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The geology, structure and ore petrology of the Dragset sulphide deposit, Near Løkken

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THE GEOLOGY, STRUCTURE AND ORE PETROLOGY OF THE DRAGSET SULPHIDE DEPOSIT; NEAR LØKKEN

A Preliminary Report to Løkken Gruber A/S and N.G.U.

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INTRODUCTION

The Dragset Cu-Zn deposit is a small greenstone-hosted, pyritic massive sulphide deposit located 8.5 km west of Løkken Verk in the Western Trondheim district of central Norway (Fig. 1). It is one of a number of stratabound massive sulphide deposits known in the Løkken area, other occurrences including the major Løkken deposit and the small Høydal deposit. Some very minor deposits of similar type are also known in the region (e.g. Fjellslett, Åskjerp, Holum, Åmot, Kong Karl, Viktoria). All of these deposits occur in a regionally inverted sequence of dominantly metabasic rocks, referred to here as the Løkken greenstones. These greenstones have been correlated with the Støren Group to the east (e.g. Wolff, 1976) and are stratigraphically overlain by metasediments of the Lower Hovin Group. The age of the greenstones is uncertain but they are probably Cambrian or Early Ordovician (Ryan et al., 1980).

This investigation of the Dragset deposit was aimed at outlining the geology of the ore environment, the nature and origin of the deposit and the history of deformation of the ores. It was hoped that such a study would add to the knowledge of ore-forming processes in the Løkken greenstones and help define the range in subtypes and stratigraphic location of the stratabound sulphide deposits in the region. As the Dragset deposit lies in an apparently more deformed part of the sequence than the Løkken and Høydal deposits, it was also thought that detailed structural analysis might give a better appreciation of the style of ore deformation in the Løkken area. This information could then be applied to the other deposits where the deformation history is less readily discerned.

Work on the project was carried out by the author during a five month period of study leave from the Canberra College of Advanced Education, Canberra, Australia. This work involved 38 days in the field, mapping the Dragset deposit and surrounding area, taking structural measurements and sampling the ores and host rocks. Short visits were also made to the Høydal and Løkken deposits and two days were spent logging drill core from Dragset at Løkken Verk. Data collation and laboratory studies involving petrographic, mineragraphic and geochemical analysis, were carried on during the period from August to November, 1985. Some further work, including microprobe analysis of selected ore and gangue minerals, is planned and a final report outlining the results of this and other outstanding work will be submitted in 1986.

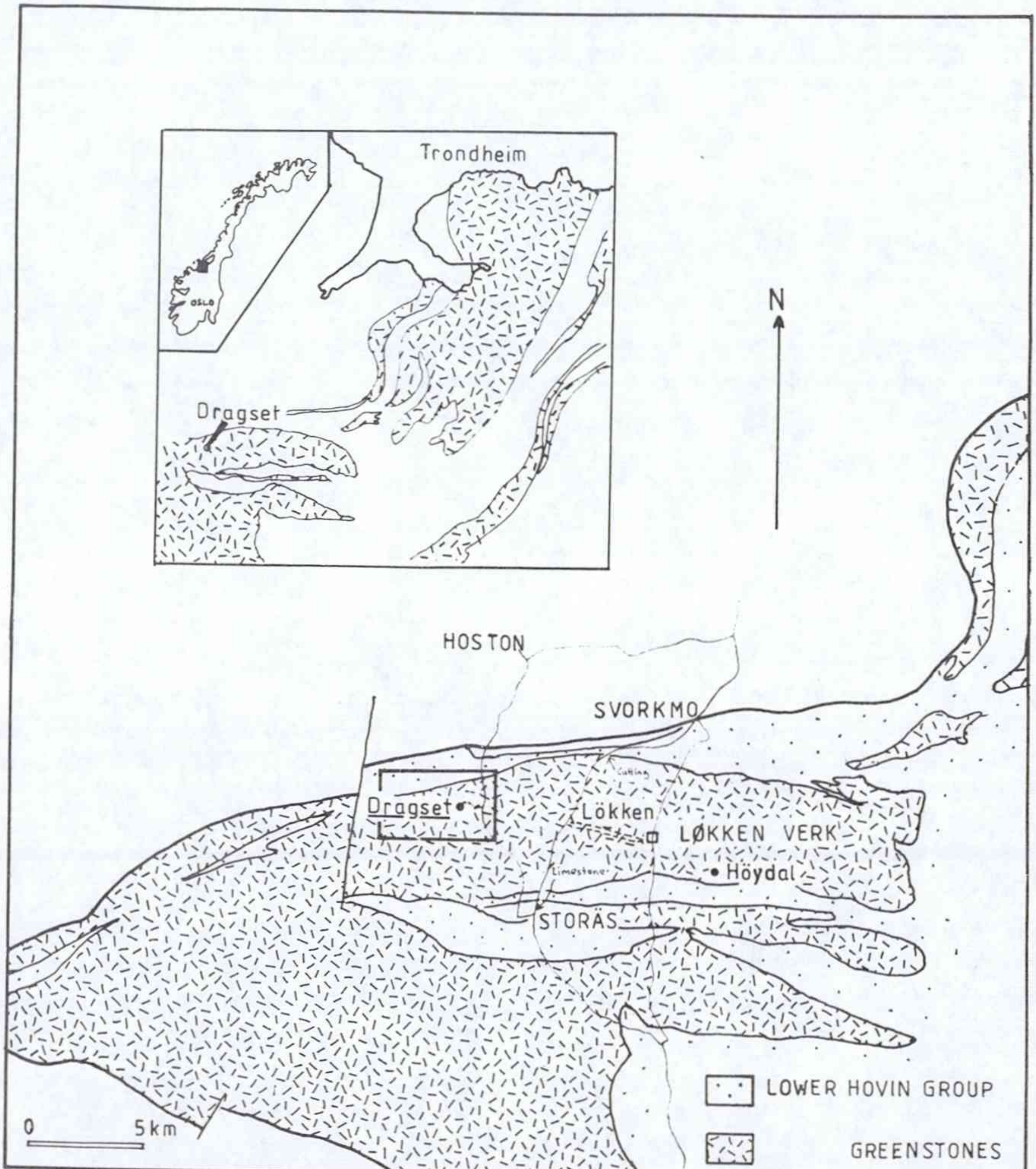


Figure 1. Location of the Dragset area in central Norway.

HISTORY OF MINING AT DRAGSET.

The Dragset deposit was probably discovered between 1655 and 1700. Both the massive sulphide and disseminated feeder zone ores appear to have outcropped at the surface. Before 1867 the deposit was worked on a small scale (near surface tunnels) but after this date and until 1904 larger scale mining was carried out by Ørkdalen Mining Co. (G. Grammeltvedt pers. comm.) From 1904, after a company merger, and until 1909 the deposit was worked by Orkla Grube Aktiebolag and then finally abandoned. Mining was initially by underground methods with the numerous, small and separate ore lenses being taken out in narrow open stopes. These openings were supported by ore pillars and wooden stulls. There were four main levels, each worked from separate addits driven into the slopes on the north-eastern side of the deposit. These levels were connected by the stopes and a number of internal shafts, with the workings extending to a depth of 65 m below the outcrop of the ore. At a later date, possibly soon before the mine closed, three open pits were developed and these extended at their greatest depth to the third level. The function of these pits was probably to recover some of the ore left in the underground workings and extraction was via the underlying levels. Exploration and mining methods appear to have been very systematic and the early miners had a good understanding of the structural control on the massive ores. Near surface strike limits to the ore were defined by costeaning and the sinking of shallow exploration pits (see Fig. 8). Several ore types were recognised by the miners including a schist ore (skifer malm), a massive pyritic ore (svovelkis) and a massive copper-rich ore (kopperkis). Production records for the deposit are incomplete but for the period 1867-1909, 65,000 tonnes of ore were mined with a production grade of 3.5 % Cu. Treated ore included hand picked ore with a grade of 5-12 % Cu and washed ore with a grade of 2.5-3 % Cu (Borchgrevink, 1954). Estimates based on these figures, likely remaining ore and the size of the mullock dumps for the different levels suggest a premining resource of about 100,000 tonnes of ore. At least for part of the production period the ore was roasted, crushed and sheltered in a small plant close to the mine. The plant, located on Maliseterbekken below the Gruvedam, was operated by water wheels. Ore was apparently transported from the mine to the plant by an inclined tramway. After 1904 it is likely that the ore was transported to Løkken Verk for treatment.

GENERAL GEOLOGY AND STRATIGRAPHY.

The greenstone succession in the Dragset area can be broadly subdivided into two lithological associations (Fig. 2):

