Bergvesenet

Postboks 3021, N-7441 Trondheim

Rapportarkivet

Bergvesenet rapport nr	Intern Journal nr	Internt arkiv nr	Rapport lokalisering	Gradering
BV 4641	2137/00			**Fortrolig**

Kommer fra ..arkiv	Ekstern rapport nr	Oversendt fra	Fortrolig pga	Fortrolig fra dato:
		Crew Development Corporation	Muting	

Tittel

The Røros - Meråker district mines - a structural assessment.

Forfatter	Dato	År	Bedrift (Oppdragsgiver og/eller oppdragstaker)
Witt-Nilsson, Patrik	Febr	1999	Crew Development Corporation Rosmarus Geological Consulting

Kommune	Fylke	Bergdistrikt	1: 50 000 kartblad	1: 250 000 kartblad
Røros Holtålen Tydal Meråker	Sør-Trøndelag		17201 17202 17203 17204 17211 17212 17213 17214	Trondheim Røros

Fagområde	Dokument type	Forekomster (forekomst, gruvefelt, undersøkelsesfelt)
Geologi		Kongens Arvedal Rødalen Lergruvbakken Christianus Sextus Fjellsjø Mugg Gamle Storwarts Qvintus Olavsgruve Klasberget Abrahamshøgda Klinkenberg Matz Fjellgjelt Killingdal From Rogn Bukkhåmmåren Karslåtthøgda Svenskmenna Guldalsgruva Godthåb Gressli Langdalsvollen Ramsjø Selbygglian Lillefjellet Gilså Dronningen Bjørneggfjellet
Råstoffgruppe	**Rastofftype**	
Malm/metall	Cu Zn	

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

Structural descriptions of the mines

CREW
DEVELOPMENT CORPORATION

Høvik 26/10-00

Til Bergvesenet
Postboks 3021
7441 Trondheim

2137/00 Nei

PR BL

PRB
/3

Rapporter fra mutingsområder i Rørosområdet.

Under henvisning til "Lov om Bergverk", oversendes vedlagt kopi av rapporter fra undersøkelser i Rørosfeltet og ved Høydal gruve i Løkkenfeltet. Egen liste summerer opp de forskjellige rapporter, kart, analyseresultater etc.

Med vennlig hilsen for Crew Development Corporation

Bernt Røsholt

Bernt Røsholt
Prosjektleder

Vedlegg.

O.H. Bangsvei 54-58, 1363 Høvik Norway
tel. +47-67 59 24 24 fax. +47-67 59 24 25
email: crew@crew.no

The Røros-Meråker district mines - a structural assessment

Patrik Witt-Nilsson

ROSMARUS GEOLOGICAL CONSULTING
Djäknegatan 19:450
S-754 23 Uppsala
Sweden

February 1999

Index

1. The locality numbers correspond to the regional mine descriptions by Røsholt & Wilberg.

1. Introduction

The interpretations presented below for the mines from the Røros and Meråker districts are solely based on structural field data and field observations made during a 6 week field campaign in july-august 1998. Although more mines and prospects than what is presented here were visited, areas where the structural data was deemed to be insufficient for any kind of structural description have been omitted. No previously published data has been included.

The structural data are plotted on a lower hemisphere, equal-area Schmidt net using StereoPlot 2.0 and is presented below for each individual mine. Planes (bedding, foliations, axial planes, cleavage etc.) are presented as poles to planes to give a clear overview and to facilitate structural interpretations. A review of the data collected is presented below.

Foliations:

In most localities the foliation is subhorizóntal or only gently folded resulting in a poor spread of data points. This means that foliation data on their own are often insufficient for accurate determinations of the fold-phases, unless compared with other structural data such as minor fold-axes, mineral stretching lineations and bedding/cleavage intersection lineations etc.

Fold-axes:

In most localities, there are two main phases of folding. When describing the different generations of fold-axes the terms F1 and F2 are used. F1 folding usually refers to isoclinal folds as these are the earliest fold phase. Other types of F1 folds may occur as well and will be described when present. F2 folds are generally either gentle buckle-folds (when located in more psammitic units) or chevron-folds (in phyllitic schists). Interference-type folding (basin-dome structures) where to fold axes intersect at right angles appear in many localities and are described when present. Where three fold-phases occur, chevron and/or kink-folding is generally referred to as F3 folding. Other types of intereference folding also occur.

Chevron or kink-folds:

Chevron folds with a N-S trend occur throughout the Røros district. These folds vary in wavelength from a few centimetres to over a metre. Chevron or kink folds also occur within fold hinges of larger folds with other trends, especially where a competent unit has been buckle folded and contains phyllites in the core. Here it can be seen that they are parallel with the larger folds. Moreover, where space accommodation problems have occurred a rotation of the axial planes is often the result.

Axial planes/fold cleavage:

Axial planes and fold cleavage are measured wherever possible unless obviously folded when instead the general vergence is noted.

Mineral stretching lineation:

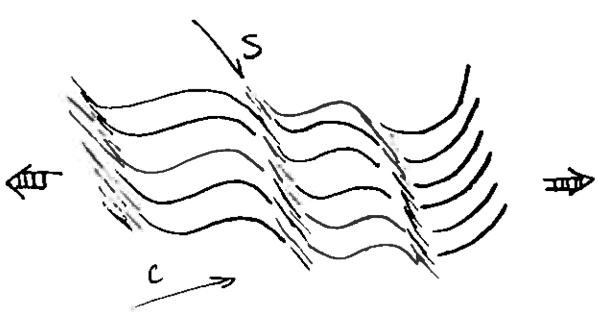
The mineral stretching lineation often appears as aligned mafic minerals (biotite/hornblende etc.). They may give an indication of the original movement direction of the nappe units. In the mafic metavolcanics they occur as aligned hornblende (garben schiefer). They indicate minimum greenschist facies regional metamorphism during thrusting.Elongated quartz grains and aligned biotite grains also occur.

Bedding/cleavage intersection lineation:

The bedding cleavage intersection lineation can often be found on flat surfaces as a weak trace of phyllosilicates transecting a foliation surface. The phyllosilicates (mica) has aligned with the new cleavage and produces thin lines when intersecting a bedding or foliation surface. Where fold axes are hard to define the intersection lineation gives a hint to the trend of the fold axis. However, where coaxial refolding has occurred a transecting lineation may occur.

Crenulation lineation:

Crenulation lineation is mostly present in the subhorizontal phyllitic schists. They appear as mm to cm scale crinkles on the foliation surfaces. They mostly occur on the shallow limbs of folds where they are the result of flexural slip between layers. This means that they are parallel to the main fold axis. Where larger fold axes are present this can be confirmed. Care should be taken to distinguish crenulaion lineations from extensional C-S shear-band crenulations. This set of late regional extensional fabric overprints most earlier structures. The C-S fabric looks very similar to the crenulation fabric until studied; however, one implies late compression and the other late extension. Where a crenulation lineation has been noted on surfaces but no determination of its origin has been made then it is just presented a a late overprinting fabric.



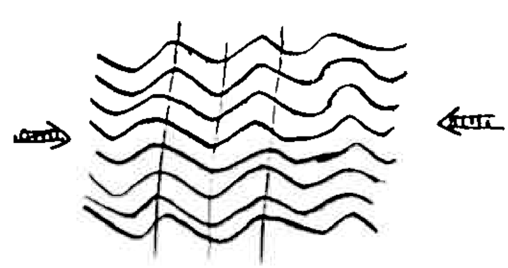


Figure 1. Diagram of crenulation due to (A) extensional C-S fabric and (B) crenulation due to compression. These two may be hard to distinguish on flat foliation surfaces but are the result of different processes.

Boudinage:

There are two general types of boudinage within the schistose metasediments and metavolcanics; intrafolial boudinage of metasedimentary horizons with varying internal competence contrasts and the brittle or pinch-and-swell type boudinage of of quartz veins. Even units that are apparently homogeneous in their composition may boudinsge due to internal anisotropy of the rock. A reorientation (metamorphic or tectonic) of mica grains along discreet foliation planes may cause varying dergrees of anisotropy resulting in intrafolial boudinage. Straight-necking boudinage of competent quartzite veins is ubiquitous. In most localities there is at least one set of conspicuous elongated quartz rods and in some localities two sets may occur. In the latter case the two are often perpendicular and compose a chocolate tablet-type boudinage. Boudinage of more competent horizons within shaly units also occur but these are less frequent and more difficult to spot. Simple shear boudinage occur as well. In many localities the boudins are parallel with the F1 isoclines suggesting these could be used to indicate original compression/fold direction. In some localities the quartz "blebs" have formed as quartz infill in boudin necks of competent units.

Sulfide structures:

In sulfides the order of competence has been shown to be, from the most to the least competent, pyrite>sphalerite>chalcopyrite>pyrrhotite>galena. However, <sphalerite-chalcopyrite-pyrrhotite may vary/alternate some due to prevailing metamorphic conditions. Only pyrite is more competent than most silicate rocks (Marshall & Gilligan 1987). Durchbewegung structures (Vokes 1963, 1969; McQueen 1987; Marshall & Gilligan 1989) are often formed from interfolding and shearing of ore and silicate-rich host-rocks. The involvement in tight to isoclinal folding disrupts and separates the silicate layers. The sulfide ore flows into the voids created, resulting in separation of layers. The sulfides may invade all brittle fractures and layer interfaces and wedge off pieces of wall rock and sub-divide "xenoliths" in the ore matrix (Marshall & Gilligan 1989).

The essential requirements for durchbewegung structures are interlayering of materials of varying orsubstantial competence contrast under varying metamorphic and tectonic conditions. The deformation will be partitioned into the different horizons and some layers will as a result behave ductilely whereas others will deform by brittle fracturing. This may result in in brittle "xenoliths" of a more competent phase (pyrite) being surrounded by a more ductile phase (chalcopyrite). It is postulated that durchbewegung structures are the result of high-strain in partitioned domains of non-coaxial rotational deformation by extreme heterogeneous flow during, most likely, a polyphase or overprintingn event.

Glacial effects on the topography:

In many localities well developed cylindrical hills transect the countryside. These are largely the effect of erosion due to ice movement. In the Røros tract the prevailing movement direction was NW-SE (see figure). Where the trend of the fold axes is parallel to subparallel to the ice movement this fabric appears to be enhanced, as, for example, around Klinkenberg mines; however, in other localities where the dominant fold phase is at a large angle to this movement direction, it not so obvious.

2. Structural descriptions of the mines

The Røros Nordgruvefelt

1. Kongens/Arvedals gruve

Location: UTM 0619670/6951140 to 0616850/6951097

Structural data (Fig. 4a-f)

Foliations: (best fit, 130 data points)	9°-271
Fold-axes: (28 data points, two poor maximas)	8°-272
	13°-050

The fold-axes spread between 035-115 with two poorly defined maxima at c. 050 and 092. In the Kongen area the most prominent fold-phase are the E-W trending folds. This structure also controls the orientation of the mineralisation. However, a large overturned tight fold with a W-plunging fold axis was photographed W of Kongens, towards Rødalen (see photo below).

The plunge-direction of the major cylindrical fold-axis visible in the Arvedal section of the mine varies between 265 and 295. The fold-axis undulates with a wavelength of about 30-40 metres. The dome-and-basin type pattern suggests fold interference. An alternative interpretation may be some sort of folded mega pinch-and-swell structure. This would be due to the fold-axes of the gentle N-S trending folds. The fold interference pattern shows that the fold-hinges of the earlier E-W plunging fold have been folded. On the ice-scoured surface near the main parking-lot east of the Arvedals mine it is possible to observe one of the large overturned (southwards) fold. This fold refolds isoclines with a similar plunge-direction and has in turn been refolded by a gentle S- (200) plunging fold. The gentle F2 folds (with kink-folds forming in the hinge-zones) and the direction of the basins indicate a fold phase at 020-045, i.e., N-S folding pre-dates E-W buckle-folding.

Cleavage: (8 data points, refolded)	N20E°/65°NW
Axial planes: (11 data points, refolded)	N20E°/55°NW

Although the cleavage and axial planes are similar in strike-direction the dips clearly plot in two separate areas varying by about 10-15°. However, it is most likely they still belong to the same fold event. It may be due to convergening/diverging refraction cleavage planes.

Chevron folds: (3 data points)	8°-202
Crenulation lineation:	-
Bedding/cleavage intersection lineation:	-
Mineral lineation: (4 data points)	32°-271
Boudin necks: (13 data points)	±10°-017/197
Kink-bands:	ESE-directed
Thrust planes:	East-directed

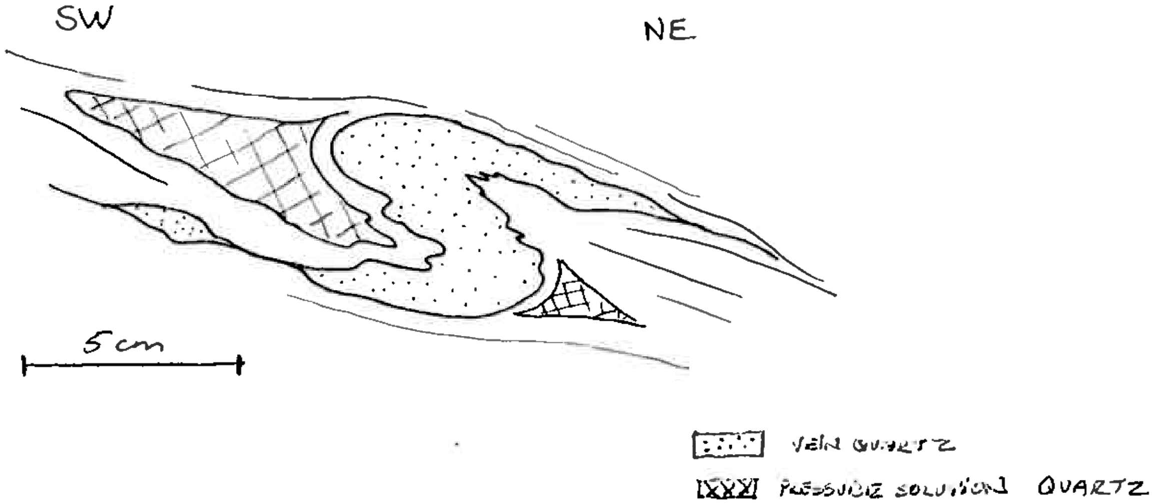


Figure 2: Sketch of folded pinch-and-swell boudinage of a quartz vein. The folded boudins indicate movement towards the SW. This shear-sense indicator was found in the lower limb of a larger overturned (S-vergent) fold. This large fold is readily seen in the Arvedal section of the large collapsed adit composing the Kongens gruve.

Figure 3: Large overturned, tight to isoclinal fold. The fold has an E-W trending fold axis refolded by gentle N-S trending buckle folds.

Kongens

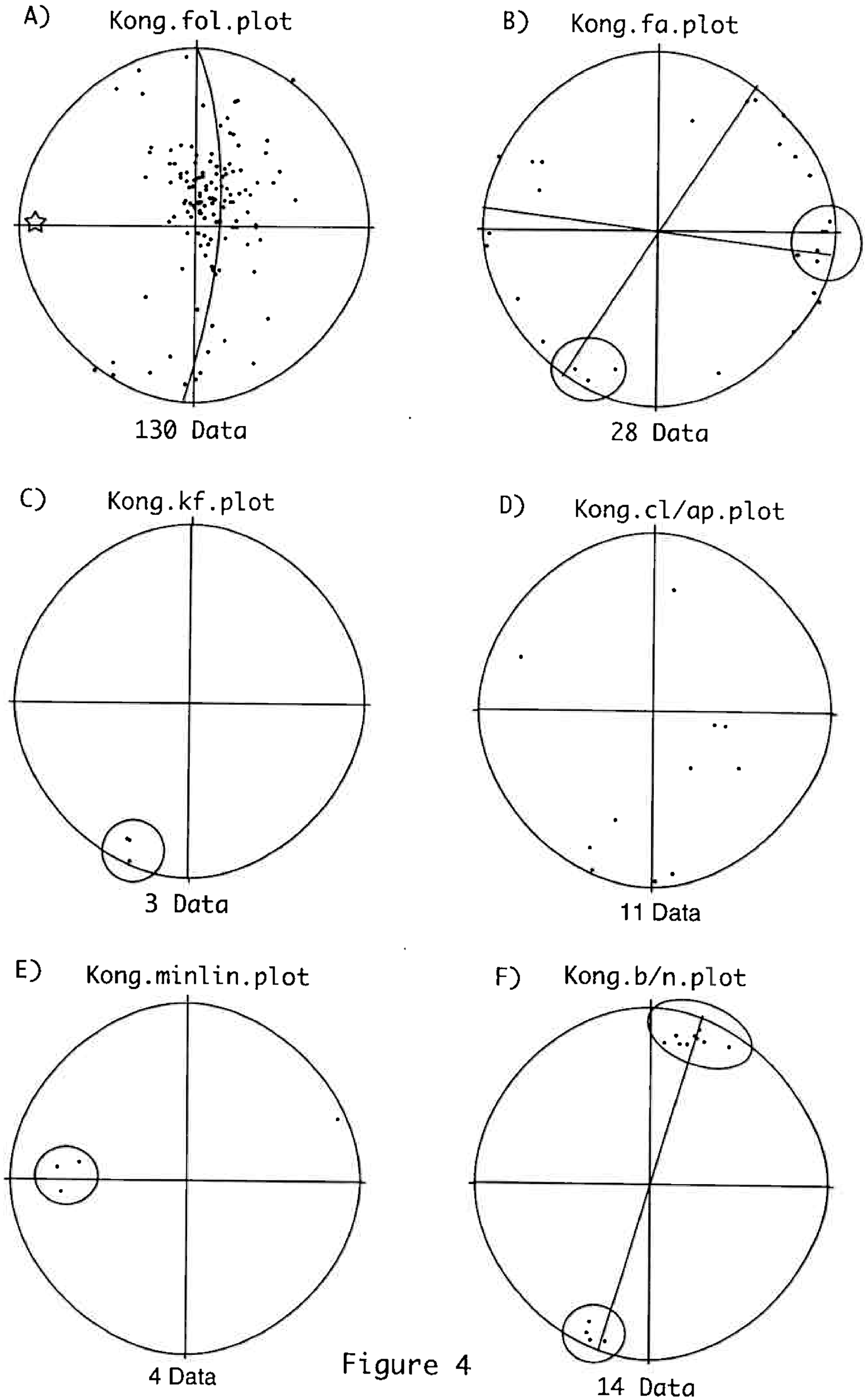


Figure 4

2. Lergruvbakken

Location: UTM 0619630/6948718

At Lergruvbakken it is possible to sample the entrance of the mine, c. 20 metres of exposed outcrop. Only limited structural data were available the mine entrance, such as foliation planes, a few minor fold axes and boudin necks. No major folds were exposed. There is also a pit nearby but the cliffs are strongly fractured and many parts are faulted and rotated due to blasting. This data is included but may scatter some.

Structural data (Fig. 5a-f)

Foliations: (best fit, 24 data points)	6°-082

A statistical evaluation plots the poles to foliation at c. 6°-082.

Fold-axes: (5 data points, two poor maximas)	7°-271 2°-166

The fold-axes plot around 10°-255 and 8°-110, which defines a poor maxima at c. 3°-270. The former value is slightly different to that defined by the foliation data but considering the number of data points it could be considered acurate

Cleavage:	-
Axial planes:	-
Chevron folds: (3 data points)	10°-324 10°-066
Crenulation lineation: (3 data points)	8°-261
Bedding/cleavage intersection lineation: (3 data points)	7°-088
Mineral lineation:	-
Boudin necks: (14 data points)	11°-128 (poor) 10°-221
Kink-bands:	both NE and NW directed

Lergruvbakken

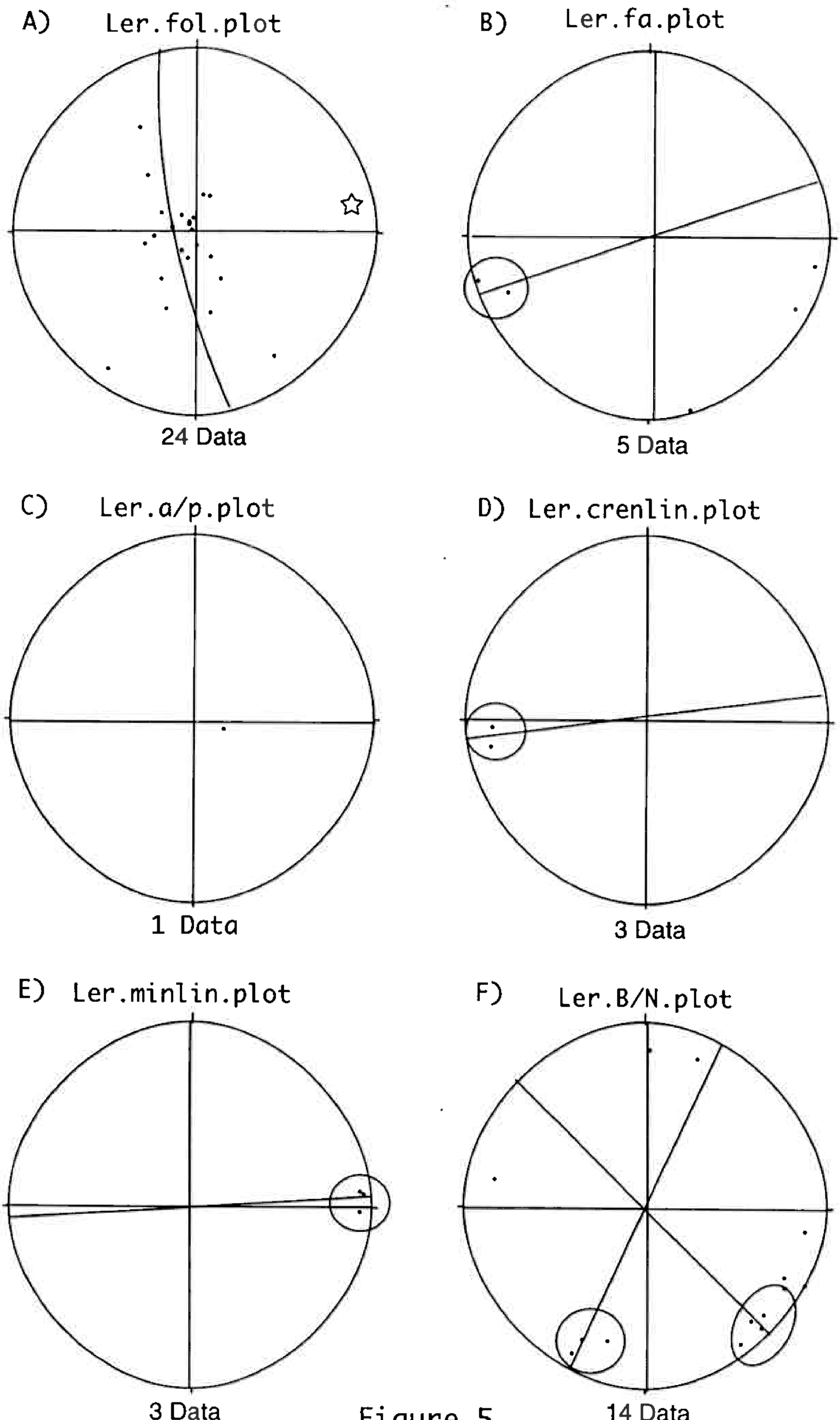


Figure 5

3. Christianus Sextus

Location: UTM 0619680/6952750

Data from the Christianus Sextus mine was collected along the western side of the mine. The mine fronts a c. 4-500 metre stretch of old adits, some with good exposure of the bedrock. Most adits have, however, been covered in tailings. Several adits have been blasted to discourage any attempts to enter the old workings. The general dip and dip direction of the ore body is c. 35°-300 to 310 (from within the adits).

Structural data (Fig. 6a-f)

Foliation: (69 data points, best fit)	too scattered
Fold-axes: (21 data points)	c. 10°-000 to 060

The fold axes spread between 000 and 060. The pattern suggests refolding by a steep (c. 80°-SE) fold but no such fold phase is to be found. This direction is similar to the chevron folds and the map-scale cross-folding. These NW-SE folds are relatively shallow in their plunge and do not fit the data. However, a late NNE-SSW trending fold phase could refold the old folds around small circles with a similar spread of the data. It is however possible that it is due to block rotation of the front of the mine due to a collapsing roof. Large rotated blocks are abundant infront of the mine and may also be responsible for the data spread.

Cleavage: (4 data points)	refolded
Axial planes:	-
Chevron folds:	-
Crenulation lineation: (5 data points)	11°-137° 11°-228°

There is a crenulation lineation which has developed within the more micaceous horizons (chlorite/graphite schists) in the sericite altered phyllitic schists.

Bedding/cleavage intersection lineation:	-
Mineral lineation: (2 data points)	WNW-ESE

There are two sets of mineral lineations. One set is an early mineral stretching lineation (amphibole grains) and is probably related to thrusting. This may locally be decussate (garben schiefer) in texture. This lineation is refolded by the F2 folds. The second lineation is a crenulation lineation perpendicular to the mineral lineation.

Boudin necks: (6 data points)	4°-200

The quartz boudins have been folded by the F1 isoclines (see sketch below). This means that a foliation fabric existed prior to the formation of the earliest recogniceable fold phase. In several localities can the boudins be seen to shorten and fold earlier pinch-and-swell structures.

Kink-bands: (1 data point) N23°E/72°NW

Mineralisation structures:

The host rock is strongly altered around the mineralisations. The lower contact is a c. 30 cm wide alteration zone whereas the upper contact often is less than 10 cm wide. F1 isoclines can be seen within the pyrite and zink ore. The ore appears to be remobilised from F1 positions along foliation planes to NNE-SSW F2 fold hinges. The banding of pyrite and sphalerite with layer-parallel isoclines is characteristic of mobilised ore (Stanton 1970). The otherwise competent pyrite is granulated and transported along the sphalerite layers. The pure pyrite horizons are parallel to the foliation surfaces but are more competent and not affected by the late deformation. Some contacts appear to have been slip surfaces where e.g. the underlying rocks may be folded but not the overlying. The ore also contains "xenoliths" of highly deformed (leached and crenulated) country rock, however, there are few signs indicating that the ore has transmitted the stress to at an earlier stage incorporated inclusions. The mineralisations appear to truncate the deformed rocks (Fig. 7), indicating a late stage remobilisation of the ore (Fig. 8). The isoclinally folded and boudinaged milky quartz veins have been enveloped by the ore. This ore is a combination of chalcopyrite and pyrite, making it much more ductile. The ore is often found in the low-strain zones around the quartz lenses. The ore sometimes exhibits pinch-and-swell structures (Fig. 9). When comparing layers of chalcopyrite and pyrite, the chalcopyrite often exhibit more signs of deformation. Thin (c. 5 mm) veins of ore has been folded by W-vergent, tight to isoclinal folds. These folds have chalcopyrite crystallised parallel with the new axial-parallel cleavage planes. These crystals are quite coarse-grained and may be up to 4-5 mm long. Intrafolial boudinage of the highly schistose country rock has produced local pockets of chalcopyrite ore. These have formed in rupture areas. All these structures are characteristic of durchbewegung structures.

Thrust planes:

N5°W/28°SW
N24°W/20°SW
N12°W/28°SW

Fault planes:

Along the entire back of the mine there is a c. 50 m long and aboout a metre wide fault zone. The fault contains several generations of quartz veins. The vertical and horizontal displacement is unknown. There has been some remobilisation of ore into the fault zone.

Ridges: 140/320
120/300

Scour marks: 300-340

Quartz veins: ≈N80°W/70°SW

The quartz veins have the same s_1 direction as the F2 or kink folds but are folded by the latter and probably formed at an early stage of D2/F2 deformation.

