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Tittel

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Structural Interpretation of the Bleka Gruve Vein System, Telemark, Norway

PATRIK WITT-NILSSON

Rosmarus Consulting
Djäknegatan 19:450
S-754 23 Uppsala, Sweden

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1. Introduction

The Svartdal area contains a large number of veins and vein systems. Many are, despite their differing mineralogies related, but many show a complex pattern of overprinting and truncation of earlier veins.

The veins are plotted as poles to surfaces to simplify analysis of the data. The plots are contoured to determine the maximum density and a mean value is determined. This value is corrected manually if it can be shown that it is affected by local sets of minor veins with variations in strike or dip.

When describing the vein systems, quite often two possibilities will be presented for the direction of σ_1. One is an Andersonian value where the veins appear to have formed as a conjugate vein system. The other is based on the formation of a Riedel relay-zone at low angles (c. 30°) to the main vein.

N.B. Due to the variety of structural data, collected from both surface outcrops and from within the mine adits, all will be described as if looked down upon from a surface level, i.e. when discussing shear-sense data from within the mine adits, structures seen in the roof are projected to the surface and interpreted from above; hence, rotated calcite veins with a dextral sense of shear in the adit roof would thus be described as sinistral.

Host-rock

The host-rock is a medium-grained gabbro. the gabbro is often extensively altered to quartz-albite, ankerite and ilmenite around the quartz-veins; however, many veins show secondary wall-rock alterations on one side of the vein only.

Vein types

There are basically three types of (quartz) veins:

A) *Laminated* veins (Fig. 1) which occur at the margins of shear veins. These typically contain several thin slivers or layers of wall-rock.

B) *Brecciated* veins (Fig. 2) with a large variety of internal textures. Coarse breccia may be up to 50 cm long angular blocks of highly altered wall-rock. These clast breccias often form on the releasing side of a dilational jog. The clasts sometimes contain evidence of earlier extension in the shape of thin quartz veins. It is in the junction of these veins that the relay zones form.

C) *Buck quartz* veins (Fig. 3) which are typically 10-100 cm thick. These often contain only milky white quartz and may be quite coarse-grained. These veins cut across most earlier veins.

Figure 1. Laminated vein which occur at the margins of shear veins. These typically contain several thin slivers or layers of wall-rock and have formed through multiple intrusions of fluid material.

Figure 2. Hydro-fractured veins with a large variety of internal textures. The coarse wall-rock breccia is often highly altered. These clast breccias often form on the releasing side of a dilational jog. The clasts sometimes contain evidence of earlier extension in the shape of thin quartz veins.

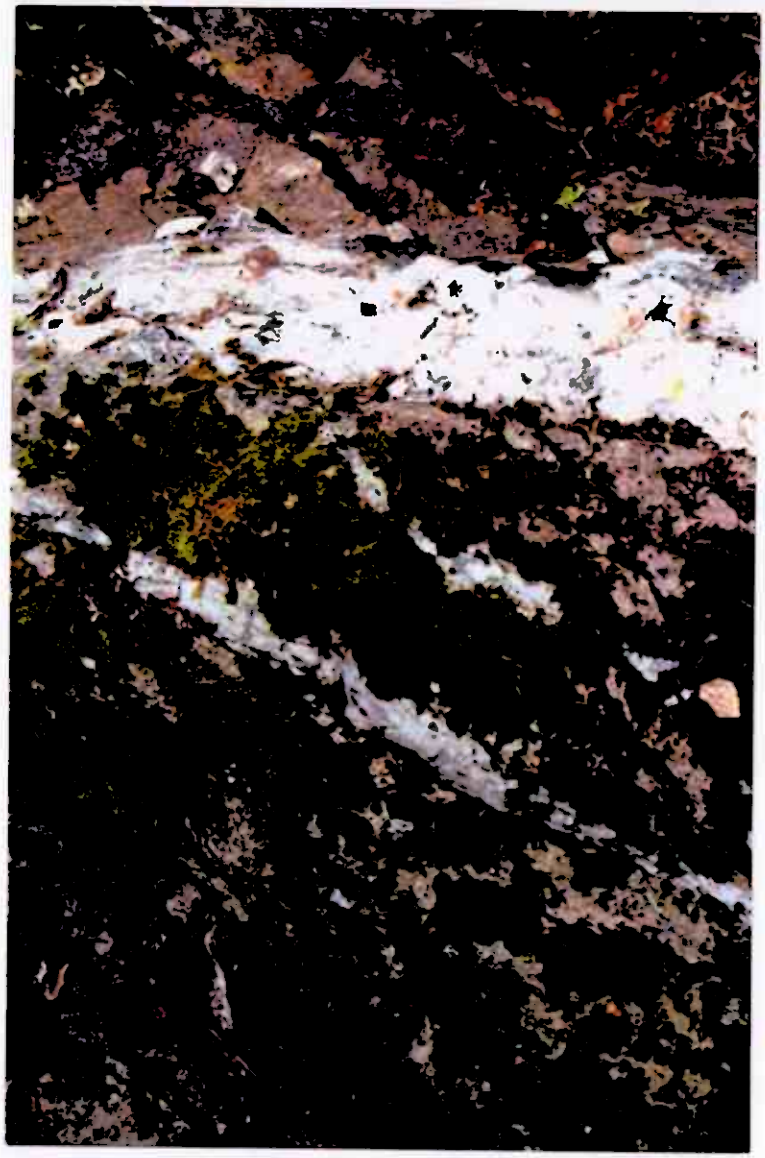


Figure 3. Buck quartz veins which are typically 10-100 cm thick. These often contain only quite coarse-grained milky white quartz. These veins truncate most earlier veins.

Field Areas

I) **Komplikationsklippan**

Area location:

UTM: 0473520/6607710 *or* BL2100+10m south (See map on Fig. 4).

Komplikationsklippan (Complication outcrop) is a c. 20 metre long and 8 metre wide moss and lichen-covered exposure of a complex relay zone (see Fig. 5). The height of the outcrop is c. 7 metres. The slope of the outcrop varies between c. 10-30 ° with a 3 metre subvertical cliff at the far end giving a 3-D view of the structure.

Due to the excellent rock exposure at the Komplikationsklippan outcrop where two en-echelon quartz veins (or K-veins) merge into a relay-zone (Fig. 6) which involves several generations of veins of varying composition, it was

chosen as a reference outcrop. A "scan-line" was placed parallel to the main K-vein and the strike and dip of the quartz vein was recorded when changes were noted. Veins intersection the main quartz vein were noted and strikes, dips mineralogy and cross-cutting relationships recorded. Here a pattern of mineralisation could be distinguished and linked with a specific system. This pattern was used for comparison with veins, or only partially, exposed veins in the whole Svartdal area.

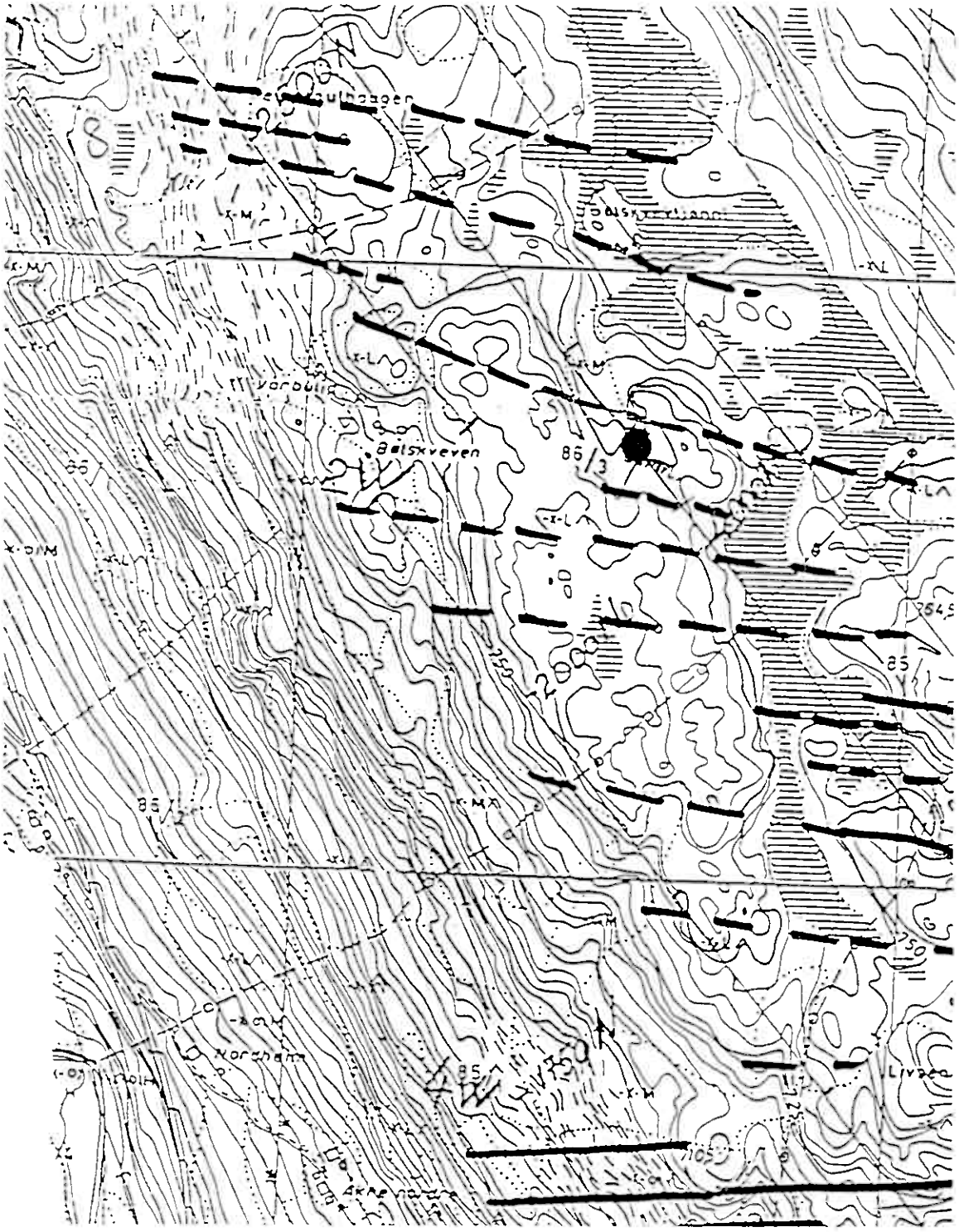


Figure 4. Map detail of the Espelid area showing the location of the Komplikationsklippan outcrop.

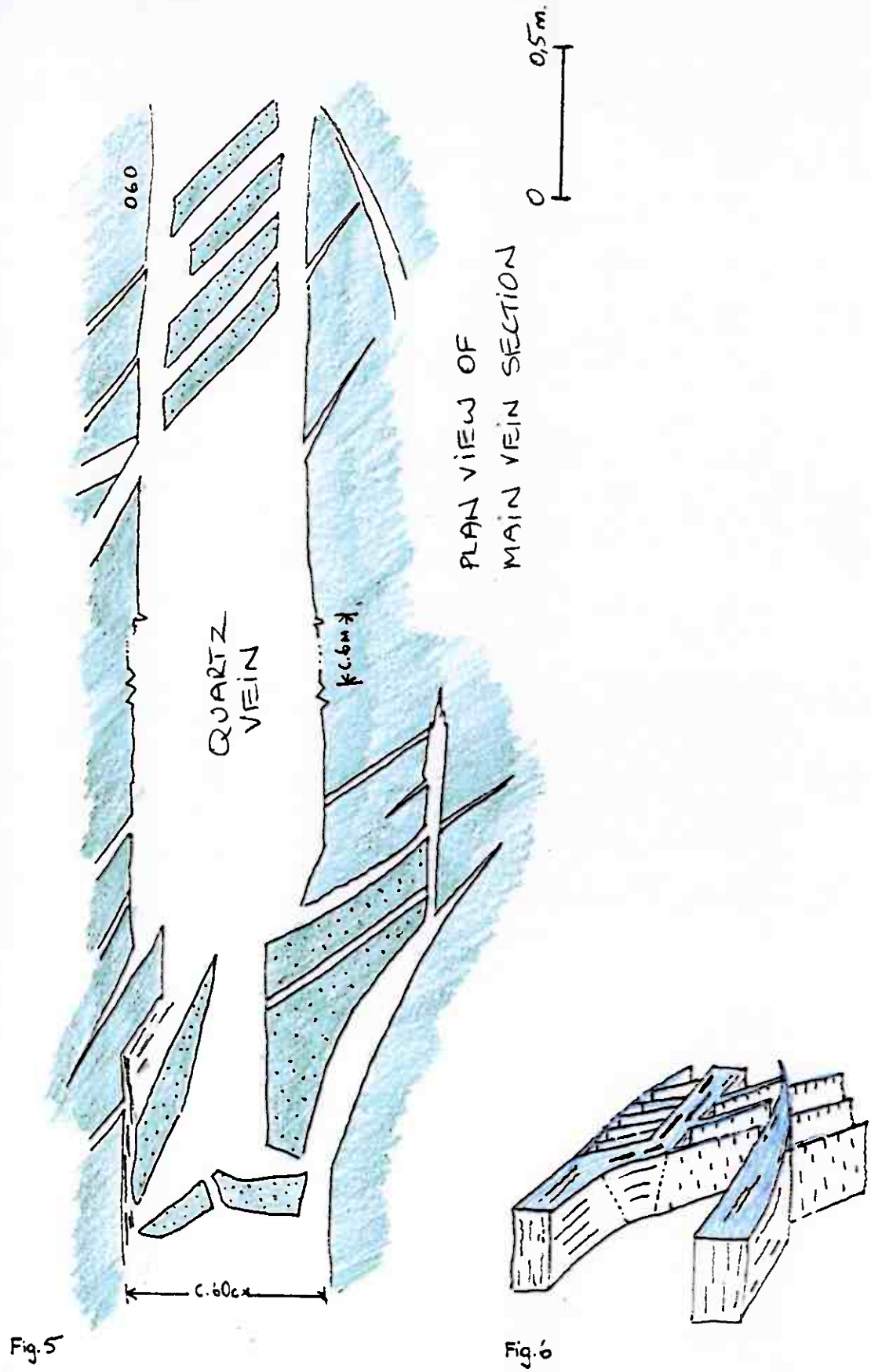


Figure 5 and 6. Figure 5 shows part of the upper K-vein at Komplikationsklippan and the pattern between the old conjugate set and the new main veins. The old conjugate is now deactivated and incorporated in the breccia in the releasing bends. Figure 6 shows an interpretation of the Komplikationsklippan.

Main vein systems:

When plotting all quartz veins on a lower hemisphere, equal-area Schmidt net, the veins plot in a crudely defined area (SE-S) swinging about the vertical by about 40°; however, when differentiating between veins with different mineral parageneses generations the plots become better constrained (see Figs. 7-9).