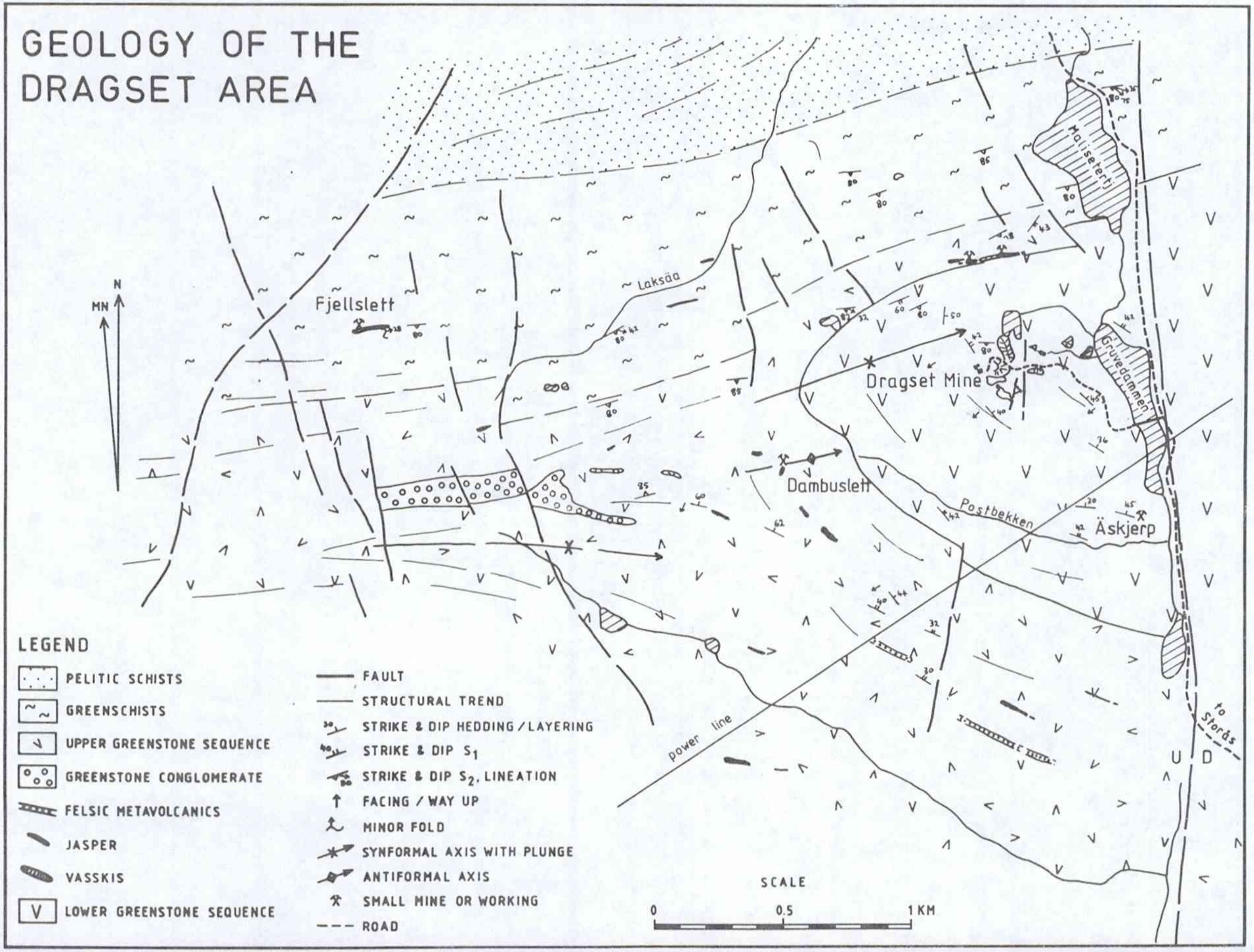
(1) In the immediate mine area and further east, the greenstones consist of massive metabasalts, pillowed metabasalts, hyaloclastitic and pillow breccias, thin layers of reworked hyaloclastite and small intrusive bodies of altered gabbro, dolerite and plagioclase porphyry. This sequence is devoid of siliceous or pelagic metasediments and does not appear to contain any vasskis (sulphidic chert) layers. Pillow morphologies in the less deformed pillow lavas clearly indicate that the sequence is upside down.

(2) Stratigraphically above (structurally below) this sequence and outcropping mainly to the west and south of Dragset is a sequence of pillowed and massive metabasalts with numerous intercalated jasper and vasskis layers, some conglomeratic units and minor felsic metavolcanics. Altered dolerite dykes cut the metabasalts but coarser grained metagabbros have not been observed. Pillowed metabasalts generally show close packed pillows and much less interpillow hyaloclastite material than the pillowed metabasalts in the lower sequence.

The two sequences are well defined by aeromagnetic data, with vasskis units in the stratigraphically higher sequence giving prominent magnetic anomalies (due to contained magnetite). These two distinct sequences appear to correlate with the two subgroups of upper and lower metavolcanics recognised by Greene et al. (1980) in the Løkken-Høydal area. Detailed analysis of major and trace element data for the host rocks at the Dragset deposit should help determine whether these rocks belong to the lower metavolcanic group.

All of the greenstones have undergone low grade regional metamorphism and show varying degrees of deformation. Metamorphic mineral assemblages in mafic, pelitic and felsic rocks (Table 1) are consistent with a greenschist facies grade of metamorphism. It is not possible to determine the precise pressure-temperature conditions of metamorphism from the presently defined mineral assemblages and compositions, however broad limits can be put on the grade using the following criteria.

Figure 2.



GEOLOGY OF THE DRAGSET AREA
N
MN
Fjellslett
Laksåa
Malisetertj
Gruvedammen
Dragset Mine
Dambuslett
Postbekken
Åskjerp
power line
to Stordås
U
D
LEGEND
PELITIC SCHISTS
GREENSCHISTS
UPPER GREENSTONE SEQUENCE
GREENSTONE CONGLOMERATE
FELSIC METAVOLCANICS
JASPER
VASSKIS
LOWER GREENSTONE SEQUENCE
FAULT
STRUCTURAL TREND
STRIKE & DIP HEDDING / LAYERING
STRIKE & DIP S1
STRIKE & DIP S2, LINEATION
FACING / WAY UP
MINOR FOLD
SYNFORMAL AXIS WITH PLUNGE
ANTIFORMAL AXIS
SMALL MINE OR WORKING
ROAD
SCALE
0
0.5
1 KM

Absence of prehnite-pumpellyite and pumpellyite-chlorite-quartz bearing assemblages in mafic rocks suggest temperatures above 350°C for pressures of 2-4 kb (Winkler, 1979). Stability of muscovite-chlorite-quartz assemblages and absence of biotite, staurolite, cordierite and aluminous silicates in pelitic schists indicate an absolute maximum temperature of less than 500°C.

The typical assemblage of albite-actinolite-chlorite-epidote-sphene in metabasalts and particularly the presence of albite rather than oligoclase and the presence of stilpnomelane and chloritoid in some greenstones suggest a temperature between 350° and 450°C (Winkler, 1979). An estimate of pressure is not possible at this stage however metamorphic pressures are likely to have been less than 4 kb, given the tectonic setting and structural position of the Støren Group in the Trondheim Nappe Complex.

TABLE 1. METAMORPHIC MINERAL ASSEMBLAGES AT DRAGSET.

Metabasalts, metadolerites and basic metasediments:

albite (An_{5-10}) - actinolite-chlorite-epidote/clinozoisite-sphene±calcite.
albite-stilpnomelane-chlorite-actinolite-sphene-calcite±epidote.
plagioclase-chlorite-quartz-epidote-sphene.

Metagabbros:

plagioclase-amphibole-clinopyroxene(relict)-chlorite-epidote-sphene±quartz.

Metapelites:

muscovite-chlorite-quartz-plagioclase-carbonate.

Meta felsic volcanics:

sericite-quartz-plagioclase-chlorite.

Chloritoid is reported in some greenschists (Chaplow, 1968).

STRUCTURE OF THE DRAGSET AREA.

The major structural feature of the Løkken area is an approximately east-west trending synform, referred to as the Løkken synform. The Dragset deposit occurs near the western closure of this structure, close to the main axis (Fig. 2). In this area the synform plunges 35° east, but further to the east near Løkken, the axis has a more gentle westerly plunge. Detailed structural measurements in the Dragset area (Fig. 3) and reconnaissance traverses further east (mainly along the Svorkmo-Storås road) indicate that the synform is asymetric with a steep, south-dipping and strongly deformed northern limb, and a moderate north-dipping southern limb. Facing evidence from throughout the Løkken-Dragset area indicates that the stratigraphy is generally overturned within this structure. South of the major synform the Løkken greenstones and Lower Hovin Group rocks appear to be folded into a series of tight antiforms and synforms, while on the northern side these rocks are thrust faulted against older and higher grade metamorphic allochthonous rocks of the Gula Group (Wolff, 1976).

In the Dragset area, folding associated with formation of the Løkken synform (here designated F_2) affected on earlier tectonic surface (S_1) as well as the primary stratigraphic layering (S_0). An axial plane surface (S_2) was heterogeneously developed during this F_2 folding. In the southern and central parts of the area this surface is generally seen as a weakly developed spaced cleavage but towards the north it becomes progressively more penetrative and in the tight northern limb of the synform is a well developed schistosity. Pillow structures in the metabasalts show a parallel increase in strain. In the south these are weakly deformed but towards the north show rotation and flattening parallel to cleavage, as well as development of an anastomosing foliation in the interpillow zones. With higher strain, the pillow interiors become foliated and pillow rims show tight isoclinal folding and transposition parallel to the S_2 foliation. Ultimately the rock becomes a greenschist with only minor, stretched pillow rim fragments to indicate its original nature.

The earlier S_1 surface also shows a heterogeneous imprint throughout the greenstone sequence and is generally subparallel to original layering (Fig. 3). At its strongest development, S_1 is a penetrative cleavage or fracture surface but in less deformed rocks it can be defined by a weak fracture direction, flattening of pillows and amygdales and elongation of clasts in fragmentary rocks.

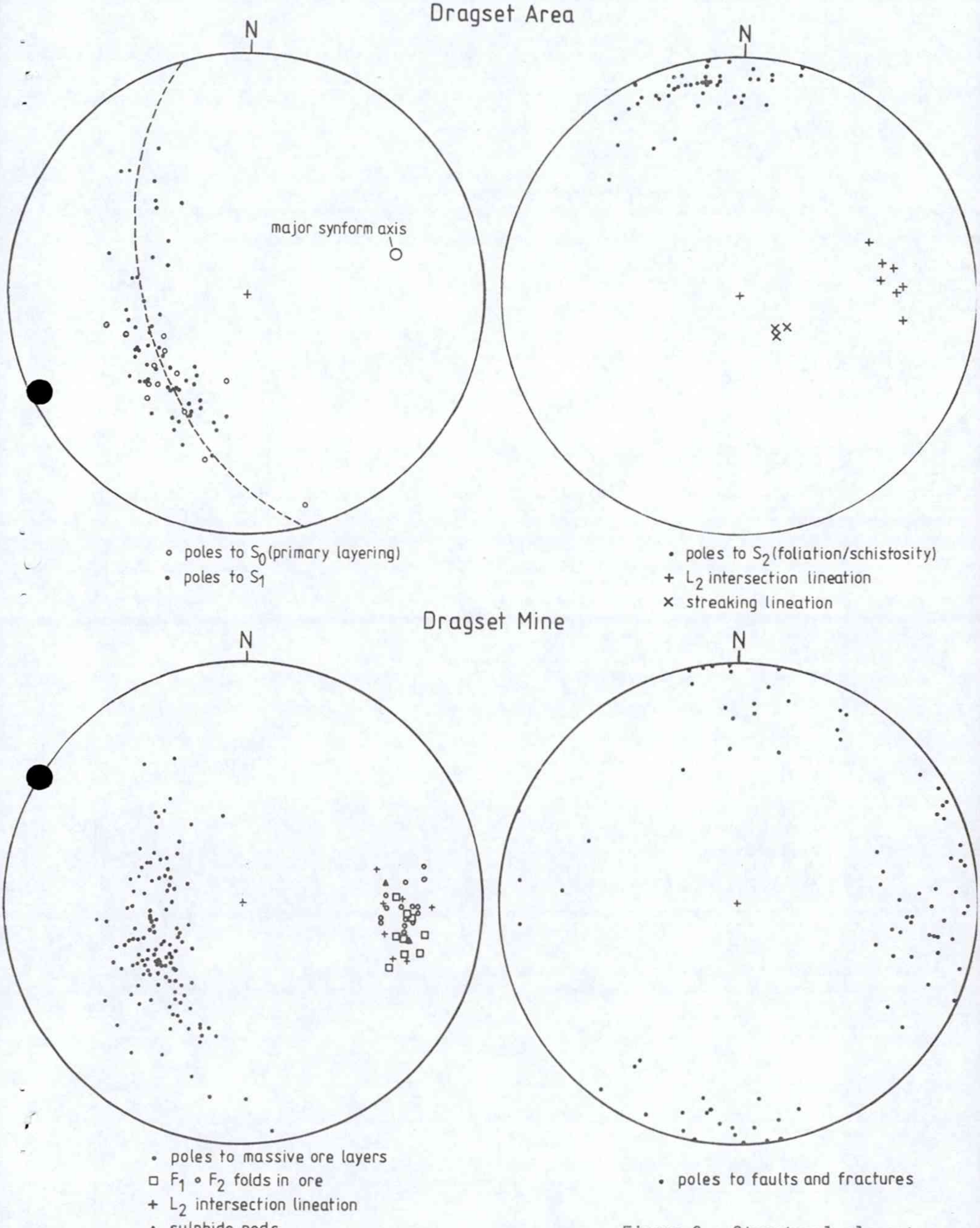


Figure 3. Structural elements.