Christianus Sextus

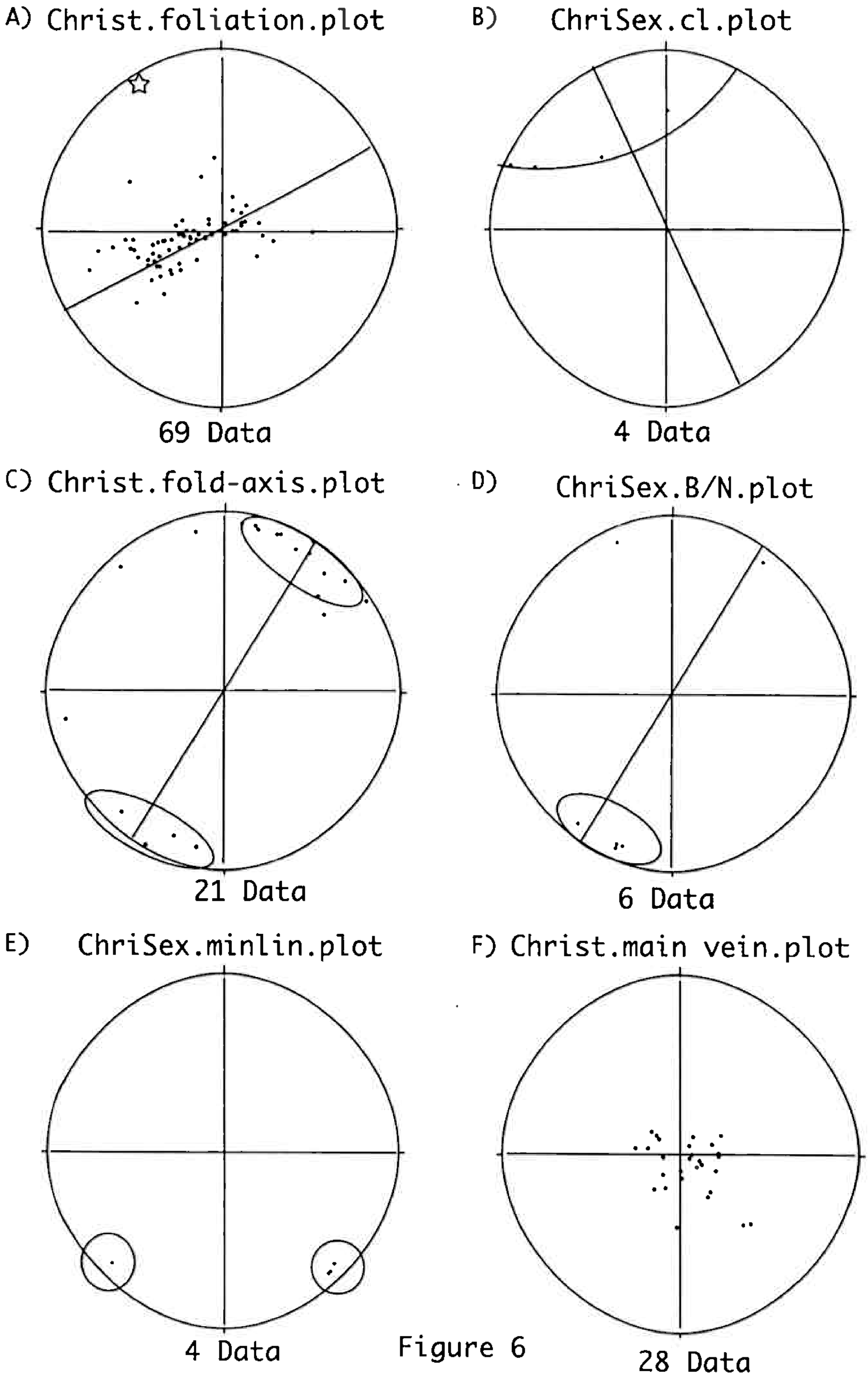


Figure 6

Figure 7: Finely laminated pyrite and chalcopyrite ore in a highly leached quartz-sericte schist. The laminated ore contains isoclines but also "xenoliths" of highly crenulated schists. These crenulations probably developed prior to inclusion within the ore suggesting minor mobilisation. Delamination of host-rock material is a typical structure in durchbewegt material. The silicate host-rock is disrupted and actively separated by inflowing sulfide ore.

Figure 8: Isoclinally folded and boudinaged milky quartz veins within the host rock and ore. The presence of ductile pyrite-chalcopyrite ore surrounding the competent quartz rods again suggests secondary mobilisation of the ore.

Figure 9: Pillar of schistose host-rock and ore. Note the thinning and pinching of the ore in the upper parts of the photograph. The ore is behaving ductilely and forming pinch-and-swell structures. Piercement veins are visible in several places and the photo shows many examples of intrusive delaminations (durchbewegung) of the foliated host-rock.

4. Fjellsjø gruve

Location: UTM 0616307/6953250

Structural analysis of the folding at Fjellsjø gruve was undertaken along a c. 300 m stretch of cliffs on the western side of the mine and small lake. Some additional data was collected from small scattered outtcrops on the eastern side of the mine and buildings.

Structural data (Fig. 11a-b)

Foliations: (best fit, 28 data points) 4°-195

The foliation data collected both east and west of the mine defines a perfectly stable fold phase with a major fold axis plunging c. 4° to 195. There is no obvious disturbance in the plot suggesting there is no cross folding or fold interference present; however, the large-scale folds on the map indicates that a major fold-phase with a trend near 160-170 should exist.

Fold-axes: (5 data points) 8°-196/023

The visible folding at Fjellsjø gruve is characterised by asymmetric folds, up to a metre in amplitude (Fig. 10). The folds are generally overturned to the east, with W-dipping axial planes. The trend of the fold axes is NNE-SSW with the fold axes plunging subhorizontally, alternating between c. 7°S and 13°N. Some kink-folds have bifurcating fold axes. The folds also show progressive tigtening of the fold hinges with accommodation problems. The fold axes are locally slightly curved; however structural plots of the fold axes do not indicate any significant disturbances of the data indicating continued compression and coaxial refolding.

The fold-axes spread between c. 1° to 195 and 7° to 027. This defines a fairly well constrained fold direction and is almost identical with foliation data.

Cleavage: W-dipping
Axial planes: ditto

Chevron or kink folds: -
Crenulation lineation: -
Bedding/cleavage intersection lineation: -

Mineral lineation: (2 data points) 6°-025

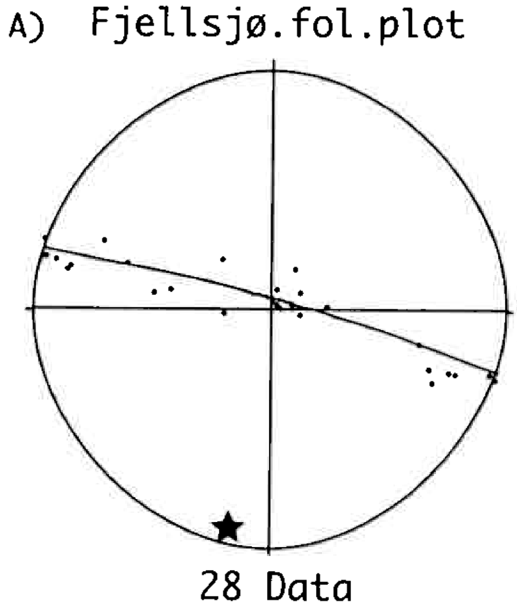
There is locally a weak lineation composed of subparallel amphibole grains (garben schiefer). When present this fabric is parallel or slightly oblique to the fold axes; however, in most cases the amphiboles compose a decussate texture with no preferred orientation. This mineral lineation is near-perpendicular to that of most localities.

Boudin necks: SSW-NNE

Two types of boudinage have been recognised. The first is intraformational, subvertical and parallel with the fold axes. This type of boudinage affects horizons with varying competence contrasts within a sedimentary unit. Here the greywackes have been ruptured and the neck regions have filled with milky quartz. The second type of boudinage has affected milky quartz veins of unknown origin. A possible interpretation for some of these flattened cigars is that they are quartz from the boudin necks which have rotated into concordance with the foliation, however there is little evidence suggesting this is so. The quartz lenses may be up to 30 cm thick and a metre long. The quartz bands seem to favour the contact between the greywackes and the shaly horizons (beef?). Where the quartz has ruptures the shale has mobilised into the void. This fabric is similar to that seen at Kongens gruve. The quartz has been subjected to chocolate tablet boudinage, parallel and perpendicular to the fold axes.

Figure 10: NNE-SSW trending fold in the metasediment c. 200 metres WSW of the Fjellsjø mine entrance. Photo taken towards the SW. The fold is overturned to recumbent, with a west-dipping axial plane indicating an eastwards vergence of the fold.

Fjellsjø gruva



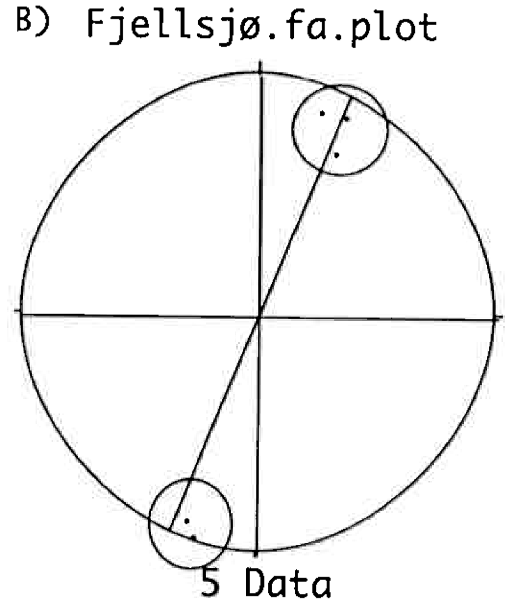


Figure 11

5. Muggruva

Location: UTM 0617233/6956672

The areas contains few visible outcrops of mineralisations. The basic volcanics contain horizons with lapilli tuffs. These have been both flattened and elongated in a N-S direction, parallel to the mineral stretching lineation (amphiboles).

Structural data (Fig. 12)

Foliation: (107 data points, best fit)	1°-180
Cleavage: (3 data points)	N9°E/68°SE
Axial planes: (3 data points)	(refolded)
Fold-axes: (25 data points, three maximas)	8°-357 2°-316 10°-222
Isoclinal (F1) fold-axes: (3 data points)	12° to 28° towards 359 to 007

The isoclines spread around 360. The pattern suggests refolding but the data points are too few to pin-point the fold phase.

Chevron or kink-folds:	-
Crenulation lineation: (12 data points)	4°-350
Bedding/cleavage intersection lineation: (5 data points)	6°-354
Mineral lineation: (15 data points)	5°-104 (194/014)

The mineral stretching lineation is subhorizontal and spreads between 90-135 degrees.

Boudin necks: (19 data points, three sets)	9°-295 8°-201 6°-230

Boudinage is responsible for some folding of the surrounding phyllitic schists. The boudins are separated and the enveloping rock flows into the voids. This produces folds with axes parallel to that of the boudin necks. Many large-scale boudinage (>100cm) have formed and rotated into the foliation. This rotation of the competent quartz vein has folded the underlying schists and produced strongly flattened and overturned folds. The extendion direction and rotation direction is towards the east.

Kink-bands:	N42°W/66°SW

Thrust (T) / normal (N) fault planes: -

N28°E/60NW (T)
N15°E/42NW (N)

(slickensides) 35°-296

N18°W/22NW (N)
N10°W/32NW (N)

Shear bands:

There is a dextral shear band set indicating extension towards the SSW.

Scour marks: -

Quartz veins: -

Muggruva

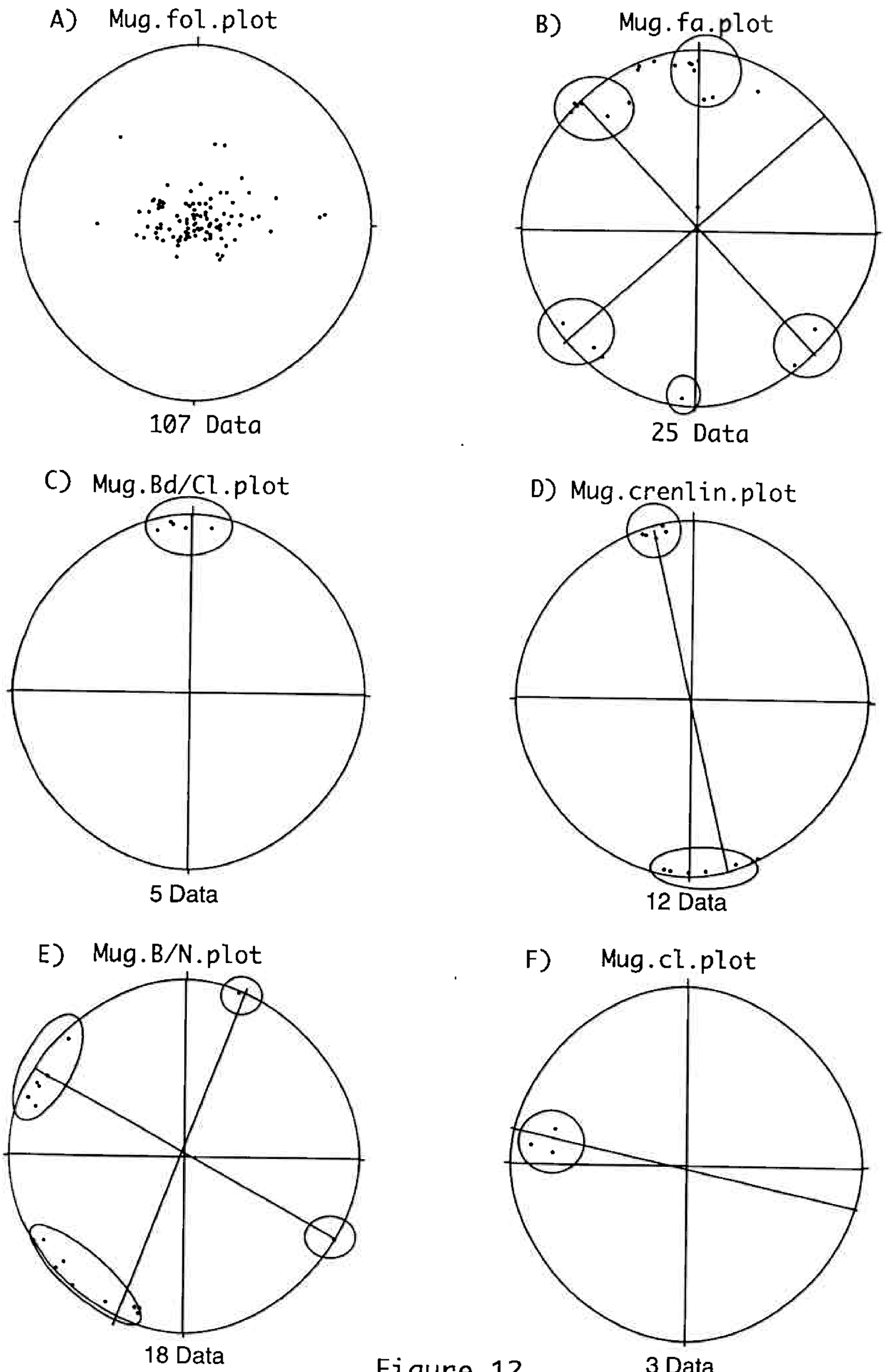


Figure 12

20. Gamle Storwartz

Location: UTM 0629157/6945927

Structural data (Fig. 13a-h)

Foliation: (93 data points, best fit)	7°-083

The foliation data from Gamle Storwartz defines fairly well an E-plunging fold structure. The subhorizontal foliation data is scattering but may be due to block rotation around the old mine entrances. Many of these pits have been blasted and covered up.

Fold-axes: (36 data points)	14°-099

N-S shortening with E-W trending folds totally dominate this outcrop. All fold generation give the same plunge direction in this locality, from the large (5 m amplitude) open to close folds to the smaller and coaxial chevron-folds, as well as the crenulation lineation. The vergence of these folds is southerly (SE-SW, see Figs. 14 and 15 below). There are no obvious N-S trending folds in this area

F1 folding: A few isoclines occur but accurate measurements of the F1 folds (3) was not possible. The wavelength of the measured overturned isoclines is c. 10 cm and the amplitude is 50-70 cm.

F2 folding: F2 folds are generally gentle to open. They appear to refold the isoclines coaxially. The larger folds show perfect examples of earlier refolded cleavage with transposition of a new axial-parallel cleavage (Fig. 16). This folding is locally chaotic with space-accommodation problems within the fold cores.

Cleavage: (2 data points)	-
Axial planes: (10 data points)	S-vergent
Chevron or kink-folds: (5 data points)	9°-082
Crenulation lineation: (4 data points)	15°-104

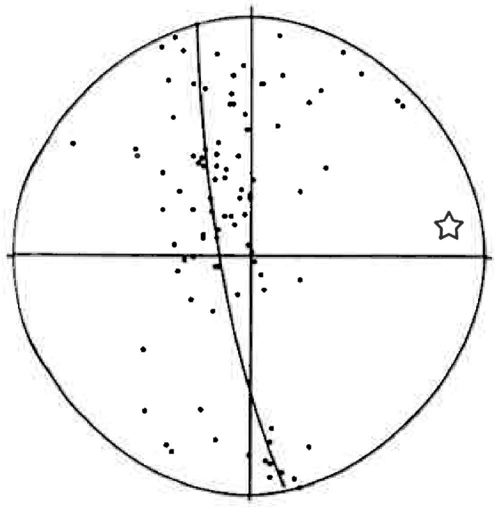
The crenulation lineations are found on foliation surfaces of the larger folds with same direction.

Bedding/cleavage intersection lineation: (6 data points)	33°-132 (222)
Mineral lineation: (4 data points)	7°-089
Boudin necks : (quartz rods): (4 data points)	6°-083

In the old pits at Gamle Storwartz a large number of folded boudins can be seen. The quartz boudins are found in the F1 foliation which suggests they formed simultaneously with F1 isoclines. All boudins are refolded by the E-W trending F2

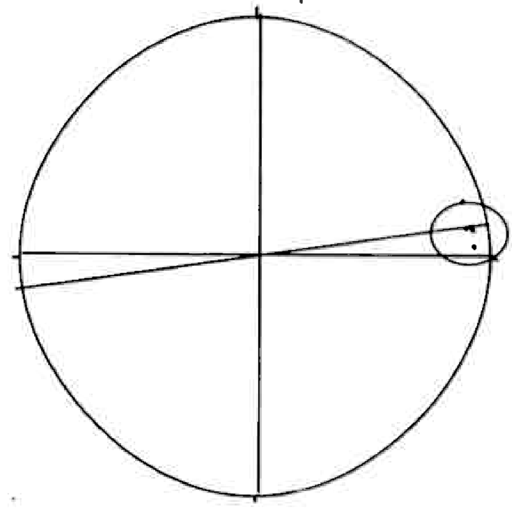
Storwartz gruve I/II

A) Storw.fol.plot



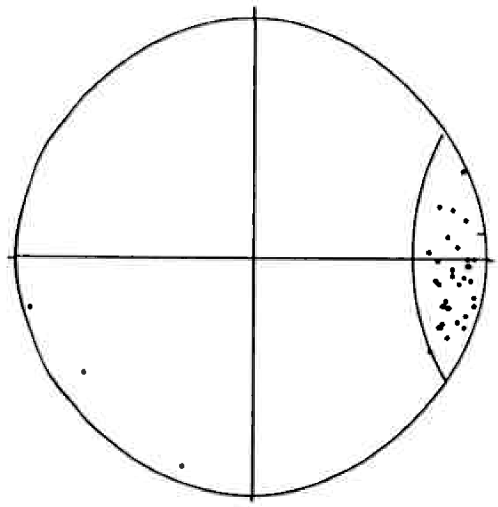
93 Data

B) Storw.kf.plot



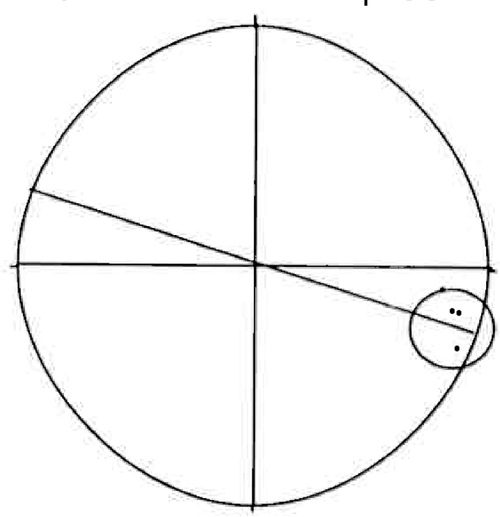
5 Data

C) Storw.fa.plot



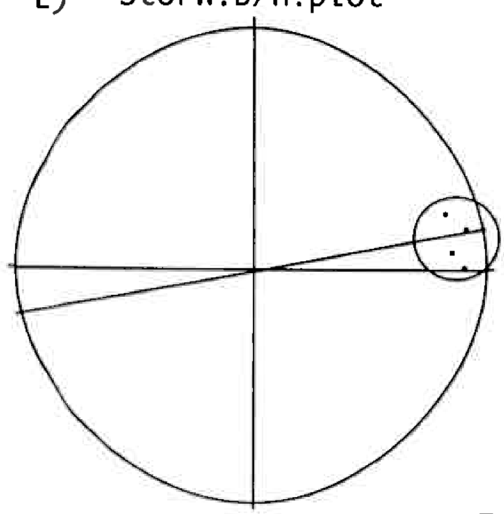
36 Data

D) Storw.crenlin.plot



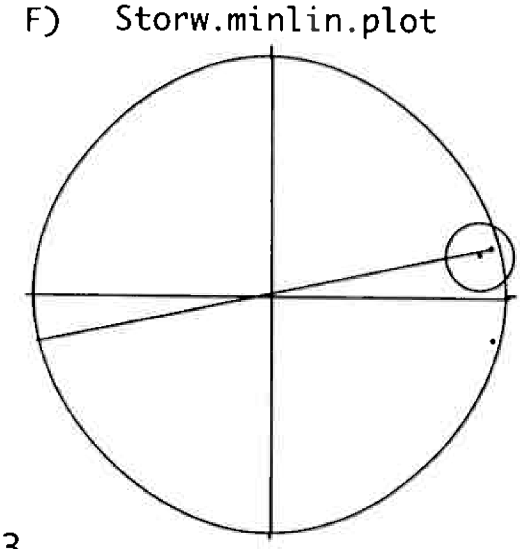
4 Data

E) Storw.b/n.plot



4 Data

F) Storw.minlin.plot

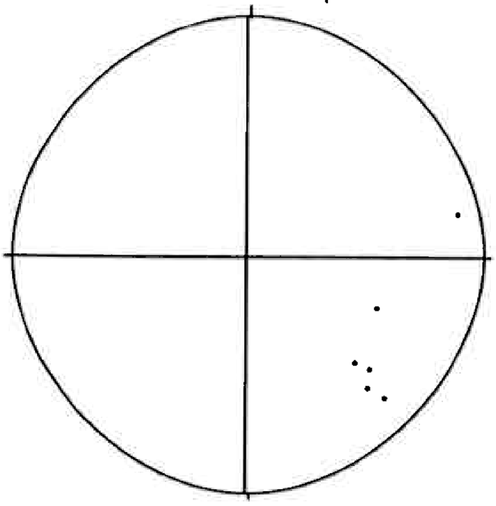


3 Data

Figure 13

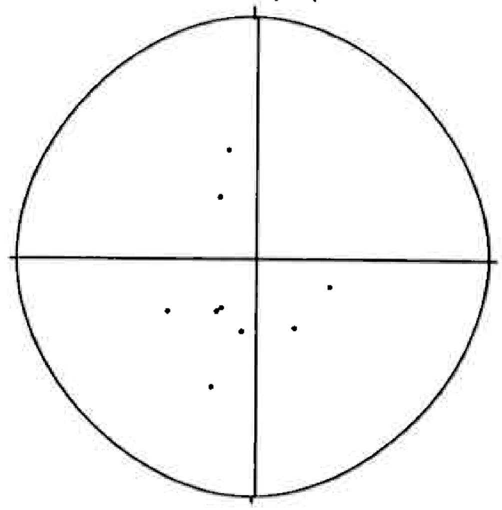
Storwartz gruve II/II

G) Storw.Bd/Cl.plot



6 Data

H) Storw.a/p.plot



9 Data

Figure 13

folds. Here the boudins are shortened in the flat-lying limb and flattened and elongated in the steep limb of F2 folds. They are also folded in the fold hinges of the F2 folds (Fig. 17) indicating thatthey are not contemporaneous with this fold phase. The formation of quartz rods/boudins thus pre-dates F2 folding.

Kink-bands:	5°-260 (S-vergent)
Thrust planes:	-
Quartz veins:	N80°E/70°NW N84°W/90°

Strain markers: elongated lapilli tuffs are elongated in the same direction as the quartz rods, i.e. c. 075-090.

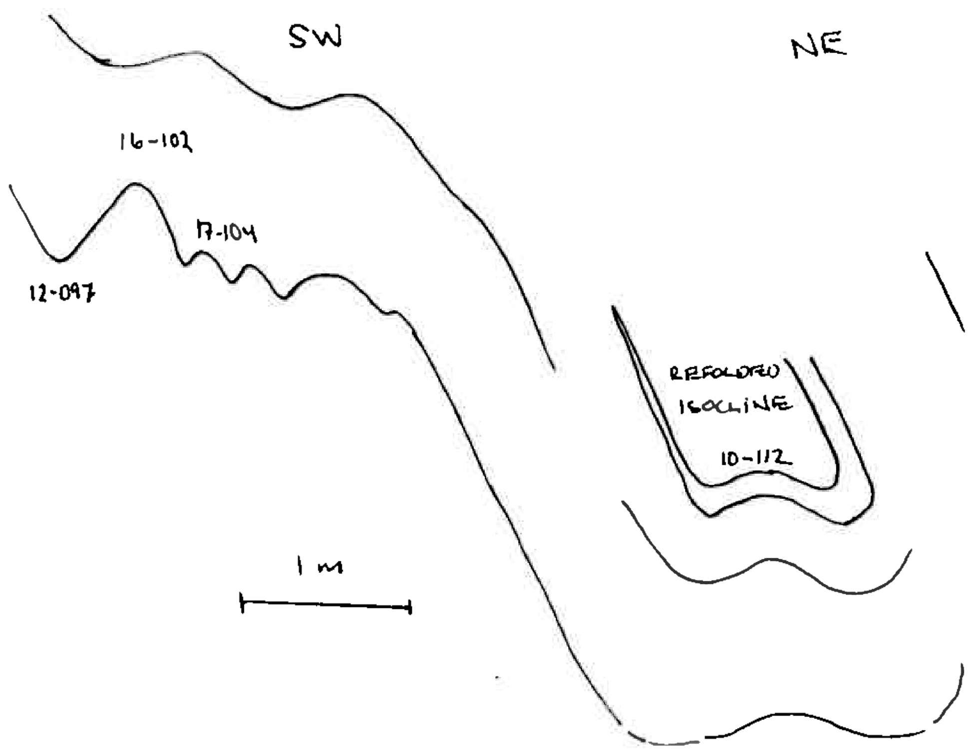


Figure 14: Sketch of overturned F2 fold which refolds an earlier (±)coaxial isoclinal fold. The large fold plunges gently towards the east and is overturned towards the south.

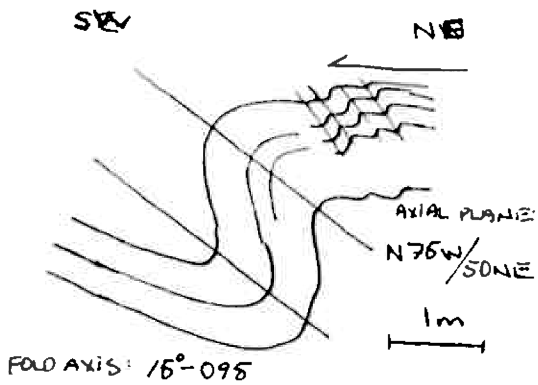


Figure 15: Large overturned SW vergent fold. The axial planes are NE trending with kink-folding of the foliation in the upper limb of the fold. This may be due to continued coaxial compression resulting in flattening of the foliation in the steep limb and crenulation or kink-folding of the subhorizontally inclined fold limb.

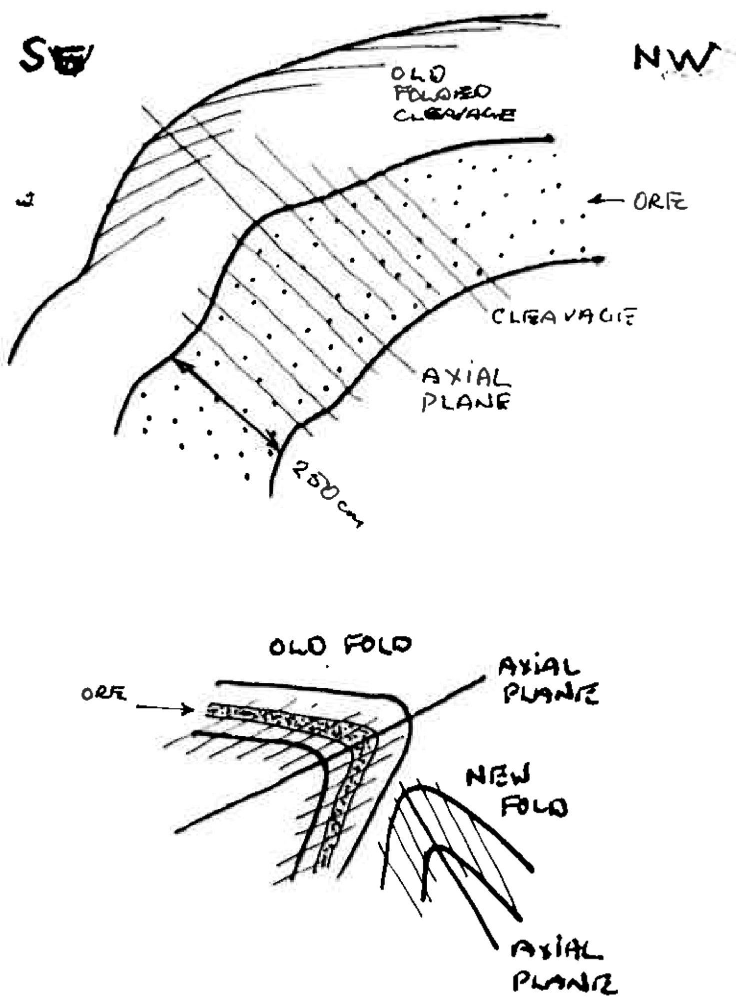


Figure 16: Refolding of a coaxial fold with transposition of new cleavage onto older. Note the levelling out of the old refolded cleavage towards the hinge of the new fold. The pattern suggests upright refolding of and earlier recumbent close fold .

