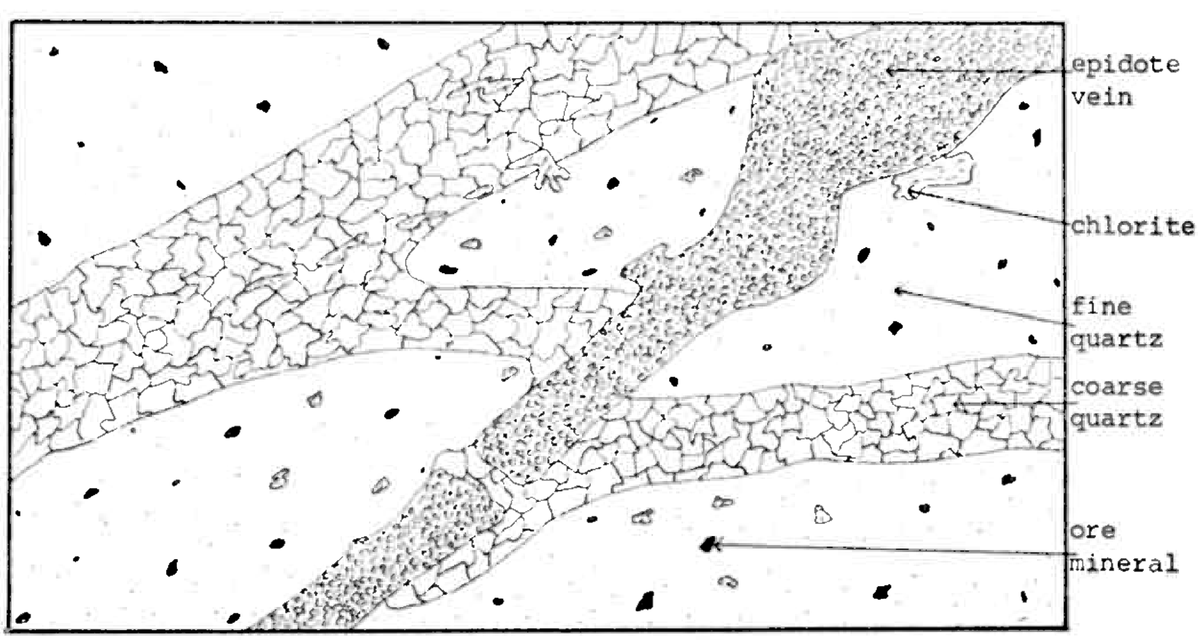
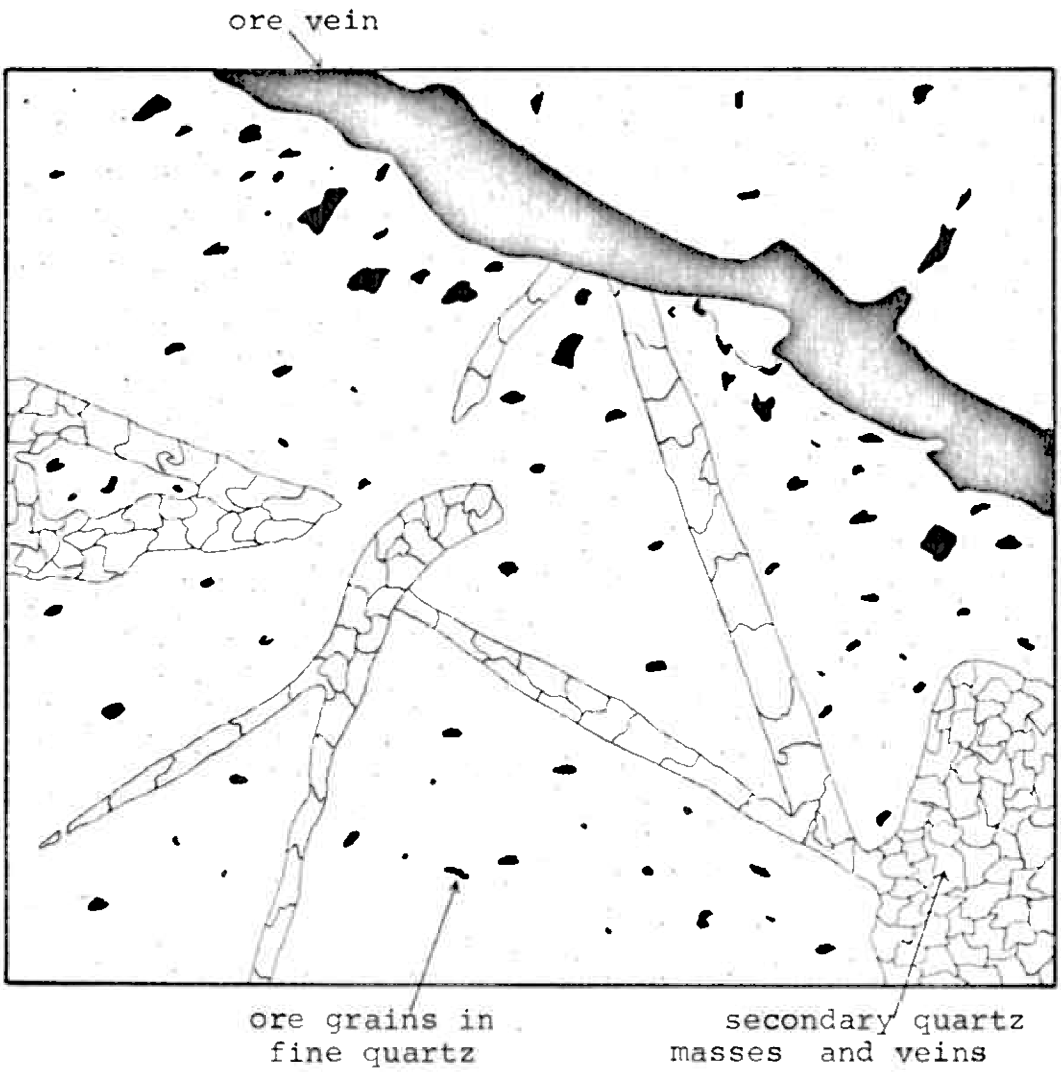