- Main quartz (K-) veins (Figs. 7-9a): N45°E-75NW

The main vein(s) the K-vein, is composed of two up to 150 cm wide quartz veins tapering and joining into a lens-shaped relay zone.

- Quartz-tourmaline veins (Figs. 7-9b): N70°E-80NW

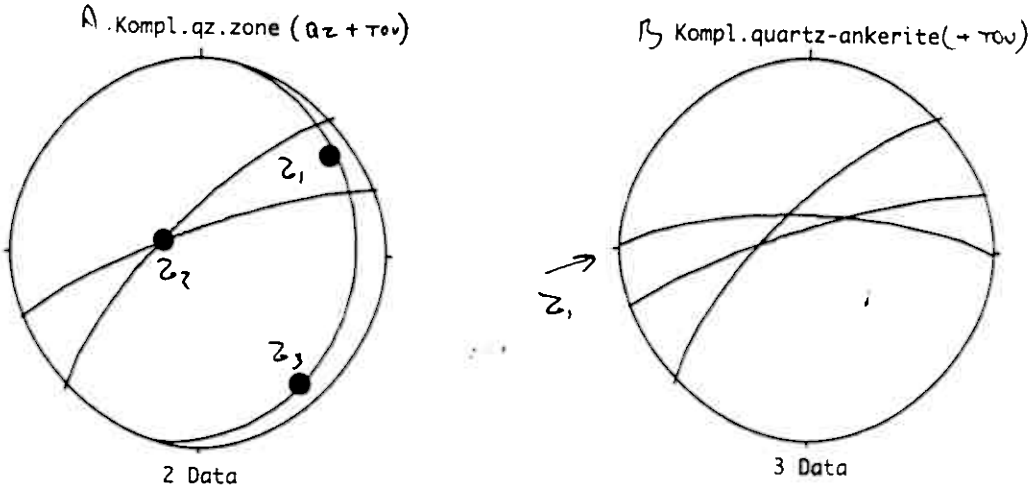
- Quartz-ankerite (Figs. 7-9c): E/W-75N

Results:

Poles to the two K-veins plot between 125° and 140° and the plunge undulates between 40 and 90°. A mean value for these data indicate that the vein strikes c. N45°E/75°NW. These veins are predominantly composed of milky quartz in a highly altered meta-gabbroic host-rock. The quartz veins contain many "xenoliths" of quartz-tourmaline composition. Tourmaline is also found in lenses or pockets along the sides of the K-veins.

Smaller veins, composed mainly of quartz-tourmaline, plot discordantly to the thicker K-veins. These smaller veins have a general 155-165° orientation and plunge ± 30° from the vertical towards northwest and southeast. A mean value for these veins is N70°E/80°NW.

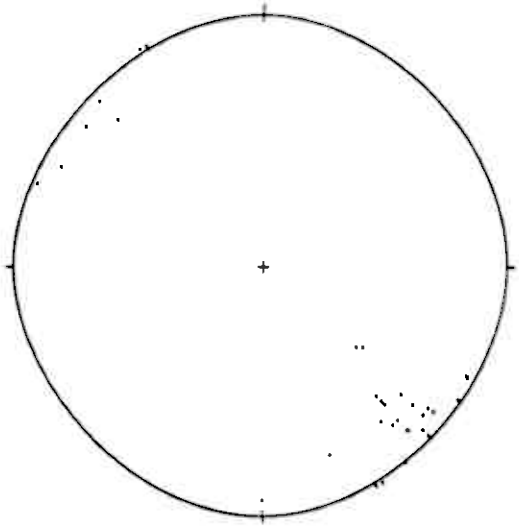
A third set of veins composed of quartz-ankerite plot between 170-190°. The dip between 50-90°towards northwest. A mean value for these veins is EW/75°NW. Unlike the quartz-tourmaline set, only one minor ankerite veins with a similar strike to the K-veins were found.



ROTATION OF σ_1 DIRECTION BETWEEN INITIAL DUCTIONAL EVENT AND SUPERIMPOSED SHEAR (RIEDEL) EVENT.