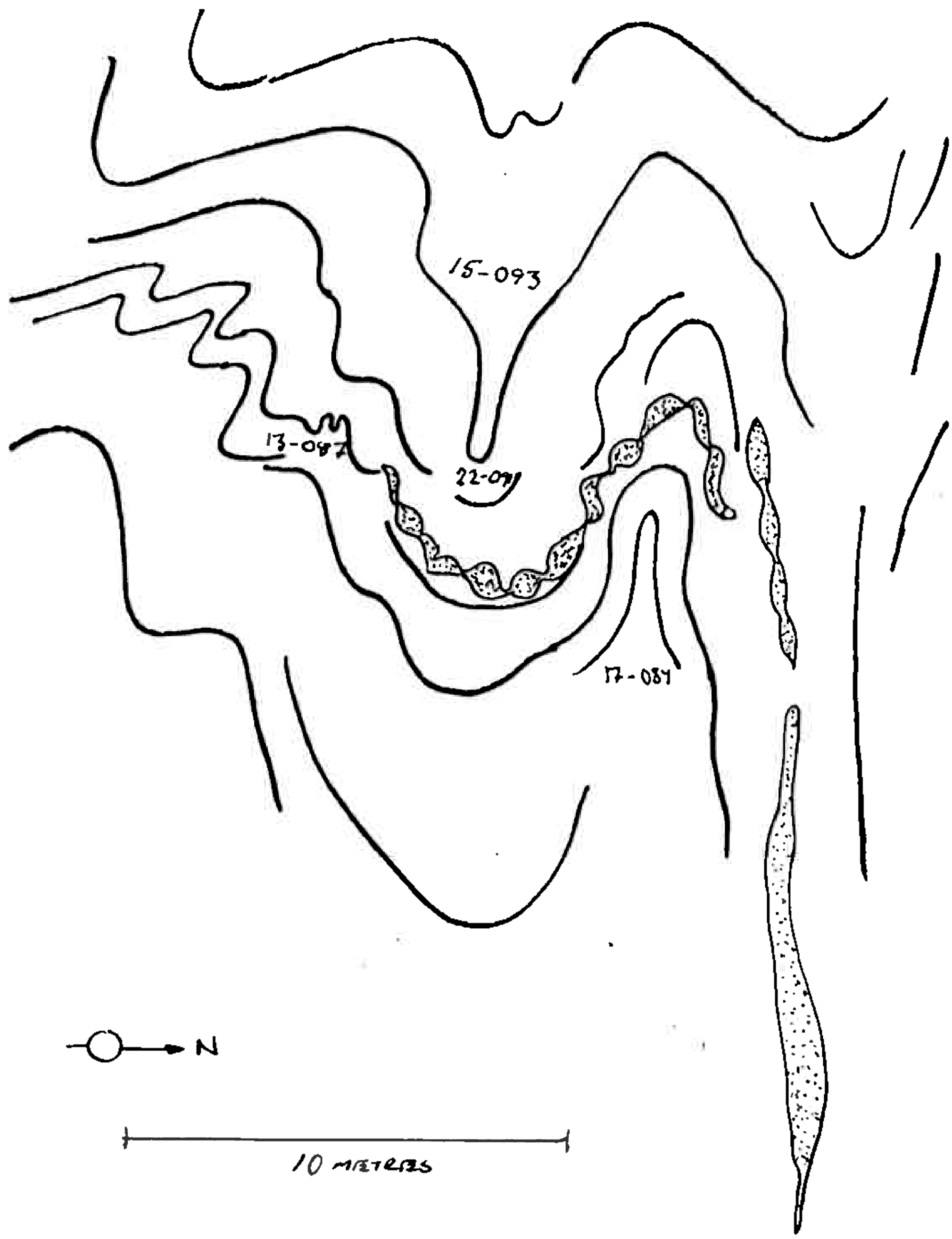


Figure 17: Large fold which refolds an earlier extensional boudinage of milky quartz veins.

24/25. Qvintus and Olavsgruva

Location: UTM 0630943/6946866

The Qvintushøgda and Olavsgruva areas do not present the best outcrop exposures in the area. Many outcrops are polished by the ice and limited acurate information can be acquired.

<u>Structural data</u> (Fig. 18a-f)

Foliation: (20 data points, best fit) 12°-092

The foliation data from Qvintus and Olavsgruva has a poor spread and are subhorizontal. This gives little indication of the major structuures in the area.

Fold-axes: (2 data points) 11°-269
4°-164

Unlike Storwartz where the dominant fold phase is E-W trending, Qvintus and Olavsgruva appear to lack this fold phase; however, kink-folds appear to be well-developed here instead.

Cleavage: -
Axial planes: -

Chevron or kink-folds: (7 data points) 6°-164

The chevron folds are perpendicular to the dominant fold phase at Storwartz.

Crenulation lineation: (4 data points) -

The crenulation lineations are found on foliation surfaces of the larger folds with same direction.

Foliation/cleavage intersection lineation: (31 data points) (I) 6°-080
(II) 14°-116

Both of the intersection lineations are within the span of the fold axes from Storwartz suggesting there may be a larger structure, however , the foliation and fold axis data is insufficient to locate it. The two sets are clearly distinct and cross-cutting in most localities. Set (I) is parallel to the kink-bands suggesting a close relationship.

Mineral lineation: -

Boudin necks : (quartz rods): (9 data points) 6°-281
10°-197

The boudin sets are near perpendicular suggesting a chocolate-tablet type boudinage.

In the old pits at Gamle Storwartz the boudins are shortened in the flat-lying limb and flattened and elongated in the steep limb of F2 folds. The formation of quartz rods/boudins thus pre-dates F2 folding. The quartz boudins are found in the F1 foliation which suggests they formed simultaneously with F1 isoclines.

Kink-bands:	-
Thrust planes:	-
Ridges:	-
Scour marks:	-
Quartz veins:	N80°E/70°NW N84°W/90°

Strain markers: elongated lapilli tuffs are elongated in the same direction as the quartz rods, i.e. c. 075-090.

Qvintus gruve

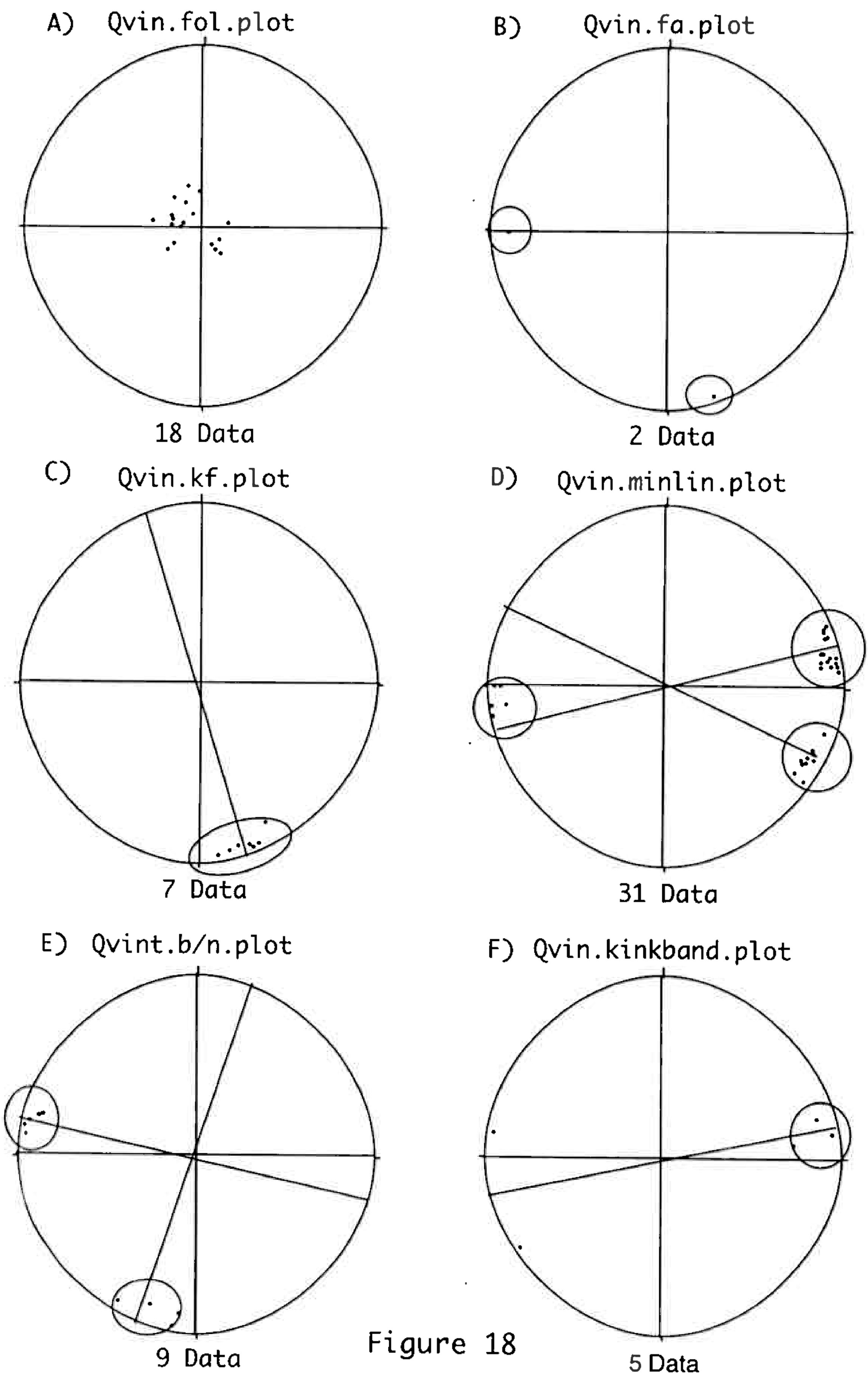


Figure 18

29. Klasberget gruve

Location: UTM 0631803/6950017

Strike of mine and pits: ≈ 300

The ore seems to be located in the hinge-zone of an open fold.

Structural data (Fig. 20a-f)

Foliation: (68 data points, best fit)	1°-315
Fold-axes: (34 data points, three fold maximas)	1°-268
	7°-295
	6°-175
Isoclinal (F1) *fold-axes:* (4 data points)	≈260 (250-268)

The isoclines spread between 250-268. They are refolded by the fold phase trending 295. They appear to have refolded in a continuous process and may just be the result of a change in convergence direction. The latter fold phase is similar to the trend of the mines. There is however a N-S trending fold-phase which may be the reason for the disturbance in the foliation data. This N-S set can be seen to cross-fold the large NW-SE structures on the map and may be late buckle folding.

Cleavage:	-
Axial planes:(7 data points)	refolded
Chevron folds:	-
Crenulation lineation: (7 data points)	5°-355
Bedding/cleavage intersection lineation:	-
Mineral lineation: (24 data points, two maximas)	5°-115 to 136

The mineral lineation appears to be refolded.

Boudin necks: (15 data points, two maximas)	9°-121
	15°-013

(chocolate-tablet boudinage)

Mineralisation structures:

The mine contains examples of durchbewegung structures with ductile chalcopyrite and pyrrhotite having intruded into the hinge region (Fig. 19).

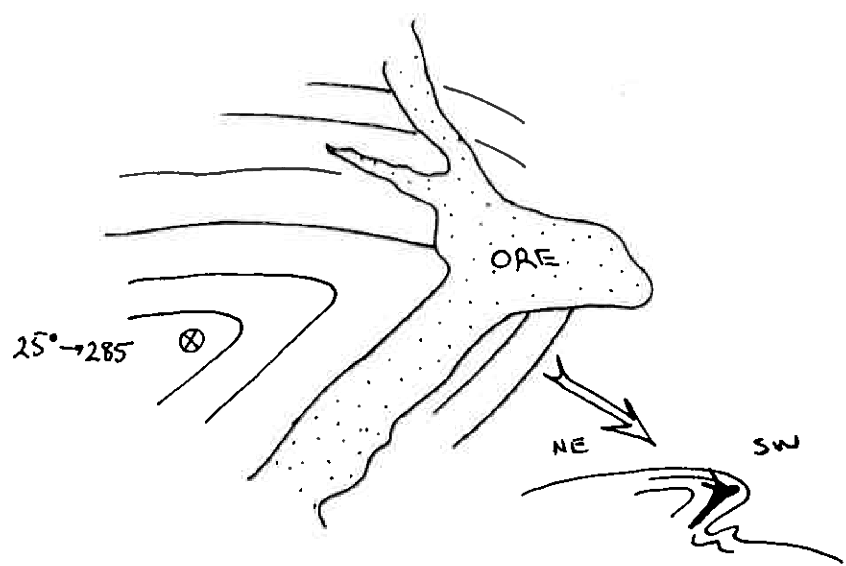


Figure 19: Tight overturned fold with remobilised ore in the core. The core is mainly chalcopyrite whereas the limbs are more pyrrhotite-rich. This is a typical result of durchbewegung. The fold plunges c. 25° towards 285.

Klasberget

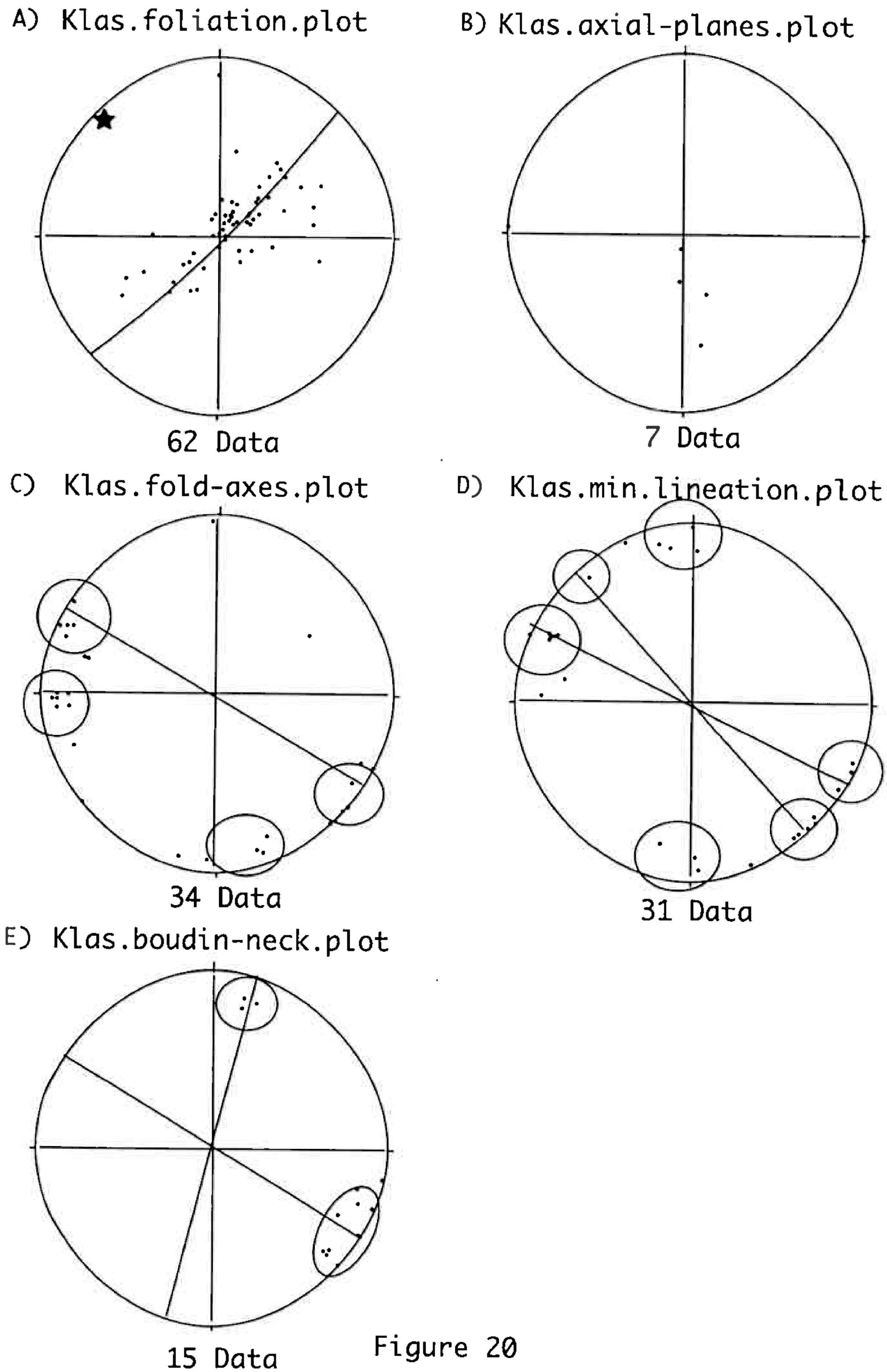


Figure 20

31. Abrahamshøgda gruve

Structural data (Fig. 21a-e)

Foliation: (51 data points, best fit)	NW (≈10°-315)
Fold-axes: (8 data points, two poorly constrained maximas)	17°-293 40°-203
Cleavage:	-
Axial planes:	-
Chevron or kink-folds: (17 data points)	35°-167 (good) 10°-280 (poor)

The N-S trending set of chevron folds is ubiquitous in this area. They are similar in trend to the large scale structures which can be observed on the map (Fig. 22).

Crenulation lineation: (7 data points)	9°-280
Bedding/cleavage intersection lineation:	-
Mineral lineation:	-
Boudin necks:	-
Kink-bands:	-
Thrust planes:	-
Ridges:	-
Scour marks:	-
Quartz veins:	-

Profile:

A profile was constructed perpendicular (NE-SW) to the trend of the major structure around Abrahamshøgda (Fig. 23). The structure on the map has been somewhat simplified. Note that the height is exaggerated c. 5:1. The structure reveals two sets of major folds. An early NW-SE set and a later N-S set. The combination of cross-folding and topography and the lack of structural information such as plunge of fold axes, lineations etc. has made interpretation somewhat difficult. Other interpretations are possible.

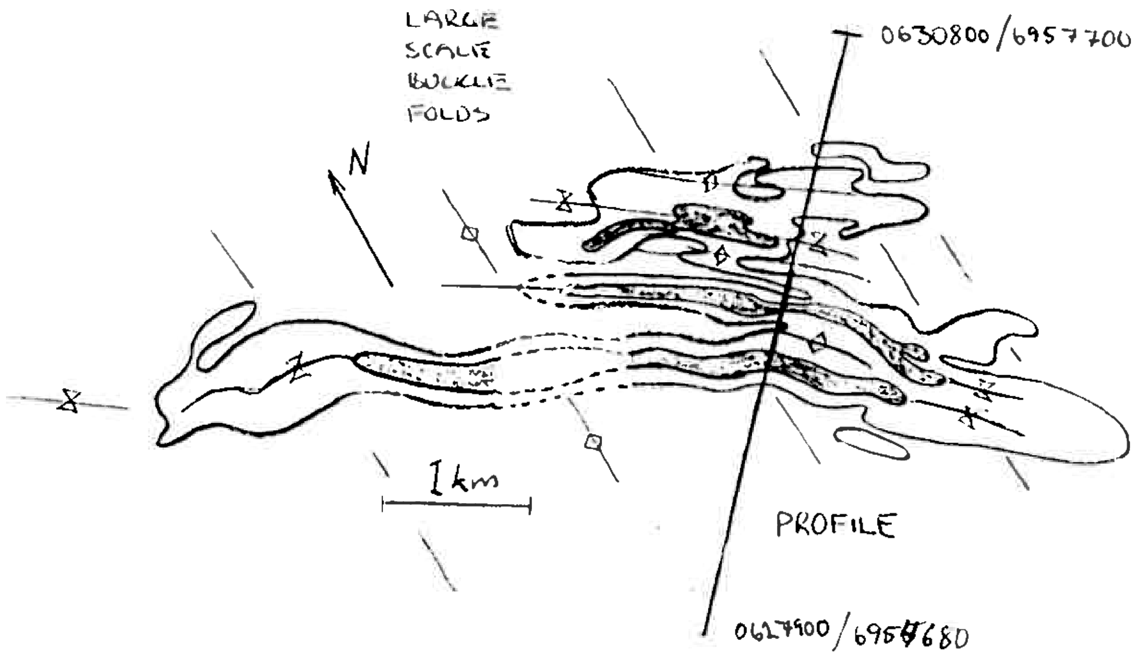


Figure 22: Simplified sketch of the Abrahamshøgda structure. The map shows two set s of folds. Dark areas are basin-type (enclosed) synclines. This is due to varying plunges of the hinge-lines. The undulation of the hinge-lines is due to the cross-folding by N-S fold axes.

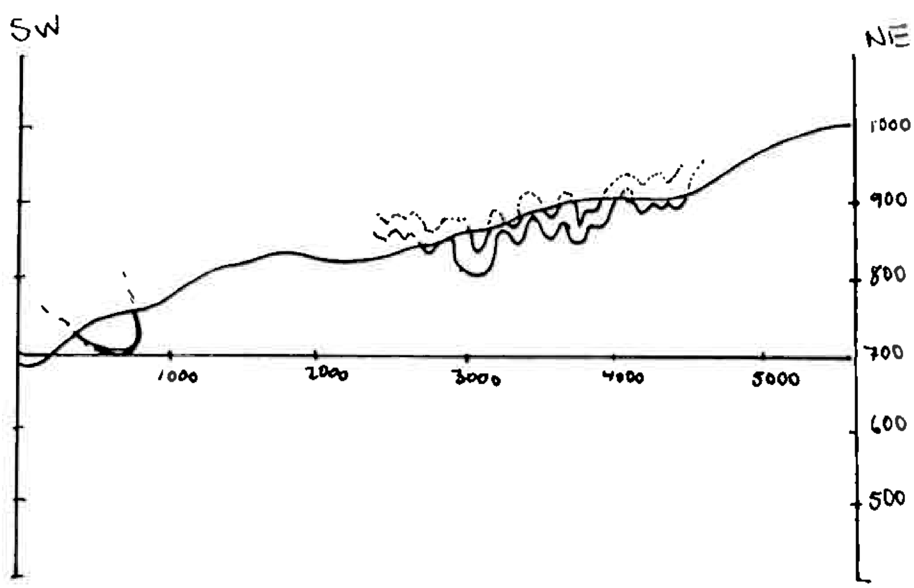


Figure 23: Cross-section through Abrahamshøgda with interpretation of the folding. Note that the height is greatly exaggerated.

Abrahamshøgda

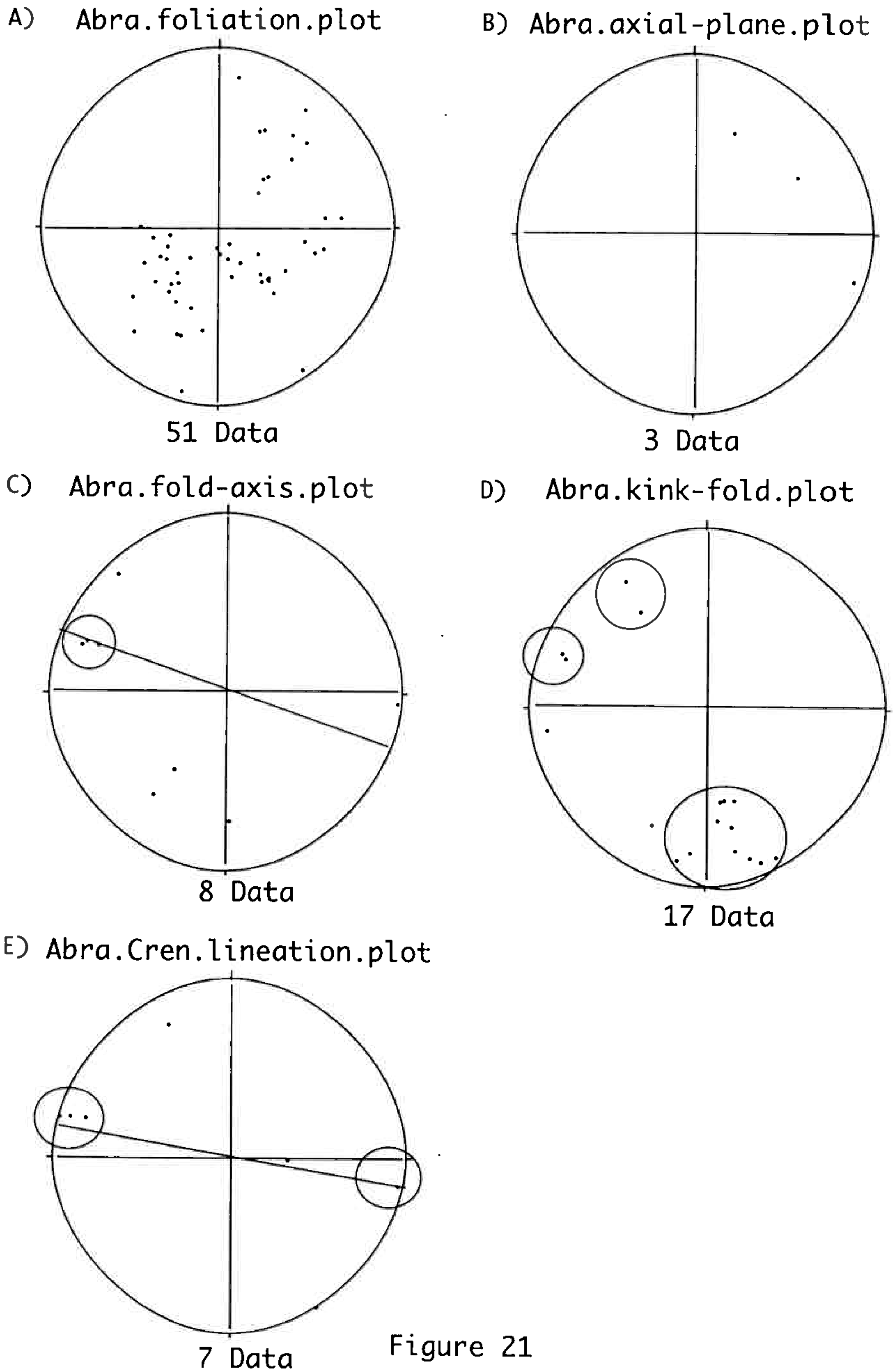


Figure 21

32/33. Klinkenberg/Matz gruve

Location: (UTM 0635629/6958360)

The Klinkenberg mines including Matz gruve are found in an area distinguished by elongated ridges and intervening valleys (Fig. 25). The ridges generally strike 300-320°. The ridges are subparallel to the major fold-axes and the strike of the mines (Fig. 26).

Due to the large data set and the obvious scattering of data points from polyphase deformation and refolding the area was subdivided into regions of relatively homogeneous structure. By this fashion the separation of flat-lying isoclines was fascilitated and a general movement direction determined.

Structural data (Fig. 24a-h)

Foliation: (97 data points, best fit)	8°-320
Fold-axes: (85 data points)	6°-306
Isoclinal (F1) fold-axes:	6°-303

The isoclines spread between 290-325°. The pattern suggests refolding, and it is likely that it is the F2 kink- and chevron folds that are responsible. A great circle of isoclines defines a steep east plunging fold (75-90°towards 080) but no such structure has been observed. It is possible that it is the combination of isoclines from a large area with slightly varying trends and plunges of fold hinges which confuses the issue. It is possible that some have had their hinge-lines rotated during thrusting and folding.

The F1 isoclines fold the ore, or the ore is situated in tight to isoclinally folded layers. The ore is also showing flow structures, i.e. small isoclinal folds indicating movement within the mineralised horizons.

F2 -F3 fold-axes: (chevron and kink folds)	10°-357.