DIAGRAM 3

-P.P.L. at x 4 magnification

THE CHERT

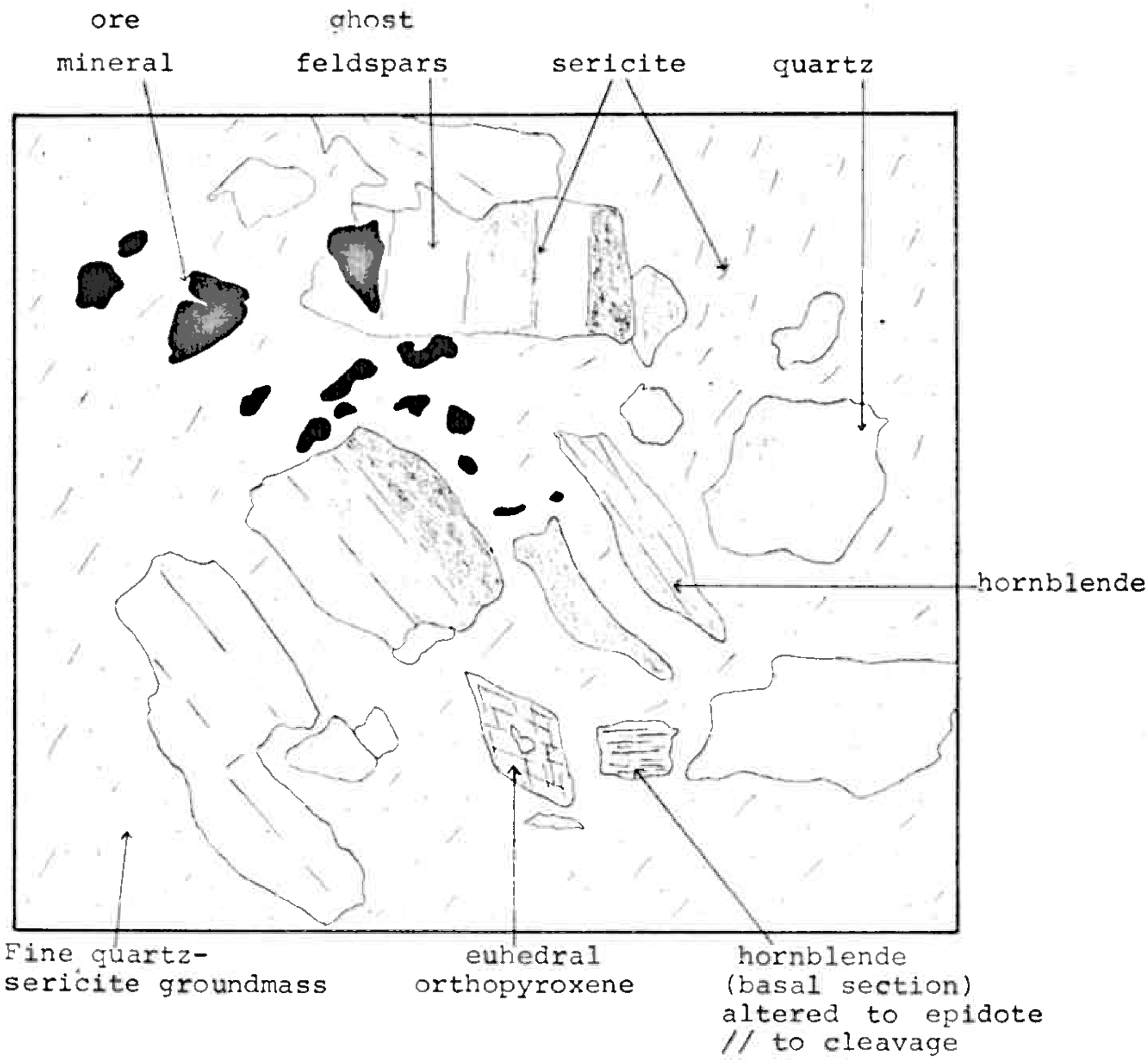


The diagram shows a fine groundmass of quartz and an ore mineral, in which large masses and veins of secondary quartz occur. Both these however are cross cut by larger veins of the ore mineral.

DIAGRAM 4

-X.P.L. at x 4 magnification

The coarser, green granodiorite



The diagram shows that the plagioclases occur as relict phenocrysts, which are being broken down to sericite and secondary quartz. Other original phenocrysts of orthopyroxene and hornblende are evident. These are set in a fine, altered groundmass of quartz sericite and an ore mineral.