Lack of well defined marker units and limited exposures make it difficult to interpret this surface, however observations of deformed massive ore layers in the Dragset deposit suggest that S_1 is related to an early stage of large scale recumbent folding (designated F_1). Where ore layers have been affected by recumbent F_1 folds, S_1 is developed as an axial planar surface to these folds and is folded by small scale, open F_2 folds. Low strength and multi-layered parts of the greenstone stratigraphy (including the ore sequence) appear to have preferentially accommodated strain associated with the F_1 deformation.

Several lineations are developed in the deformed rocks including a common S_1-S_2 intersection lineation (L_2), with approximately the same orientation as F_2 fold axes (Fig. 3). In some areas where the greenstones contain bedded tuffaceous or sedimentary units, an aggregate streaking lineation is developed in the S_1 surface and is apparent where this surface is parallel to S_2. This lineation has been affected by the later F_2 folding and development of S_2. On the northern limb of the Løkken synform the S_2 schistosity commonly shows a crenulation lineation and minor kink folding presumably related to deformation subsequent to F_2. The crenulation shows a variable pitch, generally between 25° and 50° to the east.

Brittle deformation of the greenstones has produced several groups of faults including: (1) large low angle thrust faults; (2) major high angle faults; and (3) numerous smaller faults and fractures. Major low angle thrusts have sliced up the greenstone sequence to the east of the Dragset area (e.g. just west of the Orkla River and above the Løkken orebody) but only small scale thrust faults have been observed near Dragset. Some of the large thrusts, including the one above the Løkken orebody, appear to have had a protracted history of movement (R. Juhavo, pers. comm.). The major high angle faults show mainly vertical displacements and generally trend approximately north-south, although in the center of the synform east of Løkken Verk, a group of these faults appear to form a conjugate set with ENE and WNW trends. A major north-south fault in the eastern part of the Dragset area clearly offsets the stratigraphy and associated aeromagnetic trends on both the north and south limbs of the Løkken synform. Calculations based on the limb offsets and respective dips indicate a vertical displacement of approximately 500 m with a downthrow on the eastern side. The high angle faults have exerted some control on the drainage pattern and can generally be detected from aerial photo interpretation.

Several of the large north-south faults control the major north flowing streams in the region (e.g. Bjøråa, Orkla and Løkken valleys). Other smaller faults and fractures can be seen cutting the stratigraphy throughout the area. These shows various orientations and are commonly developed normal to the limbs of the Løkken synform and also subparallel to the axial surface of this structure.

STRUCTURAL HISTORY AND INTERPRETATION.

The regional deformation history involved emplacement of the greenstone sequence (Støren Nappe) as part of the Trondheim Nappe Complex, probably by overthrusting (Oftedahl, 1980). Several periods of folding, possibly before or during and after nappe transport, produced the present configuration of folded nappe layers (e.g. Wolff and Roberts, 1980). The observed structures in the Dragset area and at the Dragset deposit are consistent with two main phases of deformation. A third phase can be inferred from minor kink folding and crenulation of the S_2 surface and plunge reversals of the main F_2 synformal axis. Studies in other parts of the Trondheim Nappe Complex (e.g. Olesen et al., 1973; Guezo, 1978; Rickard, in press) suggest an earlier deformation, not evident at Dragset, so that the F_1 and F_2 folding events described here possibly equate with regional F_2 and F_3 phases of folding.

A structural synopsis for the Dragset-Løkken area and the orebody at Dragset is presented in Fig. 4. The deformation history involved early large scale, isoclinal folding (local F_1) which produced recumbent folds and an axial planar surface (S_1). Subsequent open folding (local F_2) deformed the stratigraphic layering and S_1 surface and produced the upright but asymetric Løkken synform. A steep, south dipping axial plane surface (S_2) was variably developed during this folding, showing its strongest expression in the steep, highly strained northern limb of the synform. A progressive increase in strain across the synform resulted from more intense deformation and tighter parasitic folding within the northern limb. This implies that the zone of greenschists along the northern side of the synform developed during the F_2 folding and not as the result of later shearing through this area. Major thrusts appear to have been initiated during or soon after the F_2 folding, as they have not been folded by the F_2 synform. Thrusting may have been in response to compressive stresses related to irregular shortening and space constraints within the core of the Løkken synform. The thrust faults also acted as the locus for further movement during later deformation.

SEQUENCE OF STRUCTURAL DEVELOPMENT IN THE DRAGSET AREA
AND DRAGSET SULPHIDE DEPOSIT

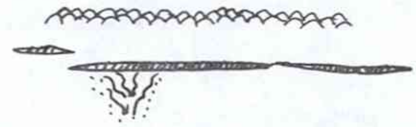
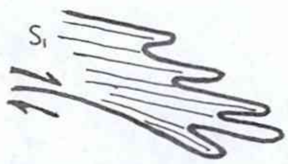
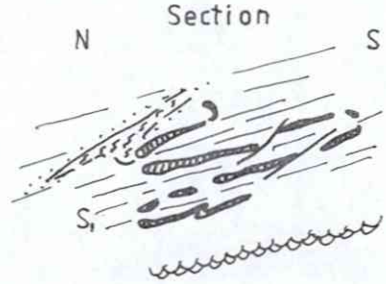
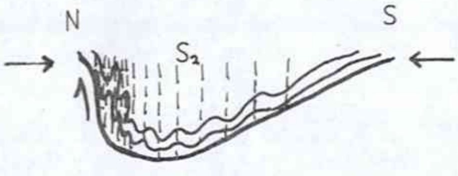
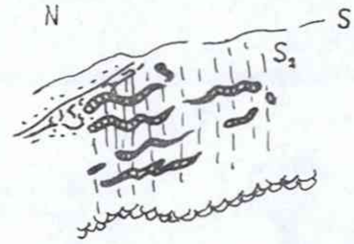
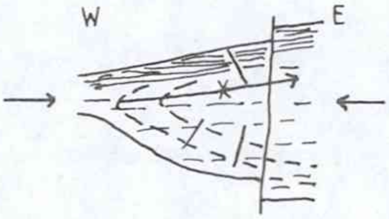
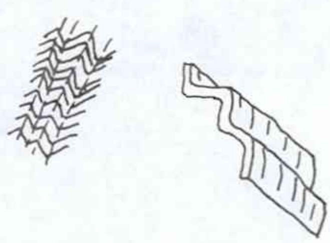
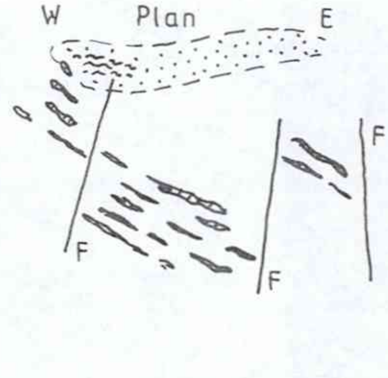
REGIONAL STRUCTURES	PHASE	DRAGSET DEPOSIT
	1. Deposition - S_0	
Overthrusting(?)	2. Nappe emplacement(?) Inversion of sequence Pre F_1 deformation	
 large recumbent folds	3. F_1 folding - S_1 isoclinal recumbent	
 Løkken synform	4. F_2 folding - S_2 upright open Thrusting (?)	
	5. Post F_2 deformation crenulation cleavage kink folding faulting 	

Figure 4. Structural synopsis.

High angle faults appear to have formed during east-west compression along the axis of the Løkken synform after the F_2 folding. This late deformation may also account for the plunge reversals along the main synformal axis and the minor kink folding and crenulation of the axial plane surface (S_2). The smaller faults and fractures probably include early structures related to the larger cross-cutting high angle faults as well as some faults, including normal faults, related to post-compression stress relief within the synform.

SOME OBSERVATIONS ON THE REGIONAL GEOLOGY.

Rocks of higher metamorphic grade outcrop north of the Løkken synform and include amphibolites, muscovite-biotite schists and gneisses. An amphibolite collected 1 km north of Laksøyan on the Storås-Hoston road contained the assemblage hornblende-clinopyroxene-calcic plagioclase-quartz. These rocks structurally underly, and are probably in thrust contact with, rocks in the synform which in this area include schistose greenstones, deformed mafic metasediments, limestones and dark phyllitic rocks (original calcareous shales). The high grade rocks have been referred to as Gula Group (Wolff, 1976) but Kollung (1985) has recently proposed a number of separate nappes and thrusted units in this area, containing both high and low grade metamorphic rocks. Kollung also interprets thrust boundaries between the Løkken Greenstones (metavolcanites) and the dark phyllites outcropping just south of Laksøyan, and suggests inthrusting of a narrow limestone lens within the greenstones. Reconnaissance observations by the author suggest that these rocks could be structurally conformable with the Løkken Greenstones and may be part of the Lower Hovin Group. The upper part of the greenstone sequence here contains greenschists derived from metabasalts and mafic sediments or reworked tuffs. Similar rocks occur further east on the Svorkmo-Storås road several kilometers south of Svorkmo (Fig. 1). The rocks at this locality include highly deformed schists which were probably formed from a mixed sequence of greenstones, greenstone tuffs or sediments and some pelitic sediments. Some of the metasediments contain what appear to be deformed pebbles of greenstone and chert. On the southern side of the Løkken synform, just north of Storås a new limestone locality has been found in excavations for a new garage (Fig. 1). This limestone structurally underlies greenstones and may even be within the greenstone sequence. It is possible that this limestone and the one shown within the greenstones on Kollung's map are in fact interbedded with the greenstones and not inthrusted slices. If the above interpretations are correct then it appears that the upper part of the Løkken Greenstone sequence contains a significant sedimentary component in some areas.