The style of F2 folding is dependent on the competence of the different lithological units. A solid quartzitic unit will buckle whereas a shaly phyllite unit will deform by asymmetric chevron folding; however, when plotting the F2 folds on a stereonet the buckle- and chevron folds do not plot perfectly coaxially indicating that the less competent shaly units have probably rotated during compression and accommodated the stress more easily. The chevron-folds also locally contain a transecting cleavage supporting this statement (Fig. 27). Some folds are polyclinal, i.e. have more than one axial surface (Fig. 28). This is due to the formation of kink-bands (Fig. 29). These have resulted in some beautiful examples of box-folds within the schistose horizons.

The intersection between F1 and F2 fold axes (Fig. 30) has formed a complex pattern between Type 1 (dome-and-basin) and Type 2 (refolded fold) patterns of Ramsay (1967). The Type 1 pattern is seen in the mine where the angle between F1 and F2 is the greatest. Type 2 refolding is seen inthe oldest parts of the mine and involves refolding by upright folds of an earlier recumbent fold. The fold pattern suggets that there is flat-lying isoclines (c. 295-310) which have been refolded by near-coaxial (F3?) folds (325-335). The latter have produced the refolding when folded by the 350-360 set of buckle and crenulation folds.

Cleavage: (13 data points)	22°-217 (307)
Axial planes: (6 data points)	Refolded
Crenulation lineation: (16 data points)	15°-180
Bedding/cleavage intersection lineation: (7 data points)	19°-263 (353)
Mineral lineation: (7 data points)	17°-236 (326)
Boudin necks: (5 data points)	20°-320 (refolded)
Thrust planes:	N5°W/28°SW N24°W/20°SW N12°W/28°SW

The duplex (Plate 1) found SW of Klinkenberg (UTM 0634639/6957416 to UTM 0634825/6957562) displays E-directed thrusting with a back-rotated duplex (see sketch below). The fold-axes within this duplex is parallel with the late (±N-S trending) cross-folding chevron folds.

Ridges:	120-140/300-320
Scour marks:	300-340
Quartz veins:	≈N80°W/70°S

The quartz veins have the same S1 direction as the F2 or kink folds but are folded by the latter and probably formed at an early stage of D2/F2 deformation.

Strike of ore:	330 to 350, dip to SW

The ore is forming basin-and-dome type structures due to the interference folding. This can be seen in the roof of the mines and from the contours of mined areas. The ore is also behaving ductilely during deformation. This is seen in the formation of cuspate-lobate mullion structures, with pinched anticlines (Fig. 31). These structures are due to the chalcopyrite ore being less competent than the surrounding sericite schists. The cuspate/lobate structures indicate that there is a strong competence contrast between the two layers. The less competent componenet (the one forming points, in this case the chalcopyrite) is now behaving ductilely (Fig. 32). That the ore is migrating within the host rock is also visible in the walls where "xenoliths" of crenulated host-rock swim in the banded ore. The chalcopyrite/pyrite ore should be too incompetent to transfer this type of deformation and must thus have brecciated the already crenulated rock. This suggests that the horizons in which the pyrites are located may not be the original layers, or it may be that the ore is just interfingering the host rock where the foliation and fractures allow it. It can be seen that the chalcopyrite/pyrrhotite/sphalerite ore has travelled up fault zones. This may indicate that some thrusting-out of fold limbs has occurred and that it has been facilitated with the aid of the ore. Some of these structures resemble the piercement veins of Marshall & Gilligan (1989).

Klinkenberg I/II

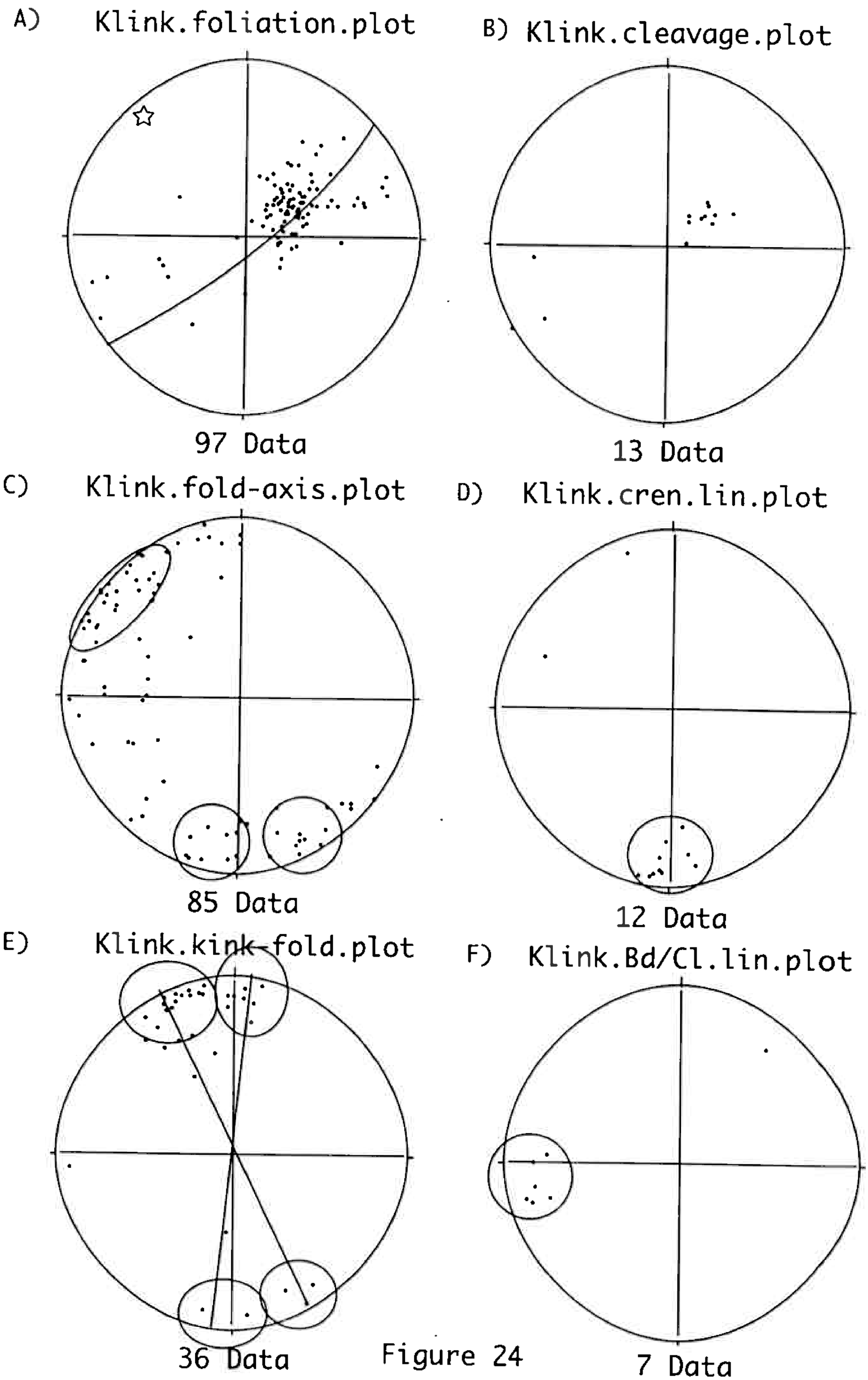
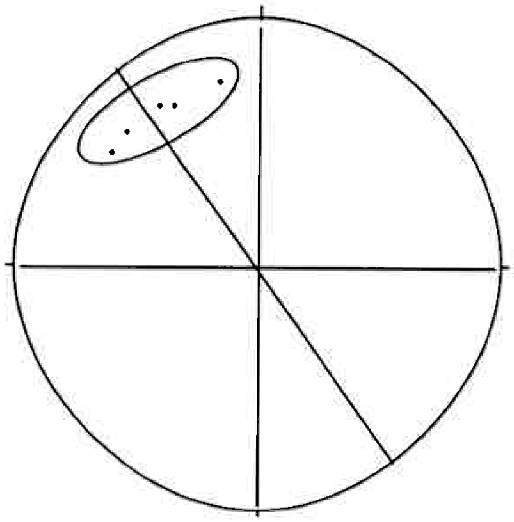


Figure 24

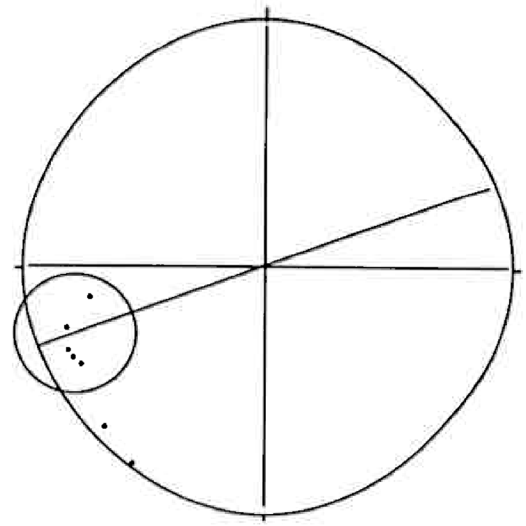
Klinkenberg II/II

G) Klink.boudin-neck.plot



5 Data

H) Klink.minlin.plot



7 Data

Figure 24

Figure 25:View of hummocky landscape around Klinkenberg mine. Photo towards southeast. The hills strike approximately NW-SE.

Figure 26: Photo of old part of mine with steep foliations in the hangingwall of the ore.

Figure 27: Chevron folds in the roof of the mine. The folds have curved fold hinges and also display transecting cleavages. This suggests that the fold hinges have been rotated but a new cleavage has not had time to develop. The folds refold an axial parallel crenulation lineation.

Figure 28: Crenulation and kinkfolding of highly foliated quartz-sericite phyllitic schists. The folds range from chevron folds to box folds and polyclinal folds with more than one axial surface. The ore horizons have been pinched and also have mullioned surfaces indicating low competence in contrast with the host rock.

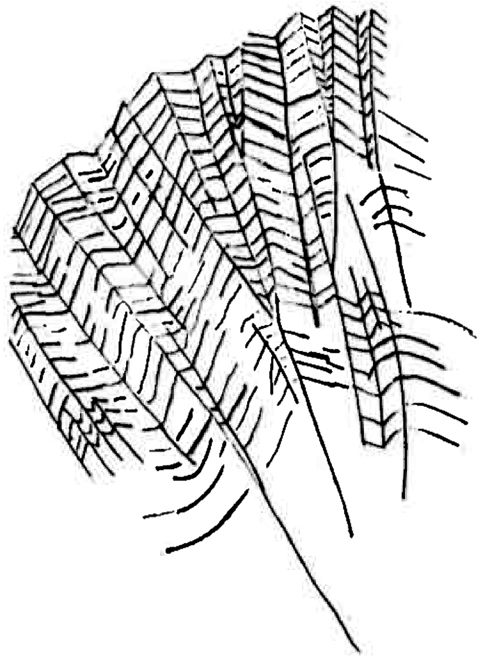


Figure 29: Sketch of complication zone where many folds have bifurcating fold-hinges. The trend of this set is c. 330.

Figure 30: Cross-folding (interference folding) between an earlier N-S (250°) crenulation by a later WNW-ESE (290°) set of kink folds and crenulation lineations. The result is a small scale "dome-and-basin" structure.

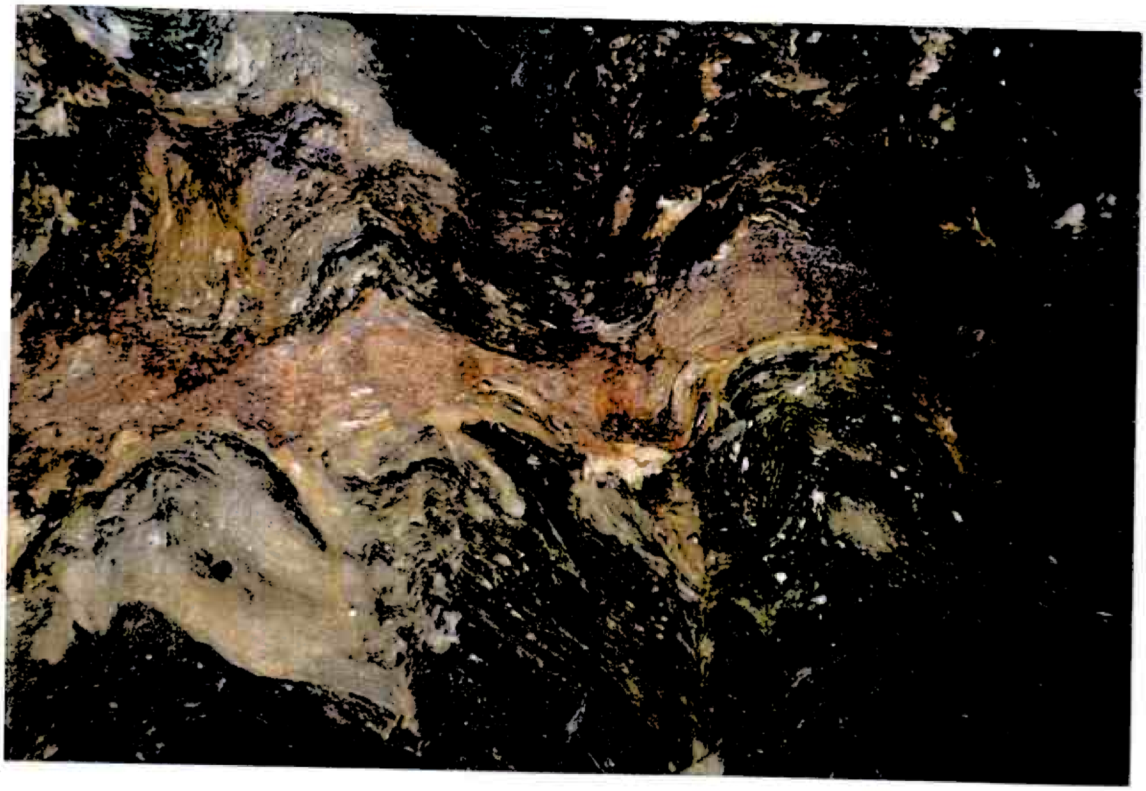


Figure 31: Pyrrhotite-rich ore showing a competence contrast with the surrounding phyllitic schists. The ore has developed a cuspate-lobate structure where the less competent sulphide ore in producing angular tips which project into the more competent host rock.

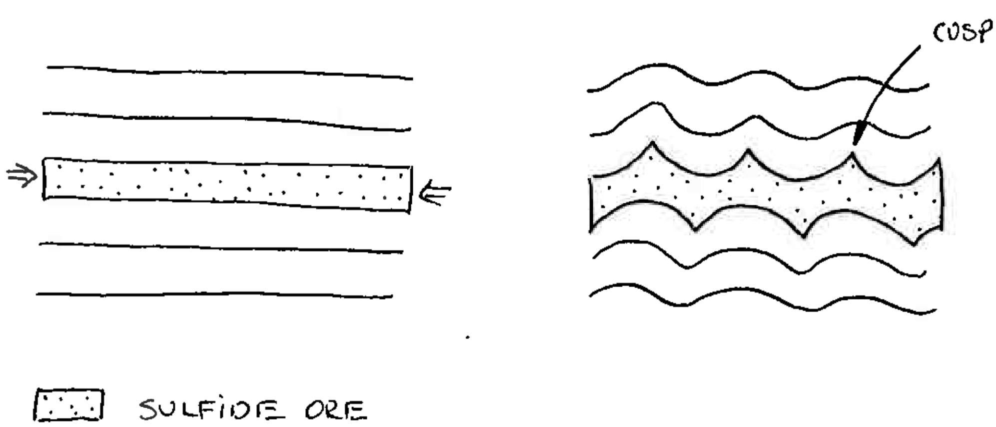


Figure 32: Sketch of the cuspate-lobate sulphide ore within the phyllitic host rock. Only the incompetent ore produces sharp cusps.

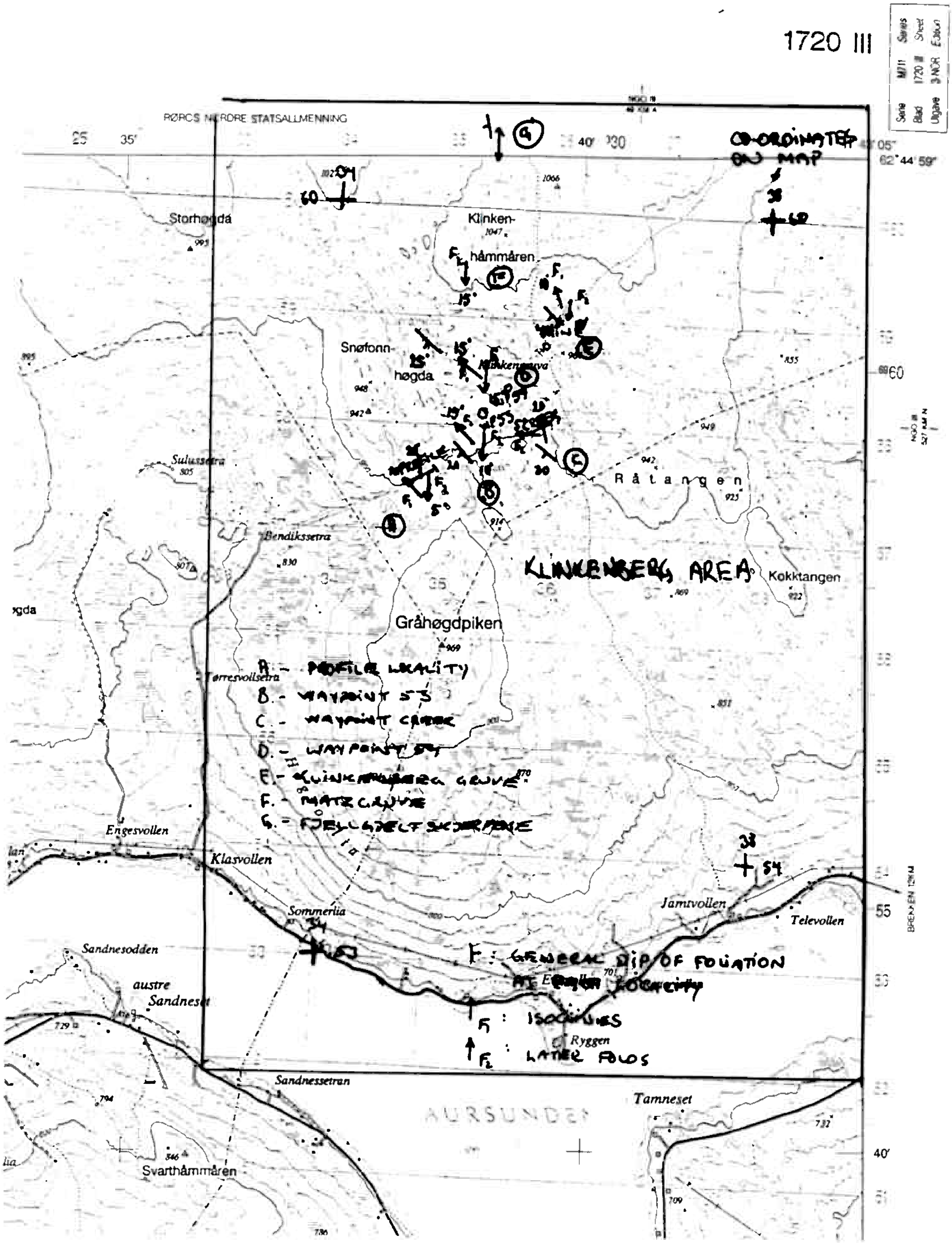


Figure 33: Map detail of the Klinkenberg area with overlay showing F1, F2 and dominant dip of foliation in 7 smaller areas. F1 isoclines are generally NW trending with F2 folds trending N-S.

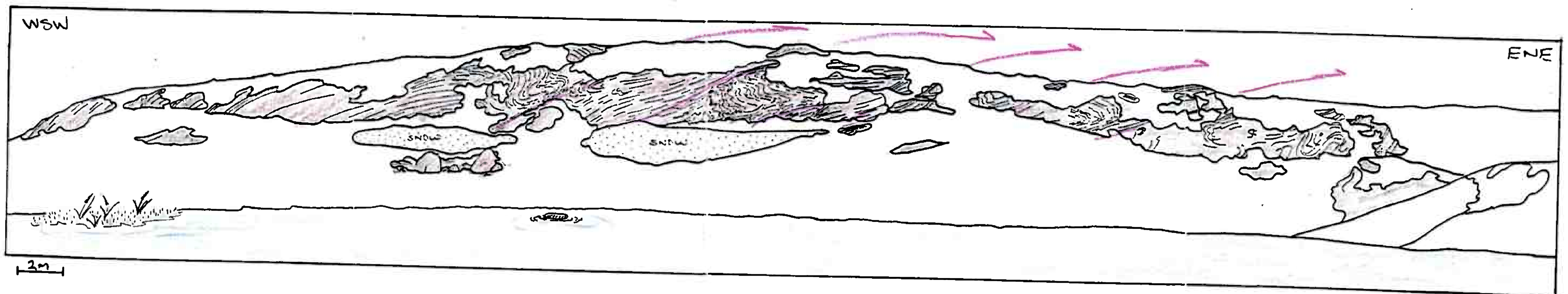


PLATE 1.

THRUST DUPLEX SHOWING BACKWARD ROTATING THRUSTS AND STEEPENING OF THE CONTACTS.
SEE WAYPOINT PROFILE

Klinkenberg area

The extent of the Klinkenberg area and the large number of structural field data prompted subdivision of the area. Smaller areas have been isolated to facilitate interpretation of collected data. The use of smaller areas has made determination of the significance of different structures easier, and local variations in trends can be noted and filtered (compare Klinkenberg I/II and II/II with Waypoint plots). Foliation data from all areas indicate a major structure towards the NW; however, fold axes are chaotic.

Waypoint profile

Location: UTM 0634639/6957416

Structural data (Fig. 34)

Foliation: (23 data points, best fit)	22°-263
Fold-axes: (13 data points)	8°-314 (±15)

The data spreads between 300 and c. 330.

Cleavage:	-
Axial planes:	-
Chevron and kink-folds: (9 data points)	1°-171

The foliation data is somewhat unclear. Most foliation data reflect the dip and dip direction of the thrust planes within the thrust duplex. The thrusts indicate E-directed shortening; however, many fold axes plot with a NW-trend. Fold data indicate a major NW-trending structure with some E-trending folds. No isoclines were found. Late N-S trending kink folds post-date earlier events.

Waypoint Profile

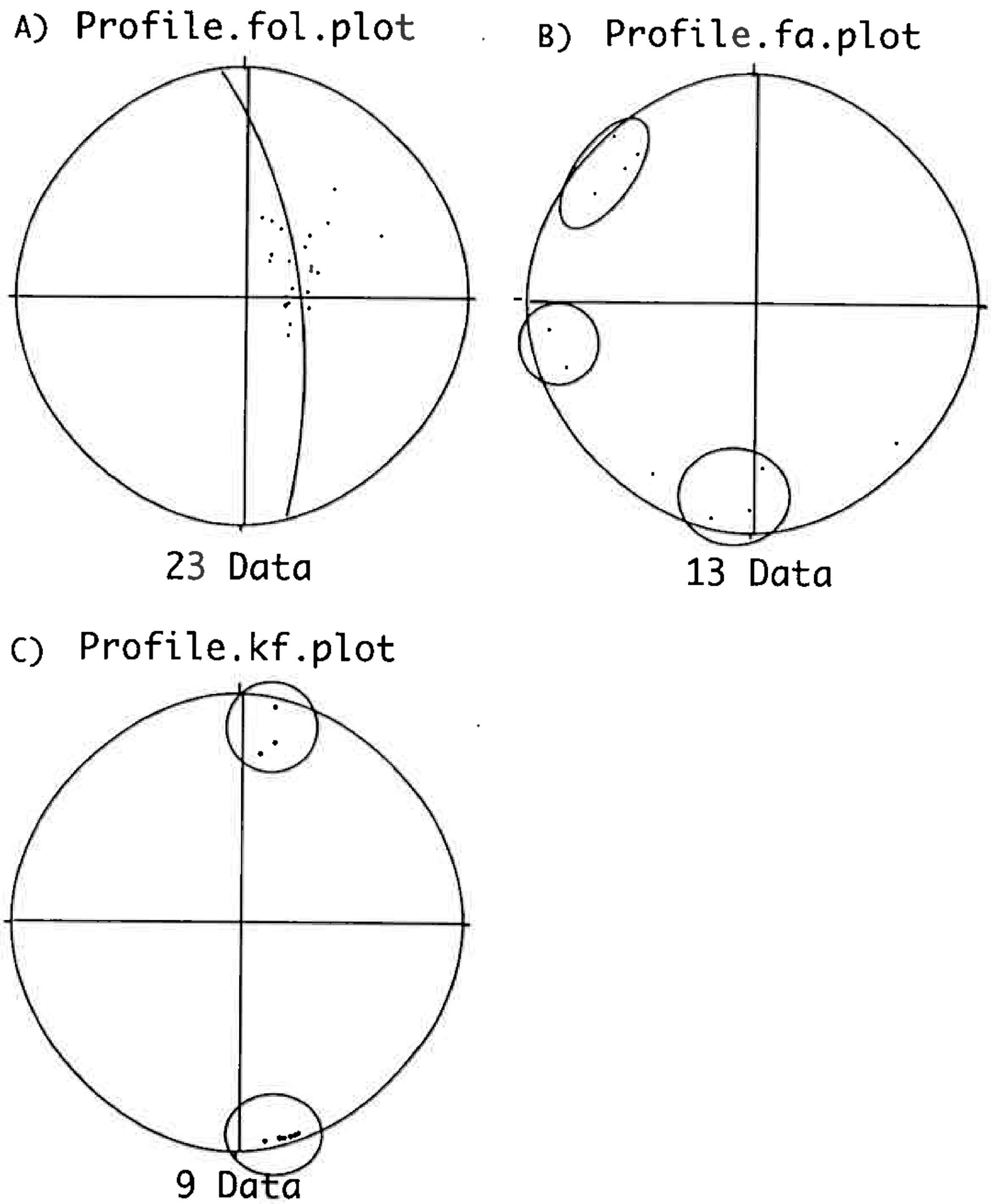


Figure 34

Waypoint 53

Location: UTM 0635335/6958107

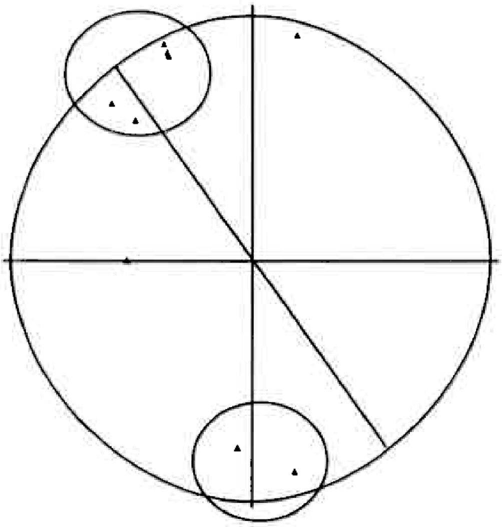
Structural data (Fig. 35)

Foliation: (22 data points)	too clustered
Fold-axes: (9 data points)	10°-345
Cleavage:	-
Axial planes:	-
Crenulation lineation: (6 data points)	13°-181
Boudin necks: (4 data points)	refolded

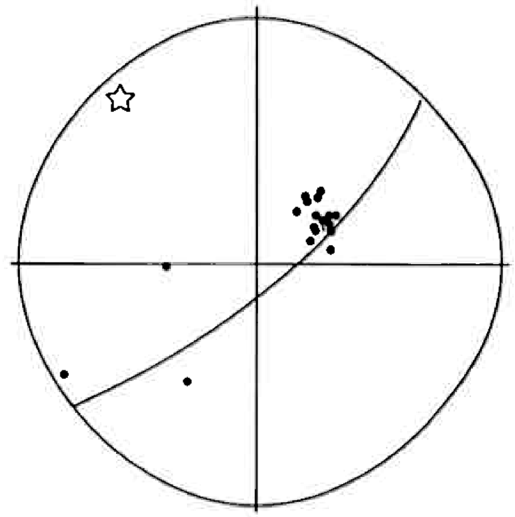
The foliation data plots too close together and is insufficient on its own for interpretation. The fold axes are all isoclines and can be fitted on two small circles indicating refolding by a NW-trending (c. 345°) fold axis. The N-S trending crenulation lineation post-dates both the isoclines and the NW-trending structure.