Thin Section

Under the microscope the rock is clearly not homogenous. From the Diagram (3) it is apparent that much of the rock consists of very fine crystals of quartz, and an ore mineral. This fine groundmass is cut through by veins of coarser quartz grains and also by veins of the ore mineral. It is apparent that the latter must post-date the quartz veins as these are cross-cut by the opaque veins of the ore mineral. However, the disseminated ore grains in the groundmass do not occur in the quartz veins suggesting that these were a later development.

The Acid Intrusives

There are 3 specimens included in the report, representing these lithologies. Two of these are an average pale green in colour whilst the other is light, flesh pink.

Hand Specimen

The coarser-grained specimens of the two green rocks is also slightly darker in colour and more granular in texture. The visible minerals in the hand specimen are quartz, which occurs as individual crystals up to 4 mm in diameter, hornblende, as dark green to black specks or laths of up to 5 mm in length and 2 mm in width, and plagioclase, as green crystals of about 2 mm in diameter. These are set in a very fine groundmass which is probably mainly fine quartz. Cutting through this rock is the occasional small 1-2 mm thick veinlet which consists of rusty pink quartz with pockets of very fine pyrite.

Thin Section (refer to Diagram 4)

Under the microscope the minerals identified are listed overleaf:

Quartz	40%
Feldspar	30%
Hornblende	5%
Ortho pyroxene	5%
Magnetite	8%
White Mica	10%
Calcite	2%

The plagioclase occurs as relict phenocrysts where in most cases ghost twinning is definable and they still form the largest crystals in the rock at about 5-8 mm in diameter. Also, smaller phenocrysts, of hornblende appear as brown, often twinned prismatic crystals and the occasional orthopyroxene is present. The irregular shaped crystals of an ore mineral indicate that magnetite is also present in trace quantities. Small amounts of calcite can also be observed under the microscope. These crystals are set in a very fine grained quartz groundmass. This rock is probably best categorised as a Granodiorite.

Hand Specimen

The finer-grained specimen of the two acid intrusives has a higher proportion of green feldspar which again occurs as phenocrysts of up to 4-5 mm in diameter. These are set in a very fine-grained quartz, chlorite, sericite groundmass, which is in general pink-green in colour.

Thin Section

In thin section the feldspar phenocrysts are even more broken down as they are being replaced by sericite which, as well as making up most of the groundmass, occurs within the feldspars themselves. Most of the quartz is fairly coarse-grained of up to 1 to 2 mm occuring in pockets often parallel to the foliation. The mineralogy is as follows.

Burde vært med en anslag over
hvor i feltet / hvor stor del av de totale
sure anslr som representeres av hver av
de tre stykkene

Feldspar	50%
Quartz	20%
Sericite	25%
Chlorite	5%

As such, this probably represent a highly altered Granodiorite, where the hornblende has broken down to chlorite. Mineralization, however, is of fairly low intensity, there being only a low density of disseminated pyrite or magnetite which is highly deformed and streaked out, as shown in Diagram 5.

Hand Specimen

The pink acid intrusive specimen is generally very fine-grained to to crypto-crystalline with the occasional pheno-cryst of quartz up to 4 mm in diameter. Throughout the rock very fine-grained disseminated pyrite is evident and small pockets of this mineral can also be seen. The rock otherwise is fairly homogeneous.

Thin Section

Under the microscope the Diagram (6) shows that there are 4 major constituents as listed below.