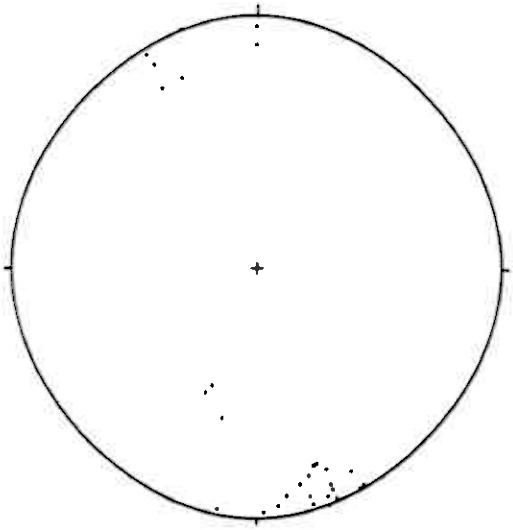
Komplikationsklippan

A) Main vein



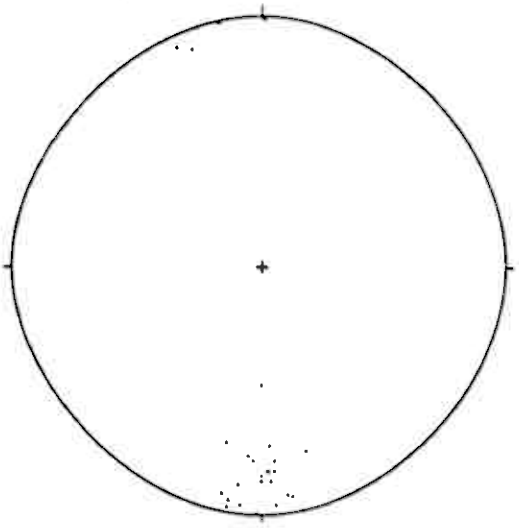
31 Data

B) Qz/tourmaline



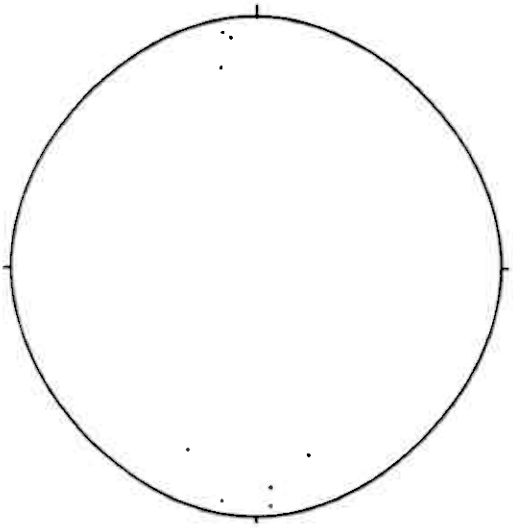
29 Data

C) Qz-ankerite



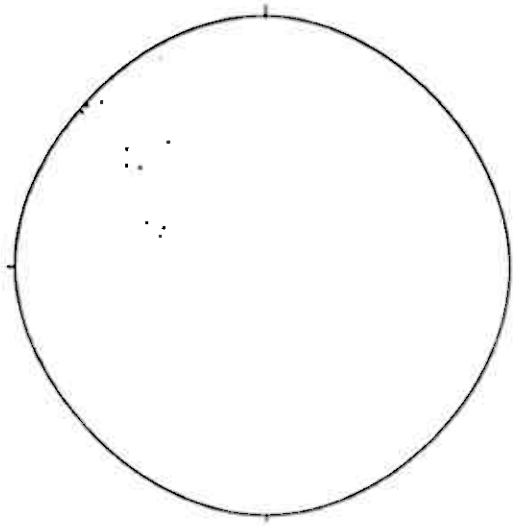
26 Data

D) Qz-chlorite/chl



8 Data

E) Feldspar-tou/qz

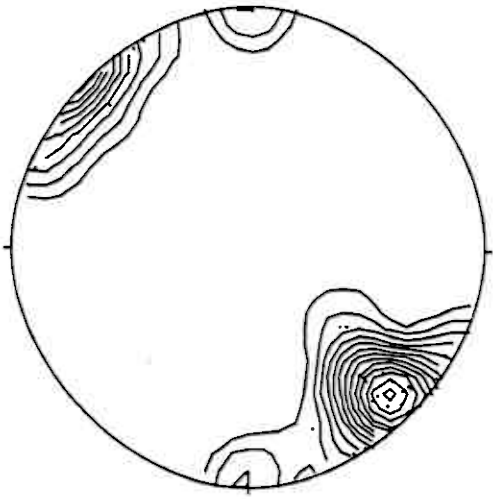


10 Data

Figure 7

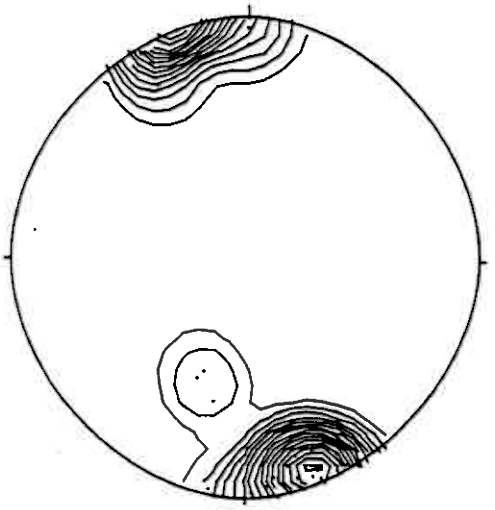
Komplikationsklippan

A) Main quartz vein



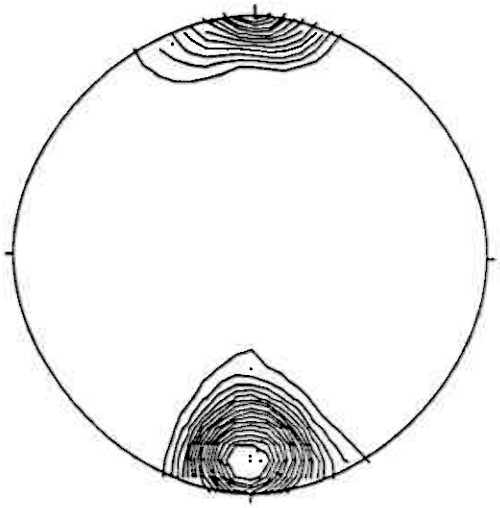
31 Data

B) Quartz-tourmaline



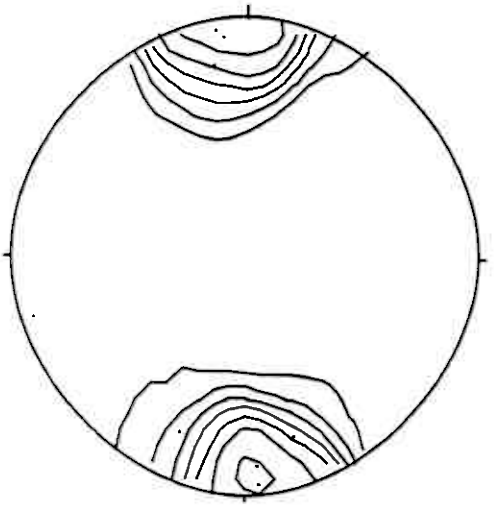
29 Data

C) Quartz-ankerite



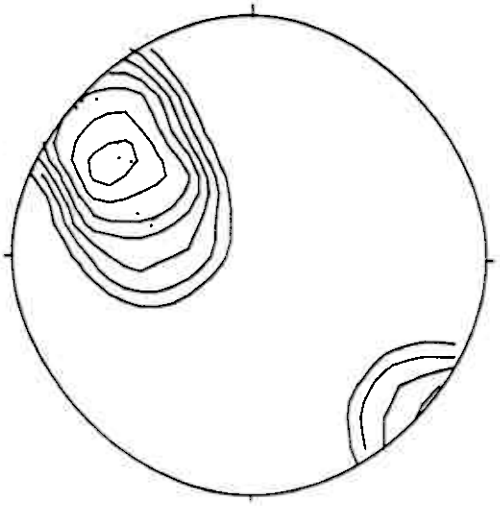
26 Data

D) Quartz-chlorite



8 Data

E) Feldspar-tourmaline

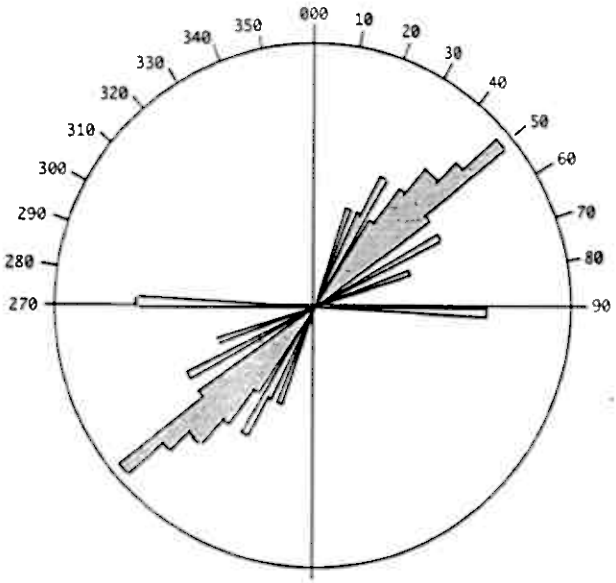


9 Data

Figure 8

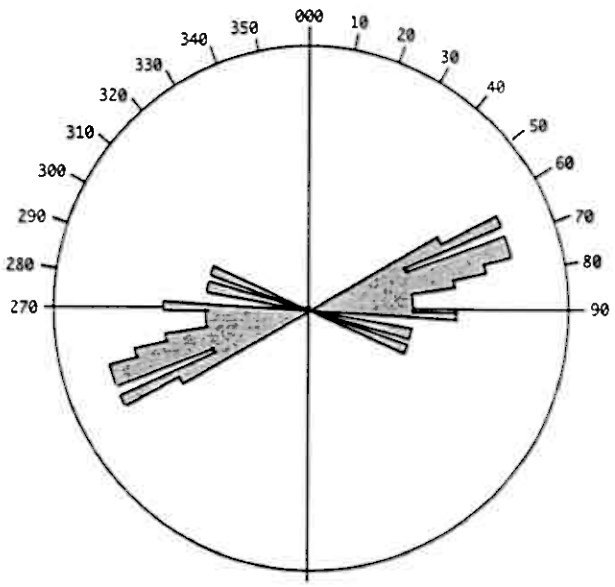
Komplikationsklippan

A) Main quartz vein



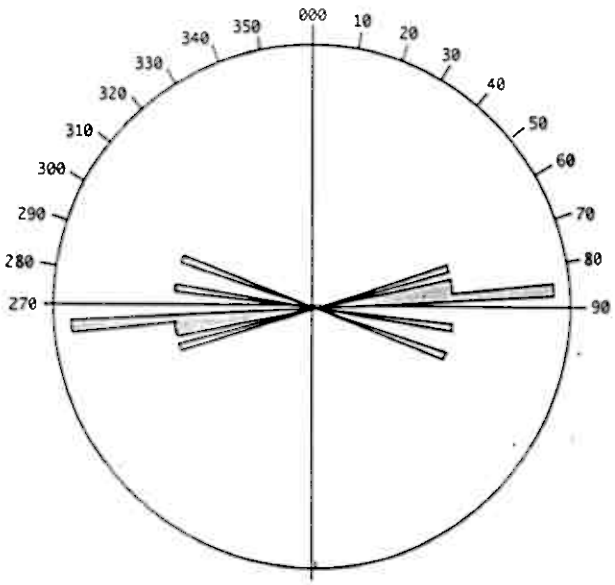
Values: 31 Interval: 3°
Radius: 20%

B) Quartz-tourmaline



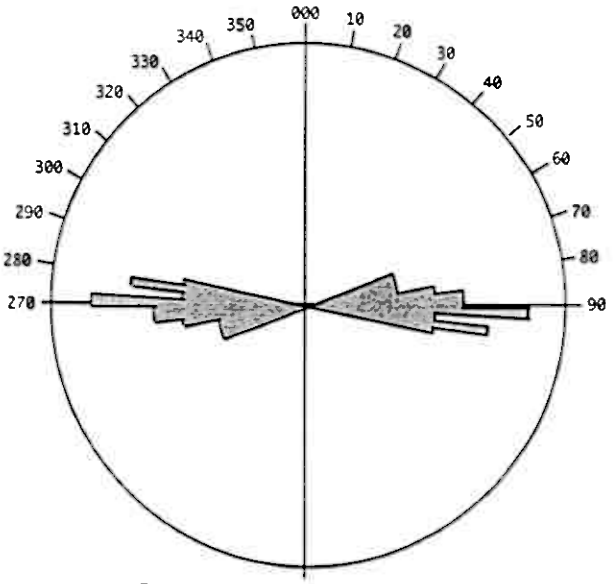
Values: 29 Interval: 3°
Radius: 20%

C) Quartz-chlorite



Values: 8 Interval: 3°
Radius: 40%

D) Quartz-ankerite

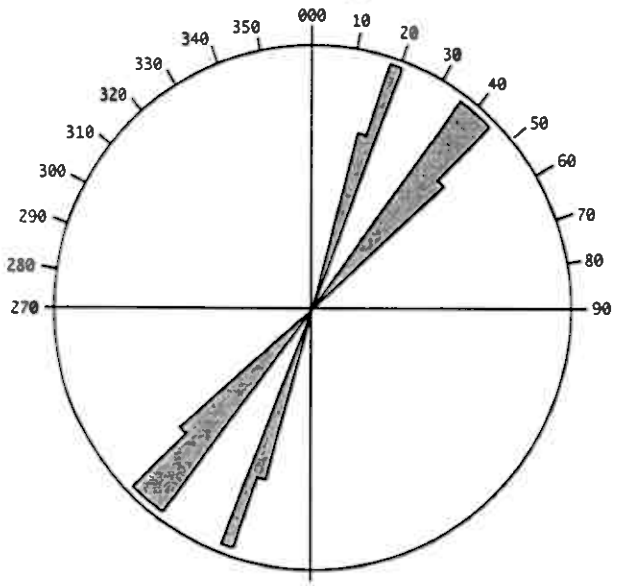


Values: 26 Interval: 3°
Radius: 30%

Figure 9

Komplikationsklippan

E) Kompl.fsp-tou/qz.data



Values: 10 Interval: 3°
Radius: 20%

Figure 9b

Figure 10. Intersection between two quartz vein sets where the NE-striking set is the dominant and has reactivated one limb of an earlier conjugate vein set. The other vein set is visible as thin quartz veins inside the highly altered wall-rock breccia.

K-vein/quartz-ankerite zone: 70° towards 330.

Quartz-ankerite veins occur only in one direction in the relay zone and appear to have formed early in the history of the relay zone. However, the quartz-tourmaline veins which appear to post-date the latter have a slightly different orientation. The number of quartz veins containing tourmaline generally increase near relay zones. They form a W-plunging pillar structure in the area.

K-vein/quartz-tourmaline zone: 65° towards 275

Relay zones:

The relay zone is characterised by two sets of veins with an angle of c. 30 and 50° to the K-vein. One is probably a conjugate to the K vein during early compression whereas the second is most likely a Riedel-shear (C′) vein related to shearing along the main K vein. The spacing of these minor Riedel-shear veins is c. 20-25 centimetres (Fig. 5). The first set is composed of quartz-tourmaline and obviously associated with the larger K-veins. The second set, the quartz-ankerite veins, has a larger angle to the K-veins and seem to predate the large K-veins altogether.

Due to the cross-cutting relationships between these sets of veins, they form a contained area between themselves at the intersection points (Fig. 10). The K-veins and the quartz-ankerite veins form a subvertical relay zone, or pillar, plunging steeply northwestwards (Fig. 11).

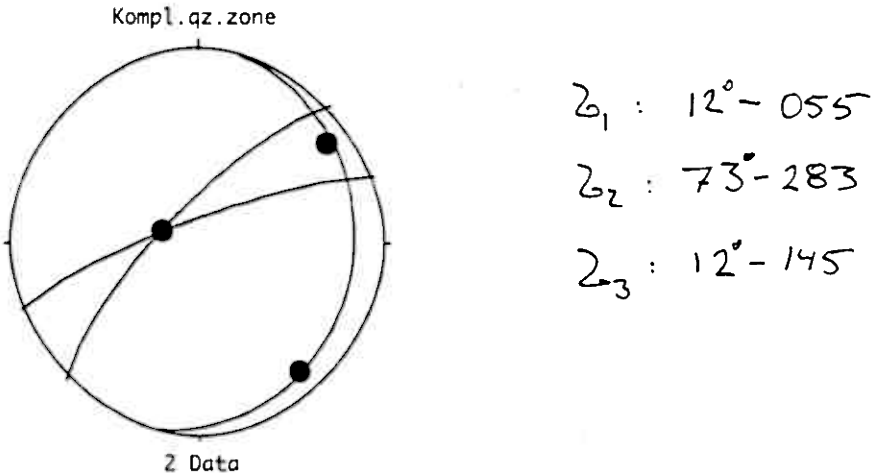


Figure 11. Best-fit planes for the quartz veins with the intersection point representing the dilational jog between the vein sets.

They also occur in both vein sets in the relay zone and truncate many earlier veins. The laminated quartz-tourmaline veins have been intruded by the buck quartz veins. The latter veins have been subjected to shearing along the host-rock contact and contain sub-horizontal sinistral slickensides.

II) Espelid

Area location: 2000N-3000N/4W-1.5E (see Fig. 14)

Main vein systems:

The veins visible in the Espelid area (outside the Komplikationsklippan relay-zone) are almost entirely quartz veins. There are some nice examples of intersecting vein sets (Fig. 12).

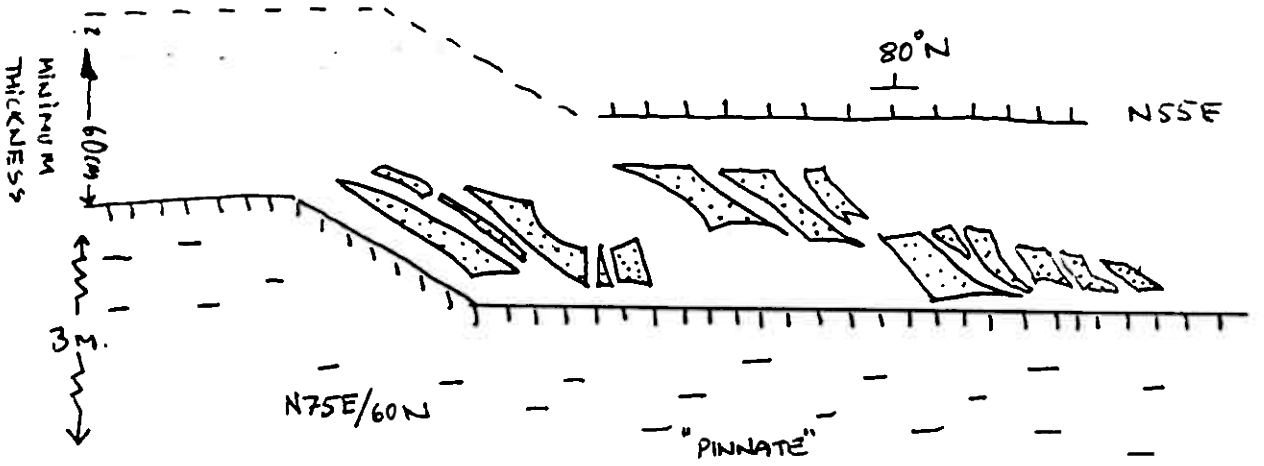
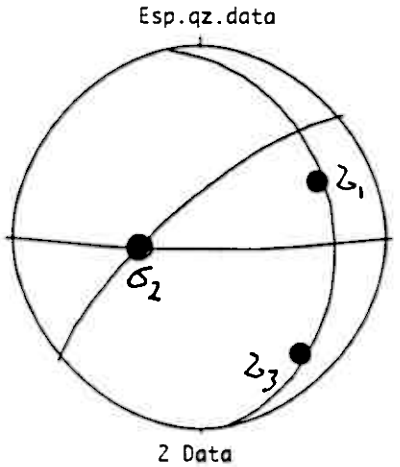


Figure 12. Buck quartz vein with large breccia clasts in the releasing bend of two intersecting vein sets. The dominant set is the competent buck quartz veins and the minor set is the intersecting veins (probably an old conjugate set).

- Main quartz (K-) veins (Fig. 13): N50°E-75N E/W-85

Relay zones:

K-vein/quartz-quartz relay zone (Fig. 15): 55° towards 265.



σ_1 : 28-068

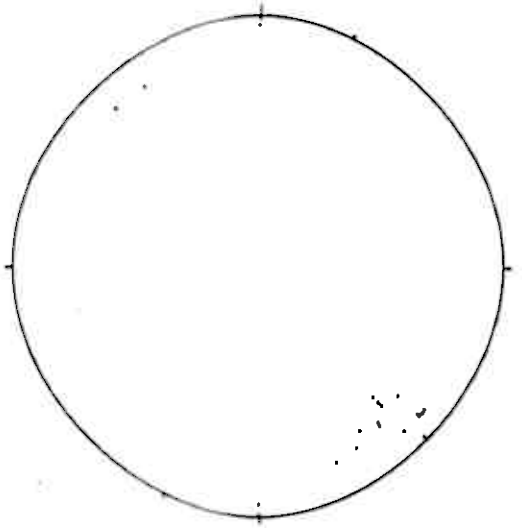
σ_2 : 61°– 260

σ_3 : 5° – 158

Figure 15. The diagram shows the two planes and the intersection point defining the steeply plunging dilational jog.

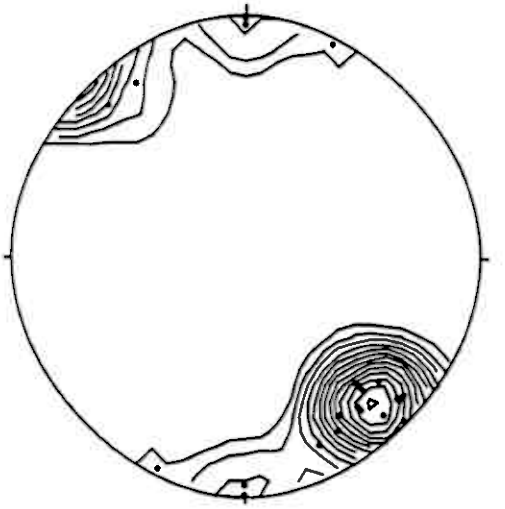
Espelid

A) Quartz veins



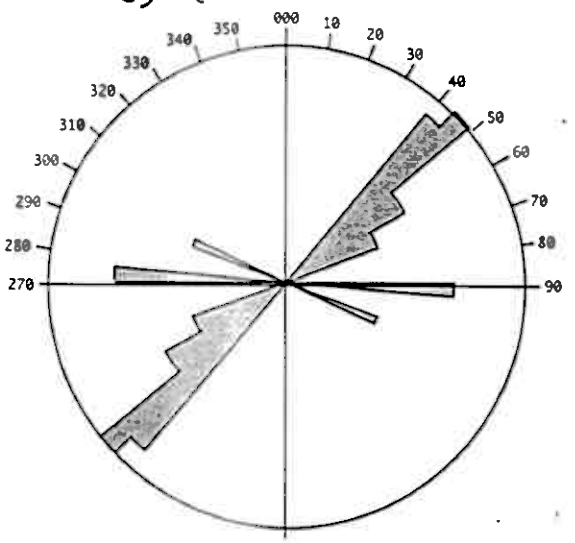
22 Data

B) Quartz veins



21 Data

C) Quartz veins



Values: 21 Interval: 18°
Radius: 20

Figure 13

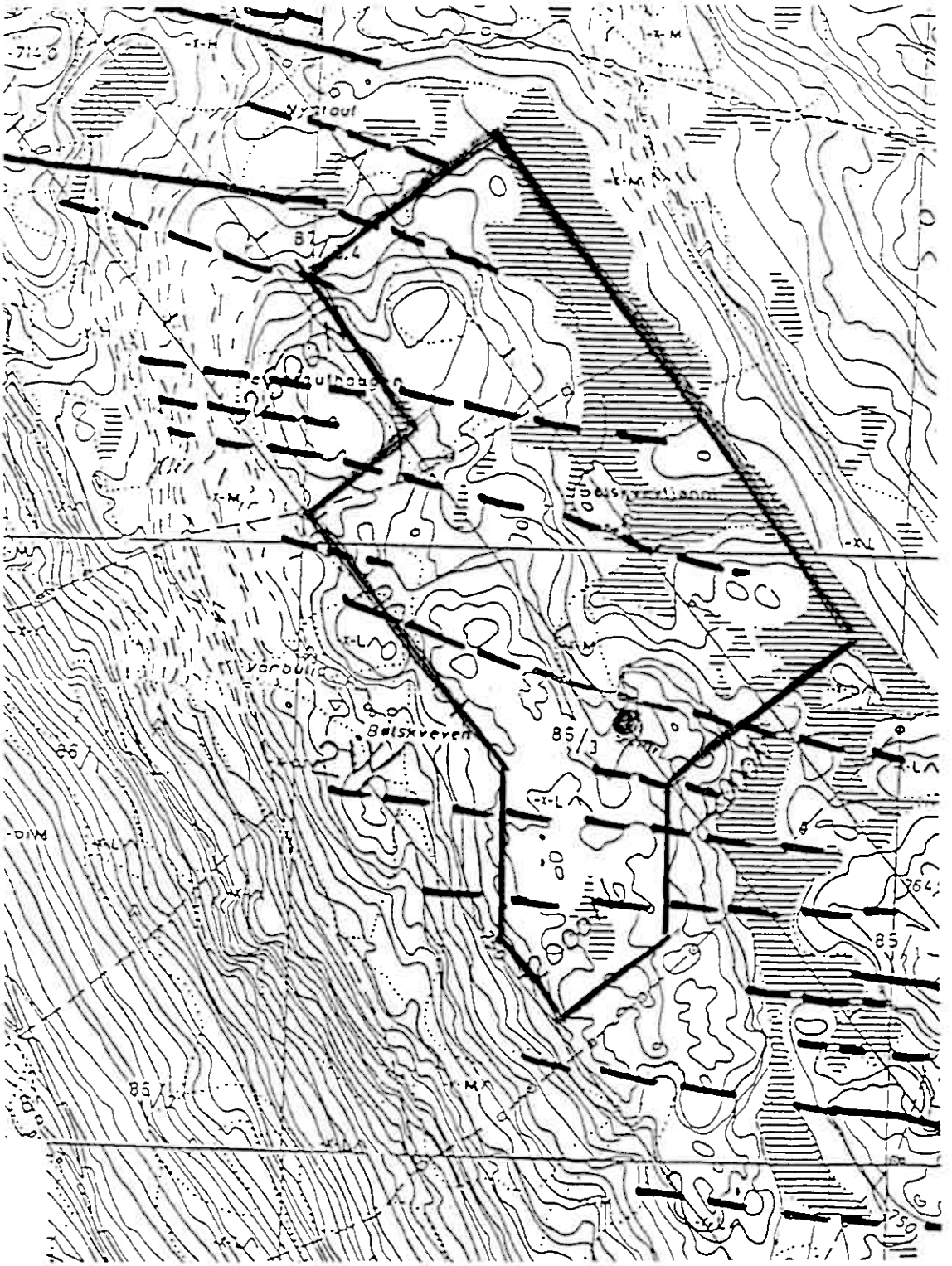


Figure 14. Map detail over the Espelid area. Map area between N2000-3000/2W-1.5E.