THE DRAGSET DEPOSIT.

Host Rocks.

The sulphide deposit at Dragset occurs within the stratigraphically lower sequence of the greenstone succession (Fig. 2). The host rocks are massive and foliated, fine grained metabasalts with some altered dolerite dykes. These dykes cut both the massive and disseminated feeder zone ores as well as the enclosing metabasalts. The metabasalts appear to have been mainly sheet flows (1-6 m thick) with some pillowed layers and interflow hyaloclastitic-pillow breccia zones. Some of the flows appear to be fractionated and show compositional and textural differentiation, with darker, stilpnomelane rich (more Fe rich, less magnesian and less aluminous?) zones stratigraphically overlying, greenish-grey metabasalt and pillowed flow contacts. The greenstones enclosing the massive ore lenses are strongly foliated and fractured, with abundant calcite veining. The structural hangingwall to the ores (stratigraphic footwall) contains more abundant pillowed zones and hyaloclastitic breccias. Dyke-like bodies of mafic plagioclase porphyries have also been observed in drill core of these rocks. The rocks structurally below the ore zone are mainly massive sheet flow metabasalts showing a blocky polygonal jointing, but 80 m below the ore (higher up in the stratigraphy) there is a prominent zone of pillowed metabasalts with numerous metadolerite dykes. Pillow morphologies in this unit clearly indicate that the mine sequence is inverted and hence that the orebody is upside down. Unlike the Løkken and Høydal deposits there are no jasper or vasskis layers associated with the ores.

Petrographic observations of the host greenstones show that they are generally deformed and strongly metamorphically recrystallised with few relict igneous textures close to the ores. The rocks commonly consist of decussate and fascicular actinolite, overprinting albite, with granular epidote and irregular patches of chlorite. Ubiquitous sphene occurs in small dispersed aggregates or in aligned clusters of tiny grains. Epidote, calcite and quartz occur in secondary veins. In strongly foliated rocks the S_1 foliation appears to be defined by aligned aggregates of sphene, epidote and in some cases chlorite. This surface probably formed during or just after the regional metamorphism. At the mine, the S_2 surface is defined by micro fractures, calcite-quartz veins and some chlorite veins, and clearly post-dates the metamorphism.

Where S_2 is a more penetrative schistosity (e.g. north of the Dragset deposit) the rocks show preferred orientation of chlorite and sphene aggregates, breaking up and realignment of amphibole prisms parallel to the schistosity and rotation of epidote porphyroblasts within this surface. These textures also attest to the post-metamorphic timing of S_2 and the F_2 folding.

The Ores

In its present form the Dragset deposit consists of a series of stacked, massive ore layers which show considerable fracturing, shearing and folding. These layers are mostly conformable with the S_1 surface in the enclosing greenstones (and probably also with the primary layering) and have been folded with this surface during subsequent (F_2) folding. To the north east of the massive ores and in the stratigraphic footwall there is also a clearly defined feeder zone (Fig. 8). This consists of chalcopyrite and pyrrhotite-veined, chloritic pods close to the massive ores, enclosed in a broader zone of chlorite altered and silicified greenstones containing fine disseminations and veinlets of pyrite.

1. Ore Structures and Geometry.

Two groups of folds are preserved in the massive ores, including: early isoclinal, recumbent folds of the ore layers and primary layering; and upright open to tight folds of ore layers and the S_1 foliation (Fig. 5). The recumbent folds are generally only defined by ore layers where these are thin. More commonly the massive pyritic ore has broken up in the hinge zones of these folds, resulting in segmented or separated massive ore lenses. Shear movements parallel to the axial planes of the recumbent folds have also caused some imbrication of the massive ore layers. Where folds are still preserved they show a plunge of approximately 30° towards the ESE (Fig. 3). It is generally impossible to determine facing in these folds, but at the extreme northwest end of the deposit, stratigraphically lower feeder zone rocks have been folded around a segmented massive ore hinge, indicating facing to the south (Fig. 5A). The upright folds tend to be more open structures and are common on a mesoscopic scale in the remnants of ore in the mine workings. These folds are almost coaxial with the recumbent folds (Fig. 3) but are clearly later structures as they fold the axial surface to the recumbent folds. Some of the massive ore layers appear to show thickening in the hinge zones of these upright folds.

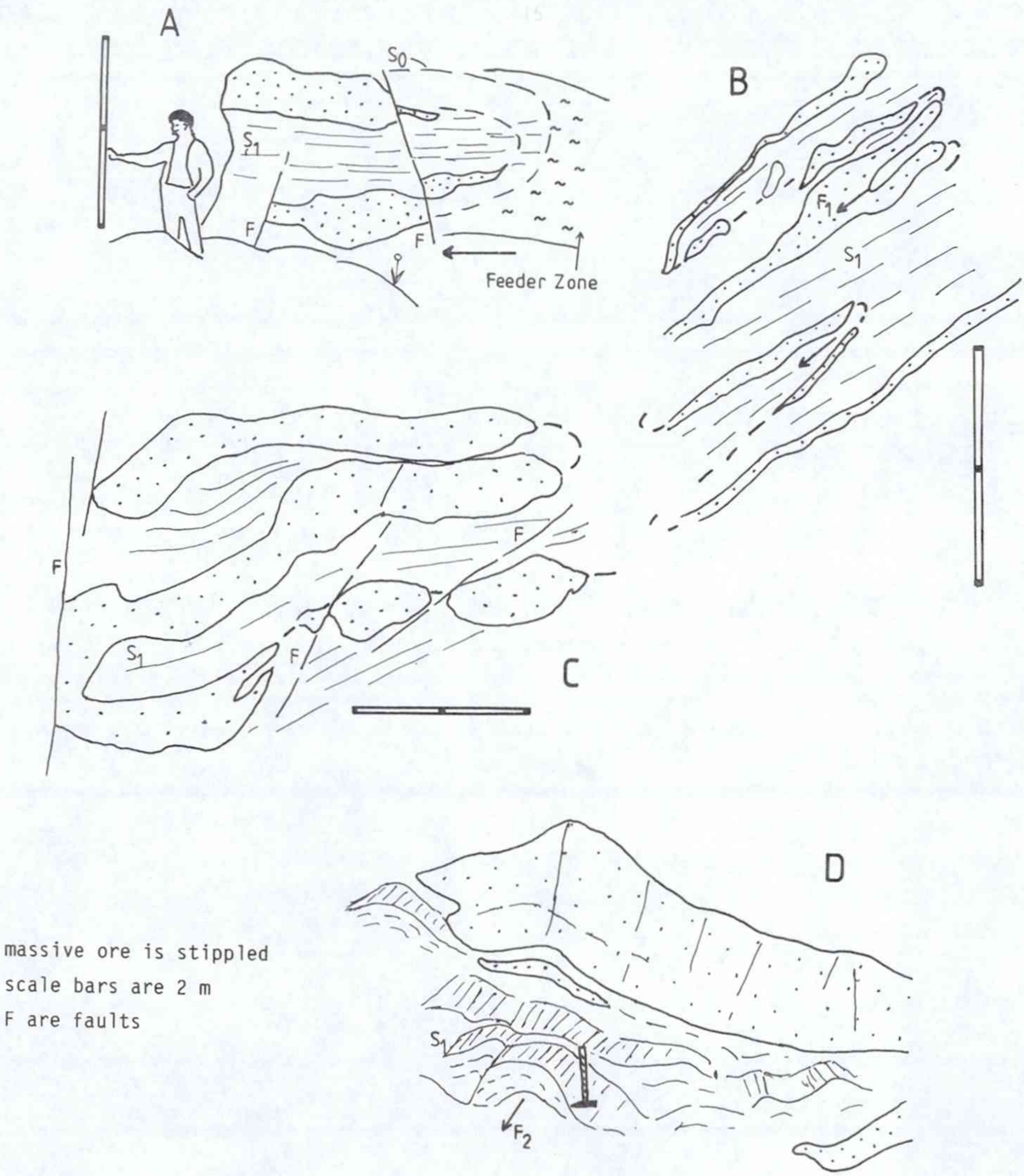


Figure 5. Sketch views of mesoscopic ore structures at the Dragset deposit.
A. Disrupted F_1 fold of massive sulphide layer. Arrow indicates facing.
B. Isoclinal F_1 folds of thin massive sulphide layer to produce separate stacked layers.
C. Ore layer showing recumbent isoclinal F_1 folding, hinge disruption and break up of limbs by low angle shearing. The ore and S_1 surface are also affected by F_2 folding.
D. Segmented and thickened massive ore layer showing F_2 folding.

As well as affecting the form of the massive ores the folding has largely determined the present orientation of the orebody, such that the massive ore layers now lie parallel to the regional S_1 direction and the ore zone as a whole is elongated parallel to the F_1 (and F_2) fold plunge direction. This structural control is obviously an important consideration in exploring for extensions to the ore in this and other environments in the Løkken synform.

The behaviour of the massive pyritic ores during folding, particularly the F_1 folding, is interesting. The massive ore layers appear to have deformed in a semi-ductile manner, initially forming folds which then broke up by brittle failure in the hinge zones, probably as the folds tightened. This break up, together with movements along the axial surface direction, resulted in the series of separate multiple ore lenses mainly representing the isoclinal fold limbs. Evidence for the folding in the form of fold hinges is therefore rarely preserved in the massive ore layers. It is planned to investigate the reasons and mechanisms for this type of deformation behaviour in more detail.

The massive ore zone has also been considerably affected by late stage faulting. These faults are mostly vertical or steeply dipping structures with a range of strikes (Fig. 3) but including two prominent directions, roughly east-west and north-south or slightly east of north. Movement has been mostly vertical with a strike slip component in some cases. Block faulting about three major fault zones has produced significant offsets of the north-east dipping massive ore layers (Fig. 8). In the southwest of the deposit massive ores also appear to have been rotated within a wide fault zone.

The feeder zone ores have also been affected by the deformation. These ores now occur in the structural hangingwall of the deposit since the sequence has been structurally inverted. Parts of the feeder zone are strongly foliated (pencil schists) with pronounced development of both the NE dipping S_1 and steeply dipping S_2 surfaces. This is probably due to the greater chlorite content of the altered feeder zone rocks, particularly in areas close to the massive ores. The broad zone of pyrite veining and dissemination is now oriented parallel to the fold plunge trend (Fig. 8) and appears to plunge east. Cores from five diamond drill holes around the feeder zone were examined to try and establish its three dimensional form. This was thought to be important as the plunge of the intersection of the massive ore layers and the feeder system or exhalative vent should define the original direction of the ore-forming system.