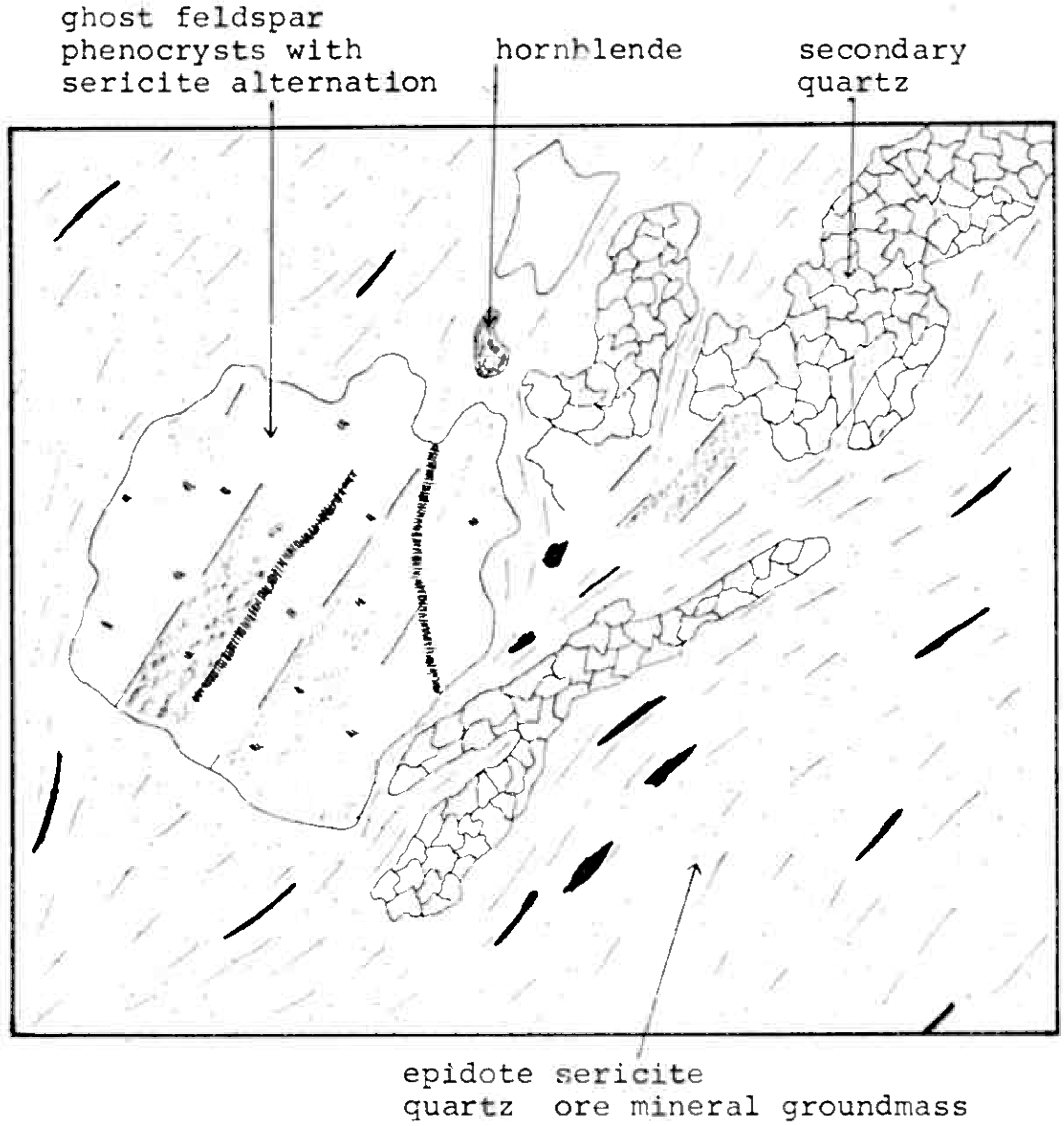
Plagioclase	30%
Quartz	40%
Sericite	9%
Pyrite	1%

The sericite occurs as inclusions or as a replacements within the ghost plagioclases which show lamellar twinning and form phenocrysts of up to 4 mm in size. Also as phenocrysts of approximately the same sizes are brown crystals of K feldspar. These occur in a very fine groundmass of quartz with crystal sizes < 1 mm. Mineralization is fairly low there being small amounts of disseminated pyrite occurring as well formed cubes up to 1 mm across.