III) Bleka South

Area location: 200S-100N/4W-0.5E (see map Fig. 16)

Data collected along the road below and above the mine.

Main vein systems (Figs.17-19):

•Main quartz (K-) veins:	N53°W-63NE N71°E-66NW
•Quartz-tourmaline veins:	N1°E-78SE N85°E-64NW
•Quartz-ankerite:	N11°W-58NE N88°W-63NE

Results:

These data are all based on minor veins in the road cuts and do not provide any convincing data for interpretation. It is also very different from that found in the Bleka mine only a short distance away.

Relay zones:

K-vein/quartz-ankerite relay zone (Fig. 20a):	60° towards 015.
K-vein/quartz-ankerite relay zone (Fig. 20b):	60° towards 025.
K-vein/quartz-ankerite (Fig. 20c):	55° towards 045.

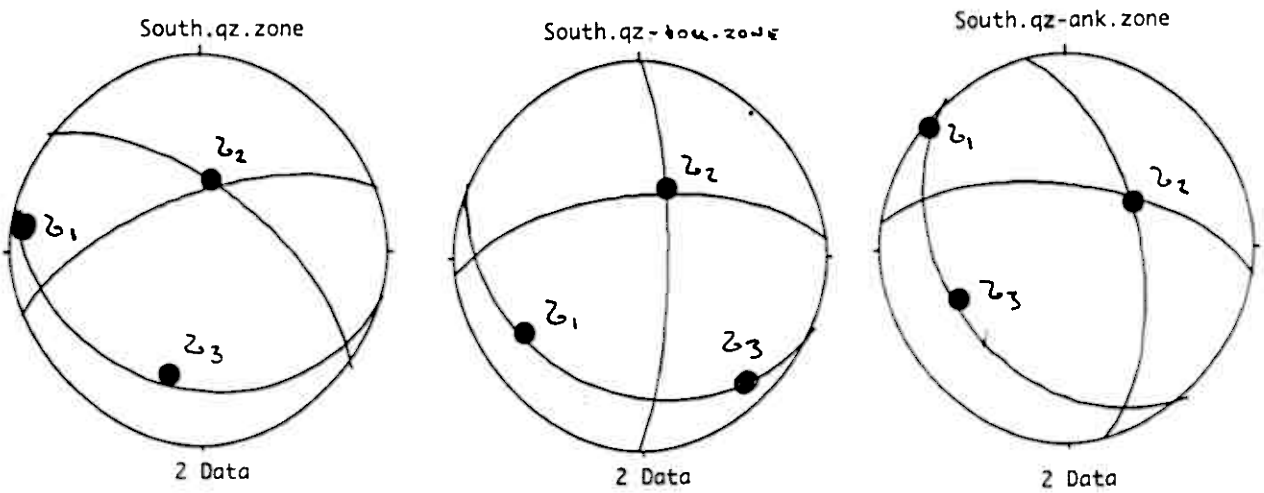


Figure 20: Plunge of quartz (A), quartz-tourmaline (B) and quartz- ankerite (C) extensional jogs.

A/ σ_1 = 2° → 281
σ_2 = 61° → 015
σ_3 = 28° → 191

B/ σ_1 : 27° – 244
σ_2 : 61° – 022
σ_3 : 12° – 134

C/ σ_1 : 4° – 314
σ_2 : 56° – 051
σ_3 : 34° – 224

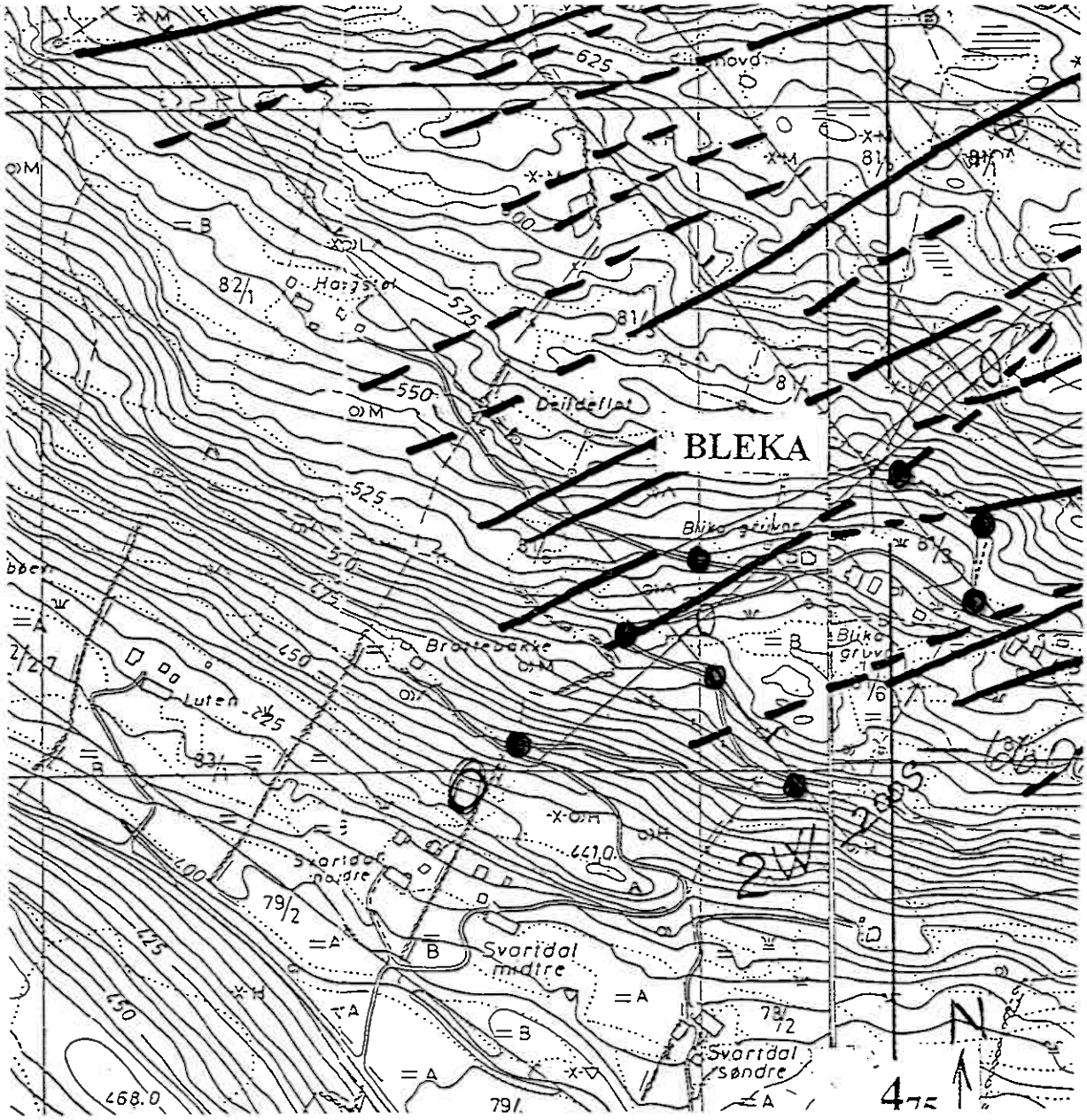
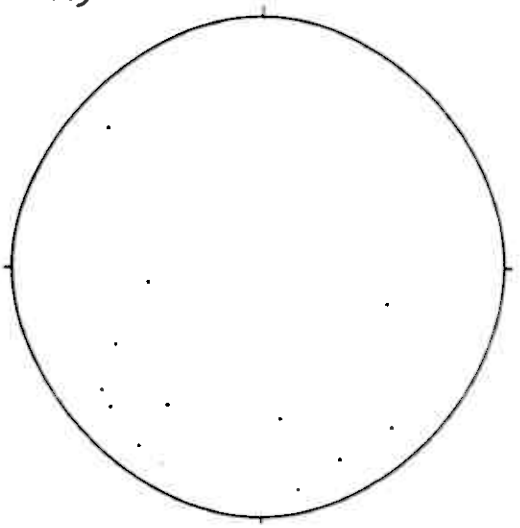


Figure 16. Map detail over the area south of Bleka Mine. The main sample localities marked on the map.