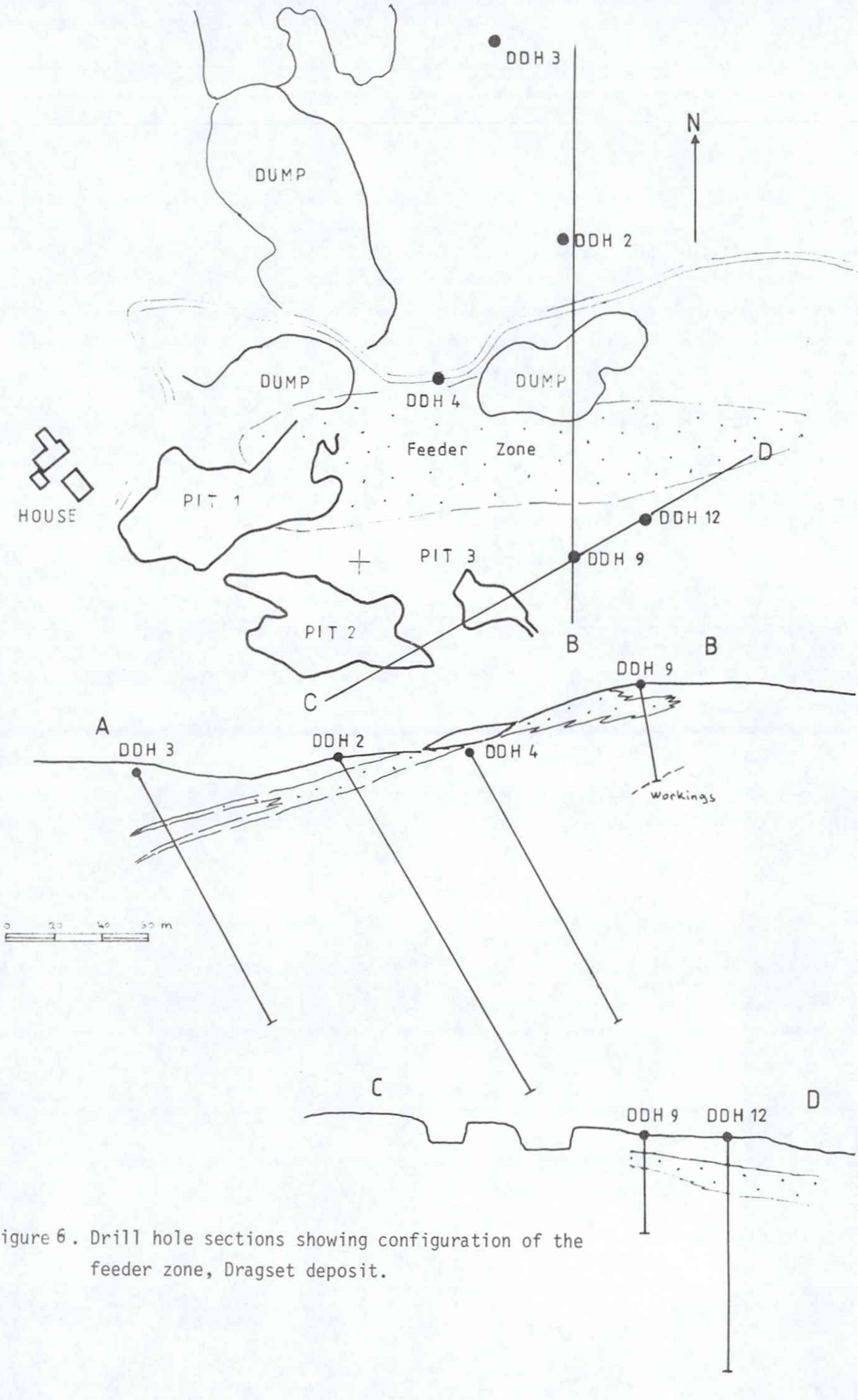


Figure 6. Drill hole sections showing configuration of the feeder zone, Dragset deposit.

The results of the drill core logging are shown in Fig. 6. It appears that the feeder system is very irregular, dips at a low angle to the northeast and has flattened in the S_1 direction. The intersection plunge is probably about 20° to NNW. The feeder system appears to be very shallow close to the massive ores, and most of it was probably higher up dip so that it is now eroded away. This might also suggest that a large part of the massive ore zone has also been eroded away.

1. Ore Types, Mineralogy and Textures.

Two main ore types are present at Dragset: disseminated feeder zone ores; and massive pyritic ores. A number of subtypes can also be recognised. The feeder system contains zones of highly chloritic, disseminated ore with abundant chalcopyrite-pyrrhotite veinlets and lesser pyrite, as well as areas with finely disseminated pyrite and pervasive pyrite veining containing only traces of base metal sulfides. Massive ore subtypes include: fine grained pyritic ore with minor chalcopyrite and sphalerite; highly siliceous and coarser pyritic ore developed near the feeder zone; and chalcopyrite- and sphalerite-rich pyritic ores, some showing banding. The mineralogy of the main ore types is summarised in Table 2.

Common fabrics in the massive ores include an irregular banding, generally defined by sphalerite-rich layers a few mm to several cm wide. In some cases the banding is subparallel to the margins of the massive ore layers but in other areas it may be folded or very irregular and appears to have been disturbed during the deformation. Chalcopyrite-rich zones and patches can be seen in the Cu-rich massive sulphides. Small veins of remobilised chalcopyrite are common around the massive ores and also cut included greenstone and chloritic layers within the ore. The very pyritic massive sulphides commonly show a very fragmentary type of texture with brecciated, irregular and angular fragments or blocks veined by coarser grained and possibly recrystallised pyrite. Chalcopyrite can also be concentrated in these veins. The veins are 1-5 mm wide and clearly formed later than the fine grained pyrite. This fabric appears to be tectonic but more detailed studies are required to confirm this.

Preliminary mineragraphic observations have revealed a variety of interesting textures in the massive and feeder zone ores.

TABLE 2. ORE MINERALOGY AT DRAGSET.

	Massive Ores	Feeder Zone Ores
Primary minerals	Pyrite	Chalcopyrite
	Chalcopyrite	Monoclinic pyrrhotite
	Sphalerite	Pyrite
	Monoclinic pyrrhotite	Sphalerite
		Cobaltite (?)
	Magnetite	
Secondary minerals	Pyrite	
	Mackinawite	
	Goethite	
Gangue Minerlals	Quartz	Chlorite
	Actinolite	Albite
	Chlorite	
	Calcite	
	Plagioclase	

Massive pyritic ores generally consist of aggregates of fine grained (0.02-0.6 mm) subhedral pyrite with intergranular, anhedral chalcopyrite, minor sphalerite and gangue. The pyrite grains and aggregates commonly show chalcopyrite "healed" microfractures. Some ores contain larger pyrite subhedra (up to 3 mm in diameter), particularly where the pyrite has developed in a dominant chalcopyrite or sphalerite matrix. Pyritic ores close to late-stage faults preserve evidence of cataclastic deformation including extreme granulation of the pyrite and numerous trans-aggregate fractures. There are a number of texturally different pyrite types, possibly representing different generations of growth or recrystallisation. These include coarser grained, probably recrystallised, pyrite with numerous small (<0.03 mm) inclusions of chalcopyrite, sphalerite, pyrrhotite and gangue minerals. Most of the foreign inclusions were probably incorporated during recrystallisation growth of the pyrite, however the very small pyrrhotite inclusions may have formed in response to small scale compositional readjustments in the recrystallising pyrite. They probably reflect a slight increase in FeS activity in the pyrite due to small losses of sulphur during deformation and recrystallisation. Other pyrite types observed are inclusion free, fine grained pyrite; very fine pyrite showing symflectite-like intergrowth with chalcopyrite; and porous pyrite developed as rims around earlier pyrite subhedra. The latter may be a supergene pyrite.

Copper-rich massive ores generally consist of subhedral pyrite grains dispersed through a chalcopyrite matrix. There are no examples of chalcopyrite occurring in separate aggregates without pyrite except in some small remobilised chalcopyrite veins.

Sphalerite appears to have two modes of occurrence in the massive ores. In low-Zn ores it occurs as a minor phase in small anhedral aggregates associated with chalcopyrite and as small inclusions in pyrite. Some of these inclusions show chalcopyrite desease, however the sphalerite intergranular to pyrite is free of this texture. In Zn-rich banded ores additional sphalerite occurs in separate zones that pervasively "flood" through the pyritic host. Pyrite inclusions and margins to these bands are highly irregular and embayed suggesting that the sphalerite might be replacing the pyrite. The sphalerite-rich zones also commonly contain abundant subhedral grains of magnetite (0.02-0.5 mm), some with rimming aggregates of pyrrhotite, as well as small blebs of minor chalcopyrite. The magnetite may reflect a higher fO_2 during sphalerite deposition or its development could possibly be related to later reaction of oxidised(?) Zn-bearing fluids with pyrite to form the sphalerite.

Monoclinic pyrrhotite is a common trace constituent in the massive ores and in some areas comprises 5 % of the sulphides. In addition to forming small inclusions in pyrite, the pyrrhotite occurs as larger, irregular aggregates, mostly associated with chalcopyrite. The greater abundance of pyrrhotite distinguishes the Dragset ores from those at Løkken and Høydal. Some of the pyrrhotite shows secondary (supergene) alteration to mackinawite.

Feeder zone ores close to the massive ore zone contain intergrown chalcopyrite and pyrrhotite as the predominant sulphides, with lesser pyrite and trace sphalerite. The sulphides are associated with chlorite-albite veins cutting the altered greenstones. In one sample several pyrite subhedra contain minute grains of a white, highly reflectant mineral which resembles cobaltite.

No Ag-rich minerals, such as tetrahedrite or tennantite, have yet been found in the ores and it appears likely that minor Ag is hosted by the common sulphides. More detailed mineragraphic and electron microprobe work should provide more information on minor phases in the ores and on the distribution of minor and trace elements.

2. <u>Ore Geochemistry.</u>

Twenty two representative ore samples from the Dragset deposit were analysed, in order to determine the overall ore composition and dilineate metal trends and variations within the deposit. Massive ores were sampled at various locations by taking 1-3 kg of chips across the width of the ore layer along several continuous sections about 1 m apart. Two large grab samples were taken of the disseminated feeder zone and some sphalerite-rich massive ore was sampled by taking a large, single piece of the complete ore layer. Sample locations are shown in Fig. 8 and the analyses and analytical methods are presented in Table 3. In addition to analysing the total sulphide fraction, a magnetic separate was also taken from each sample and the amounts of magnetite and pyrrhotite determined gravimetically.