DIAGRAM 5

-X.P.L. at x 4 magnification

The finer, green granodiorite

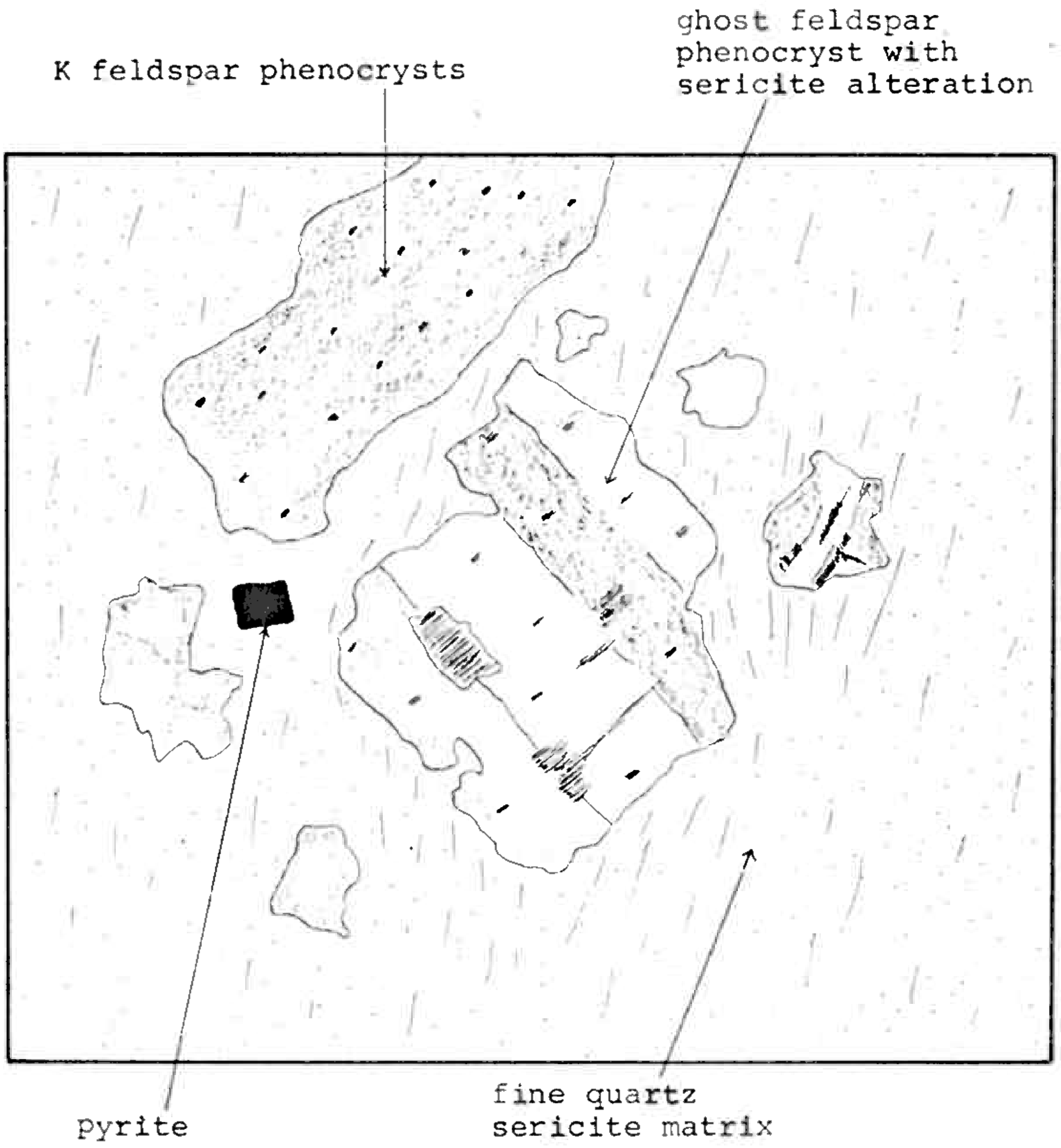


The diagram shows the development of secondary quartz in association with the breakdown of the feldspars through sericitization. The feldspars occur as embayed ghost phenocrysts within a fine grained heavily altered groundmass.

DIAGRAM 6

- X.P.L. at x 4 magnification

The pink acid intrusive



The Diagram shows feldspars occuring as embayed, ghost phenocrysts, which are being broken down into sericite. Also K feldspar occurs as brown phenocrysts and are effected by sericitization to a lesser degree. These are set in a fine quartz groundmass.

INTERPRETATION

GEOLOGICAL HISTORY AND ENVIRONMENTAL RECONSTRUCTION

The oldest rocks of the area are those of the greenstones which probably originated as basaltic pillow lavas and tuffs, though no primary volcanic structures were observed. The presence of epidote clasts, taken to represent deformed pillow structures, suggests that the greenstones were erupted into a sub-marine environment. There is no evidence of an ophiolite sequence and it is therefore unlikely that these represent an ancient oceanic floor. It is more likely that these greenstones originated from basalts injected into/onto the crust in a back arc environment. The presence of acid intrusive bodies may be taken to substantiate this theory, in that subsidence, thinning and assimilation of the sialic crust would give a ready supply of granitic magmas.

As the granitic rocks occur as batholithic type intrusions within the greenstones, then they must post-date the latter. However, it is evident that there was more than one episode of granitic injection resulting in the formation of Granodiorites and leucogranites. It is likely that the first phase resulted in the intrusion of the granodioritic masses and was followed closely by the intrusion of the leucogranites which in most areas probably remobilized the granodiorite bodies.

The spotted greenstone, thought to represent a diorite intrusive body, may have been emplaced between the two granitic injection phases, as this itself has been intruded by the leucogranite, and therefore pre-dates it. However, the relationship between the spotted greenstone and the granodiorite was not seen.

The contact between the rocks of the greenstone belt and the metasediments is mainly faulted, there being only one locality where the sediments clearly overstep the contacts between the greenstones and the intrusives (GR 11006). The exact relationship between the two belts is therefore difficult to determine. However it is clear that the conglomerate must be younger than the greenstone belt rocks as they contain clasts of their lithologies and physically overlie them. The sedimentary sequence must therefore represent deposition of material derived from an adjacent area where the greenstone belt rocks had been uplifted and were actively undergoing erosion.

The energy conditions in the environment of deposition must initially have been very high in order for the transportation of the large clasts of the conglomerate to occur. However, the distance over which transportation took place was probably fairly short as the clasts are generally angular in shape.

The conglomerates pass upwards into finer arkoses, some of which are cross-bedded and others which seem to have vague parallel laminations. This suggests deposition in an aqueous environment and possibly represents the formation of a beach, against an uplifted land mass.

During the period of uplift the greenstone belt rocks probably underwent a certain degree of deformation. This, however, has been obliterated by a later phase which effected both the greenstone belt and the sediments.

The later phases of deformation resulted in the NE to SW anticlinal and synclinal folds which are evident both from the photographs on a large scale, and from the outcrops on a smaller scale, although these only seem to occur in the sediments. These folds represent a compressive phase of ductile deformation with forces acting towards the NW and SE and may suggest deep burial.

Rather than any folding being evident in the greenstone belt rocks, extensive tectonic interleaving of the different lithologies, on near horizontal thrust planes is apparent and from rodding directions it seems that movements occurred in a

NE → SW direction. This would therefore suggest compressive forces acting towards the NE and SW and the interfingering may be thus related to an earlier phase of deformation.

The last phase of deformation is represented by the NE to SW trending faults which originate from a more brittle type of deformation resulting in the fracturing of the rocks. This may therefore have occured at higher levels in the crust.

The cleavages in the greenstone belt rocks and the sediments trend in a NE → SW direction and are likely to be associated with the ductile period of deformation. In the South East of the area (GR 085040) kink bands were observed in the conglomerates and in the acid intrusive. These trended in a NW → SE direction and show that further deformation did take place after the cleavage had developed.