Waypoint 53

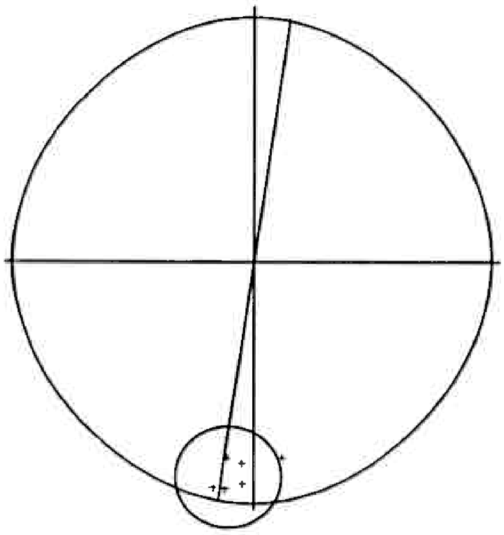
A) WP53.fold-axis.plot



B) WP53.fol.plot



C) WP53.crenlin.plot



D) WP53.Bd/Cl.plot

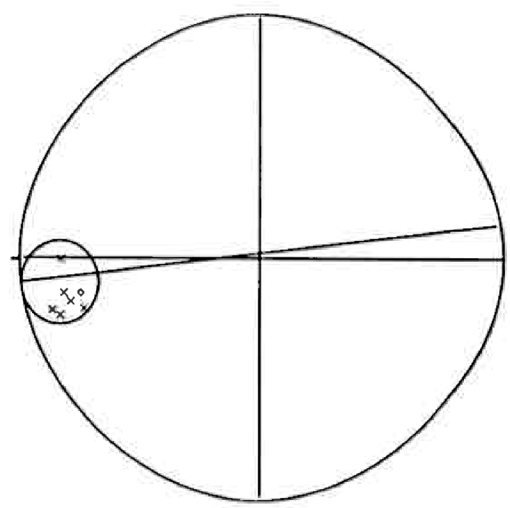


Figure 35

Waypoint Creek

Location: UTM

Structural data (Fig. 36)

Foliation: (7 data points, best fit) 15°-300

Fold-axes: (8 data points) -

The data produces two maximas with three data points, one at c. 330 and another around E-W (270°).

Cleavage: -

Axial planes: -

Chevron and kink-folds: -

Foliations define a great circle with a plunge towards NW but the fold axes are more chaotic with some plotting towards the NW while other plot towards the W and SW. The NNW folds are related to foliations while W to WSW trending folds are possibly being movement related.

Waypoint Creek

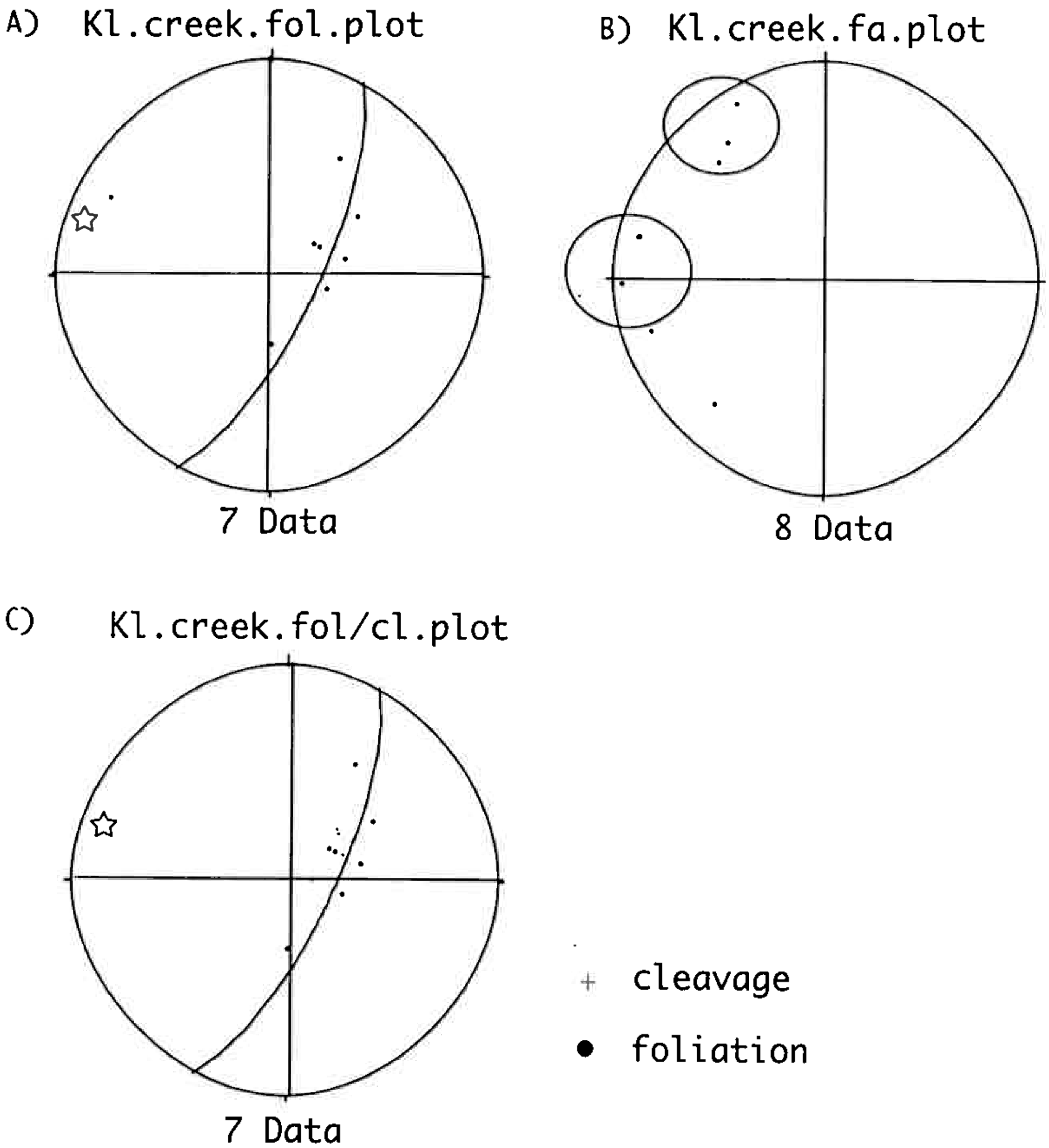


Figure 36

Waypoint 54

Location: UTM 0635029/6958360

Structural data (Fig. 37)

Foliation: (15 data points, best fit)	too clustered
Fold-axes: (9 data points)	12°-300

The fold-axes are all isoclines!

Bedding/cleavage: intersection lineation:	12°-235
Axial planes:	-
Crenulation lineation: (5 data points)	23°-181

The foliation data at Waypoint 54 is concentrated and of little help for interpreting larger structures but the flat-lying foliation data and the apparent lack of any F2 folding has produced a well constrained cluster of F1 isoclines. The isoclines are NE trending and the vergence is supported by mineral stretching lineations which trend NE-SW with a subhorizontal plunge. Crenulation lineations are N-S trending and overprint earlier structures.

Waypoint 54

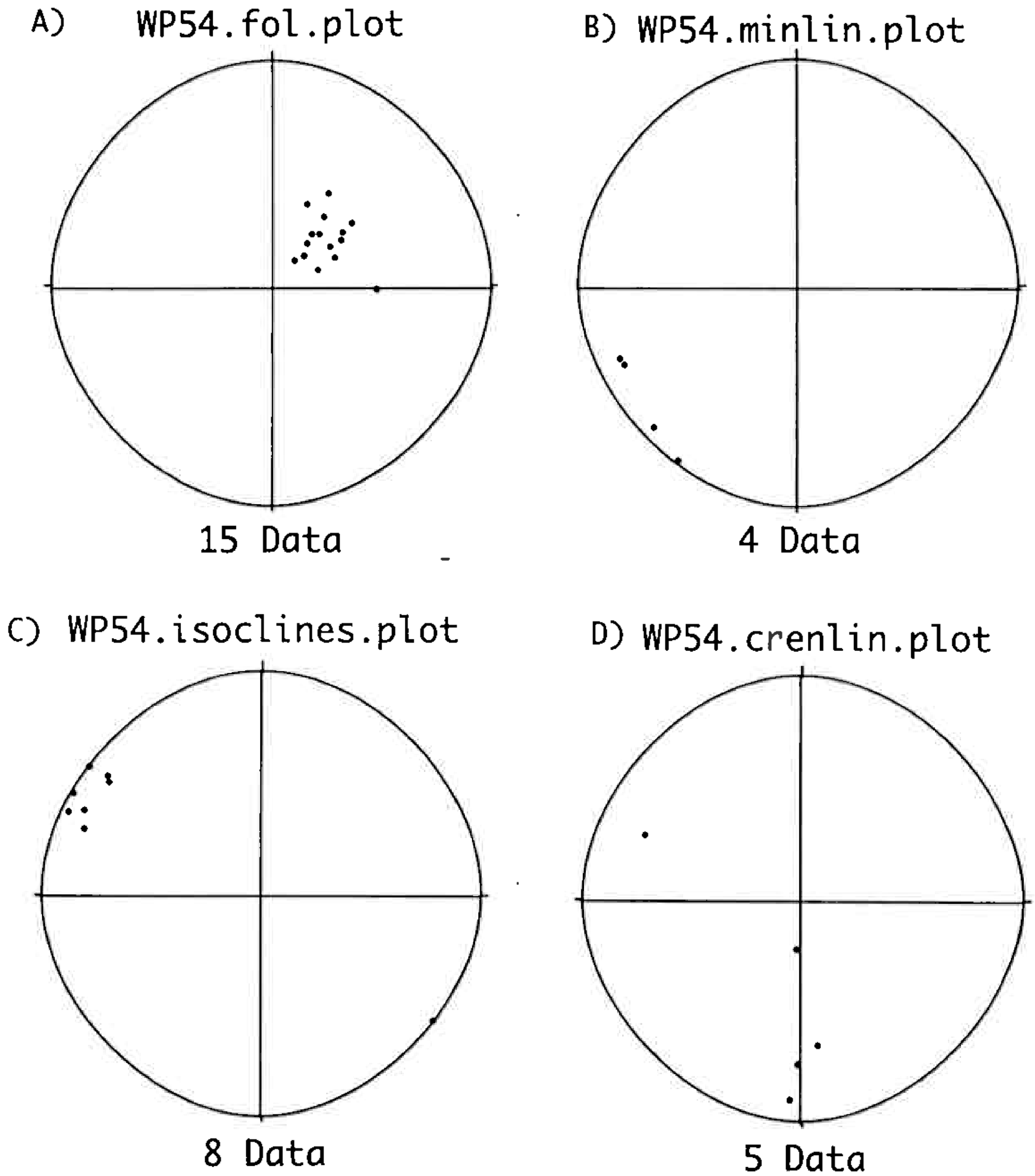


Figure 37

Klinkenberg mine

Location: UTM 0635629/6958360

Structural data (Figs. 38 & 39)

Foliation: (13 data points, best fit) 1°-320

Fold-axes: (19 data points) 8°-345 (refolded)

F1 (8 data points)
F2 (11 data points)

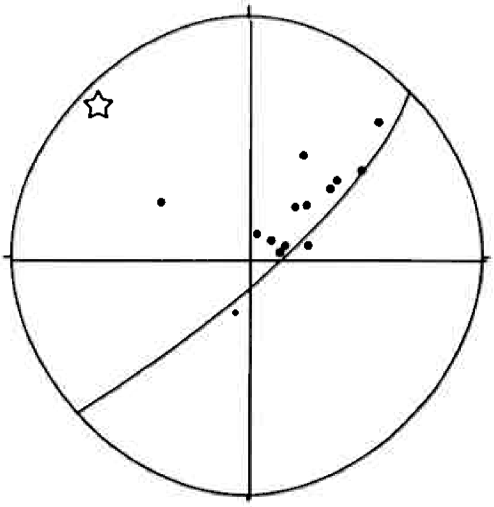
The F1 isoclines are refolded by the above F2 folds around a small circle (see Fig 38c)

Cleavage: -
Axial planes: -

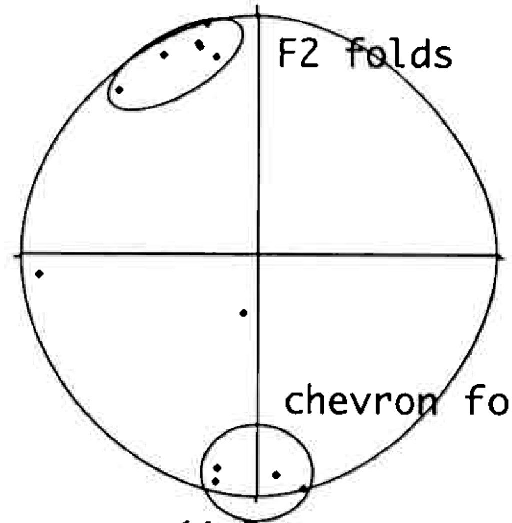
At Klinkenberg mine tha foliation data indicates a major structure towards the NW. F1 isoclines trend from SE to SW suggesting refolding by NNW-trending F2 folds. The F2 folds are indeed NNW trending with N-S trending F3 chevron folds. The latter may just be a continuation of folding during rotation. This is visible in the curvature of the axial planes of many of the chevron folds. The mine displays many good examples of durchbewegung structures and the general competence contrast between different sulfide ores. The pyrite horizons are generally competent and up to a metre in thickness whereas the sphalerite and chalcopyrite horizons have been altered physically to form cuspate-lobate structures where they are behaving ductilely compared to the phyllitic host-rock.

Klinkenberg mine

A) Klinkmine.fol.plot



B) Klinkmine.fa.plot



C) Klinkmine.isoclines.plot

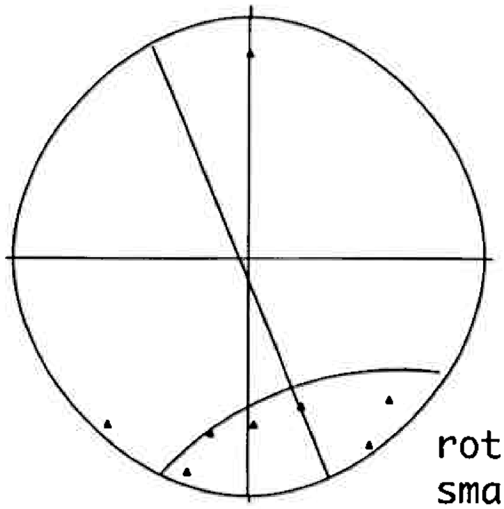
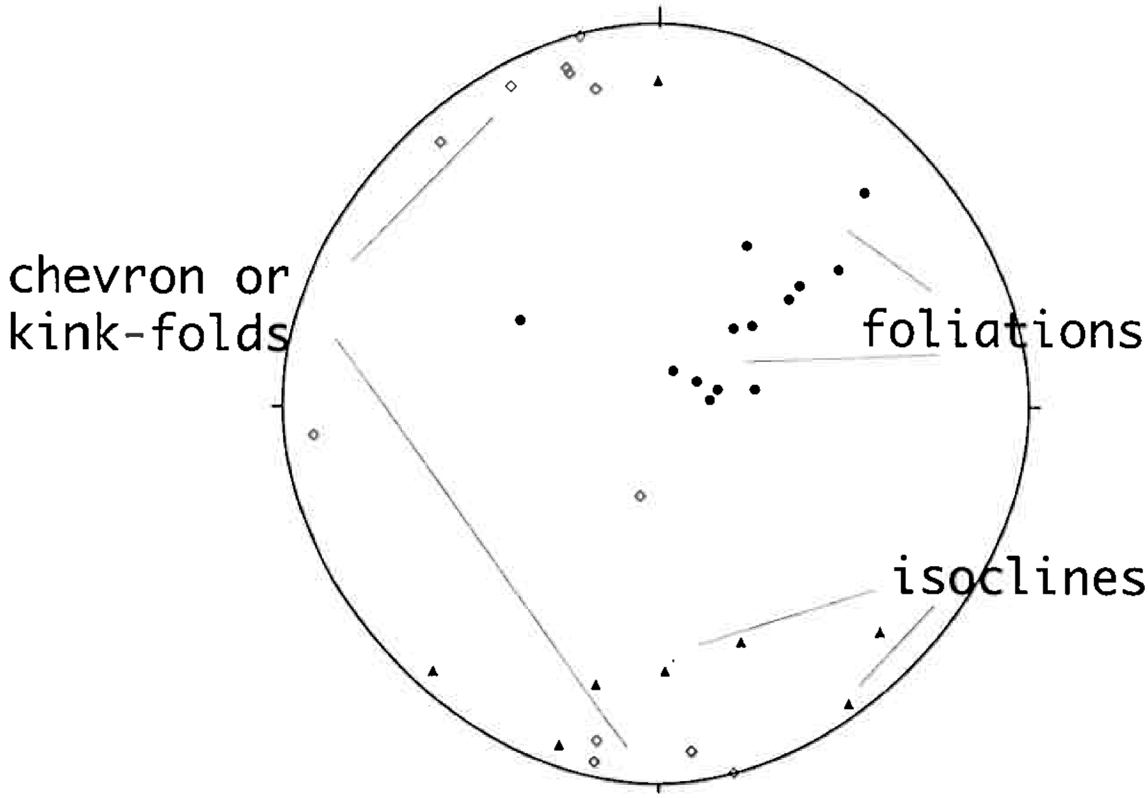


Figure 38

Klinkenberg mine.compilation



32 Data

Figure 39

Matz gruve

Location: UTM

Structural data (Fig. 40)

Foliation: (7 data points, best fit)	southwards
Kink-folds: (5 data points)	15°-180
Cleavage:	-
Axial planes:	-

Terrible foliation data but a well defined set of N-S trending chevron and kink-folds.

Matz gruve

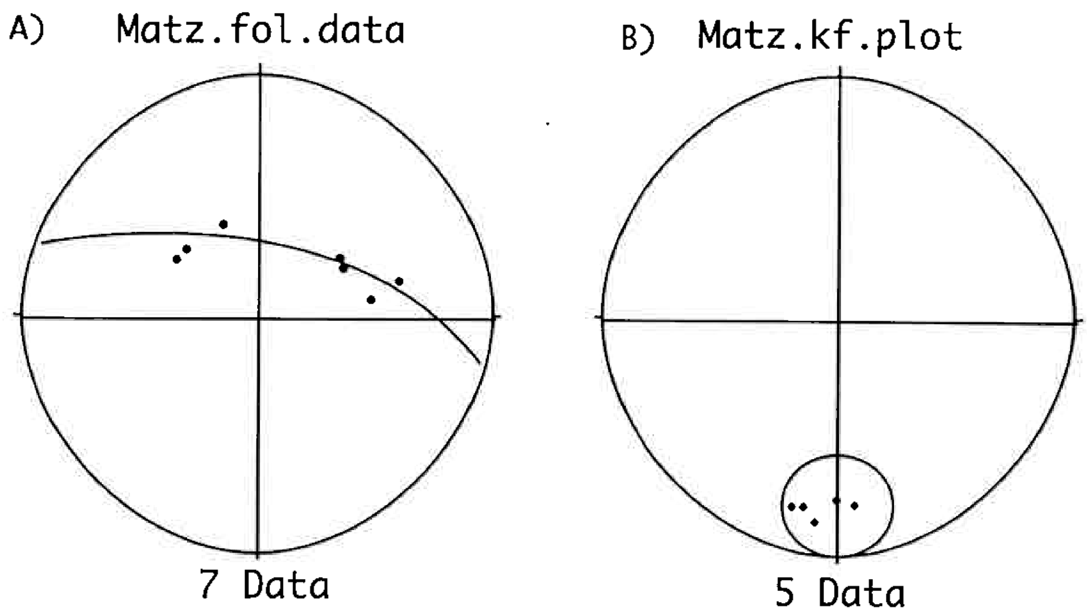


Figure 40

Fjellgjeltskjerpene

Location: UTM

Structural data (Fig. 41)

Foliation: (11 data points, best fit)	°-
Fold-axes: (3 data points)	15°-170/350

The plunge of the folds vary from N to S

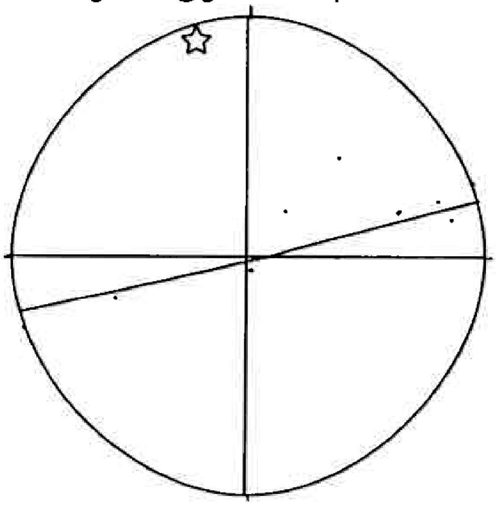
Cleavage:	-
Axial planes:	-
Crenulation lineation: (10 data points)	N-S (±15°)

The lineation plunge between 10° to either north or south.

The foliation data defines a major structure towards the NNW which is corroborated by the fold axis data. A N-S trending crenulation lineation post-dates folding.

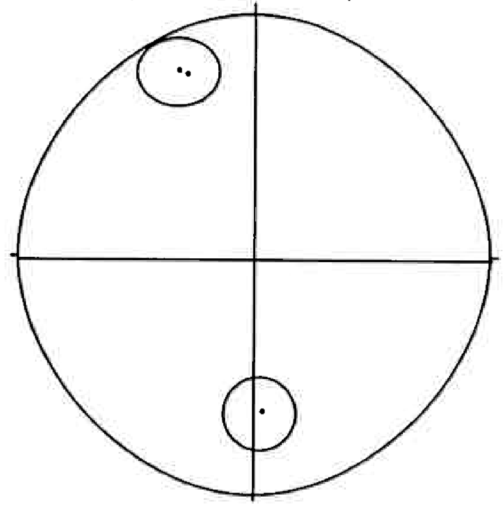
Fjellgjeltskjerpene

A) Fjellgj.fol.plot



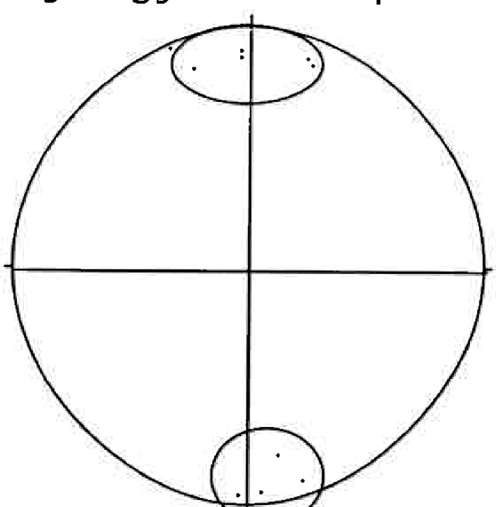
11 Data

B) Fjellgj.fa.plot



3 Data

C) Fjellgj.crenlin.plot



10 Data

Figure 41

The Holtålen district

45. Killingdal gruve

Location: UTM

Structural data (Fig. 42a-d)

Foliation: (26 data points, best fit) 35°-280

The poles to foliation define a poorly constrained great circle indicating a fold axis at c.30°-270. The data also indicates that it has been disturbed through later refolding.

Fold-axes: (5 data points) 46°-269

Although only 4 fold axes were found (buckle folds) they indicate two folding events. One event suggests a steep fold at c. 67°-306, the other a shallow plunging 16°-354.

Cleavage: -
Axial planes: -

Chevron and kink-folds: (4 data points) 6°-015

Four(!) kink-folds were found in the Killingdal area. These confirm the N-S fold event that was suggested from the buckle folds.

Crenulation lineation: -
Bedding/cleavage intersection lineation: -

Mineral lineation: -
Boudin necks: (6 data points) 38°-266

Boudinaged quartz vein were found in several places. These boudin necks have an average plunge of c. 38°-266.

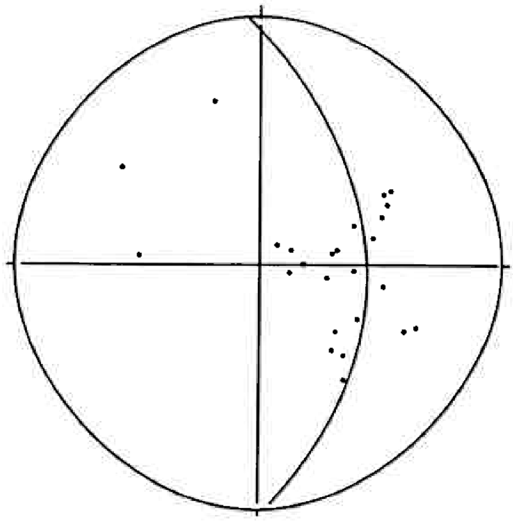
Kink-bands: -

Thrust planes: -

Quartz veins: -

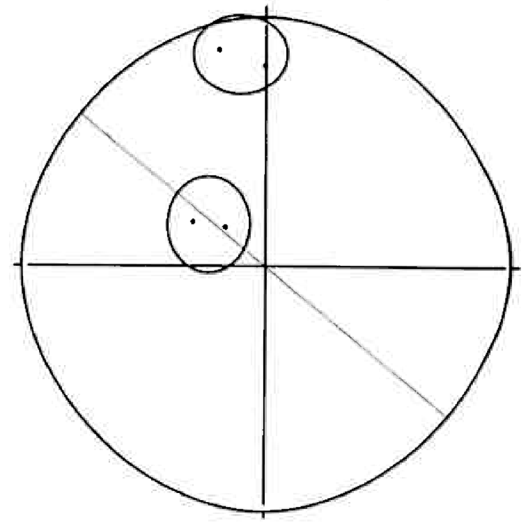
Killingdal

A) Kill.foliation.plot



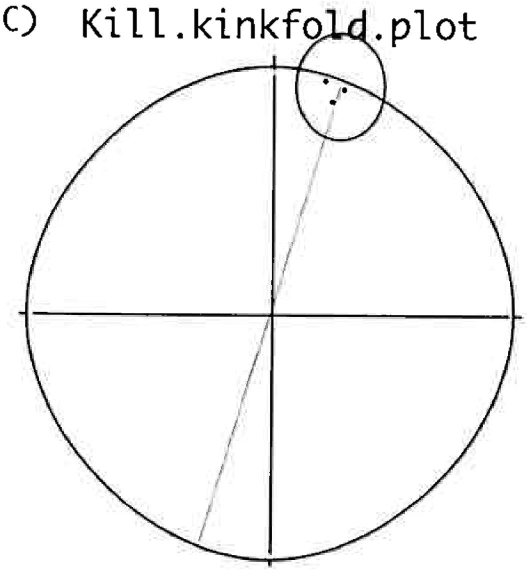
26 Data

B) Kill.fold-axis.plot



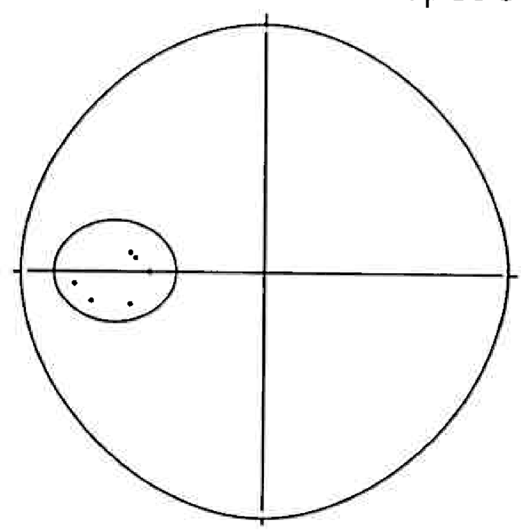
4 Data

C) Kill.kinkfold.plot



4 Data

D) Kill.boudin-neck.plot



6 Data

Figure 42

50/51 From & Rogn gruve

Location: UTM

Structural data (Fig. 43a-b)

Foliation: (18 data points, best fit)	42°-266

The poles to foliation in the Rogn gruve area falls onto a well defined great circle indicating a fold structure at c. 42°-266.

Fold-axes: (5 data points)	46°-269

The plunges of the folds in the Rogn gruve are much steeper than in other visited mines. The Rogn gruve mines are also located the furthest west of all claimed localities and are found quite near the tectonic boundary. However, the fold data agrees very well with all other structural data.