The sulphide analyses clearly reveal the high Fe content of the ores, reflecting their basic pyritic nature. There is also a surprisingly wide variation in Cu/Zn ratios throughout the orebody, ranging from 0.08 to 19.4 (mean 0.81) for the massive ores. The Ag content ranges from 4-41 ppm and there is no apparent correlation between Ag and any of the other elements. Lead values are extremely low and Pb also shows no obvious correlation with the other elements. The Co content of the ore varies between 20 and 700 ppm while Ni values are low and fairly constant. Cadmium shows strong positive correlation with Zn indicating that this element is hosted by sphalerite.

TABLE 3. ORE COMPOSITIONS FROM THE DRAGSET DEPOSIT.

	1	2	3	4	5	6	7	8	9	10	11
wt%	D1-3	D1-4	D1-13	D1-11	D1-12	D1-14	D1-16	D1-17	D2-13	D2-6	D2-7
Fe	17.8	19.5	22.9	22.2	33.7	39.8	36.4	41.2	40.2	30.1	41.6
Cu	1.83	3.74	4.38	0.166	3.59	1.34	3.15	2.68	3.89	0.154	1.30
Zn	0.058	0.059	0.226	2.18	0.137	4.35	5.80	0.986	3.09	2.40	2.47
S											
Gangue*											
Cu/Zn	32	63	19	0.08	26	0.30	0.54	2.72	1.26	0.06	0.53
ppm											
Ag	5	12	10	4	11	11	41	23	27	6	17
Pb	5	23	30	92	97	137	61	56	179	68	70
Cd	4	5	9	74	8	165	178	37	109	59	88
Co	152	130	193	35	138	58	145	277	144	43	196
Ni	55	110	55	40	60	40	50	40	80	50	45
Mn	1337	1427	200	73	129	117	247	62	96	300	240
wt%											
Magnetite	-	trace	-	-	trace	-	2.8	-	-	0.4	trace
Pyrrhotite	3.7	5.3	-	-	0.3	-	2.9	-	-	3.1	2.4

* By difference, - = not detected.

Cu, Zn, Pb, Cd, Co, Ni and Mn analysed by A.A.S. following digestion in HNO_3 and HCl. Ag by A.A.S. following HNO_3 digestion, Fe determined as total iron by titrimetric analysis. S determined gravimetrically.

1-2 Feeder Zone Ores

4-21 Massive ores

22 Sphalerite-rich ore.

TABLE 3 (Cont.)

	12	13	14	15	16	17	18	19	20	21	22
wt%	D2-11	D2-12	D2-14	D2-15	D1-8	D2-16	D2-9	D2-10	D3-7	D3-8	D1-8
Fe	38.9	37.9	34.0	37.4	36.8	43.3	38.8	40.9	40.9	33.5	33.1
Cu	6.32	3.74	0.583	1.27	0.903	0.417	0.918	1.63	2.50	2.91	1.07
Zn	0.883	1.14	7.31	1.80	2.08	1.34	2.82	2.21	4.25	6.61	19.02
S											
Gangue*											
Cu/Zn	7.2	3.28	0.08	0.71	0.43	0.31	0.33	0.74	0.59	0.44	0.06
ppm											
Ag	24	14	9	15	15	20	23	13	24	30	35
Pb	89	88	113	77	45	235	146	112	94	103	42
Cd	29	43	242	64	66	48	93	63	147	225	595
Co	690	413	42	23	108	80	209	175	368	694	121
Ni	40	50	50	40	50	40	50	50	60	70	50
Mn	98	143	128	144	535	133	116	157	161	172	201
wt%											
Magnetite	-	-	-	-	0.3	-	-	-	trace	trace	4.6
Pyrrhotite	-	-	-	-	0.9	-	-	0.4	0.8	0.2	2.6

Comparisons between average ore compositions and compositional ranges for the Løkken, Høydal and Dragset deposits can be made from Table 4. The Dragset massive ores are very similar in composition to the Løkken ores (Astrup section). The mean Cu/Zn ratio is similar, and the average total contents of Cu and Zn are approximately the same for the two deposits, with Dragset perhaps being slightly more Zn rich. The Pb and Co values at Dragset appear to be lower than those at Løkken. By comparison the Høydal ores are significantly more Zn-rich with lower Cu and higher Pb, Ag and Cd. The Zn/Cd ratios are similar in all three deposits suggesting similar Cd contents in the sphalerite.

The extreme disruption of the thin massive ores at Dragset by folding and faulting hinders attempts to examine metal variations or zoning. It is virtually impossible to reconstruct the massive ores and determine the relative positions of the now separate ore lenses and so it is very difficult to test for any positive metal trends. However the following observations can be made. Sulphides in the feeder zone and massive ores located close to the feeder system contain relatively more Cu+Fe (Fig. 7). Some of the massive sulphides appear to be more Zn-rich at the expense of Fe, and samples showing relatively higher Zn generally come from areas more distal from the feeder zone, either along the strike or up the fold stack.

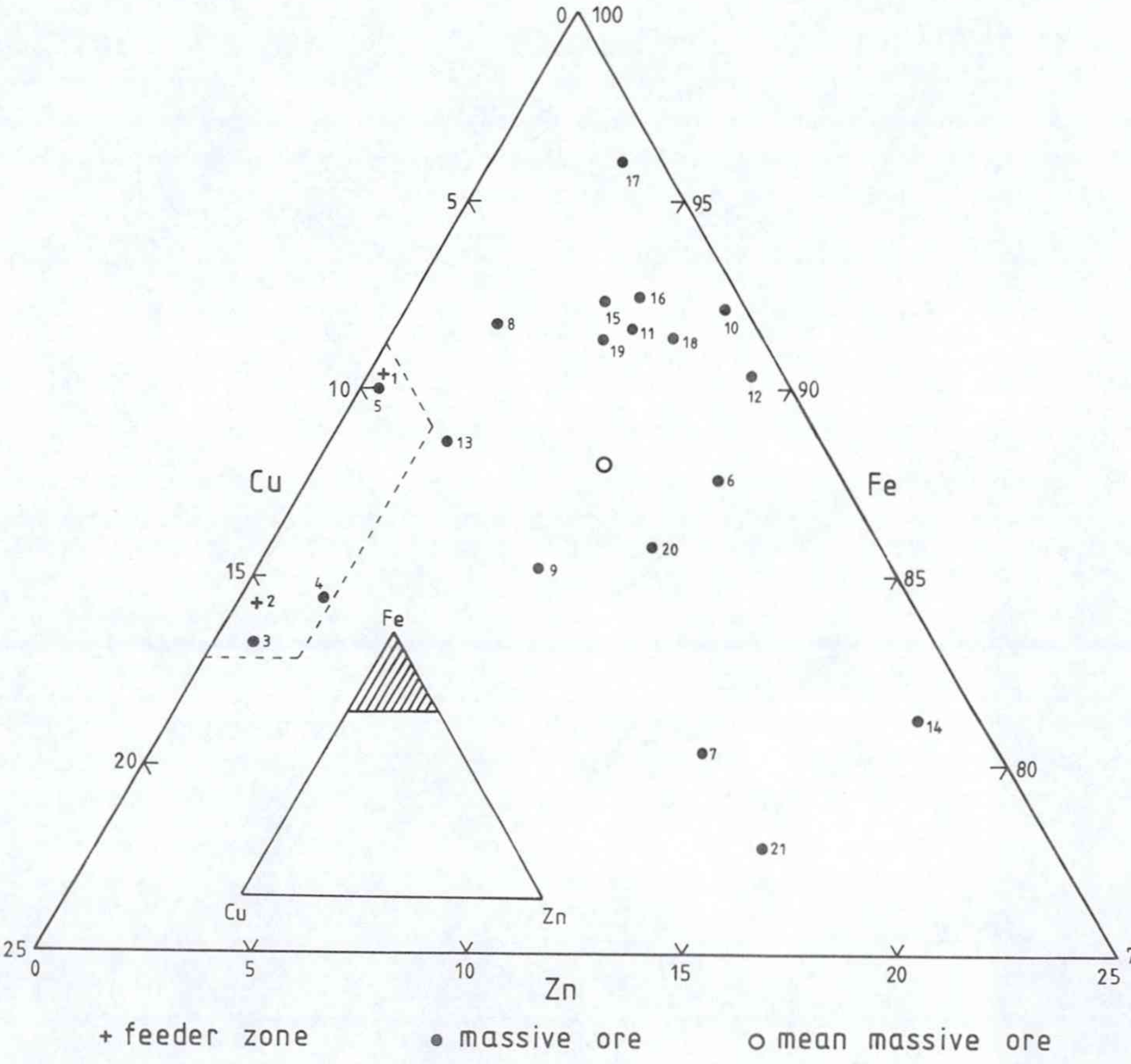


Figure 7. Ore compositions from Dragset in terms of Fe-Cu-Zn.

GEOLOGICAL PLAN OF THE DRAGSET MINE

Figure 8.