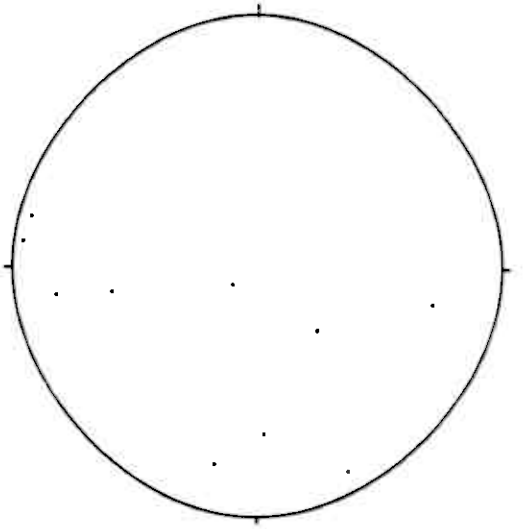
Bleka South

A) Quartz veins



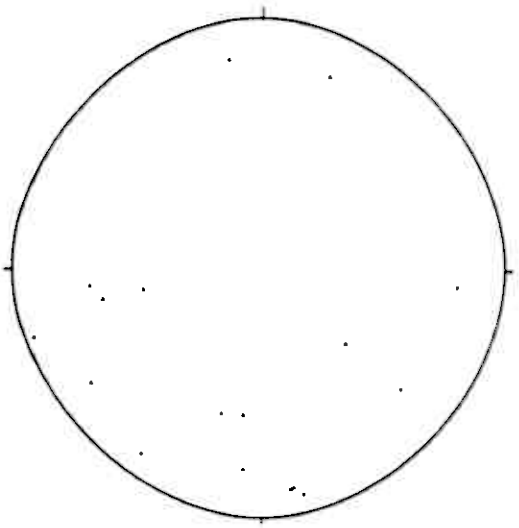
12 Data

B) Quartz-tourmaline



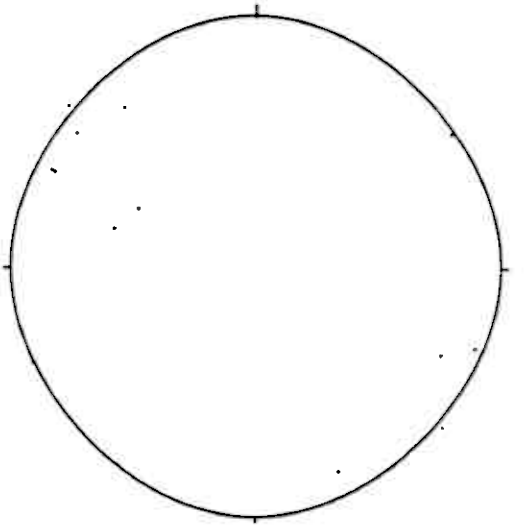
10 Data

C) Quartz-ankerite



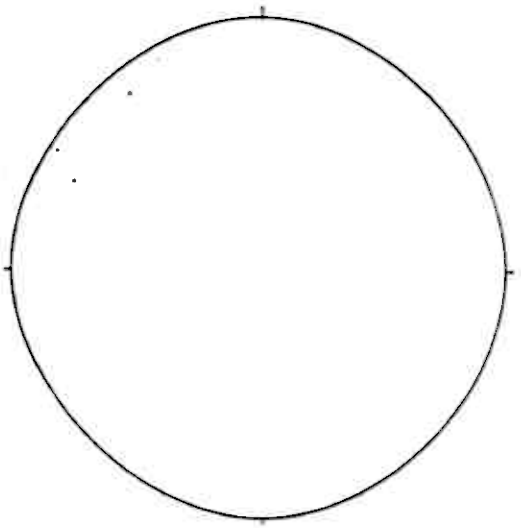
17 Data

D) Chlorite-calcite



12 Data

E) Feldspar-toumaline

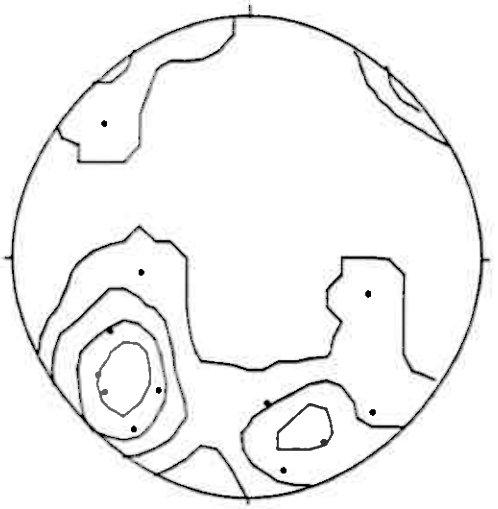


3 Data

Figure 17

Bleka South

A) Quartz veins

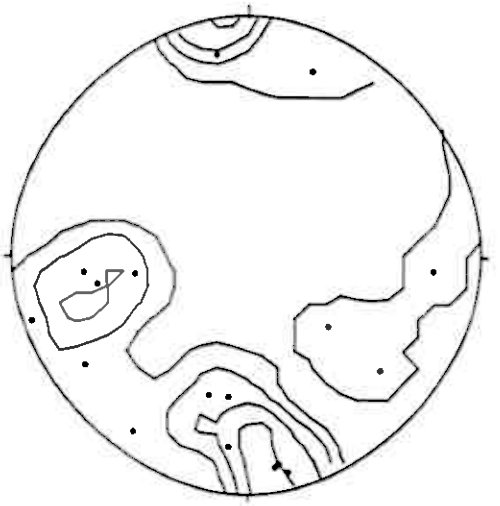


12 Data

B) Quartz-tourmaline

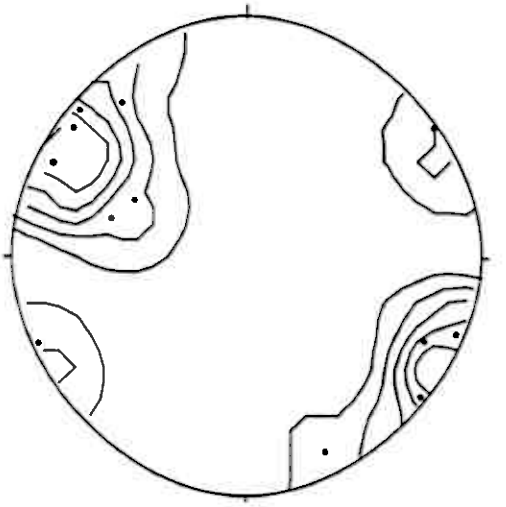
10 Data

C) Quartz-ankerite



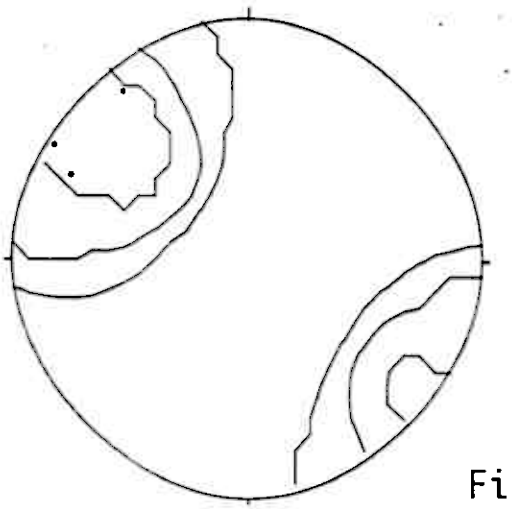
17 Data

D) Chlorite-calcite



12 Data

E) Feldspar-tourmaline

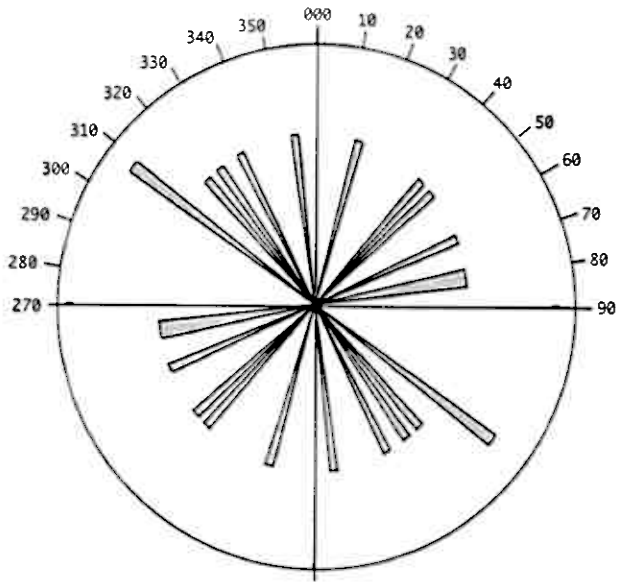


3 Data

Figure 18

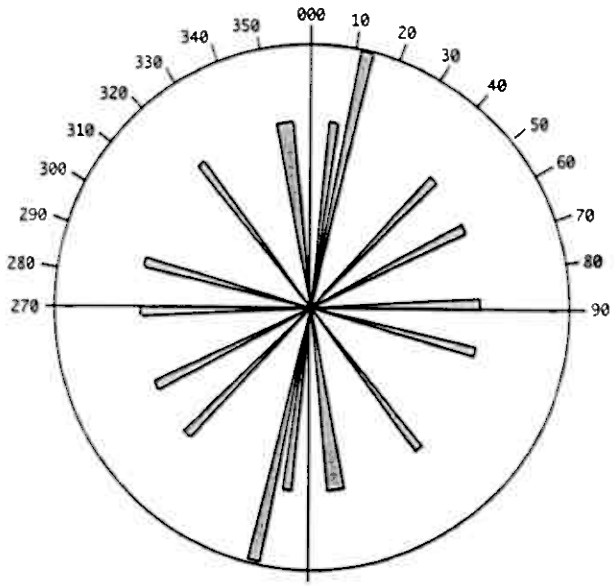
Bleka South

A) Main quartz vein



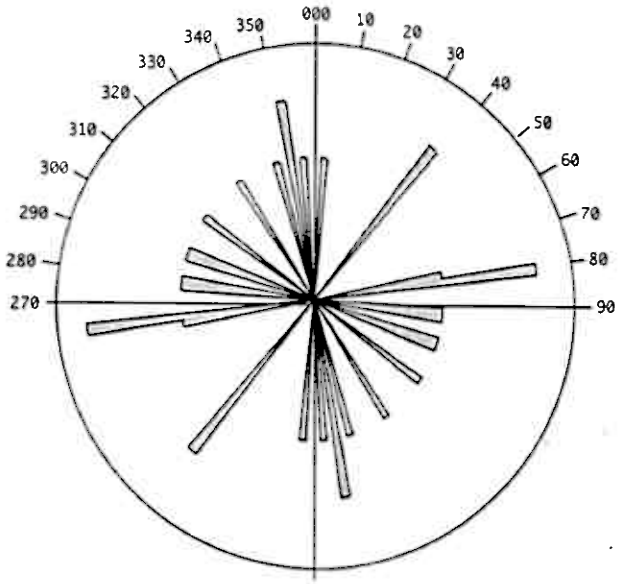
Values: 12 Interval: 3°
Radius: 20%

B) Quartz-toumaline



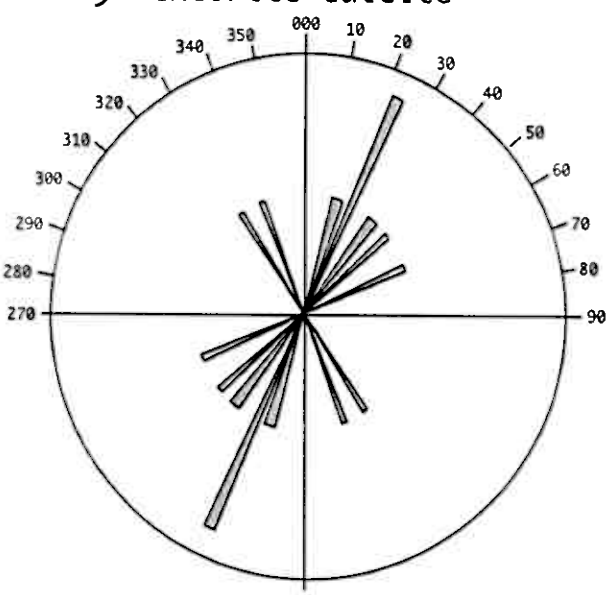
Values: 10 Interval: 3°
Radius: 20%

C) Quartz-ankerite



Values: 17 Interval: 3°
Radius: 20%

D) Chlorite-calcite

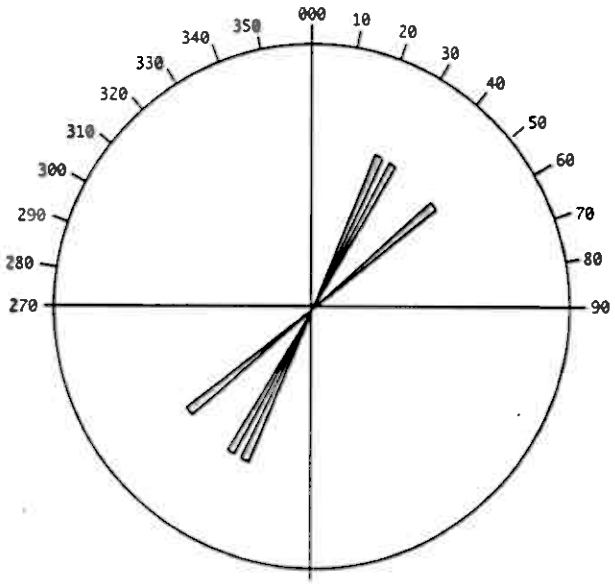


Values: 12 Interval: 3°
Radius: 40%

Figure 19 (I/II)

Bleka South

E) Feldspar-tourmaline



Values: 3 Interval: 3°
Radius: 80%

Figure 19 (II/II)

IV) Bleka North

Area location: 100N-250N/2E-6E (Fig. 21)

Main vein systems: (Fig.22)

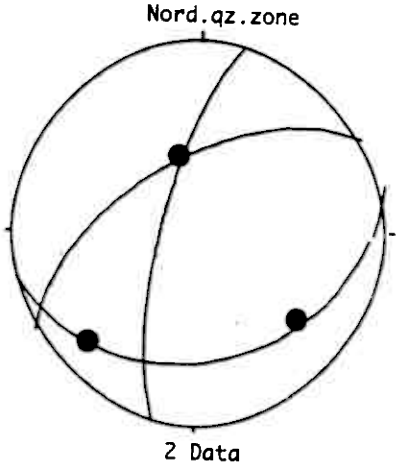
- Main quartz veins: N13°E/75NW
  N32°E/72NW
- Quartz-tourmaline veins: N32°E/72NW
  N66°E/62NW

Results:

Most veins are a combination of quartz and quartz-tourmaline veins (Fig. 23). Both systems overlap and have been utilised in finding the σ1 direction.

Relay zones:

- K-vein/quartz-tourmaline: 60° towards354



σ1: 16°-234
σ2: 60°-354
σ3: 26°-144

Figure 23: Best-fit planes for quartz (quartz-tourmaline) veins with the intersection point between the veins representing the plunge direction of the dilational jog/mineralised relay zone..

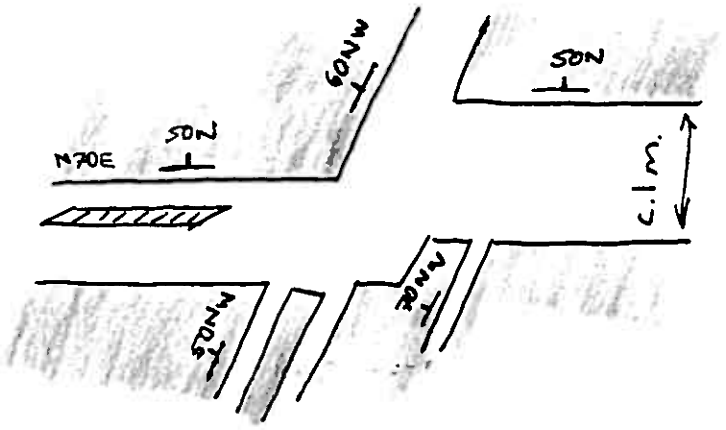


Figure 24: Relay zone between two buck quartz vein sets (175N/3.25E).

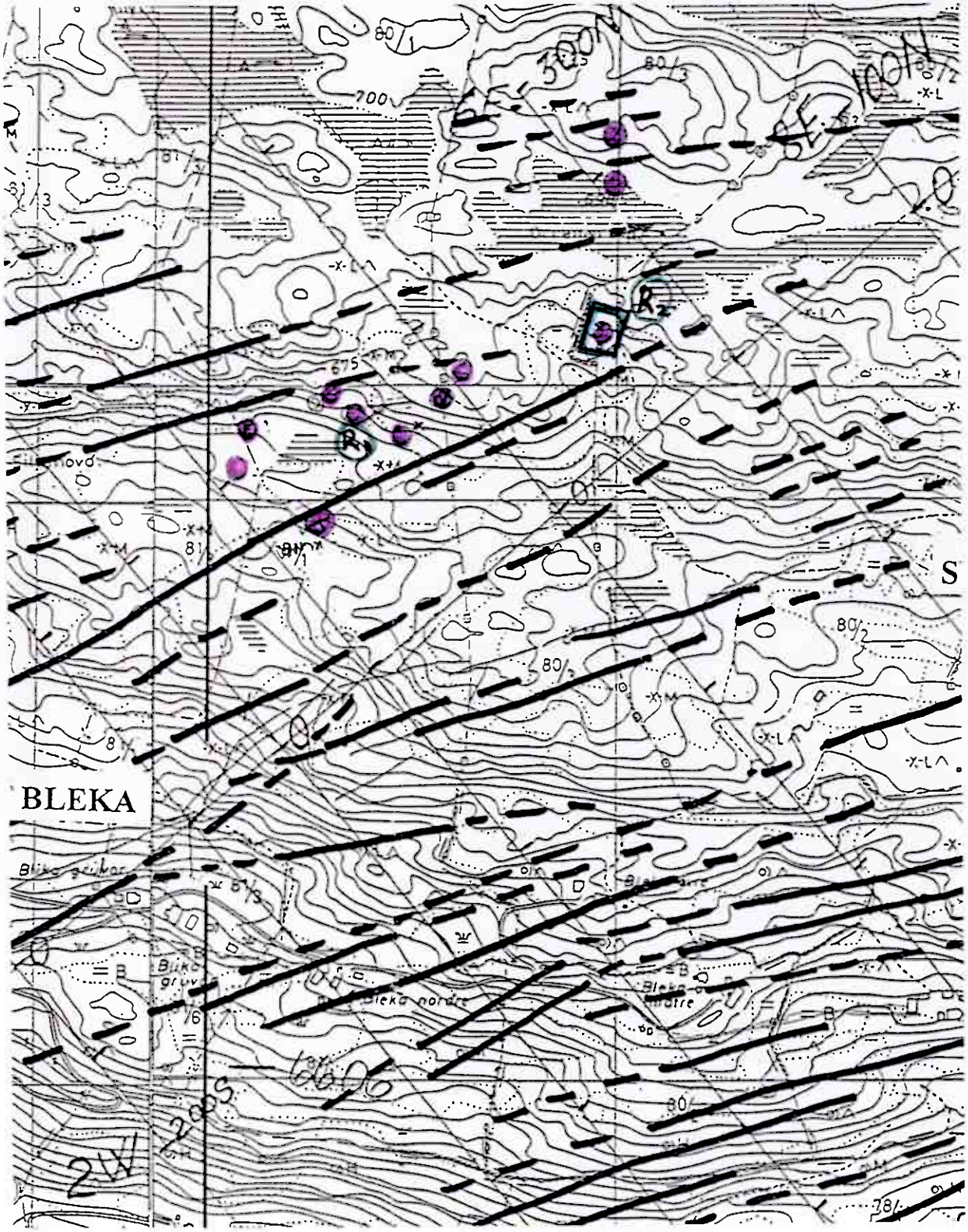
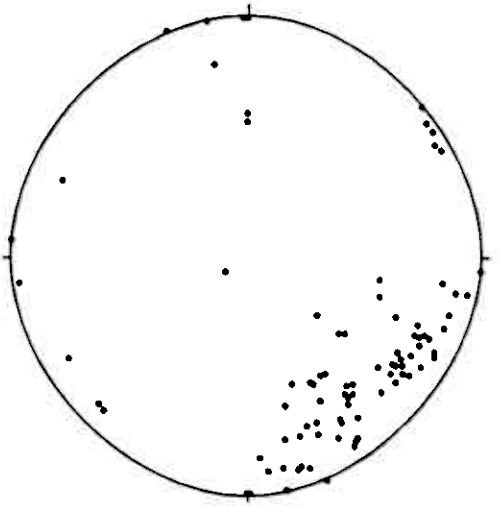


Figure 21: Map detail of the Bleka North (and northeast) area. The relay zone in Fig. 24 is marked R_1 (175N/3.25E). Another relay zone, R_2 has been marked with a rectangle.