Cleavage:	-
Axial planes:	-
Chevron and kink-folds: (1 data point)	40°-283
Crenulation lineation:	-
Bedding/cleavage intersection lineation: (2 data points)	37°-278
Mineral lineation: (3 data points)	47°-269
Boudin necks:	-
Kink-bands:	-
Thrust planes:	-
Ridges:	-
Scour marks:	-
Quartz veins:	-

From/Rogn gruve

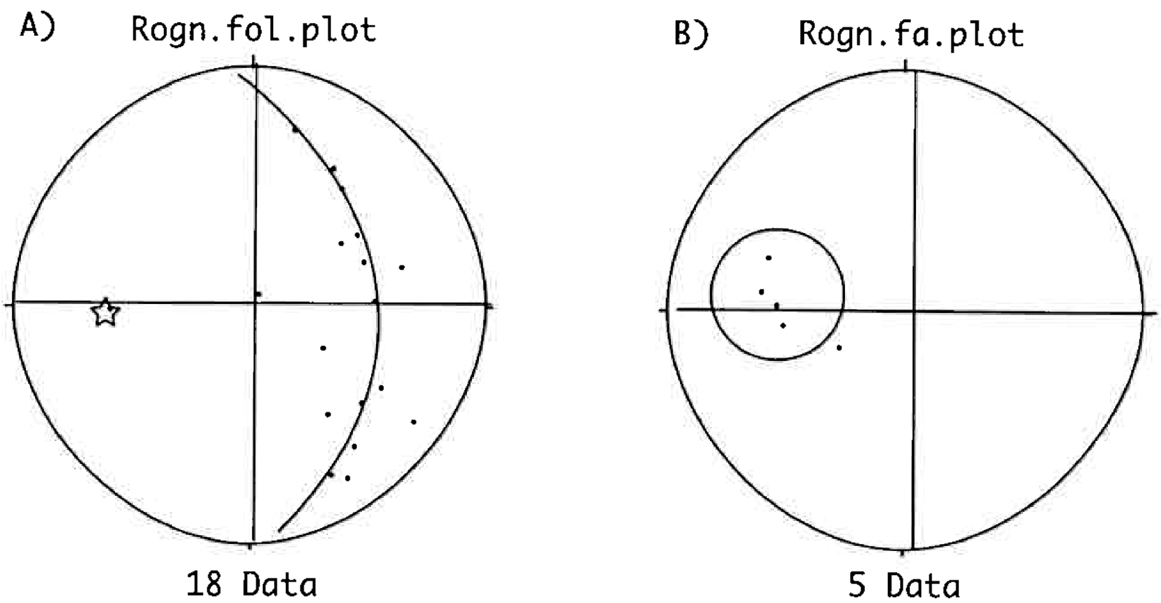


Figure 43

xx. Bukkhåmmåren

Location: UTM 0616491/6985750

Structural data (Fig. 44a-d)

Foliation: (best fit, 19 data points)	42°-250 (?)
Fold-axes: (poorly constrained, 5 data points)	29°-250 5°-190 17°-322

One isocline at 17°-322

Gentle folds with three metre wavelength and 30-40 cm amplitude in direction 31°-246. Gentle to open type folds at 8°-190. These two fold sets form a fold interference with buckling of the surfaces

Cleavage:	-
Axial planes:	-
Chevron and kink-folds: (1 data point)	2°-202
Crenulation lineation:	-
Bedding/cleavage intersection lineation:	-
Mineral lineation:	32°-241

Aligned hornblende grains.

Boudin necks: (3 data points)	10°-330 (2) 8°-026 (1)
Kink-bands:	N3°W/33SW
Thrust planes:	-
Dip of ore:	≈35°-265
Ridges:	330±10°

Bukkhåmmåren

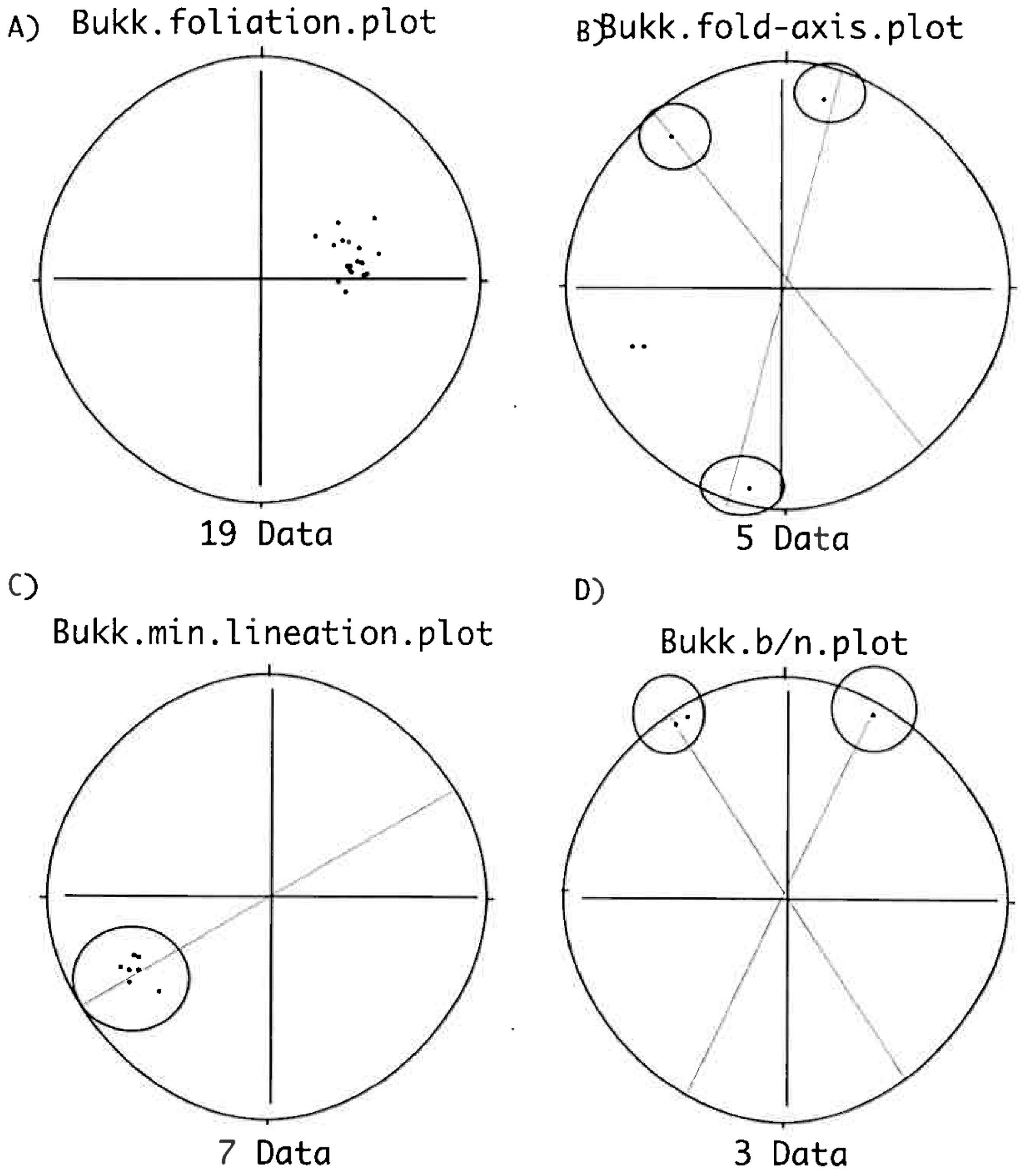


Figure 44

53. Kårslåtthøgda gruve

Location: UTM

<u>Structural data</u> (Fig. 45a-c)

Foliation: (best fit, 9 data points)	42°-250
Fold-axes: (2 data points)	58°-246
Cleavage:	-
Axial planes:	-
Chevron and kink-folds: (F2)	16°-288
Crenulation lineation:	-
Bedding/cleavage intersection lineation:	-
Mineral lineation:	52°-232
Boudin necks:	-
Kink-bands:	-
Thrust planes:	-
Ridges:	-
Scour marks:	-
Quartz veins:	-

Kårslåtthøgda

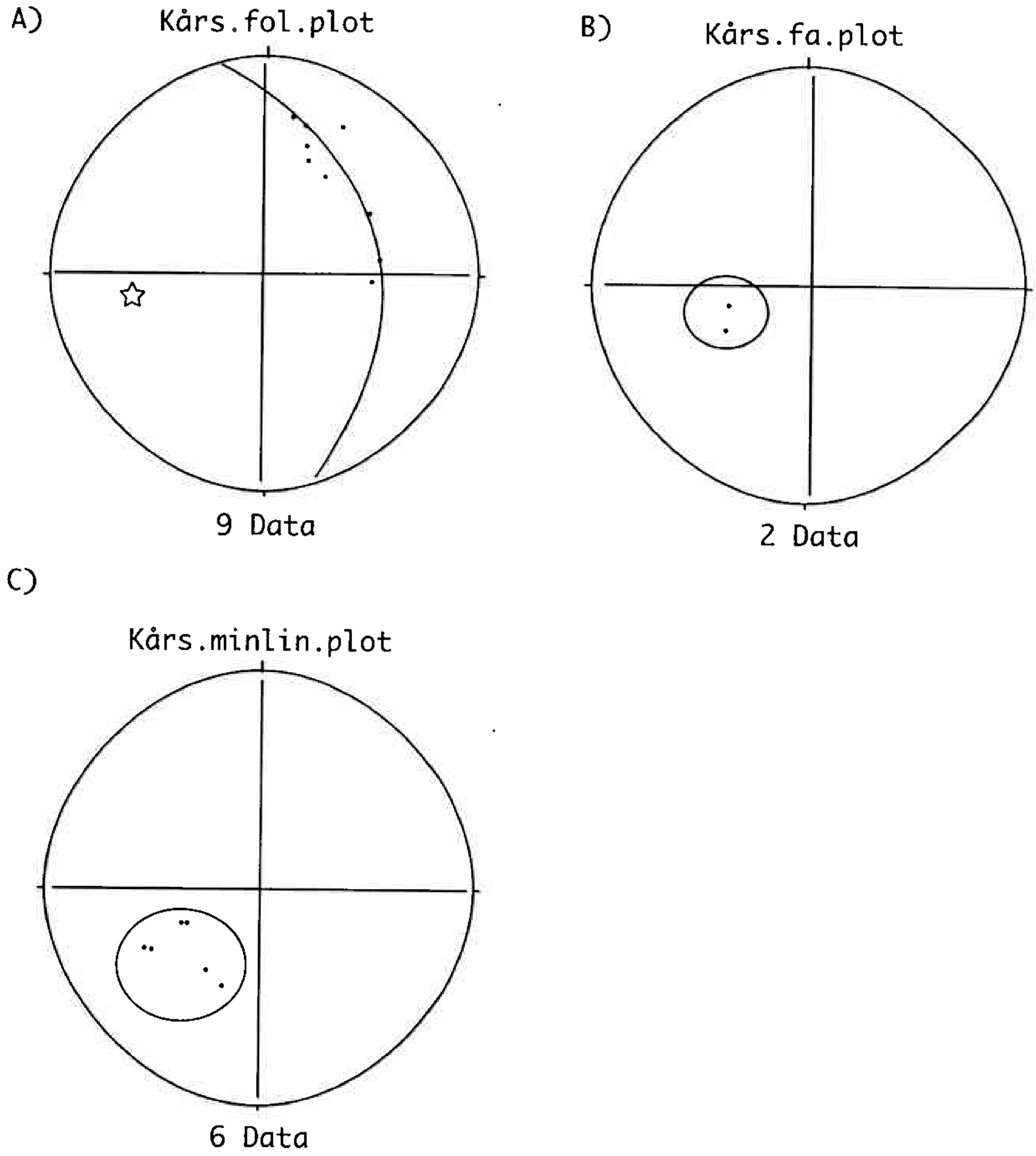


Figure 45

The Kjøli district

62. Svenskmenna

Location: UTM

Structural data (Fig. 46a-c)

Foliation: (49 data points, best fit) 6°-141

The poles to foliation fall on a great circle indicating a fold plunging c. 10°-144. There is some disturbance in the system.

Fold-axes: (15 data points) 6°-139

The fold axes alternate between c. 5°-315 and 6°-135. Two fold axes plotted at 6°-025. The folds are gentle and vary from c. 1 to c. 6 metres in wavelength. More phyllitic units have deformed by crenulation or kink folding on centimetre to decimetre-scale.

Cleavage: -
Axial planes: -

Chevron and kink-folds: -
Crenulation lineation: -
Bedding/cleavage intersection lineation: -

Mineral lineation:(5 data points) 25°-082 (172)

The mineral lineation is composed of aligned hornblende crystals on foliation surfaces. The hornblende is found in greenschists and as layers in psammites.

Boudin necks: (2 data points) 326 and 13°-022

The two quartz rods (boudins) both plotted near the two present fold phases.
The quartz veins show signs of pinch and swell structures. These are folded and were the result of early deformation (possibly thrusting). The boudinaged quartz veins suggests there must exist isoclinal folds but none were found.

Kink-bands: -

Thrust planes: -

Quartz veins -

Svenskmenna

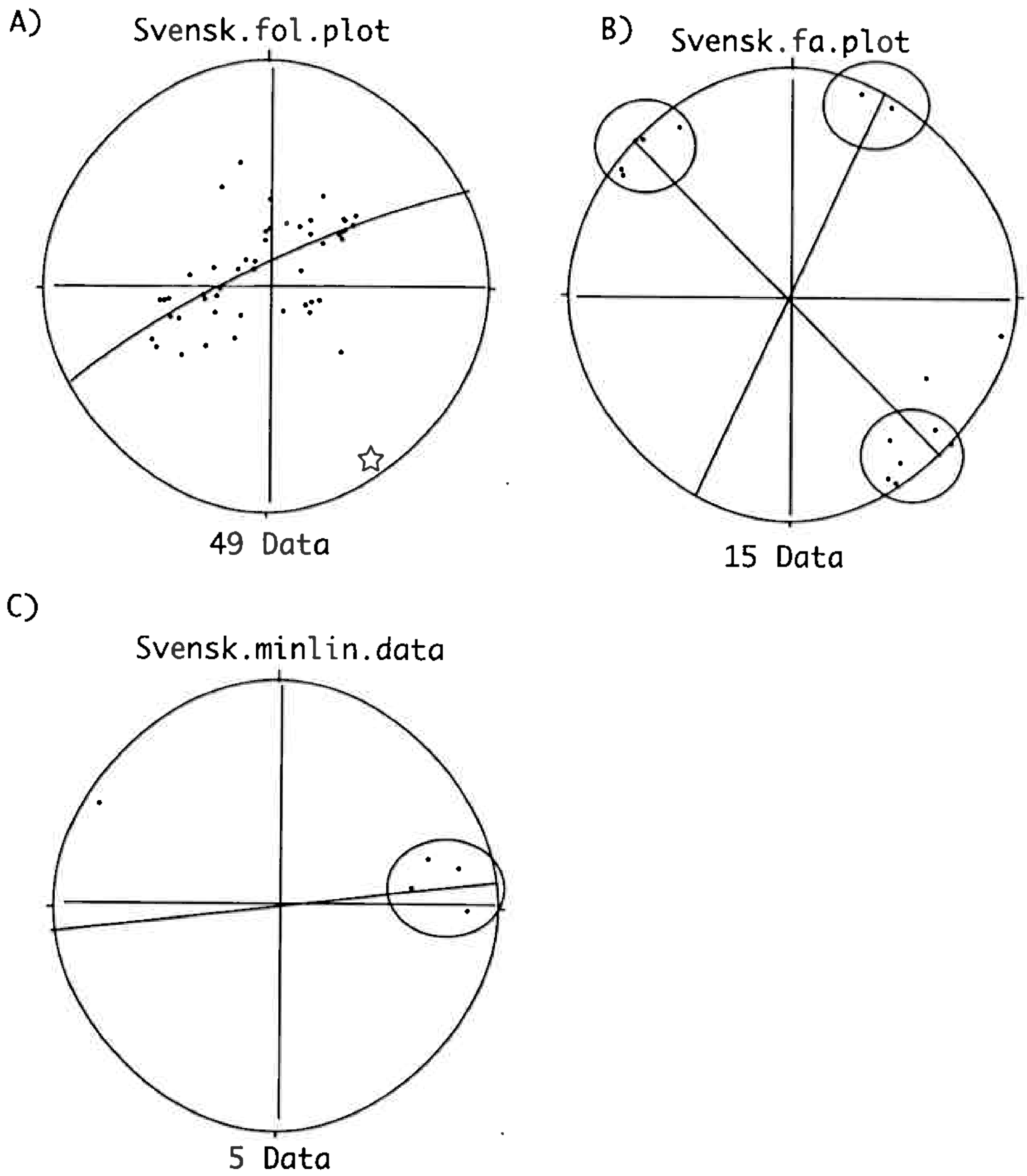


Figure 46

64. Gauldalsgruvhøgda

Location: UTM

Structural data (Fig. 47a-c)

Foliation: (23 data points, best fit) 2°-323
Fold-axes: (2 data points) 2°-322 & 20°-160

Large gentle N-S trending folds can be seen from a distance. They have wavelengths in excess of 15 metres and amplitudes of around a metre.

Cleavage: -
Axial planes: -

The axial planes to the 160-320 kink folds dip steeply (60-70°) towards SW.

Chevron and kink-folds: (5 data points) 2°-320

The kink folds are found on centimetre to decimetre scale and are overturned to the south with SW dipping axial planes (c. 70°).

Crenulation lineation: (2 data points) 7°-125 (305)
Bedding/cleavage intersection lineation: -

Mineral lineation: (1 data point) 8°-120 (300)
Boudin necks: (1 data points) 12°-113

Kink-bands: -

Thrust planes: -

Ridges: -

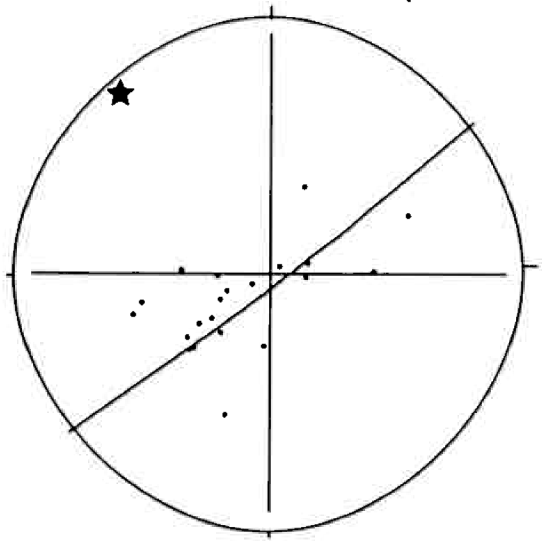
Scour marks: -

Quartz veins: -

Dip of Ore: The ore strikes approximately NW-SE and dips towards SW.

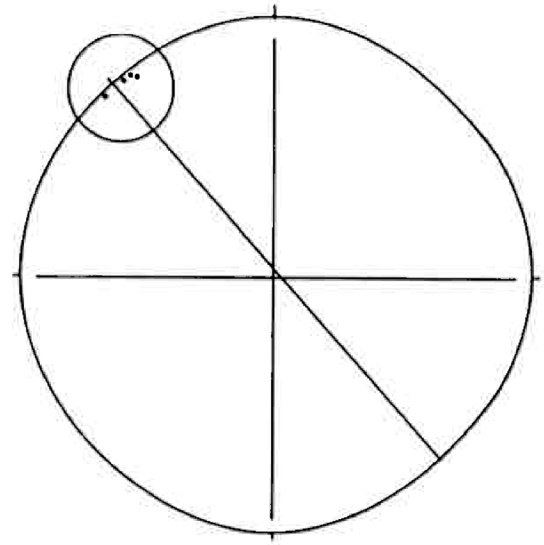
Gauldalsgruvhøgda

A) Gaul.foliation.plot



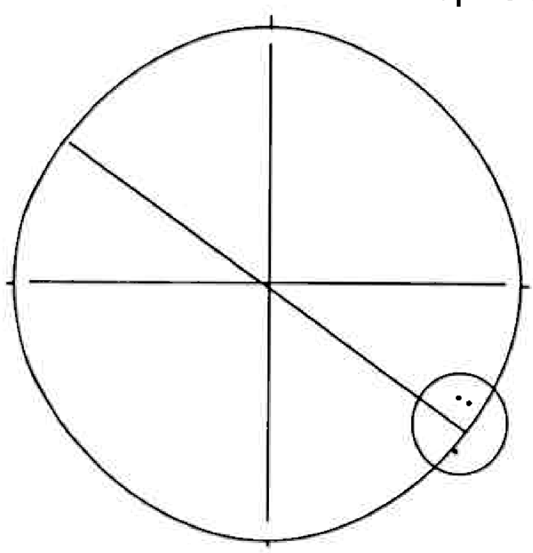
21 Data

B) Gaul.kink-folds.contour



4 Data

C) Gaul.min.lineation.plot



3 Data

Figure 47

65. Godthåb gruve

Location: UTM

Structural data (Fig. 48a-c)

Foliation: (21 data points, best fit)	27°-283
Fold-axes: (7 data points)	27°-283

Isoclinal folds: One c. 150 cm long recumbent isocline was found plunging 25°-283.

There are many quartz veins/horizons in the hornblende/chlorite schists that must be the result of isoclinal folding, however, fold-hinges are not easy to locate.

The large, gentle folds have wave-lengths of 3-4 metres with fold axes plunging c. 10° to 35° towards 280. Phyllitic/hornblende schist horizons within the larger folds have deformed through kink-folding in the hinge zone and crenulation lineations on the limbs. The crenulation/kink folds are only a few centimetres in scale.

Cleavage:	-
Axial planes:	-
Chevron and kink-folds: (5 data points)	26°-295?
Crenulation lineation:	-
Bedding/cleavage intersection lineation:	-
Mineral lineation: (3 data points)	25°-277
Boudin necks: (1 data point)	35°-330

There are many boudinage quartz veins which suggests again that isoclinal folding must exist but is extremely hard to locate.

Kink-bands:	N73°W/52°NE 32°-307
Thrust planes:	-
Ridges:	-
Scour marks:	-
Quartz veins:	-
Dip of ore:	N20°E/40°NW

Godthåb

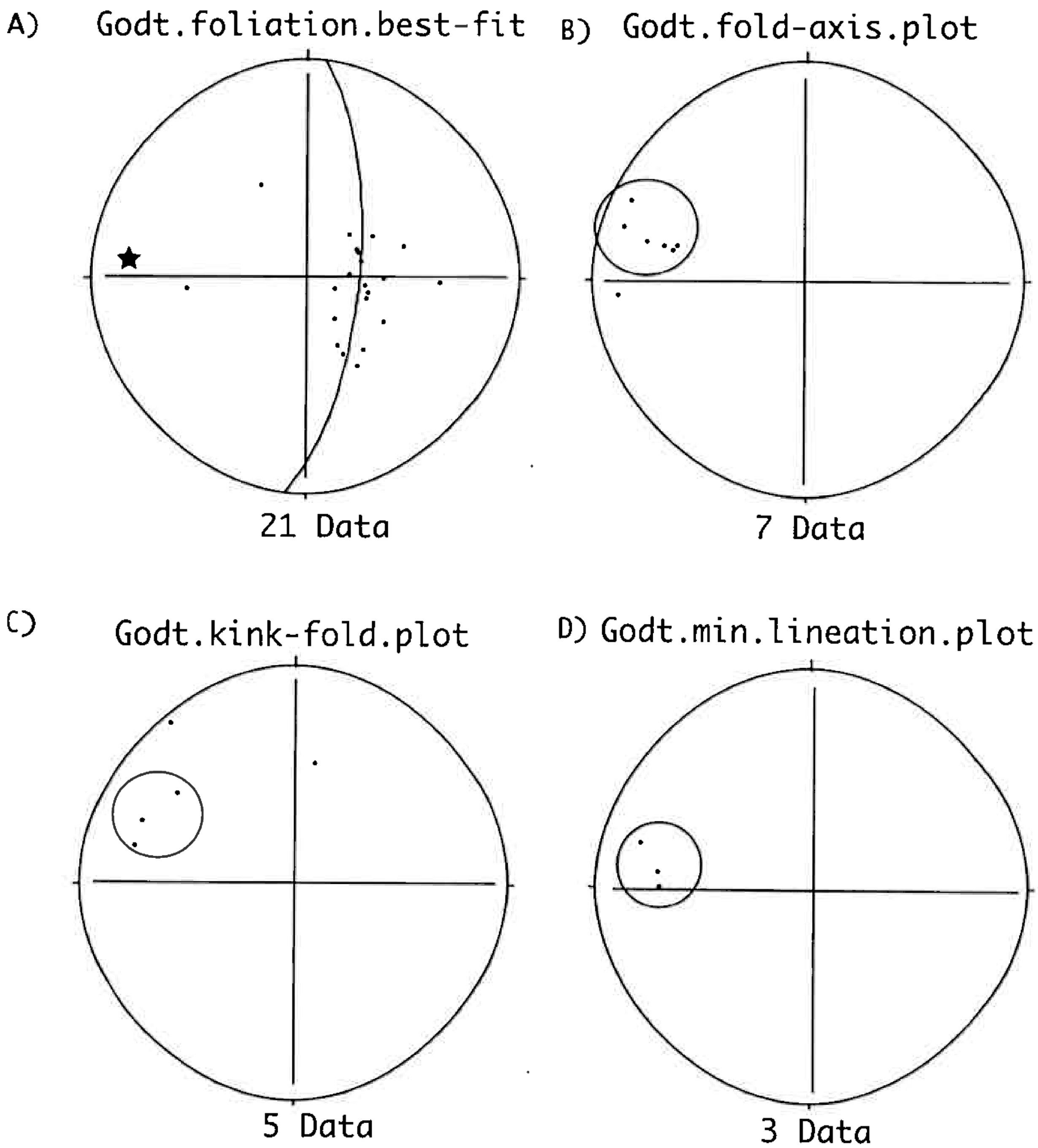


Figure 47

The Tydal district

75. Gressli gruve

Location: UTM

Structural data (Fig. 49a-c)

Foliation: (best fit, 3 data points)	50°-259
Fold-axes: (4 data points)	45°-255
Cleavage:	-
Axial planes:	-
Chevron and kink-folds:	-
Crenulation lineation: (1)	53°-262
Bedding/cleavage intersection lineation:	-
Mineral lineation:	-
Boudin necks:	-
Kink-bands:	-
Fault planes:	N15°E/50NW N28°E/60NW
Ridges:	-
Scour marks:	-
Quartz veins:	-

Gressli

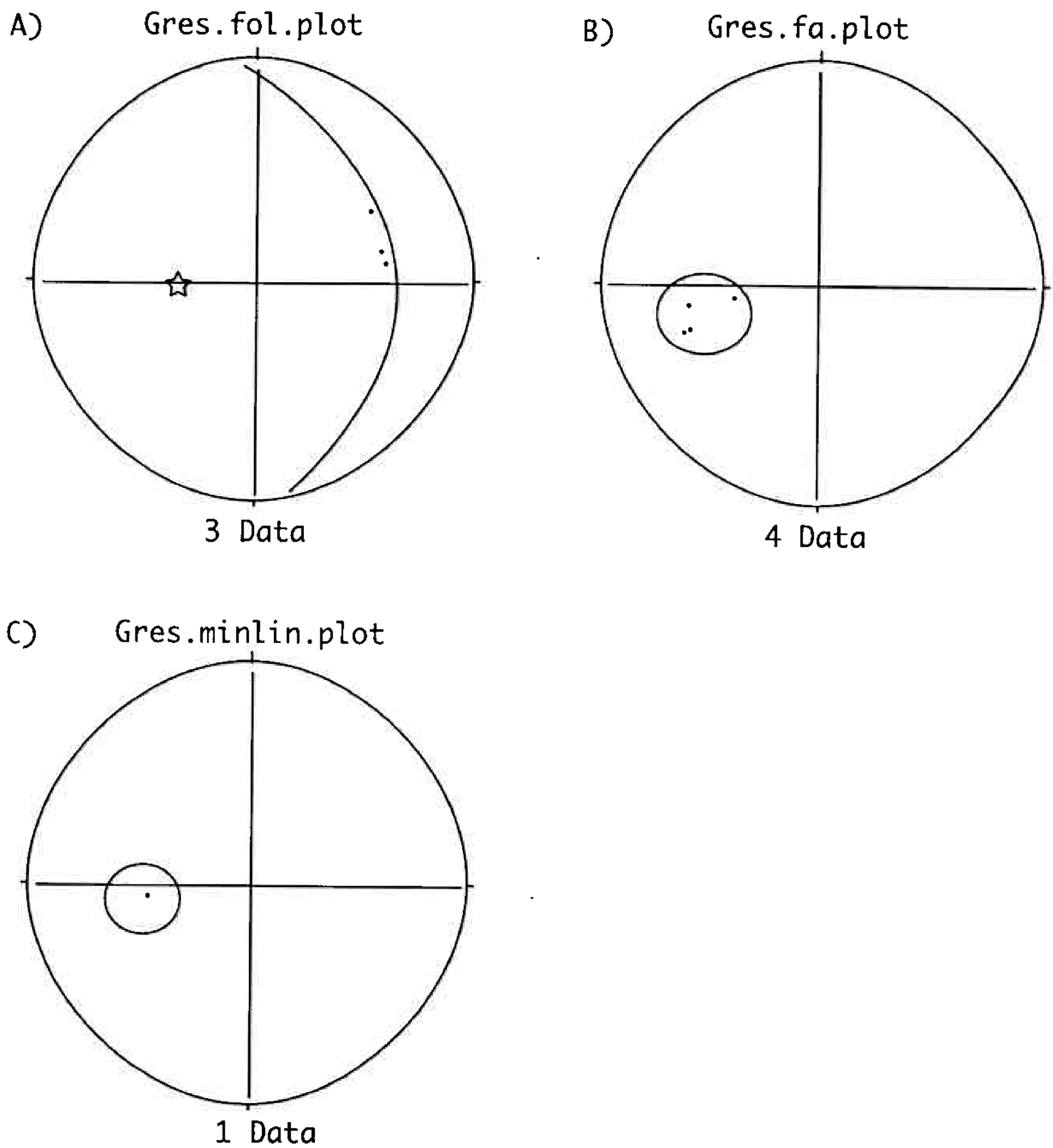


Figure 49

78. Langdalsvollen gruve

Location: UTM 0641196/6991409

Structural data (Fig. 50a-c)

Foliations: (18 data points, best fit)	uncertain
Fold-axes: (12 data points)	±30°-90/270

The isoclines spread between 074-203.