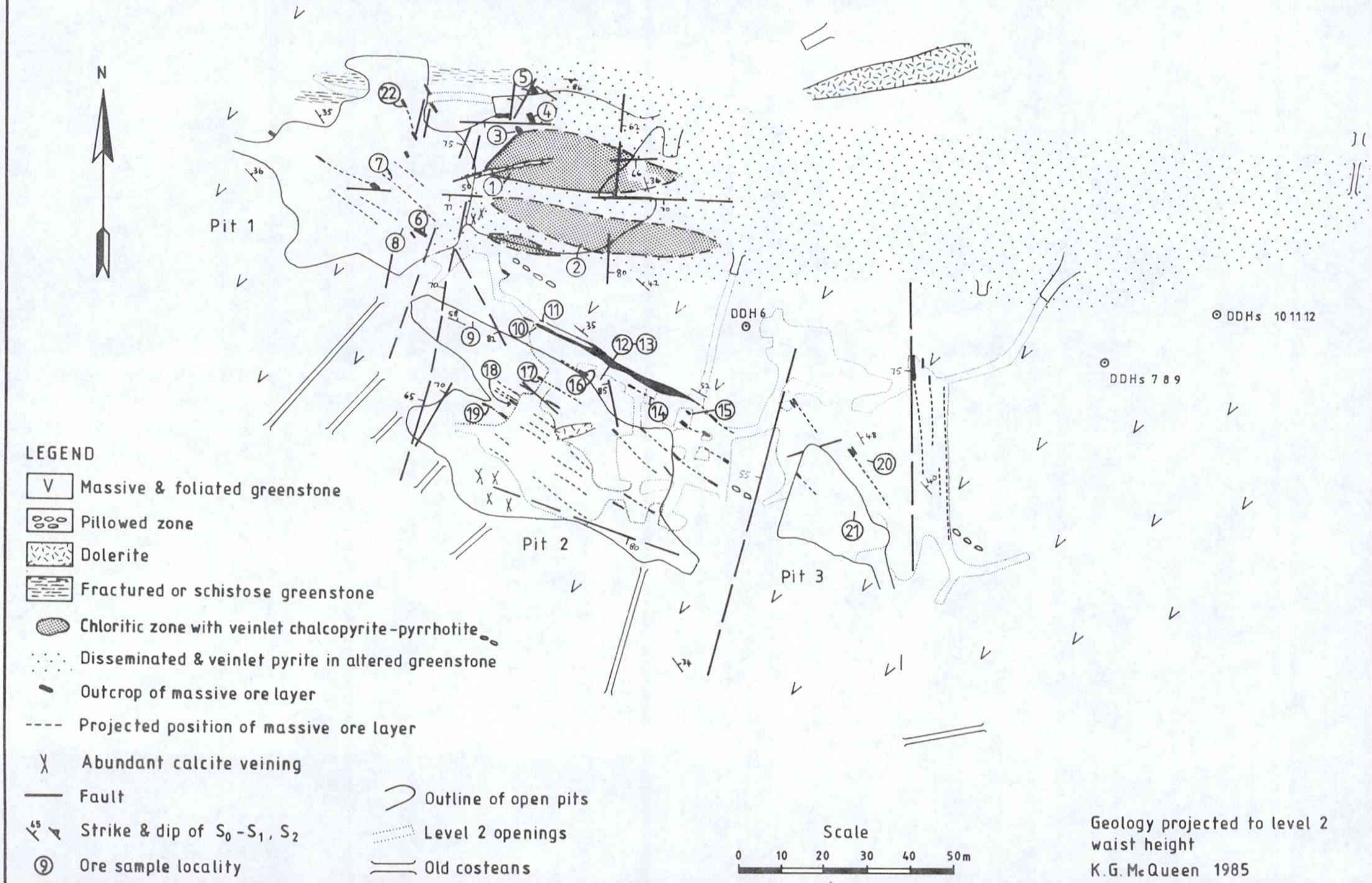


TABLE 4. MEAN COMPOSITIONS AND RANGES FOR MASSIVE ORES FROM DRAGSET, HØYDAL AND LØKKEN DEPOSITS.

wt.%	Dragset		Høydal		Løkken
Fe	36.3	(18.0-34.5)	-		-
Cu	2.20	(0.17-6.32)	1.71	(0.01-10.20)	2.15
Zn	2.73	(0.14-7.31)	7.11	(0.01-29.10)	2.35
Ag	18 ppm	(4-41)	36 ppm	(2- 115)	18 ppm
Pb	99 ppm	(30-235)	837 ppm	(32-4070)	334 ppm
Cd	92 ppm	(8-242)	208 ppm	(3- 960)	70 ppm
Co	212 ppm	(23-694)	247 ppm	(16-1910)	448 ppm
Ni	51 ppm	(40-80)	37 ppm	(11- 106)	35 ppm
Mn	171 ppm	(62-535)	121 ppm	(17- 340)	185 ppm
Cu/Zn	0.81		0.24		0.91
Zn/Cd	297		342		336
n	19		62		Continuous mill head sample (1982)

All analyses except Fe by A.A.S.

Høydal and Løkken data are from Tor Grenne (unpubl.data).

3. Ore Genesis.

A model of ore genesis for the Dragset deposit will not be present at this stage, however the following points can be made. Although the deposit has been considerably modified by deformation and low grade regional metamorphism, several features confirm a sea floor exhalative origin for the sulphides, similar to that proposed for the Løkken and Høydal deposits (cf. Grenne et al., 1980). There are two quite distinct ore types which could correspond to a fine grained, massive component deposited at the sea water-ocean floor interface from an exhalative plume or within a sulphidic mound; and a feeder system for the exhaled fluids, showing epigenetic characteristics. This makes it unlikely that the entire deposit is an epigenetic feeder system. Independant facing evidence also indicates that the feeder zone is within the stratigraphic footwall. Some of the layer conformable banding within the massive sulphides could represent original sedimentary layering although some of the sphalerite bands appear to be a later feature related to movement of Zn-bearing fluids through already deposited pyrite. The presence of some layer conformable siliceous and chloritic bands within the massive ores is also consistent with layer deposition on the sea floor.

OTHER SULPHIDE OCCURRENCES.

Within the Dragset area there are a number of minor sulphide occurrences that have been worked or prospected on a small scale. Two of these, Åskjerp and Fjellslett, contain base metal sulphides and are similar to the Dragset deposit. The others, including Dambuslett and two small workings north of Dragset, are vasskis deposits containing banded and massive pyrite with disseminated magnetite, but no base metal sulphides.

The Åskjerp deposit occurs southeast of Dragset (Fig. 2) and lies at approximately the same stratigraphic level within the lower greenstone sequence. It is an interesting occurrence as it contains both stratabound, massive pyritic ores and a small disseminated feeder zone on the eastern side. The massive ores have been worked from a small inclined stope but the amount of ore mined appears to have been small (c.a. several hundred tonnes). The workings are now flooded, however samples from the dumps include chalcopyrite- and sphalerite-rich pyritic ores very similar to those developed at Dragset. Like the Dragset deposit there appear to be no jasper or vasskis layers associated with the sulphides.

Textures in the massive ores include irregular sphalerite banding and the development of subhedral pyrite with intergranular chalcopyrite and minor sphalerite, textures typical of similar ores at Dragset. The minor feeder zone ores appear to be relatively sphalerite-rich. Minerals observed in polished section include pyrite, sphalerite, chalcopyrite, trace pyrrhotite, actinolite, chlorite and quartz.

The Fjellslett deposit occurs in highly deformed greenschists within the upper greenstone sequence and is associated with a unit of blue-grey chert and mottled jasper. Massive sulphides structurally underly the chert and are localised in a tight fold hinge which plunges approximately 25° east. There is evidence for secondary remobilisation of sulphides and quartz during deformation and the massive pyritic ores are recrystallised and slightly coarser grained than those at Dragset. Some of the ores are very chalcopyrite-rich but sphalerite appears to be less abundant than at Dragset and Åskjerp. The association of chert and jasper with the ores is more typical of the Løkken and Høydal sulphide deposits. Ore minerals observed in three samples of massive Fjellslett ore include pyrite, chalcopyrite, minor sphalerite and trace pyrrhotite and magnetite. Actinolite and quartz are the main gangue minerals.

Several vasskis outcrops within the upper greenstone sequence have been worked from small trenches and addits (Fig. 2). The purpose of these workings is unclear. It is possible that they were prospected by the early miners in the hope of finding base metal sulphides, particularly as these are known to occur close to vasskis or vasskis-like layers in some cases. It is also possible that they were worked or prospected for the contained pyrite, however the small size of the workings suggests that this is unlikely. The workings north of Dragset include a flooded addit which extends to the west for some distance (greater than 10 m). All the sulphides from this excavation appear to have been removed from the site. The vasskis layers consist of grey chert with massive layers, disseminations and cross-cutting veinlets of fine granular pyrite. Magnetite occurs as disseminated octahedra in massive pyrite and small grains dispersed through chert. Disseminated pyrite and magnetite are also present in adjacent, foliated greenstones. The vasskis are closely associated with jasper horizons in the greenstones occurring along strike from, or in some cases lying directly beneath jasper beds.

CONCLUSIONS AND IMPLICATIONS OF THE STUDY.

Although this study of the Dragset deposit is not yet complete some preliminary conclusions, ideas and suggestions can be presented at this stage. Some of these may need modification as additional data come to hand.

Structural Aspects.

One important finding of the study is the evidence for major tectonic modification of the Dragset deposit. Deformation associated with at least two major stages of folding has produced the present multiple-lens form of the deposit and affected the overall geometry and orientation of both the massive ores and associated feeder zone system. Understanding this structural control is clearly important in exploring for more ore. Extensions to ore would most likely occur along the plunge of the F_1 folds and possibly parallel to the massive ore feeder zone intersection. Later block faulting has also obviously affected the configuration of the massive ore layers.

The Dragset ores also illustrate well the style of massive ore deformation which is probably common for this type of deposit under low grade metamorphic conditions. Semi-brittle deformation of the pyrite-dominated sulphides allows initial folding of the ore layers but results in ultimate disruption of the hinge zones by brittle failure and imbrication. This can make it difficult to see the evidence for folding, particularly where the ore layers are thick. This finding has implications for understanding the nature of the major Løkken deposit which has probably been deformed in a similar way. Some cursory inspections of the main Løkken orebody revealed that the thick separate ore lenses appear to show no clear evidence for major tectonic folding. However, where the ore layers are thinner, for example in the recently discovered ore lens in the ramp (decline), fold structures very similar to those at Dragset can be seen. At this locality the ore lens has been folded over on itself in a large scale, recumbent isoclinal fold (F_1?) with a low plunge to the north. The massive sulphide layer shows disruption by brittle fracture in the hinge zone and there is also a high angle thrust across the hinge. Similar fold structures occur further down the ramp and these have low angle plunges to the north or northwest. Some small upright folds of the ore layer (F_2?) can also be seen in this area. In other parts of the deposit thrust structures appear to be important in controlling the configuration of the ore masses and these could be related to large scale folding.

Copper and zinc distributions in parts of the thick ores can also be interpreted as being the result of folding (Risto Juhava, pers. comm.). In view of these observations a detailed investigation of the ore structures at Løkken is probably warranted. This could give a better understanding of the major ore controls and the likely distribution of ore extensions.

One puzzling feature of the deformation in the Dragset-Løkken area is the apparent lack of major deformation in the greenstones around the sulphide deposits. The sequence also seems to be largely inverted with no major facing reversals to indicate megascopic folds. These features may be partly due to the fact that the greenstones contain few marker horizons which could define the strain and the major folds. It is also possible that the strain has been grossly heterogeneous within the deforming pile, with most of the deformation being taken up by parts of the stratigraphy containing layers of differing competence (e.g. the ore sequences).

Genetic Aspects and Implications for Exploration.

Mapping of the greenstones in the Dragset area and comparisons with the succession further east, suggests that the Dragset and small Åskjerp deposits occur at a lower stratigraphic level than the Løkken and Høydal deposits. The latter lie on the same horizon within the upper metavolcanic sequence, close to the lower contact of this subgroup with the lower metavolcanics (Grenne et al., 1980). If this interpretation is correct then it means that the Dragset and Åskjerp occurrences could represent another mineralised level and that the lower parts of the greenstone succession are prospective for massive sulphide deposits, not just the boundary between the lower and upper greenstones.