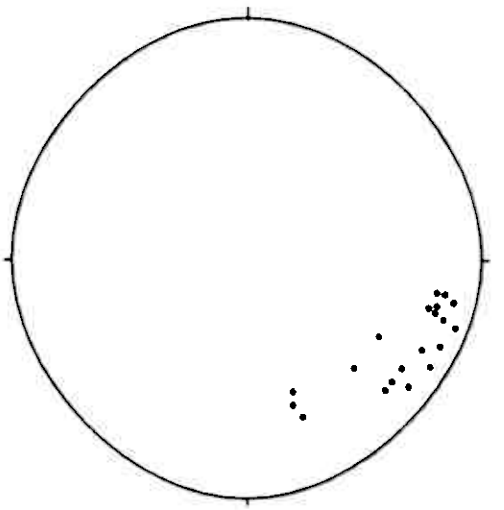
Bleka North

A) Quartz veins



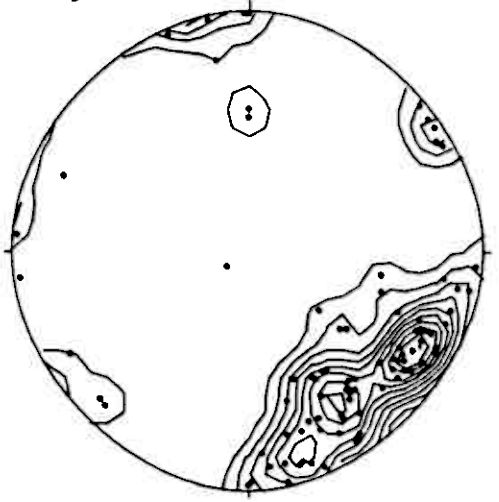
85 Data

B) Quartz-tourmaline



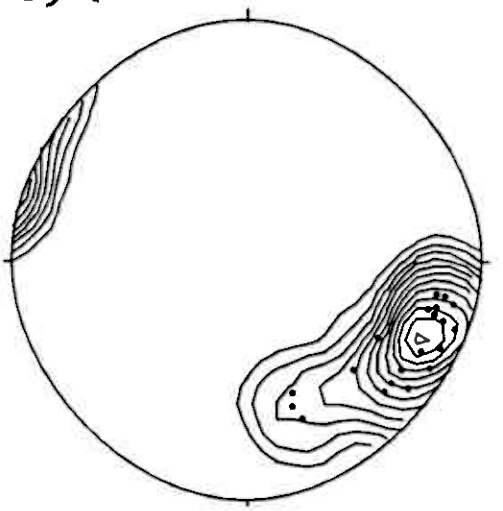
20 Data

C) Quartz veins



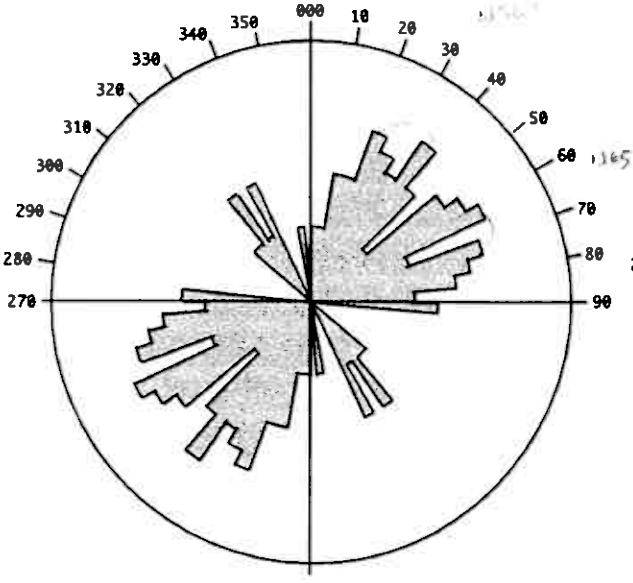
85 Data

D) Quartz-tourmaline



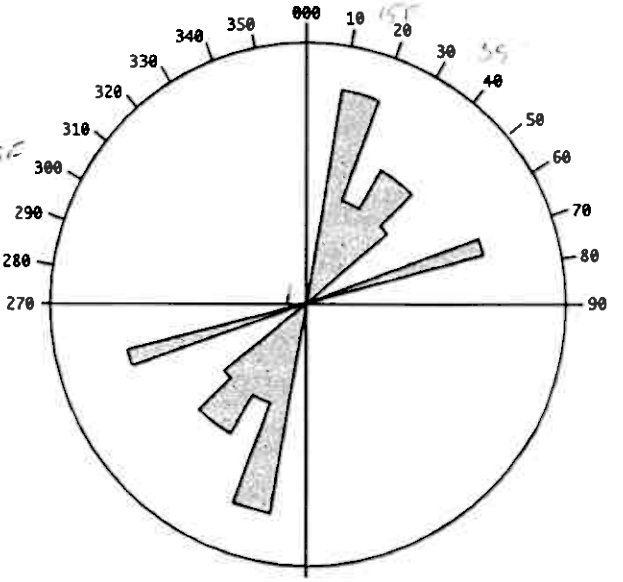
20 Data

E) Quartz veins



Values: 85 Interval: 4°
Radius:10

F) Quartz-tourmaline



Values: 20 Interval: 18°
Radius: 20

Figure 12

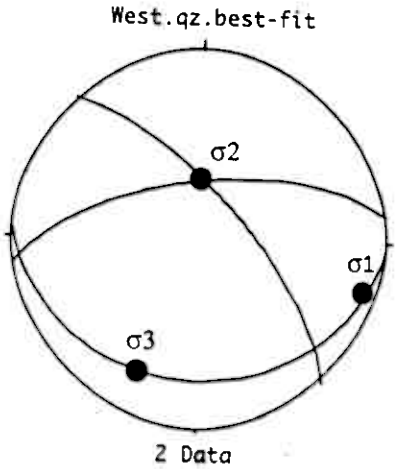
V) Bleka West

Area location: 0N-500N/2W-1.5W (Fig. 25)

Main vein systems:

- Main quartz (K-) veins (Figs. 26-28): N82°E/65NW
  N42°W/71NE
  (N16°E/72NW)
- Quartz-tourmaline veins: N28°E/74NW
- Quartz-ankerite: N83°E/76NW

Results:



σ1: 6°-104
σ2: 64°-004
σ3: 26°-194

Figure 29. The diagram shows the two best-fit planes for the vein data and the intersection point defining the steeply plunging dilational jogs.

Relay zones:

K-vein/quartz relay zone: 64° towards 004°

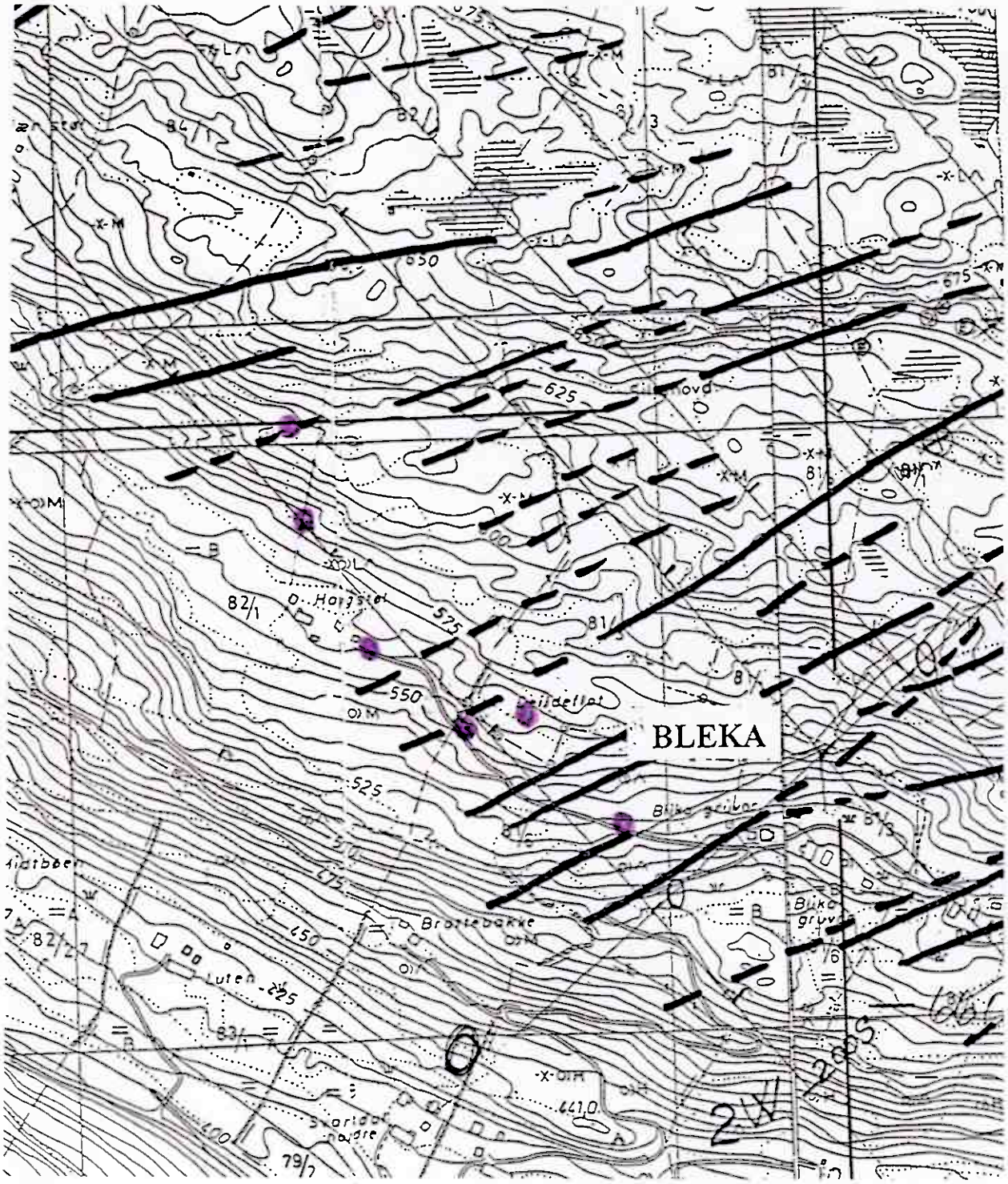


Figure 25. Map detail of the Bleka West (and northwest) area.

Bleka West

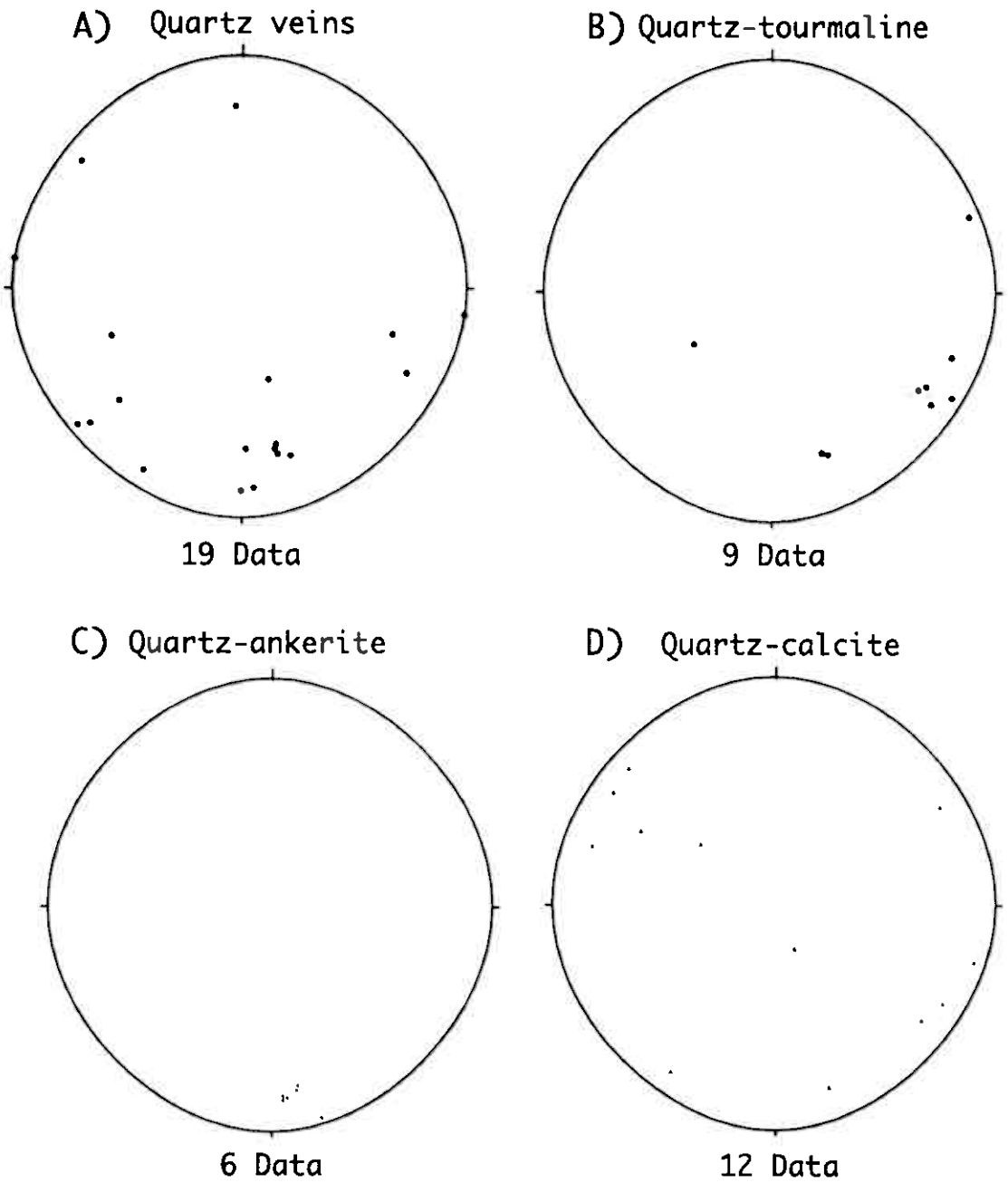
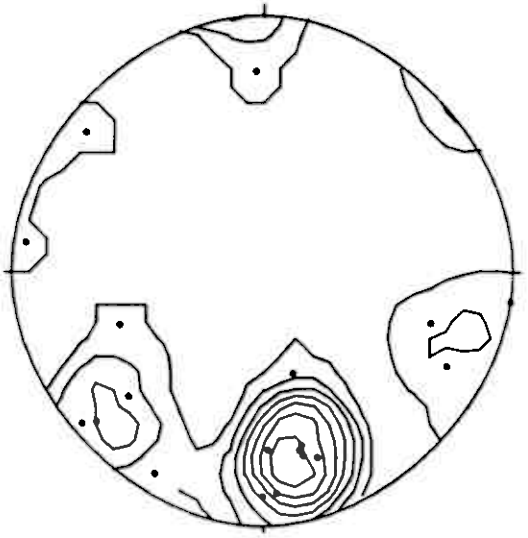