MINERALIZATION AND ALTERATION

Many of the rocks in the greenstone belt show varying degrees of alteration. The most widespread alteration products consist of the minerals epidote, sericite, quartz and chlorite.

Epidote occurs as clots, veins and disseminated grains in the greenstones and also as veins and disseminated grains in the granodiorites. A possible origin for the epidote could be from the breakdown of augite and hornblende through the process of epidotization. This process is favoured in areas where there are shear stresses acting on rocks which are in an environment of fairly low temperature, though it can crystallize in the absence of shear stresses through hydrothermal alteration (saussuritization). The primary minerals, from which the epidote is derived, are likely to have been present in the basic greenstones, and after the segregation of the epidote rich fluids, crystallization would have been likely to occur in any amygdales or vugs, or along fractures within the rock mass. This process may therefore be taken to explain the way in which the epidote clots formed at the vesicular centre of pillow structures, and how the veins were produced. As these fluids migrated through the rocks crystallization also continued within the granodiorites and disseminated grains would have been formed. The absence of epidote in the leucogranite suggests that the latter post-dates the period of epidotization.

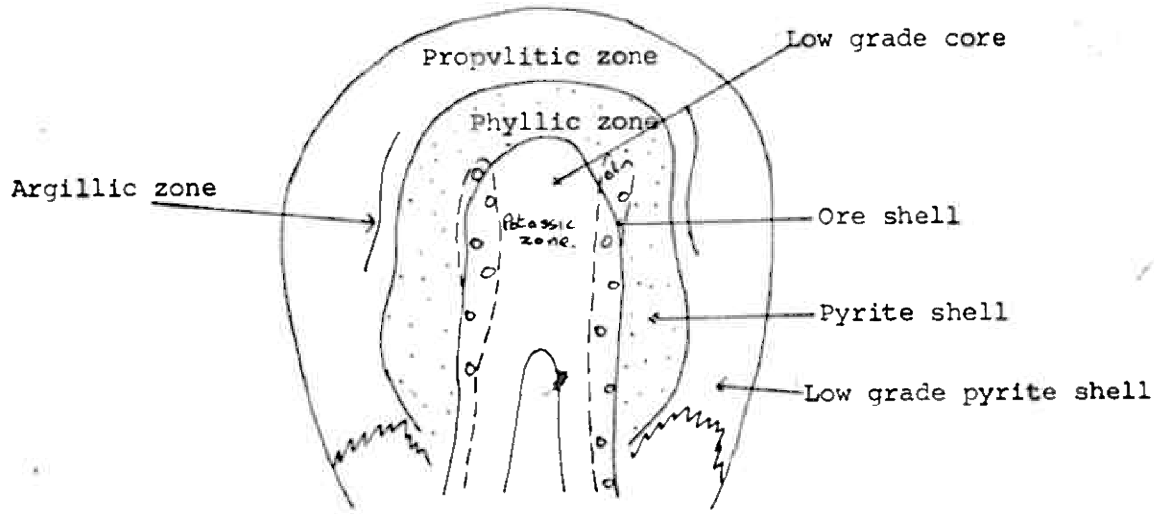
Sericite occurs mainly in the groundmass of the granodiorites and in some of the more deformed or schistoze greenstones, taking the form of minute, flake aggregates. The probable origin for this mineral could be from the breakdown of the alkali rich silicotes within the granodiorites, resulting in the almost complete resorption of the feldspar phenocrysts. The presence of sericite in the more deformed greenstones, suggests a possible migration of sericite rich fluids from the source areas in the granodiorites down planes or zones of relative mobility.

During this process of sericitization a by-product of the transformation of feldspars and primary mica to sericite is that of secondary quartz.

From the thin sections and field evidence it is apparent that secondary quartz occurs throughout all the lithologies of the greenstone belt which suggests a fairly large input of quartz rich fluids probably unrelated to the sericitization processes.