Cleavage:	-
Axial planes:	-
Chevron and kink-folds: (1)	13°-204
Crenulation lineation:	-
Bedding/cleavage intersection lineation:	-
Mineral lineation:	-
Boudin necks: (3 data points)	21°-169
Kink-bands:	-
Thrust planes:	N79°W/28°NE N57°W/80°SW
Ridges:	-
Scour marks:	-
Quartz veins:	-

Langdalsvollen

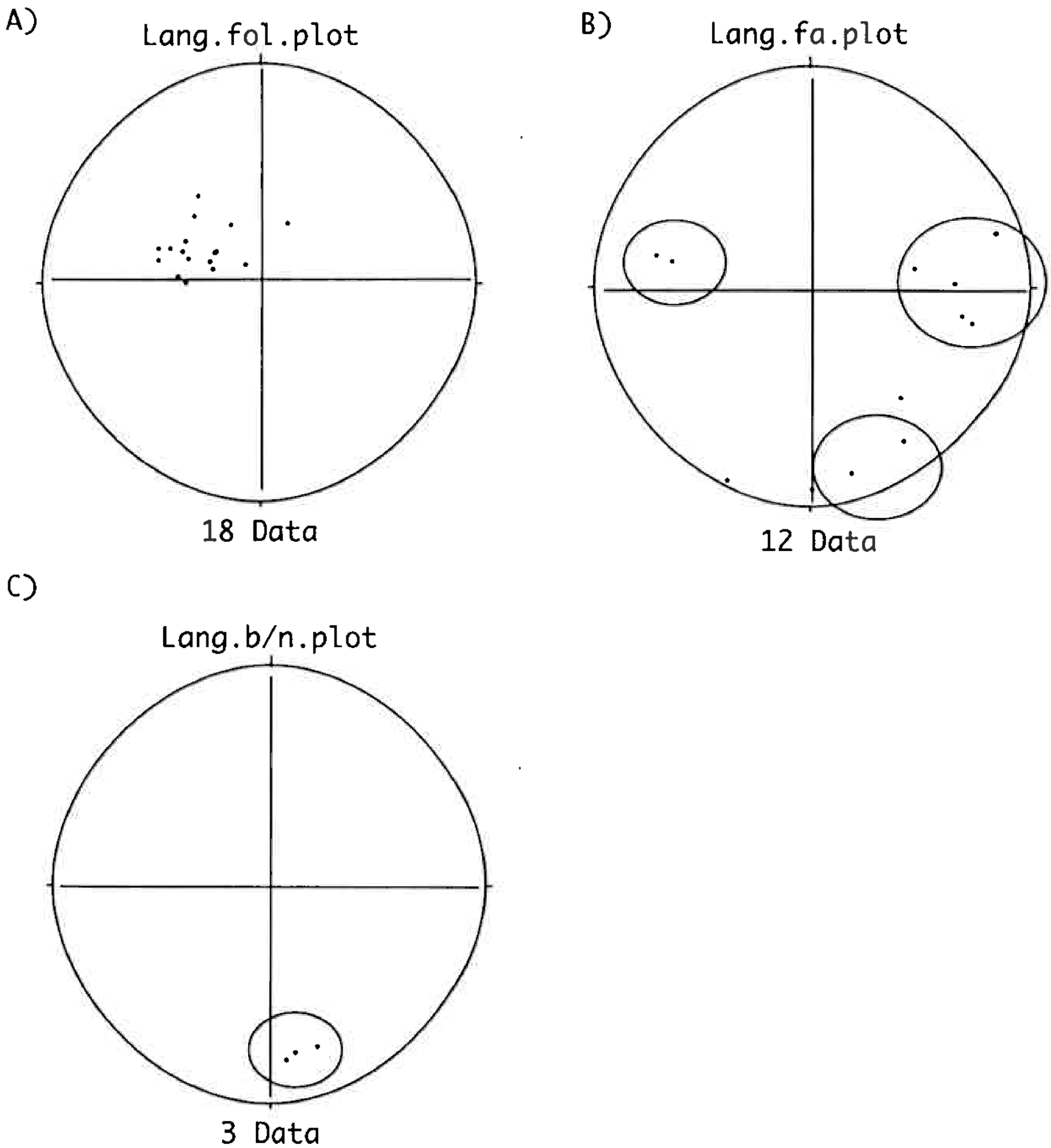


Figure 50

80. Ramsjø/Selbygglian gruve

Location: UTM

Structural data (Fig. 51a-d)

Foliation: (best fit, 54 poorly constrained data) 27°-205°

The foliation data is unreliable for pinning main fold phase due to fold interference (cross-folding, Figs. 52 & 53).

Fold-axes: (37 data points) The fold-axes fit perfectly on a great circle indicating a major fold at c. 55°-090; however, they plot in two maximas: 32°-236
22°-337.

Cleavage: N20°E/40°NW (020/200)
Axial planes: -

Chevron and kink-folds: (three maximas, 20 data points) 42°-174
44°-274
23°-336.

The third set is identical to one fold set above.

Crenulation lineation: 31°-348
Bedding/cleavage intersection lineation: -

Mineral lineation: 35°-335 (065)
Boudin necks: -

Kink-bands: N40°E/43°NW

Thrust planes: -

Ridges: -

Scour marks: -

Quartz veins: N67°E/67°NW
N65°E/70°NW

Dip of ore: 35°-340

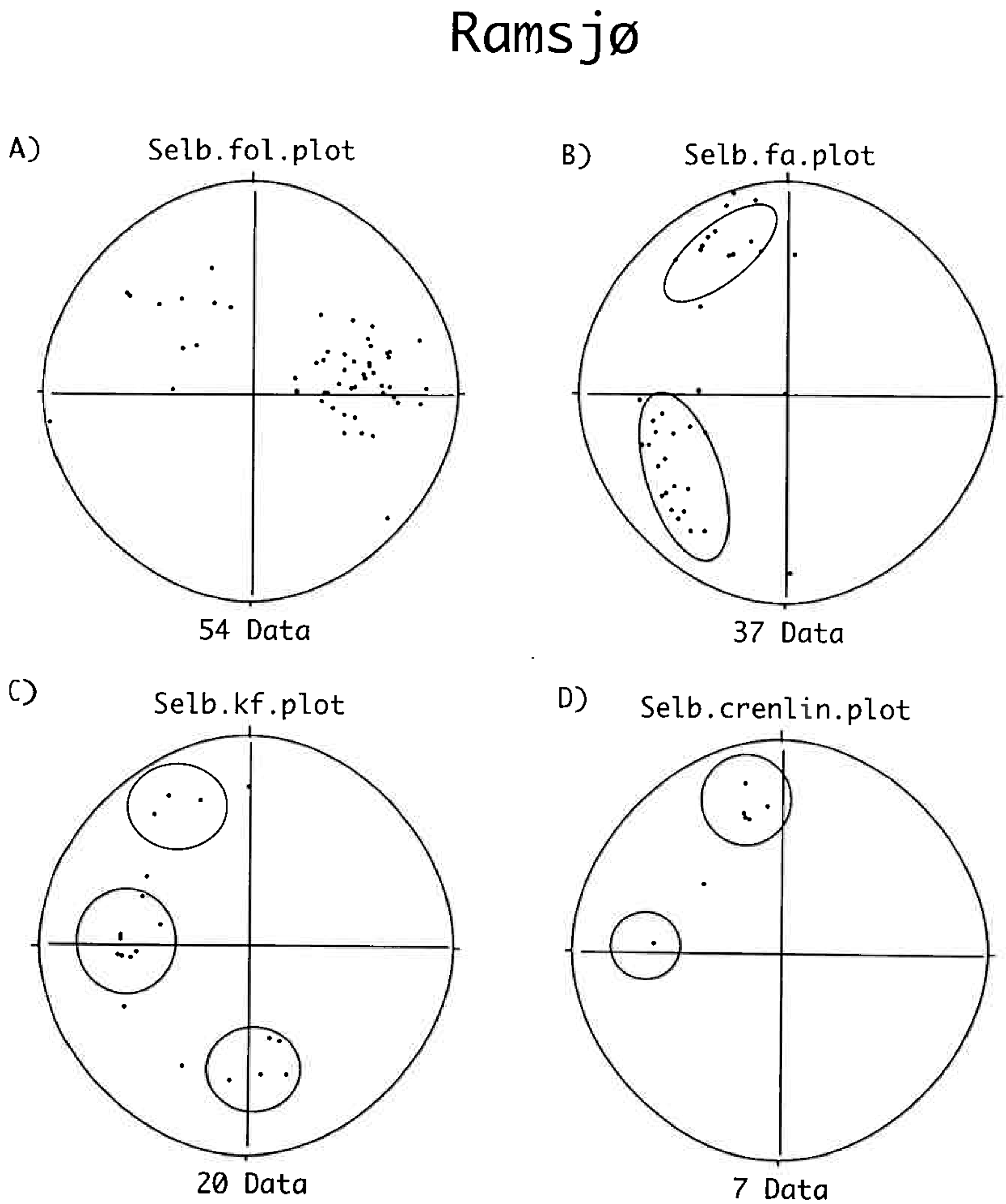

Ramsjø
A)
Selb.fol.plot
54 Data
B)
Selb.fa.plot
37 Data
C)
Selb.kf.plot
20 Data
D)
Selb.crenlin.plot
7 Data

Figure 51

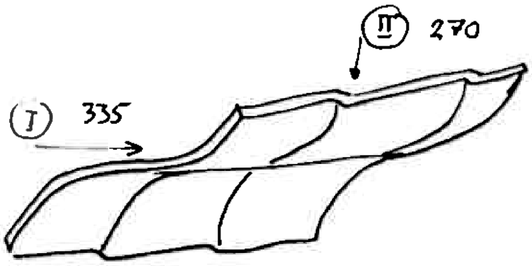


Figure 52: The Ramsjø area is characterised by cross-folding and fold interference. There are many localities where it can be readily observed. Unfortunately they give contradicting evidence and several seem to be of only local importance. here a gentle fold phase (335) is kinked by a later phase (270). This 270 phase of late shortening seems to be ubiquitous throughout the Røros-Meråker district.

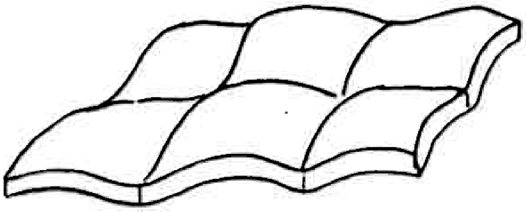


Figure 53: This is an example of two phases of gentle buckle folding which have formed a dome-and-basin structure. The wave-length of these folds is several metres.

The Meråker district

100. Lillefjellet gruve

Location: UTM

Structural data (Fig. 54a-f)

Foliation: (25 data points, best fit)	36°-322

The foliation planes describe a great circle with a fold axis at c. 36°-322. This is very similar to what the minor fold axes below indicate.

Fold-axes: (22 data points)	40°-285 30°-325 ±5°-180/360

First isoclinal folding (various directions), then perpendicular (325) close to tight folding (kinking) followed by oblique (165/345) gentle doming.

Cleavage:	-
Axial planes:	-
Chevron and kink-folds (9 data points)	29°-323
Crenulation lineation: (15 data points)	14°-348 45°-295
Bedding/cleavage intersection lineation:	-
Mineral lineation:	-
Boudin necks:	-
Kink-bands:	-

Thrust planes:

Ridges:

Scour marks:

Quartz veins:

Lillefjellet gruve

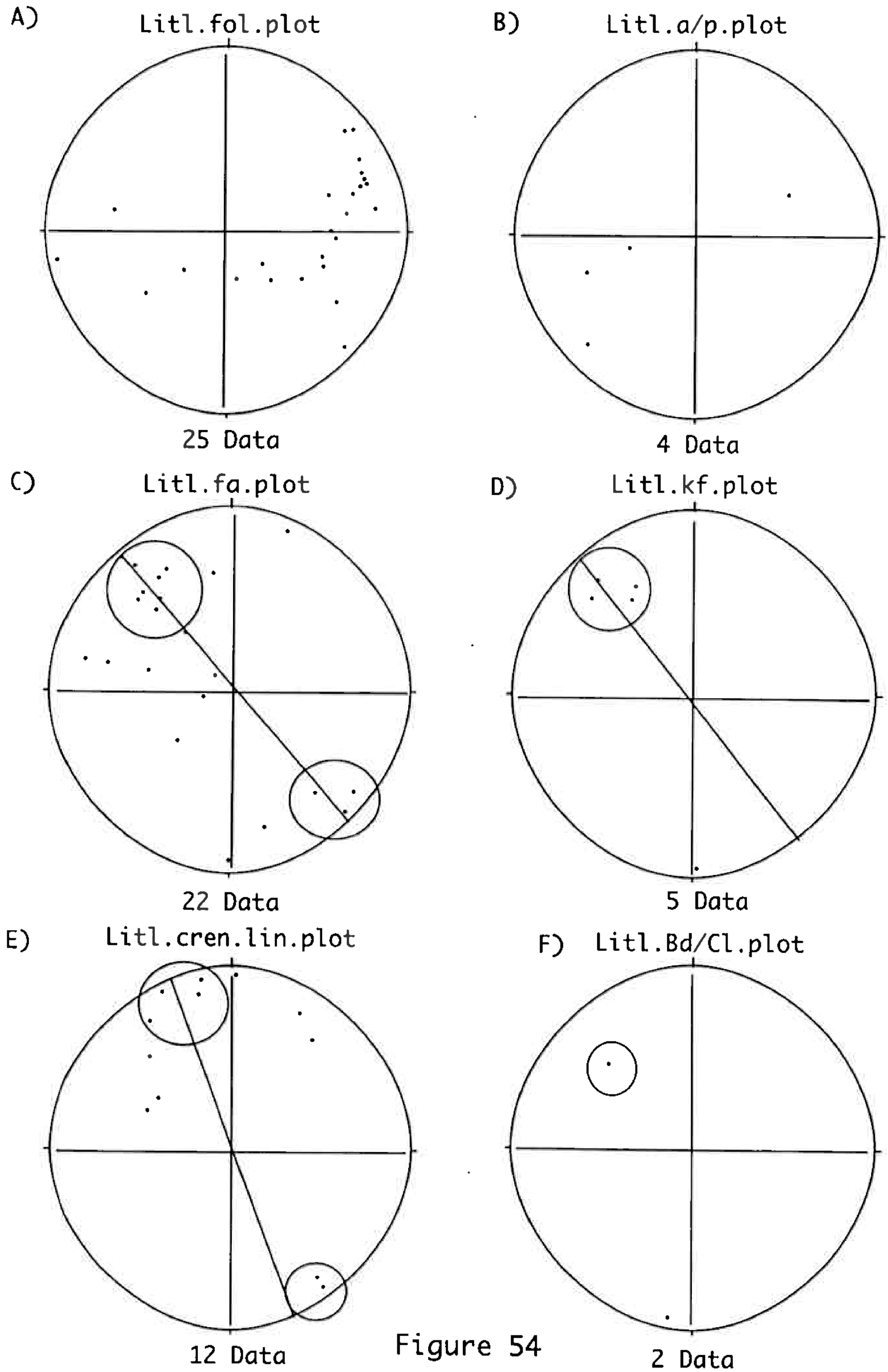


Figure 54

101. Gilså gruve

Location: UTM

Structural data (Fig. 55a-b)

Foliation: (best fit, 40 data points) 4°-351
Fold-axes: (51 data points with three poorly constrained maximas)

23°-329.
52°-276
44°-181

Isoclines at 195, 209 and 349 indicating refolding of the latter.

The first set of folds, 180±20°, is clearly refolded by the second set, 250±20°. These folds are asymmetric and suggests some sort of wrench folding (Fig. 56). Several good examples of dextral wrench folding was found.

There are some perfectly preserved examples of interference folding on some of the outcrop surfaces (Fig. 57). Many of the first fold set are close to isoclinal whereas the second set is open. A third set of (kink) folds trends towards 330. All three sets vary in plunge but most seems to be between 35-50°.

Cleavage: -
Axial planes: -

Chevron and kink-folds: -
Crenulation lineation: (2) 3°-173
3°-353
Bedding/cleavage intersection lineation: -

Mineral lineation: -
Boudin necks: -

Kink-bands: -

Fault planes: -
-

Ridges: -

Quartz veins:

Dip of ore: N45°W/70°SW

Gilså gruve

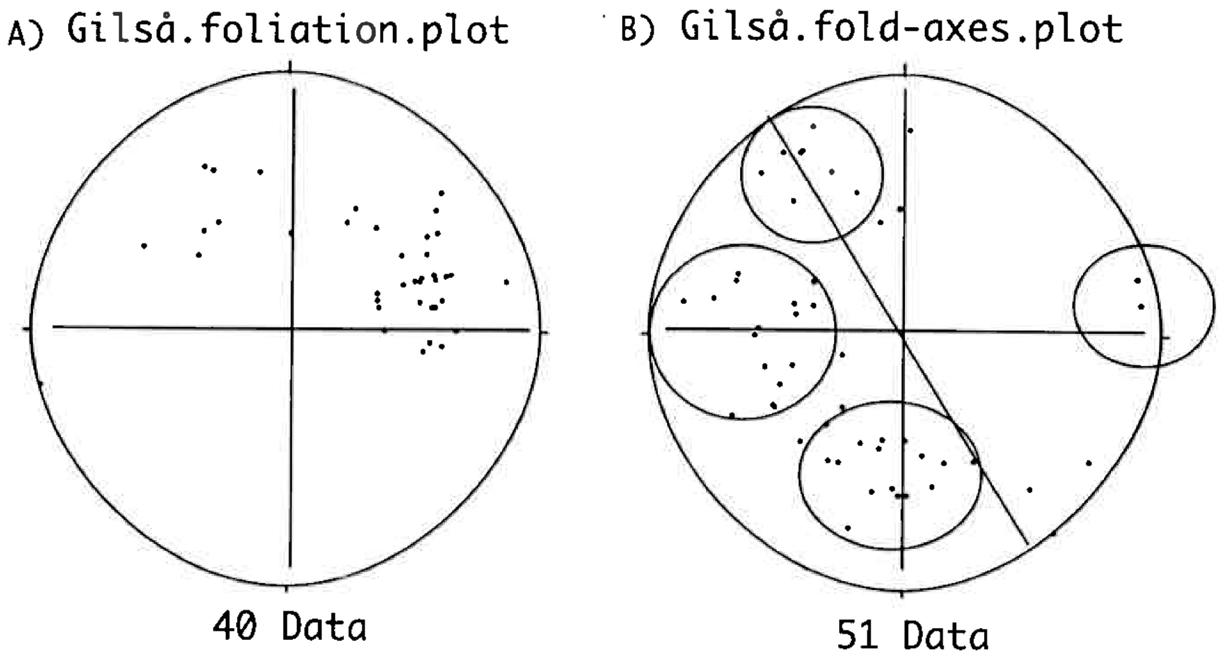


Figure 55

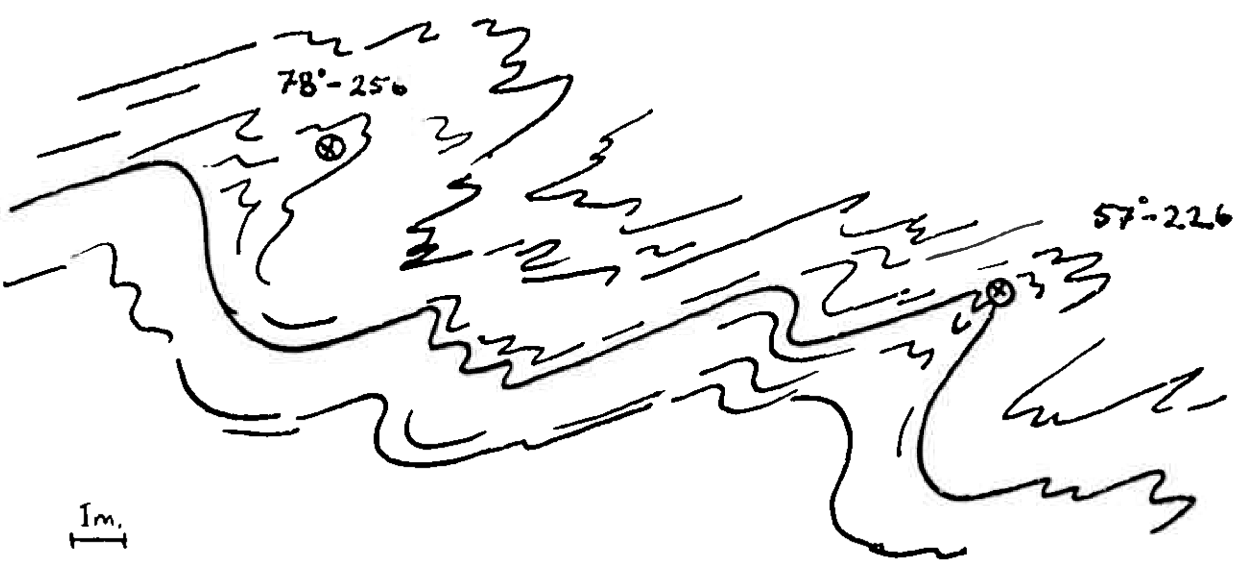


Figure 56: Subvertical to steep asymmetric wrench folds above the Lillefjellet mine. These folds plunge steeply (60-80°) towards SW-WSW. The competence contrasts between different layers has resulted in chaotic folding and sheared off fold limbs. The whole area seems dominated by this type of folding. The scale of the folding is map scale.

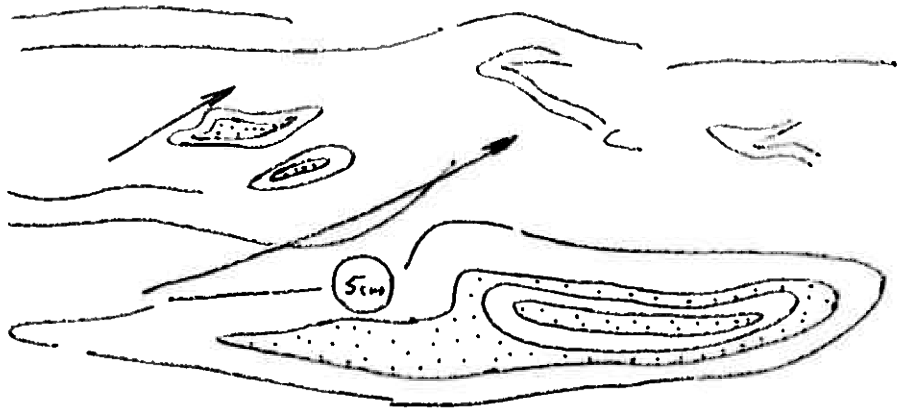


Figure 57: Fold interference, Type 2 of Ramsay (1967). The "barbs" of the "arrow" define the direction of the earlier (F1) fold phase whereas the "arrow" point in the direction of the latest (F2) fold-phase.

102. Bjørneggfjellet (Dronningen)

Location: UTM

Structural data (Fig. 58a-d)

These data were collected

Foliation: (20 data points, best fit)	4°-351
Fold-axes: (5 scattered data points)	-

A set of gentle folds with a wave-length of c. 4 metres trend in a SW (245) direction. The amplitude is c. 1 metre. These folds plunge c. 30°

Both the fold axes and the later kink-folds plot around 45°towards SW. They vary in plunge from 10-80° and the plunge-direction is 245±30°.

Cleavage:	-
Axial planes:	-
Chevron and kink-folds: (16)	c. 45°-225
Crenulation lineation:	±5°-170/350

The crenulation lineations are concentrated at 170/350 with a sub-horizontal plunge direction. These crenulations are refolded by the c. 200 to 220 set of kink folds.

Bedding/cleavage intersection lineation:	-
Mineral lineation:	-
Boudin necks:	-
Kink-bands:	-
Thrust planes:	-
Ridges:	-
Scour marks:	-
Quartz veins:	-

Bjørneggfjellet

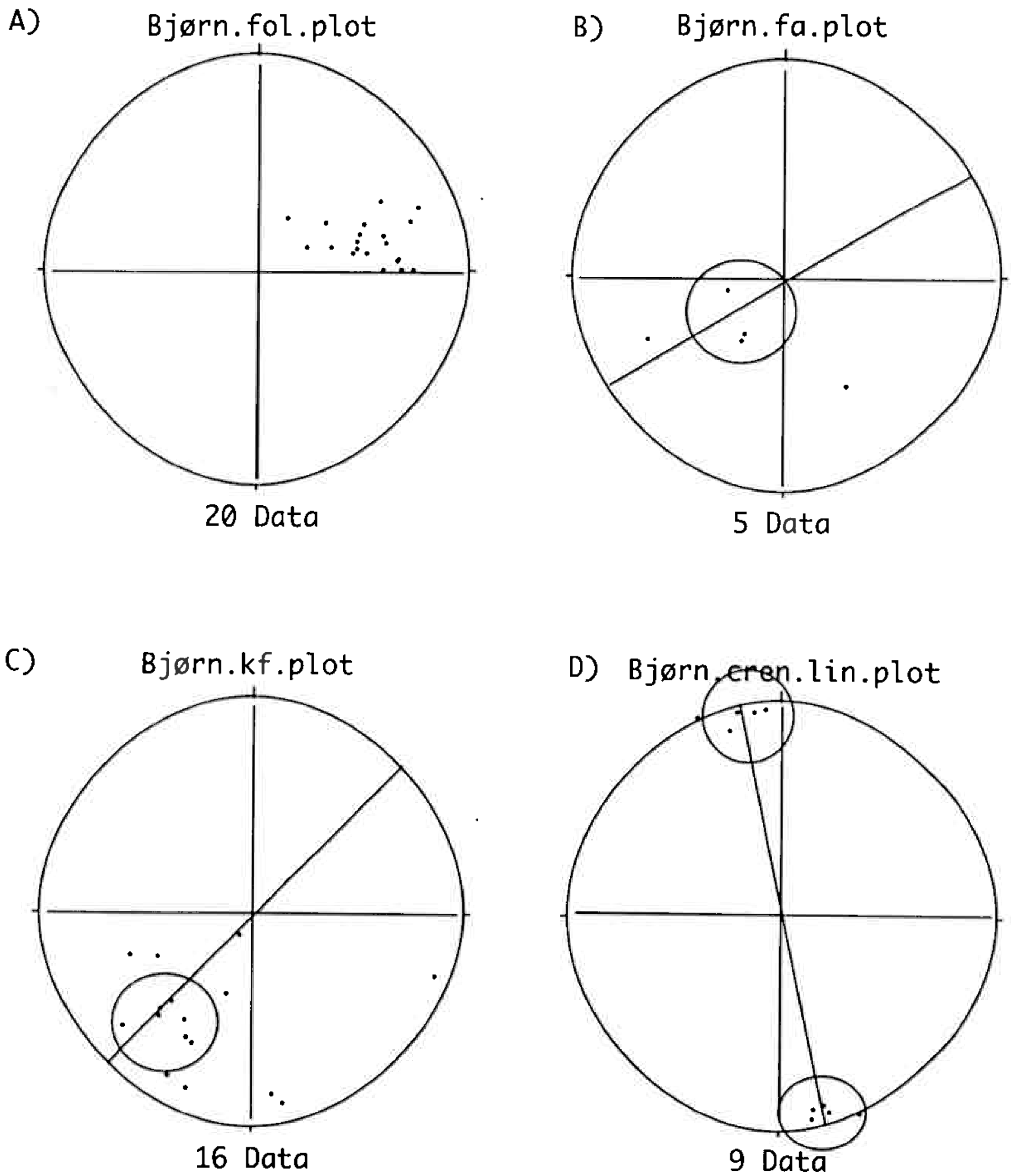


Figure 58

4. Discussion

The Røros Nordgruve and Østgruvefelt

The foliation data is in many places sufficient to deduce the latest major fold phase, and most localities have at least two distinguishable fold phases, some have three. Where three fold events can be separated, the first two are generally coaxial or only slightly oblique (often less than 30°).

The first fold-phase is isoclinal and most likely thrust-related. The isoclinal fold vergence varies between NE to SE. The trend of the isoclines have been deduced from areas with a general flat-lying foliation and little fold interference.