Figure 26

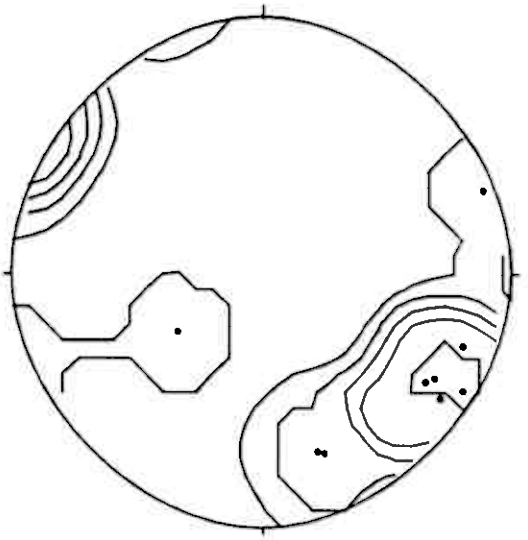
Bleka West

A) Quartz veins



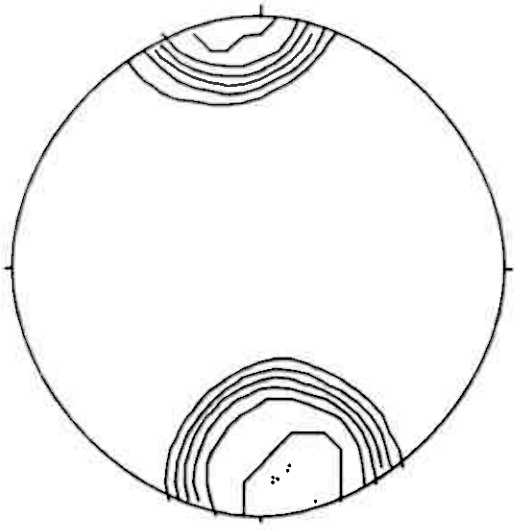
19 Data

B) Quartz-tourmaline



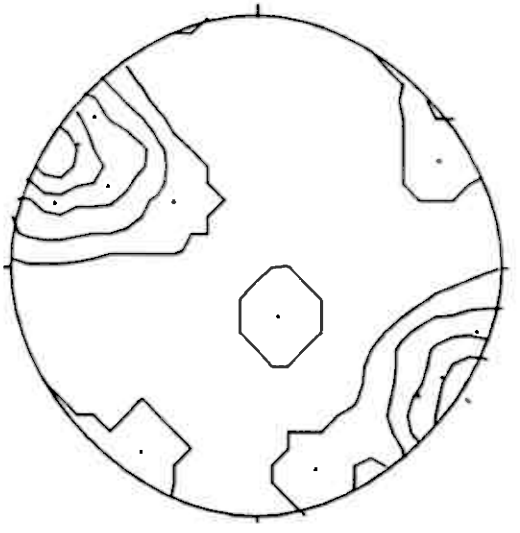
9 Data

C) Quartz-ankerite



6 Data

D) Quartz-calcite

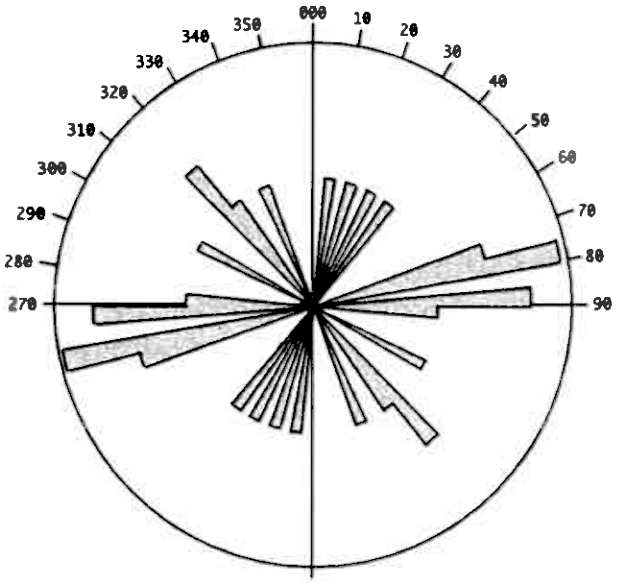


12 Data

Figure 27

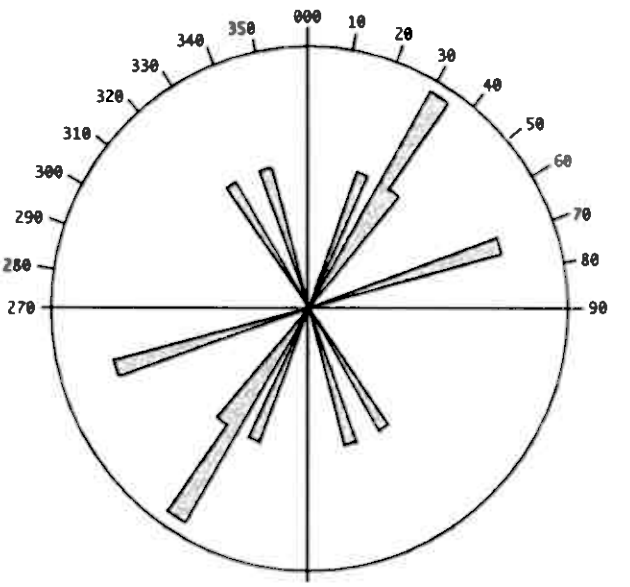
Bleka West

A) Quartz veins



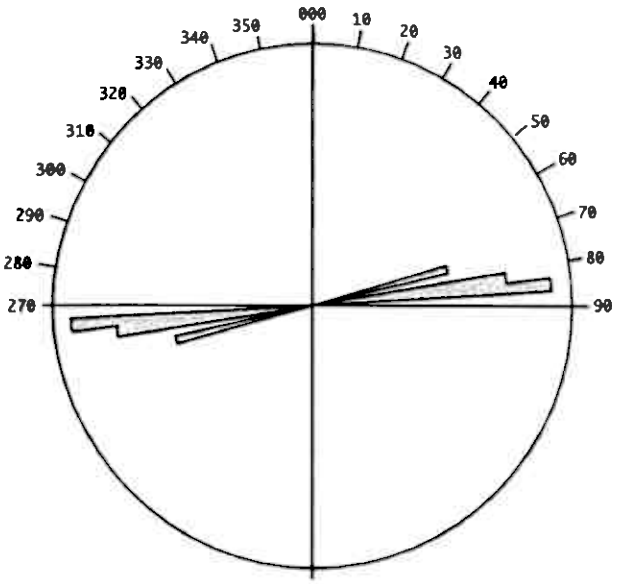
Values: 19 Interval: 18°
Radius: 15

B) Quartz-tourmaline



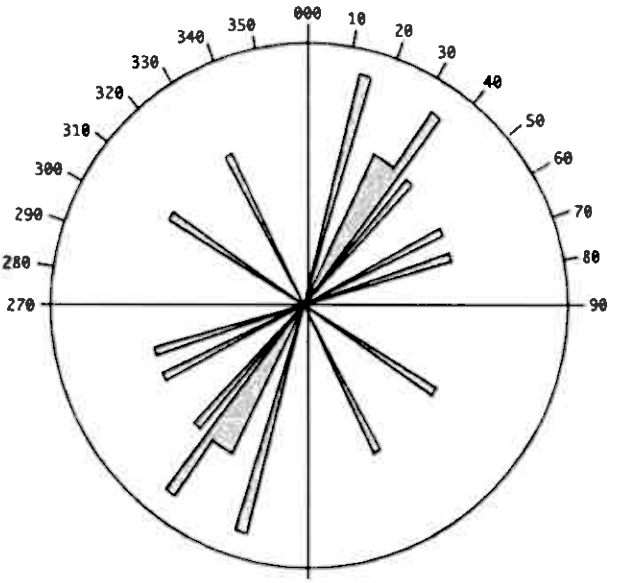
Values: 9 Interval: 40°
Radius: 25

C) Quartz-ankerite



Values: 6 Interval: 3°
Radius: 50%

D) Quartz-calcite



Values: 12 Interval: 3°
Radius: 20%

Figure 28

VI) Bleka gruve- stolle B

Area location: 25S/0.5W (Fig. 29)

Main vein systems: (Figs. 30-32)

- Main quartz (K-) veins: N44°E/86NW, N88°W/60NE
- Quartz-tourmaline veins: N83°E/71NW, N45°W/80NW
- Quartz-ankerite: N76°W/68NE

Results:

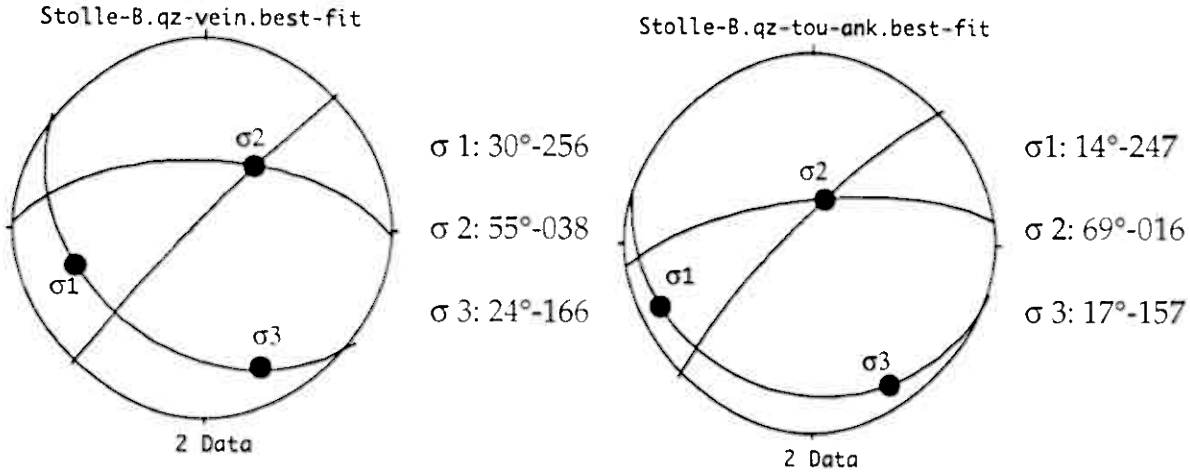


Figure 33: Best-fit planes for the vein systems in the Bleka Gruve- stolle B.

Relay zones:

K-vein/quartz-tourmaline-ankerite relay zone: 69° towards 016.

Figure 29. Map detail of the Bleka Gruve- stolle B.

Bleka gruve - stolle B

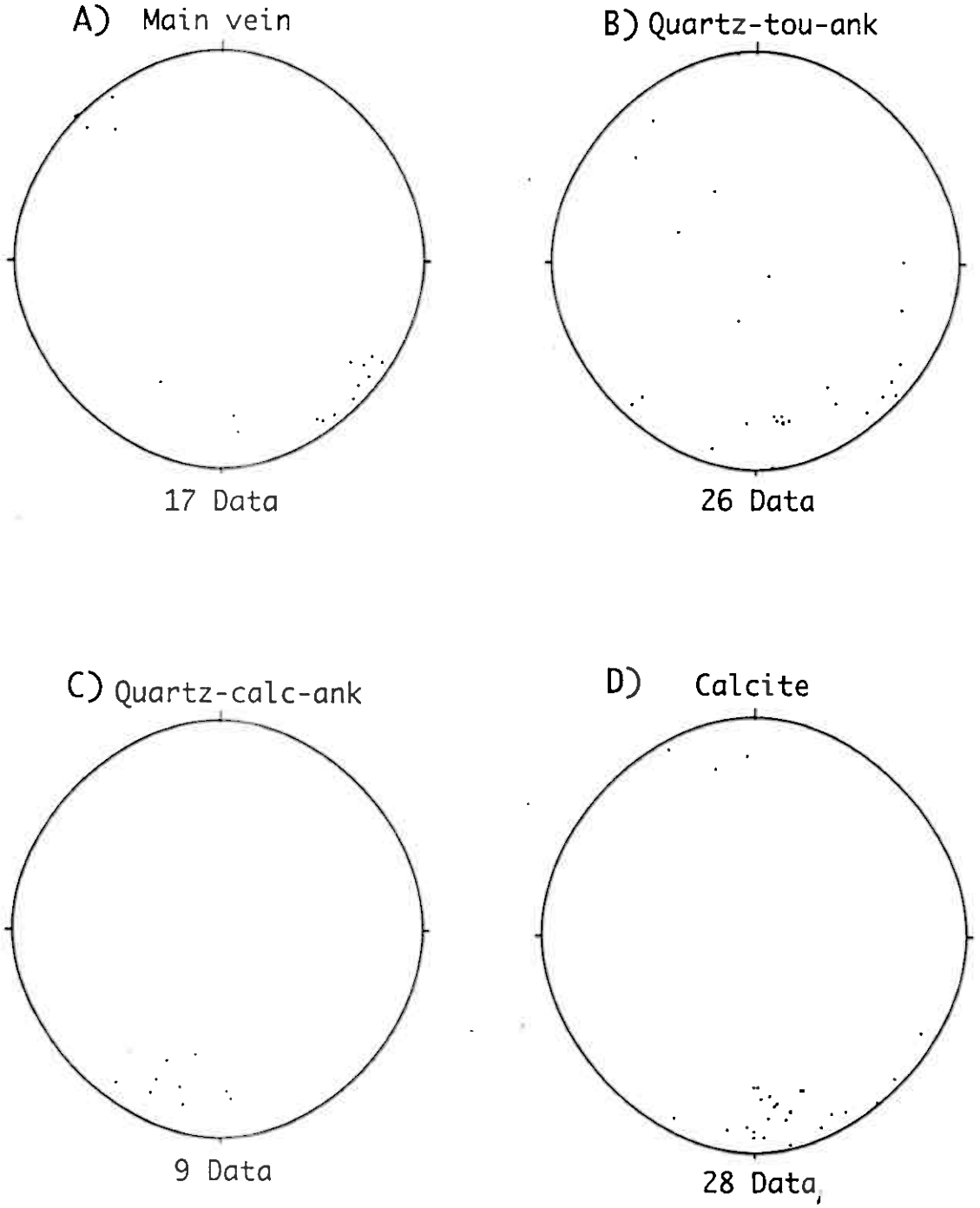
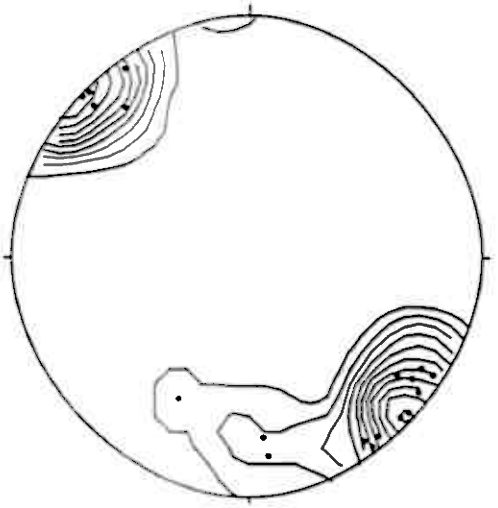