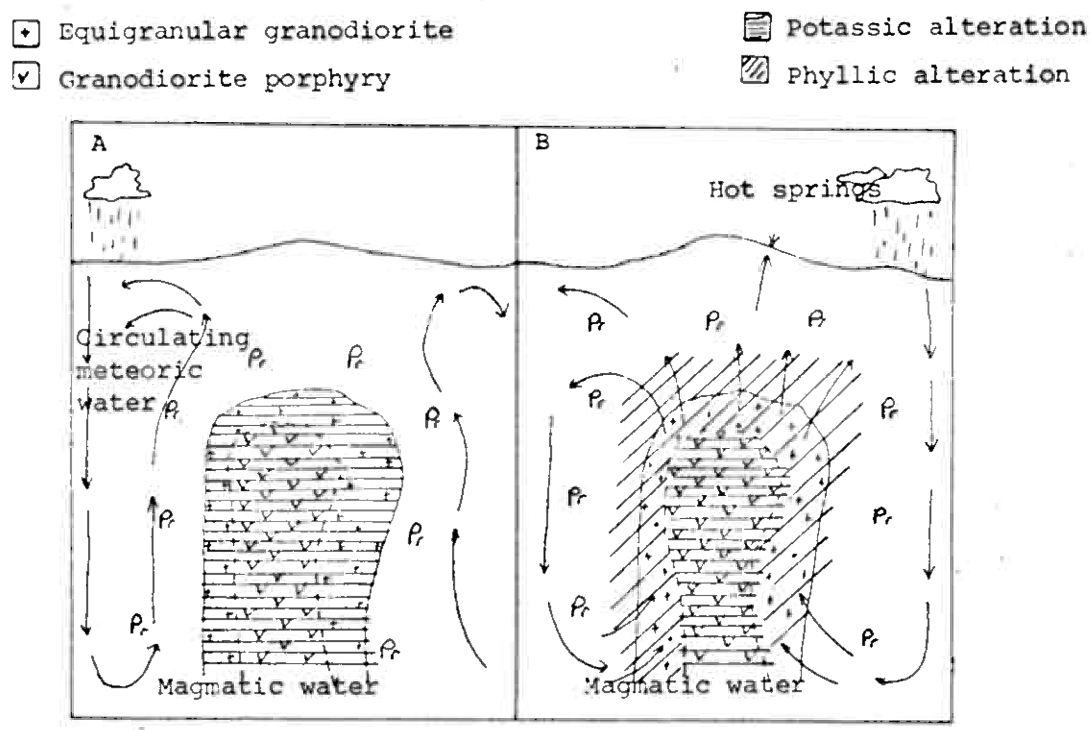
This secondary quartz occurs in the form of relatively coarse crystalline aggregates or pockets from which veins may radiate cutting through the finer groundmass. From the thin sections it is apparent that these secondary quartz veins and masses contain much less pyrite and generally cross-cut other alteration mineral veins such as the epidote. This suggests that the silicification process was quite a late phase alteration.

DIAGRAM 7



Hydrothermal alternation zoning pattern in the Lowell and Guilbert model of porphyry copper deposits with the principle areas of sulphide mineralizations shown (after Lowell & Guilbert 1970).

DIAGRAM 8



Diagramatic sections through a porphyry copper deposit showing two stages in the development of the hydrothermal fluids leading to the formation of a Lowell and Guilbert type deposit (Sheppard 1977).

THE MINERALOGY OF THE LOWELL & GUILBERT ZONES

TABLE 3

POTASSIC ZONE	PHYLLIC ZONE	ARGILLIC ZONE	PROPILITIC ZONE
Secondary orthoclase, biotite mica and chlorite +/-sericite and anhydrite (not always present)	Primary and secondary quartz, sericite. Pyrite - in veins and disseminated minor chlorite +/- illite, and rutile	Clay minerals are dominant. Pyrite in veins only. Primary biotite mica and chlorite (not always present)	Chlorite is common. Pyrite, calcite epidote usually present. Primary mafic minerals (biotite + hornblende) altered partially or wholly to chlorite (always present)
INCREASING DISTANCE FROM INTRUSION →			

Chlorite is much less common than the latter alteration products. However, from the thin section (Diagram 2) it is evident that this mineral was formed after or at the same time as the secondary quartz because individual grains are observed to cut across secondary quartz boundaries. The chlorite may be a result of hydrothermal activity or as a result of the alteration of the mafic minerals. It is much more abundant in the greenstones than the acid intrusives. The presence of chlorite possibly suggests an upgrading of the sericitization processes to potassium silicate alteration where secondary potash feldspar with minor chlorite are produced. This is further substantiated because the common sulphides associated with potassium silicate alteration are pyrite, molybdenite and chalcopyrite, all of which occur in the mapping area.

A model, in which all the alteration processes described occurs has been put forward by Lowell and Guilbert (1970) after they had examined the San Manuel-Kalamazoo orebody and compared it with 27 other porphyry copper deposits. This model demonstrates that the best reference framework to which we can relate all other features of an ore body is the nature and distribution of hydrothermal wall-rock alteration.

Diagram (7) shows Lowell and Guilberts idealized model with generally four alteration zones present around the ore deposits. Table (3) shows the main characteristics of each zone.

As most of the granodiorites and leucogranites contain quartz, sericite and pyrite it is likely that these lithologies were part of the phyllic alteration zone, but in other models this is known as advanced argillic alteration. In the case of the greenstones, these rocks contain much more epidote and chlorite, and though this situation may be a result of the original composition of the rock, according to the Lowell and Guilbert model it is suggested that the greenstones are from the propylitic zone, and were therefore further afield from the mineralization centre.

In Diagram (8) which shows the two stages in the development of the hydrothermal fluids, the relationship between the intrusive rocks and the importance of circulating magmatic water is apparent. After the intrusion of the porphyry body solidification occurs and a magmatic hydrothermal solution evolves. This then reacts with the porphyry and country rocks resulting in the potassium silicate alteration zone. In this way it is thought that the metals were introduced, and therefore would be found in greater concentration in this central zone. Further out from the intrusion convective circulation of the water in the country rocks results in the propylitic alterations.

From other actively worked molybdenum deposits, it is apparent that there is a close spatial association of the ore bodies with the potassic zone of alteration eg. the Henderson and Climax deposits. It is possible that the rocks in the Gaizervatn - Pervatn area are part of the phyllic and propylitic zones and may therefore surround or overlie a potassic zone in which the metals should be more concentrated.