Reconnaissance observations of metabasalts and gabbros from areas in the lower greenstones away from sulphide deposits indicate that minor and trace sulphides are widespread in these rocks. Results of a recent lithogeochemical study of the Løkken greenstones (G. Grammeltvedt pers. comm.) also indicate that the lower parts of the greenstone succession show the highest background S contents and a stronger correlation between Cu, Zn and S than the upper greenstones. Observed sulphides include mainly pyrite, chalcopyrite and pyrrhotite generally as tiny (<o.05 mm) dispersed grains and small aggregates.

While it is possible that these trace sulphides formed by early hydrothermal or even metamorphic introduction of sulphides into the rocks it is also possible that they represent relicts of an immiscible sulphide phase developed in the original lavas during their emplacement and cooling. Such a primary sulphide phase would be a good source of metals and possibly sulphur for later leaching by circulating sea water convection cells, particularly as metals would be more .eadily stripped from sulphides than from a silicate phase. This possible intermediate step in the sulphide-forming process warrants further investigation and could have significant implications for exploration. For example, if metals and S have been derived from dispersed primary sulphides in the greenstones then a collorary for mineralised sequences would be the presence of lavas that were S saturated at the time of extrusion or that become so during cooling. The observation of differentiated flows at Dragset may be significant in this regard, as one way to seach S saturation in a melt is by fractional crystallisation during cooling.

Another aspect of the massive sulphide deposits throughout the greenstones (not just in the Løkken area) that would be worth further investigation is the nature of the feeder zone systems. The size, alteration pattern and mineralogy of the feeder zones may bear a relationship to the size and extent of the overlying massive ores. If this were so then it might be possible to predict the likely volume of massive ore associated with a known disseminated feeder zone occurrence. Descrepencies between known massive ore and predicted volume could then be checked out and any missing ore accounted for or explored for. In order to do this it would be necessary to systematically document the feeder zones associated with all the known deposits of different sizes. A set of impirical parameters related to the volume of massive ores could then be established.

The feeder zone at Dragset appears to be different from those at Løkken and Høydal by the greater abundance of pyrrhotite and lack of large pyrite veins. The pyrrhotite appears to be a primary mineral rather than a product from the metamorphic breakdown of pyrite, and its presence may be related to differences in S activity and temperature. The amount of magnetic, monoclinic pyrrhotite in the Dragset feeder might also be sufficient to produce a weak magnetic anomaly possibly detectable by ground magnetics.

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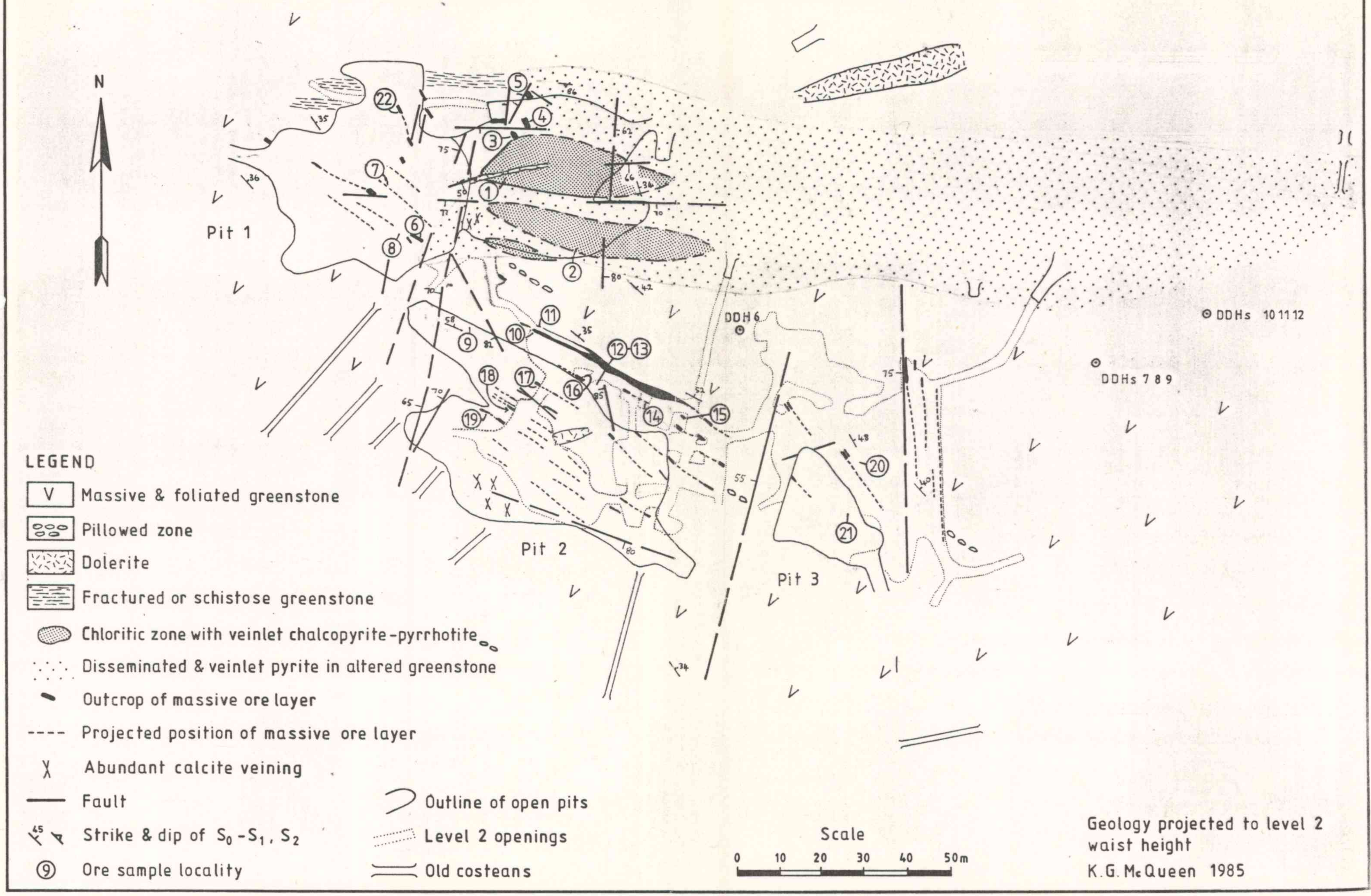
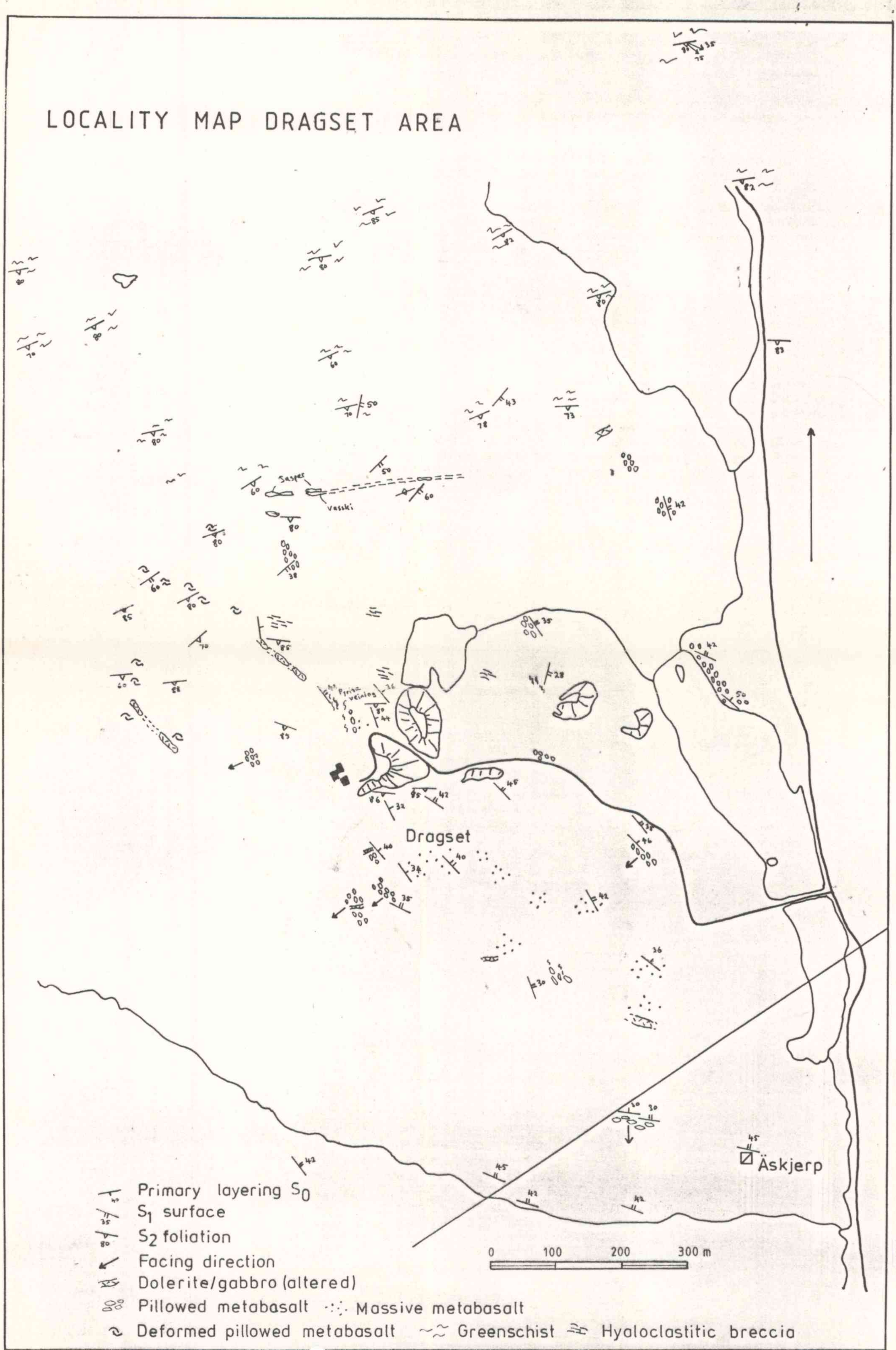
GEOLOGICAL PLAN OF THE DRAGSET MINE





LOCALITY MAP DRAGSET AREA
Pyrite veining
Dragset
Äskjerp
0 100 200 300 m
Primary layering S_0
S_1 surface
S_2 foliation
Facing direction
Dolerite/gabbro (altered)
Pillowed metabasalt
Massive metabasalt
Deformed pillowed metabasalt
Greenschist
Hyaloclastitic breccia