The second phase is gentle to close (locally tight). The similarity in trends suggests that the F2 folds may also be thrust-related, based on their often near-coaxial relationship with the isoclines. However, this fold-phase varies from E-W to NNW-SSE trending, i.e. coaxial to perpendicular to with the F isoclines suggesting there was either a change in convergence direction post-dating emplacement of the nappes or it is due to ramp geometry. In a zone from Kongens to Olavsgruva they are generally E-W trending and rotate northwestwards outside this zone.

The third phase is composed of N-S trending chevron or kink-folds. These folds have formed at much lower metamorphic grade and are found to overprint earlier fold phases throughout the district.

Where isoclinal fold axes are absent it is often possible to find elongated quartz rods. These quartz rods are most likely the result of extensional boudinage of quartzitic veins during thrusting (Fig. 59). The quartz veins were generally boudinaged parallel with the isoclinal fold axes. Locally the quartz veins were also boudinaged perpendicular to the movement direction, forming a chocolate-tablet type boudinage. The boudins may also be the result of intra-formational boudinage between metasedimentary units of varying competence (Fig. 60). These boudins may form both during thrusting (as aresult of local extension in the fold-limbs) or during periods of extension. However, in both cases do they appear to be parallel or sub-parallel with the isoclinal fold axes and perpendicular to the mineral stretching-lineation. This means that they give a good indication of the nappe transport-direction when isoclines are missing (Plate 2).

The nappe movement direction can also be deduced from the mineral stretching lineations. Many minerals (e.g. hornblende and biotite) were elongated and recrystallised during thrusting and their linear fabric (L1) is parallel with the direction of transport. The mineral stretching direction is generally also perpendicular to the quartz rods and isoclinal fold-axes (Plate 2). These three relationships give a good indication, even when only one or two of the three (isoclines, quarts rods or stretching lineation) is present. An F2 lineation related to either crenulation folding (flexural slip) or extensional S-C fabrics in phyllonites is often also present.

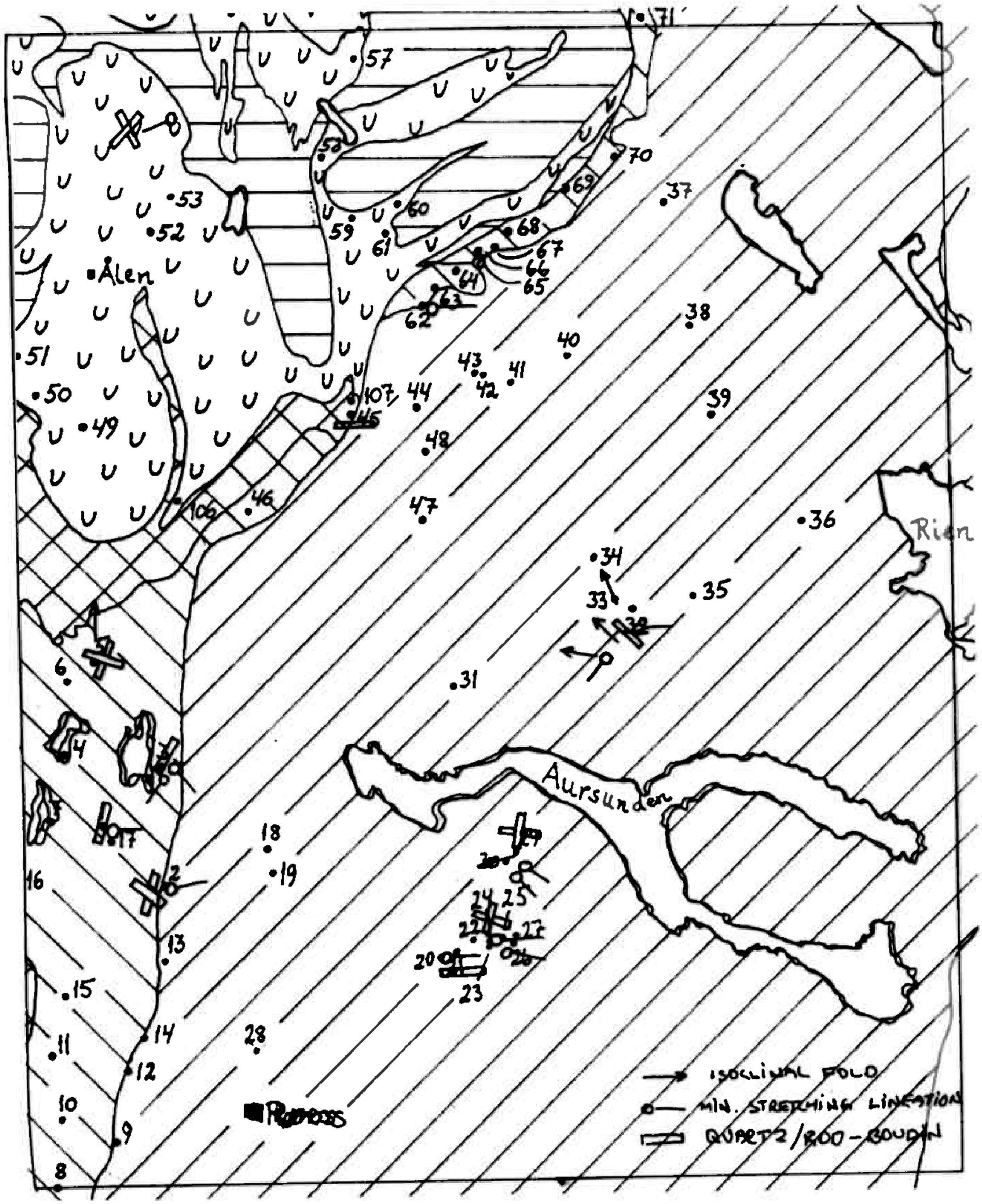


Plate 2: Map detail showing mineral stretching lineations in the Røros area. The map also includes isoclinal folds and quartz rods/boudins. The N-S trending quartz rod set is generally coaxial with the isoclines suggesting a co-genetic origin. The latter can therefore be used as kinematic indicators of some reliability. Together the data indicates a general E to SE directed nappe transport in the area.

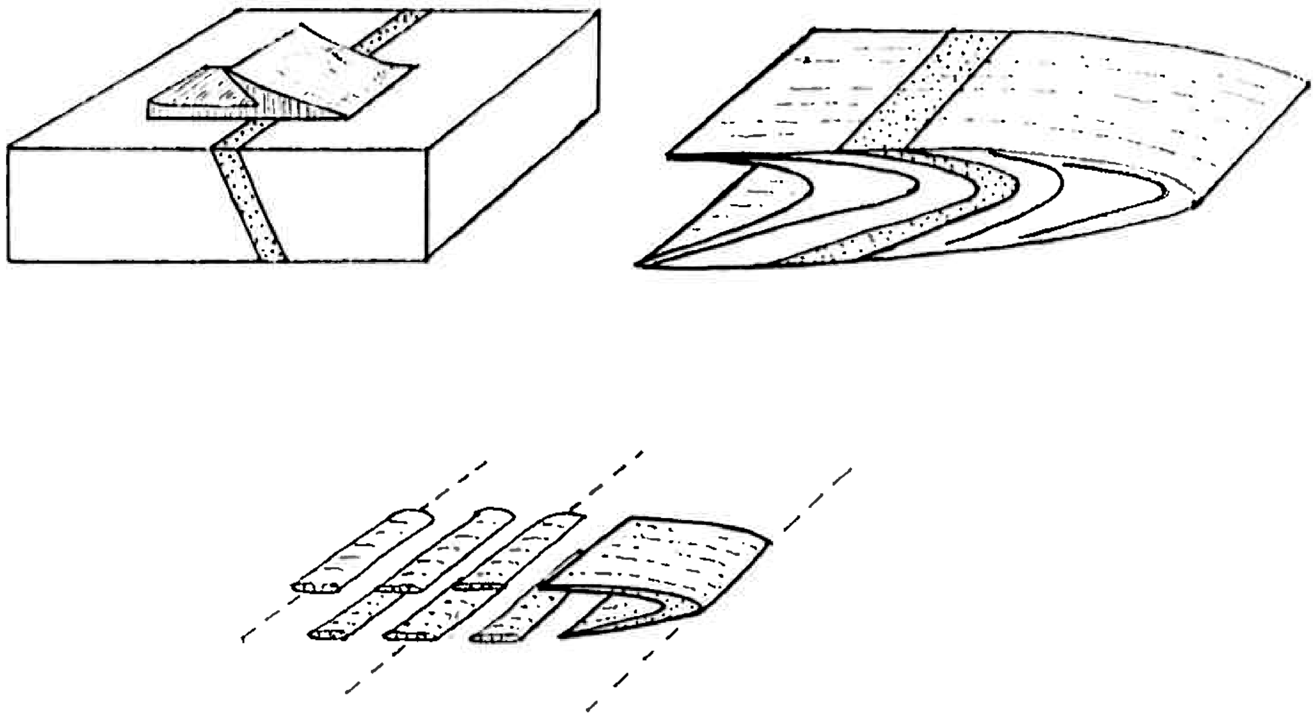


Figure 59: Sketch showing the development of isoclinal folds and their interpreted relationship to elongated quarts boudins and mineral stretching lineations.

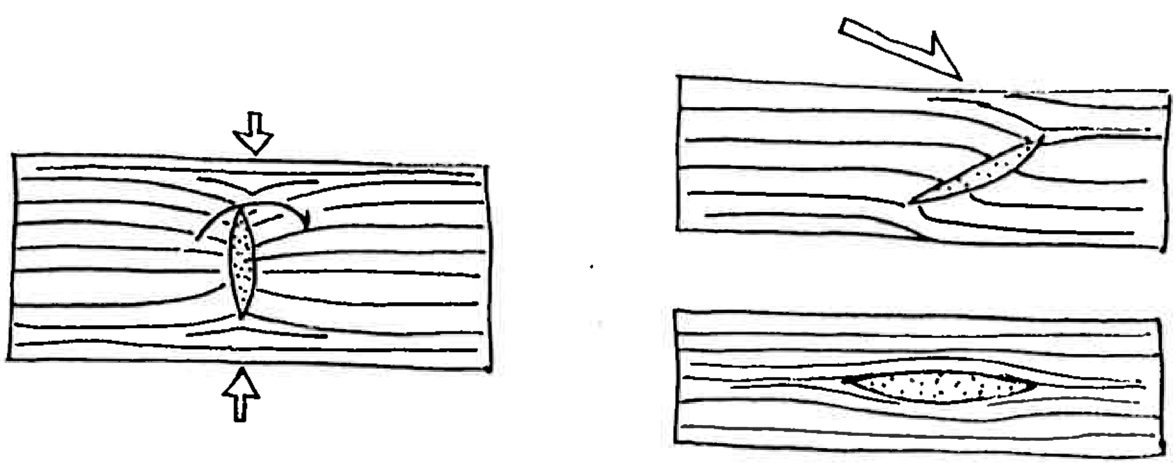


Fig 57

Figure 60: Quartz rods from foliation planes may have formed in boudin voids as a result of boudinage of more competent horizons or ore horizons. The quartz has migrated to the low-pressure zones formed between the two rigid objects. The small boudin folds that form as the surrounding foliation flow into the voids also give a good indication of the quartz rod trends. Superimposed simple shear rotate the rods into concordance with the foliation and often destry all evidence of their origin.

Kongens/Arvedals gruve

The foliation data plots on a great circle suggesting a major E-W trending (and W-plunging) fold structure, however, numerous small scale folds (isoclines) indicate an earlier NE/SW trending fold-phase. Quartz rods indicate E-directed movement (c. 100-110°). This data is corroborates by the mineral stretching lineation (c. 110°), however, both are slightly oblique to the trend of the measured isoclines.

Lergruvbakken

The foliation data forms a poorly constrained great circle indicating a major structure towards the west (WSW). This is supported by the few visible fold axes and minor chevron or kink-folds. The mineral stretching lineation is E-W trending but quartz boudins indicate ESE-directed movement. These quartz rods have also been boudinaged perpendicular to the old extension direction, forming a chocolate-tablet type boudinage.

Fjellsjø gruve

The very few foliation and fold axis data from Fjellsjø indicate a well-constrained large scale structure plunging towards the SSW. The NNW-SSE trending mineral stretching lineation is near perpendicular to thast of most other localities and may be due to local inhomogeneities in the underlying basement or in the ramps resulting in partitioning of the deformation and local deviations in the movement or compression direction.

Christianus Sextus gruve

At Christianus Sextus the foliation data plot on a great circle indicating a large scale fold structure towards the NNW but all mapped folds trend 000-060 which suggests refolding. Quartz boudins trend 045/225 and the mineral stretching lineation 135. These data both indicate nappe movement towards the SE. The many examples of durchbewegung structures suggests strong deformation and localised remobilisation of the sulfide ores.

Muggruva

The foliation data at Muggruva is very concentrated and leaves little room for interpretation, but a large NW-trending structure appears to exist and is supported by large-scale structures observable on the geological map. Isoclinal folds (few) indicate E-directed movement. The quartz rods indicate ESE-directed (refolded) movement, with a complementary (chocolate tablet) set indicating axial parallel extension. This later set is subparallel to the NW-SE cross-folding. N-S trending crenulation cleavage indicates late disturbance of the structures.

Storwartz gruve

At Storwartz mine all structural data agrees with a major fold structure trending E-W and plunging subhorizontally to c. 10°E. Both crenulation lineations and mineral lineations are E-trending. There is no evidence of any N-S trending interference.

Qvintus/Olavsgruve

Very little foliation data and only isolated folds are inadequate for interpretation, however, the abundance of mineral stretching lineations suggests movement was E to ESE directed. Two clearly distinguishable lineations are present (one may be a bedding/cleavage intersection lineation). ESE-directed movement is also supported by the quartz boudins. There is a lso a complementary perpendicular set (chocolate tablet boudinage). This set indicates axial parallel extension. NNW-SSE trending crenulation cleavage affects all structures.

Klasberget

The foliation data at Klasberget indicate a large structure towards WNW; however, E-W trending fold axes indicate S-SSE directed movement (isoclines). This may be due to refolding. Similarly, mineral stretching lineations vary between NW-SE to WNW-ESE. This set appears to be disturbed, possibly refolded by the NW-SE trending fold set which dominates the mine area. The mineral stretching lineation could be fit on a small circle with similar orientation as this fold set. Quartz boudins support ESE-directed movement. A conjugate (chocolate-tablet) boudinage indicates axial parallel extension (related to thrusting?) and refolded by F2 folds. N-S trending kink-folds refold all structures.

Abrahamshøgda gruve

The foliation data is very disturbed and hard to interpret, however, a general WNW to NW trending structure is indicated. Both minor fold axes, crenulation lineations and kink-folds are nw-trending. These early WNW-trending folds are overprinted by late lower grade N-S trending chevron/kink folds. It is these later folds that appear to disturb the foliation plots. These N-S trending folds can be distinguished on the geological map to refold the NW-trending structures.

Klinkenberg area

The extent of the Klinkenberg area and the large number of structural field data prompted subdivision of the area. Smaller areas have been isolated to facilitate interpretation of collected data. The use of smaller areas has made determination of the significance of different structures easier, and local variations in trends can be noted and filtered (compare Klinkenberg I/II and II/II with Waypoint plots). Foliation data from all areas indicate a major structure towards the NW; however, fold axes are chaotic.

Waypoint Creek

Foliations define a great circle with a plunge towards NW but the fold axes are more chaotic with some plotting towards the NW while other plot towards the W and SW. The NNW folds are related to foliations while W to WSW trending folds are possibly being movement related.

Waypoint profile

The foliation data is somewhat unclear. Most foliation data reflect the dip and dip direction of the thrust planes within the thrust duplex. The thrusts indicate E-directed shortening; however, many fold axes plot with a NW-trend. Fold data indicate a major NW-trending structure with some E-trending folds. No isoclines were found. Late N-S trending kink folds post-date earlier events.

Waypoint 53

The foliation data plots too close together and is insufficient on its own for interpretation. The fold axes are all isoclines and can be fitted on two small circles indicating refolding by a NW-trending fold axis. The N-S trending crenulation lineation post dates both the isoclines and the NW-trending structure.

Waypoint 54

The foliation data at Waypoint 54 is concentrated and of little help for interpreting larger structures but the flat-lying foliation data and the apparent lack of any F2 folding has produced a well constrained cluster of F1 isoclines. The isoclines are NE trending and the vergence is supported by mineral stretching lineations which trend NE-SW with a subhorizontal plunge. Crenulation lineations are N-S trending and overprint earlier structures.

Klinkenberg mine

At Klinkenberg mine tha foliation data indicates a major structure towards the NW. F1 isoclines trend from SE to SW suggesting refolding by NNW-trending F2 folds. The F2 folds are indeed NNW trending with N-S trending F3 chevron folds. The latter may just be a continuation of folding during rotation. This is visible in the curvature of the axial planes of many of the chevron folds. The mine displays many good examples of durchbewegung structures and the general competence contrast between different sulfide ores. The pyrite horizons are generally competent and up to a metre in thickness whereas the sphalerite and chalcopyrite horizons have been altered physically to form cuspate-lobate structures where they are behaving ductilely compared to the phyllitic host-rock.

Matz gruve

Terrible foliation data but a well defined set of N-S trending chevron and kink-folds.

Fjellgjeltskjerpene

The foliation data defines a major structure towards the NNW which is corroborated by the fold axis data. A N-S trending crenulation lineation post-dates folding.

The Holtålen district

Killingdal

The somewhat scattered foliation data and few fold axes indicate a moderate to steeply westward plunging structure and is also corroborated by quartz boudin data. All is overprinted by late N-S chevron folds.

From/Rogn gruve

The foliation and fold axis data defines a moderate to steeply (c. 40-50°) westward plunging structure.

Bukkhåmmåren

Not enough foliation or fold axis data; however, mineral stretching lineation data and a few quartz boudin data suggest a WSW plunging structure. The lineations indicate ENE directeed movement. The three isoclinal folds are located at two different orientations NNW and ESE. This means that one fold axis supports ENE directed movement and two fold axes support SSE directed movement.

Kårslåtthøgda

Foliation plots indicate a W plunging (40-60°) fold structure. The mineral stretching lineations, also 40-60° SW, suggest NE directed movement. The spread of the lineation data suggests refolding which fits well with the direction of the major structure.

The structures in the Holtålen district are consistent, with steeply plunging fold axes and lineations. The lineations swing from W-trending in Killingdal-From to SW in the Bukkhåmmåren-Kårslåtthøgda areas.

The Kjøli district

Svenskmenna

The foliation data plots on a great circle defining a major fold structure towards the NW. This is in agreement with the fold axis data, although somewhat scattered. The mineral stretching lineations are E-trending and shallowly plunging.

Gauldalsgruvhøgda

The foliation data and fold axes (4 points) again indicate a shallowly NW plunging structure. The folds are chevron or kink folds within the schistose sediments. The fold axes are parallel with the lineations. It could be that the lineations are in fact bedding/cleavage intersection lineations. Should be checked again.

Godthåb gruve

Godthåb gruve is a very limited exposure which might explain why it has a different trend to that of the Gauldalsgruvhøgda even if they are only separated by a few hundred metres. The foliations define a W-trending and shallowly W-plunging structure. This structure may be a local phenomenon. If this is a later interference folding it may explain why the data at Gauldalsgruvhøgda is a bit scattered.

Similarly to the Holtålen district the mines in the Kjøli district are W-trending; however, shallowly plunging. Only Godthåb gruve differs and this may be a local effect. The area examined around Godthåb was limited to an adit and an exposure along a small creek.

The Tydal district

Gressli gruve

The total number of structural data from Gressli is 8! This data does suggest the mine is W-plunging (30-60°). The only mineral stretching lineation is steeply W-plunging indicating eastward transport.

Langdalsvollen

At Langdalsvollen the foliation data is of little help determining the major strucctures in the area. The foliations cluster and suggest a general SW dip direction for the foliations. The fold axes plot both in an E-W trend with folds plunging in both directions. Fold axes with a N-S trend also exist. The latter are accompanied by quartz rods which plunge gently (20°) southwards.

Ramsjø/Selbygglian

The data from Ramsjø is extensive and confusing. Chevron, kink and normal gentle folds plot between c. 160 to 360. The The main folds plot in two fold maximas at c. 340-360 and then between 200-270. The kink or chevron folds suggest one general E-W fold phase and another N-S trending phase. This would be similar to other examined mines in the area. More work is needed to differentiate between the different fold phases and style of deformation.

The Meråker district

Lillefjellet gruve

The foliation data points towards a general NW plunging fold structure but the data, including the fold axes and crenulation lineations are too scattered not to have been refolded. The main fold phase appears to be NW- and SE plunging, but both W-plunging and N-plunging folds exist.

Gilså gruve

Anyones guess! This area is strongly affected by ductile deformation and strong refolding of earlier fold phases. Small-scale F3 folds are gentle and discontinuous along their axial traces. They vary in orientation between localities and may be due to local irregularities in the basement and along ramps. Prime area for more detailed work.

Bjørneggfjellet

The foliations at Bjørneggfjellet have a general WSW dip direction. This is corroborated by the SW plunging fold axes which however scatter immensely. Kink/chevron folds are similarly SW plunging. Late crenulation lineations are subhorizontal, N-S trending.

Structural interpretation

Most units retain some data related to a general E-directed transport (see above). In several mines it is possible to observe F1 isoclines as well as a mineral stretching lineation related to nappe transport. In Røros Nordgruve- and Østgruvefelt mines the general transport direction is E to ESE; however, north of Aursundsjøen (Klinkenberg and Abrahamshøgda) the transport direction is more E to NE.

In the Holtålen district the transport direction is similarly towards E to NE. Data is on the whole poor, and only on one occasion (Svenskmenna) has a stretching lineation (E-directed) been established.

Similarly, the mines in the Tydal district indicate E-directed transport.

There is no kinematic data available from the Meråker district.

The orientation of the mines always coincides with the dominant fold-phase in the area (mostly F2 folds). Structures within the Essandsjø-Øyfjell Nappe are getting steeper towards the overlying Meråker Nappe. Similarly are the folds structures steep in the western section of the meråker Nappe towards the Gula Nappe.

The style of F2 folding is dependent on lithology. In the quartzitic metasediments the folding is open to close, but in the core of the folds, especially the larger folds, the more schistose/shaly units deform into kink-folds with cross-folding which will appear to be unrelated when seen separately but when plotted their genetic relationship becomes apparent.

The Meråker district

Lillefjellet gruve

The foliation data points towards a general NW plunging fold structure but the data, including the fold axes and crenulation lineations are too scattered not to have been refolded. The main fold phase appears to be NW- and SE plunging, but both W-plunging and N-plunging folds exist.

Gilså gruve

Anyones guess! This area is strongly affected by ductile deformation and strong refolding of earlier fold phases. Small-scale F3 folds are gentle and discontinuous along their axial traces. They vary in orientation between localities and may be due to local irregularities in the basement and along ramps. Prime area for more detailed work.

Bjørneggfjellet

The foliations at Bjørneggfjellet have a general WSW dip direction. This is corroborated by the SW plunging fold axes which however scatter immensely. Kink/chevron folds are similarly SW plunging. Late crenulation lineations are subhorizontal, N-S trending.

Structural interpretation

Most units retain some data related to a general E-directed transport (see above). In several mines it is possible to observe F1 isoclines as well as a mineral stretching lineation related to nappe transport. In Røros Nordgruve- and Østgruvefelt mines the general transport direction is E to ESE; however, north of Aursundsjøen (Klinkenberg and Abrahamshøgda) the transport direction is more E to NE.

In the Holtålen district the transport direction is similarly towards E to NE. Data is on the whole poor, and only on one occasion (Svenskmenna) has a stretching lineation (E-directed) been established.

Similarly, the mines in the Tydal district indicate E-directed transport.

There is no kinematic data available from the Meråker district.

The orientation of the mines always coincides with the dominant fold-phase in the area (mostly F2 folds). Structures within the Essandsjø-Øyfjell Nappe are getting steeper towards the overlying Meråker Nappe. Similarly are the folds structures steep in the western section of the meråker Nappe towards the Gula Nappe.

The style of F2 folding is dependent on lithology. In the quartzitic metasediments the folding is open to close, but in the core of the folds, especially the larger folds, the more schistose/shaly units deform into kink-folds with cross-folding which will appear to be unrelated when seen separately but when plotted their genetic relationship becomes apparent.

The Kongens and Arvedal mines, e.g., are both W-plunging, although they appear near the N-S striking thrust contact. The Lergruvbakken and Fjellsjø mines have similar plunge directions. In the central parts of the area, the Gamle Storwartz mine also trends WSW-ENE. In this area the N-S fold-phase is poorly developed and the E-W set seems to dominate. The development of E-W trending folds is probably related to the geometry of the underlying basement ramps. Similar relationships occur further north as well.

At Klinkenberg the mine mimics perfectly the NW-SE direction of the major map-scale folds. The folds are disturbed by late N-S trending folds. Both these fold-phases are seen in outcrop-scale as chevron folds. The chevron folds, only seen in the phyllites, can be linked to large gentle folds which on the geological map appear to have a wave-length of several hundred mètres (see Figs. 22 & 23). The NW-SE trending cross-folding appears to have affected all mines in the Nord- and Østgruvefeltet except the Kongens and Storwartz and associated mines. This cross folding forms basin-and-dome type patterns in the roof of many mines.

Since the controlling folds have a much larger regional occurrence than the mines or minearlisations this suggests that folding controls the mineralisations and not vice versa. The Klinkenberg mine is a good example where the mineralisation has become economical through repetition by folding to produce 3-4 overlying horizons of variable thickness separated by a metre or so of schistose host-rock. The recumbent folding of the ore is defined by the more competent pyrite horizons whereas the less competent chalcopyrite-sphalerite-pyrrhotite have locally been mobilised.

Whether the ore as a whole is in-situ, or has migrated is not always clear. Although the ore is mostly layer-parallel with the surrounding host-rock foliation, many times quartz veins will show evidence of boudinage and separation by many hundred percent. The sericite-altered host-rock is in many places pervasively crenulated and "xenoliths" of such crenulated host-rock occurs within the ore. The competence contrast between the host-rock and the ore can be seen in many places, e.g. Klinkenberg, where the ore has folded to form a cuspate-lobate relationship with the host-rock. The ore migrates out into the narrow cusps locally with the formation of piercement veins. This type of relationship between the ore and the host-rock suggests that the crenulated "xenoliths" must have been introduced into the ore by "intrusive" brecciation and delamination.

The formation of durchbewegung structures seems to be intimately associated with cross-folding, boudinage and changing metamorphic conditions. The increase in temperature has also resulted in a grain-size enlargement of pyrite (along with decussate amphibole grains) can be observed in fold-hinges in the older parts of the mine. However, grain-size increase has not occurred in the recumbent limbs which were more succepted to deformation and migration of material. The fine banding of e.g. sphalerite-chalcopyrite-pyrite is many times due to mobilisation along layers. This is evidenced through the existence of root-less isoclines and isoclinally folded quartz veins within the mineralisations. Taken together, these observations suggest that local enrichment of sulfides is to some extent due to late cross-folding and the localisation of strain in the less competent, hence more ductile, mineralisations.

The late crenulation folding observed in almost all localities varies greatly in orientation, from E-W to N-S, but most are near N-S trending. The latter are (may be) due to late compression during thrusting. The N-S chevron folds could have resulted from a rotation of the fold axis orientation. This would have been gradual and show a progressive change in direction. A fanning of both fold axes and lineations would be expected if the transition was gradual and some of these folds do show signs of transecting cleavage or fold interference patterns. However, it is also possible that many of these crenulation fabrics are extension-related (see Fig. 1a-b) and were formed very late in the development of the Caledonides. Both varieties have been observed.

Reference list

Marshall, B. & Gilligan, L. B. 1987. An introduction to remobilization: information from ore-body geometry and experimental considerations. Ore Geology Rev. V. 2, p. 87-131.

Marshall, B. & Gilligan, L. B. 1989. Durchbewegung structure, piercement cusps, and piercement veins in massive sulfide deposits: formation and interpretation. Econ. Geol. V. 84, 2311-2319.

McQueen, K. G. 1987. Deformation and metamorphism in some Western Australian nickel ores. Ore Geology Rev. V. 2, p. 269-286.

Ramsay, J. G. 1967. Folding and fracturing of rocks. New York, McGraw-Hill, 586 pp.

Sokoutis, D. 1987. Finite-strain effects in experimental mullions. J. Struct. Geol. V. 9, p. 233-242.

Vokes, F. 1963. Geological studies in the Caledonian pyrite-zink-lead orebody at Bleikvassli, Nordland, Norway. Norges Geol. Underssøkn. No. 222, 126 pp.

Vokes, F. 1969. A review of the metamorphism of sulfide deposits. Eart Sci. Rev. V. 5, p. 99-143.