ECONOMIC CONSIDERATIONS AND FURTHER WORK

From the evidence collected so far the present author thinks it is unreasonable to attempt to make any economic viability decisions, without further work being carried out. So far no copper or molybdenite ore body has been found and the stockwork and disseminated occurrences are too widely distributed to allow the opening up of the area. However, the presence of these minerals, as they occur on the surface, suggests that there could be greater concentrations, and even an ore body, buried at depth. If an ore body is present, the exploration geochemistry carried out by Grong Gruber A/S has not picked it up. It did, however, show three areas where molybdenum and copper were rather more abundant in concentrations, occurring by the Rusty Cliff locality (GR 100090), at (GR 220190) and in the area round (GR 380350).

Further work which should be carried out would be the techniques of trenching in the three mineralogical areas shown on the geochemical anomaly maps, with the trenches running North West to South East across the geological grain. Also bore holes need to be drilled, especially in the Rusty Cliff locality, which shows the greatest degree of mineralization on the surface. This would show whether mineral concentrations increase with depth and give further information on the geology in general, which could then be related to the Lowell - Guilbert model.

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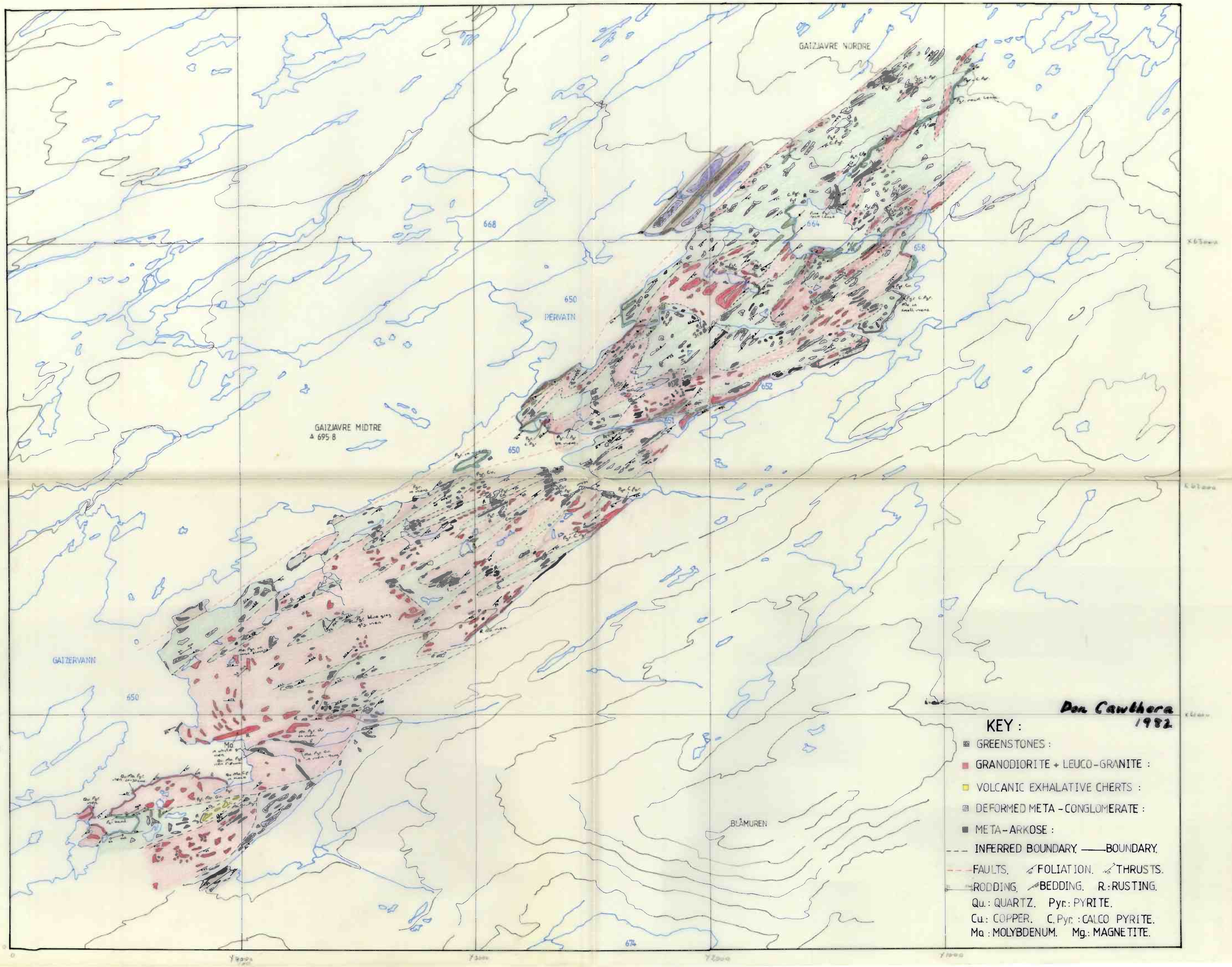

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GREENSTONES :
GRANODIORITE + LEUCO-GRANITE :
VOLCANIC EXHALATIVE CHERTS :
DEFORMED META-CONGLOMERATE :
META-ARKOSE :
INFERRED BOUNDARY. BOUNDARY.
FAULTS. FOLIATION. THRUSTS.
RODDING. BEDDING. R.: RUSTING.
Qu.: QUARTZ. Pyr.: PYRITE.
Cu.: COPPER. C. Pyr.: CALCO PYRITE.
Mo : MOLYBDENUM. Mg.: MAGNETITE.