Figure 30

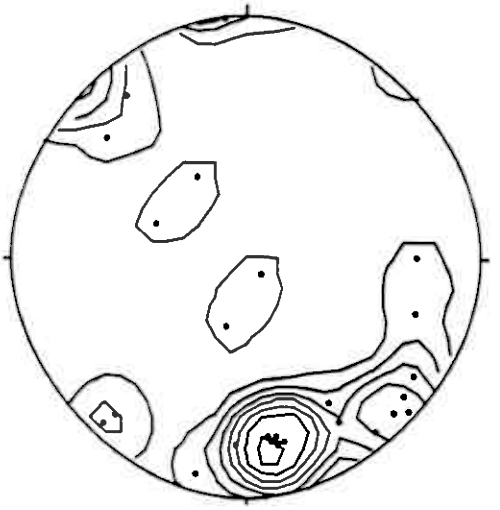
Bleka gruve - stolle B

A) Main vein



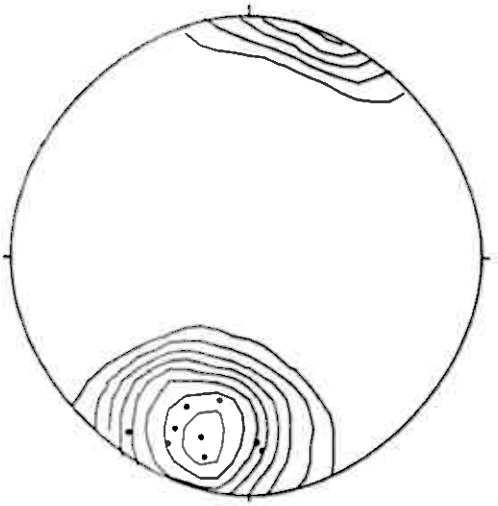
17 Data

B) Quartz-tou-ank



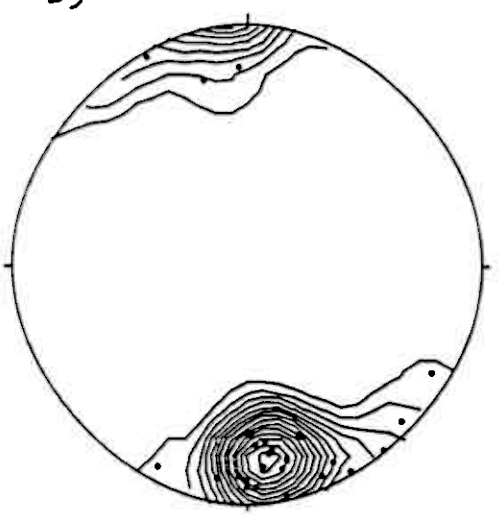
26 Data

C) Qz-calc-ank



9 data

D) Calcite

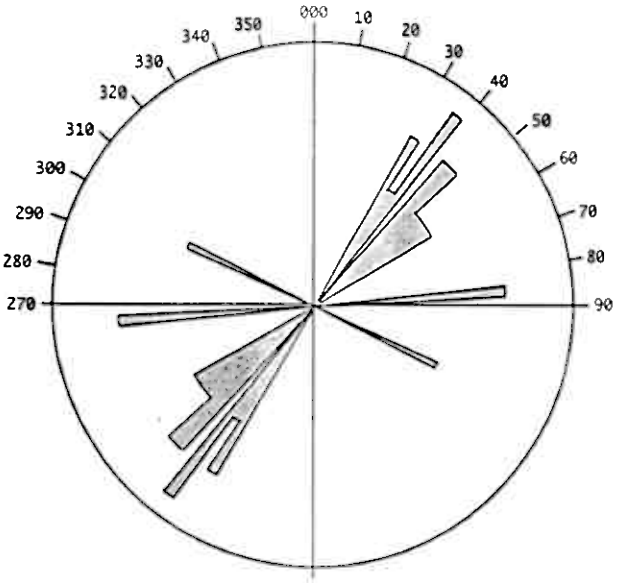


28 Data

Figure 31

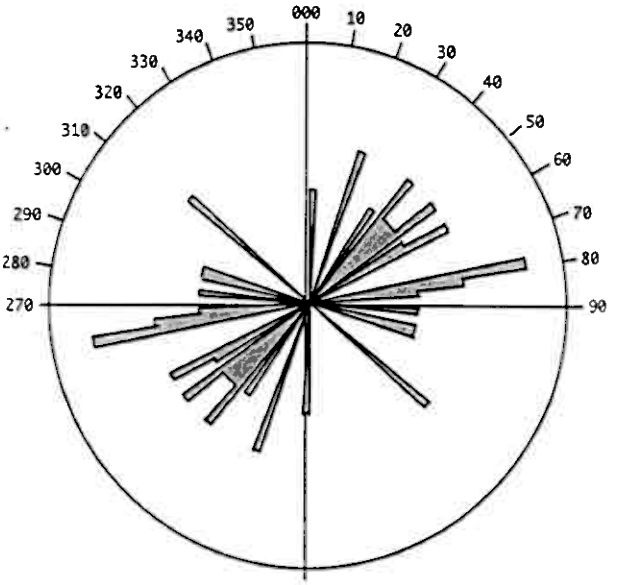
Bleka gruva-stolle B

A) Main vein
(qz-ank-tou)



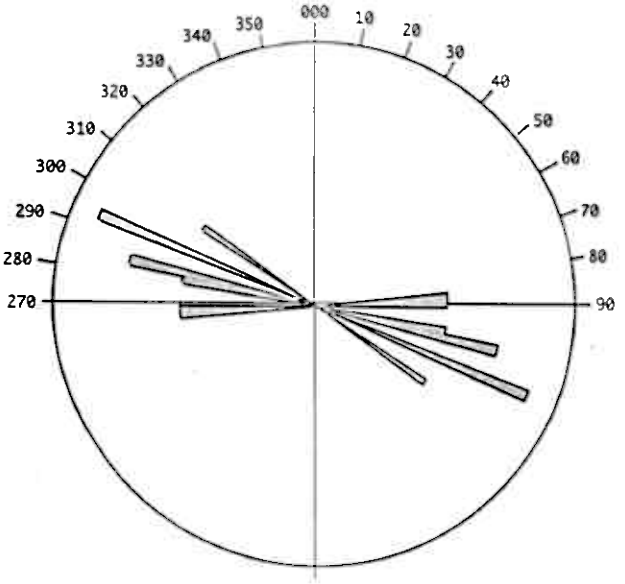
Values: 17 Interval: 3°
Radius: 20%

B) Quartz-tou-ank



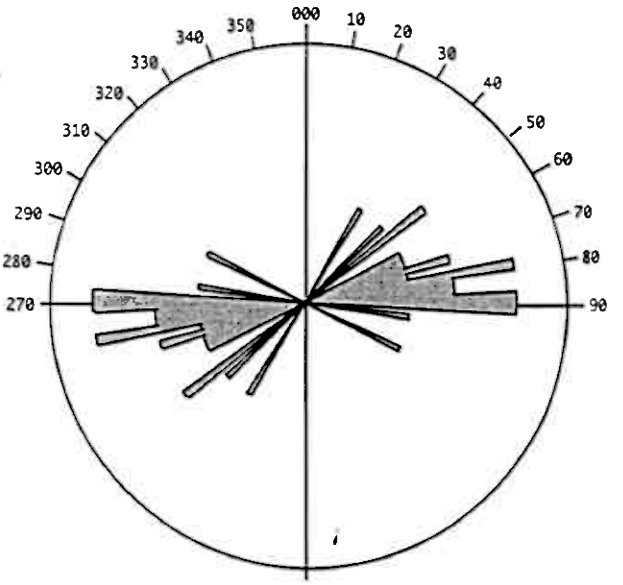
Values: 26 Interval: 3°
Radius: 20%

C) Quartz-calc-ank



Values: 9 Interval: 3°
Radius: 40%

D) Calcite



Values: 28 Interval: 3°
Radius: 20%

Figure 32

VII) Bleka gruve- stolle A

Area location: Above stolle B adit (Fig. 34)

Main vein systems: (Figs. 35-37)

- Main MINE (K-) veins: N49°E/67NW, N82°E/68NW
- Main quartz (K-) veins: N50°E/71NW, N86°W/68NE
- Quartz-tourmaline-ankerite veins: N42°E/68NW, N75°E/67NW
- Quartz-calcite veins: N77°E/71NE, N45°W/85NE

Results: (Fig. 38a-d)

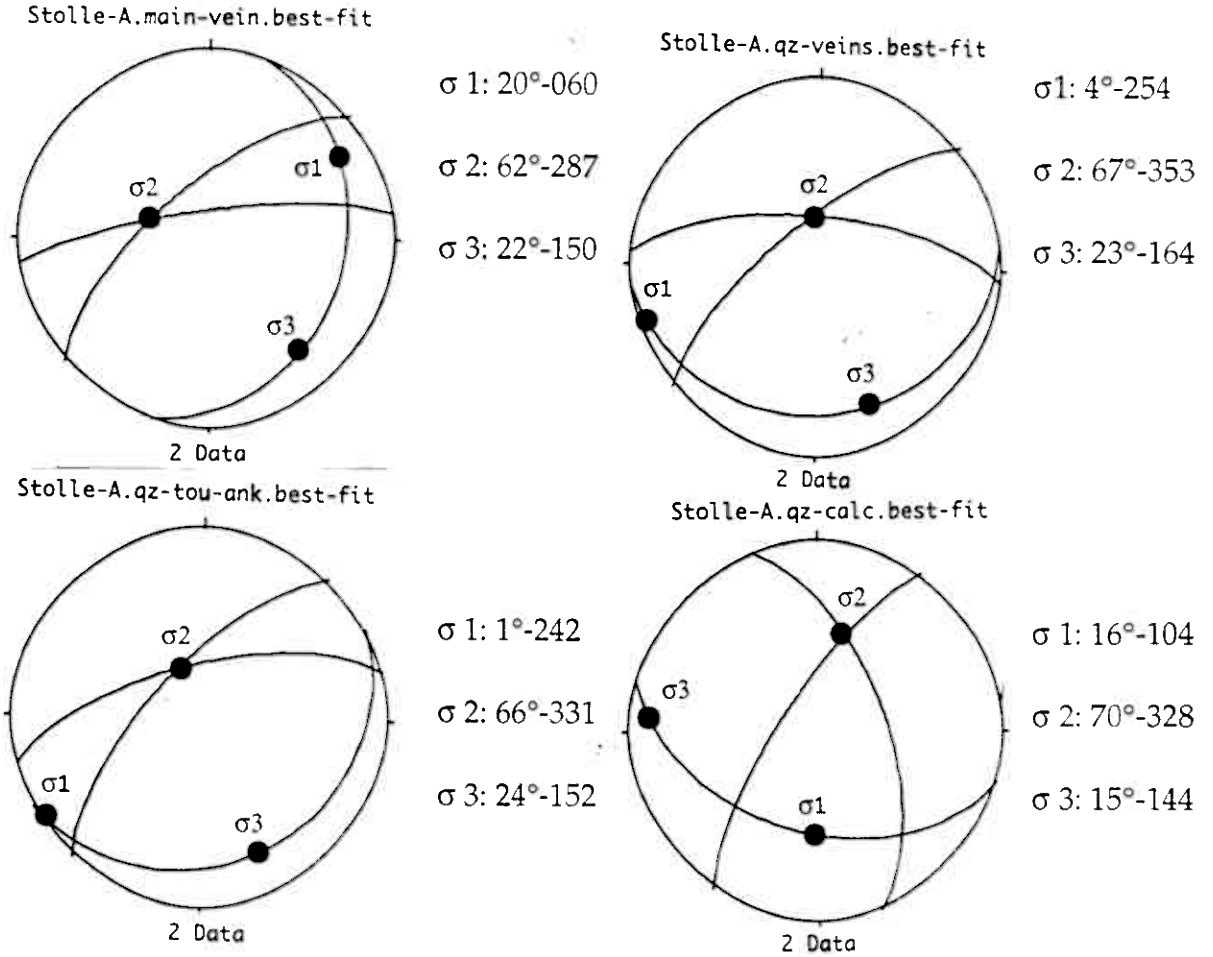


Figure 33: Best-fit planes for the vein systems in the Bleka Gruve- stolle A.

Relay zones:

Main-vein relay zone:	20° towards 060.
Quartz veins:	65° towards 355.
Quartz-tourmaline-ankerite:	65° towards 330
Quartz-calcite:	70° towards 330

Note the apparent change in stress direction between the quartz/quartz-tourmaline parageneses and the quartz-calcite veins. There has been a rotation of the main stress direction.

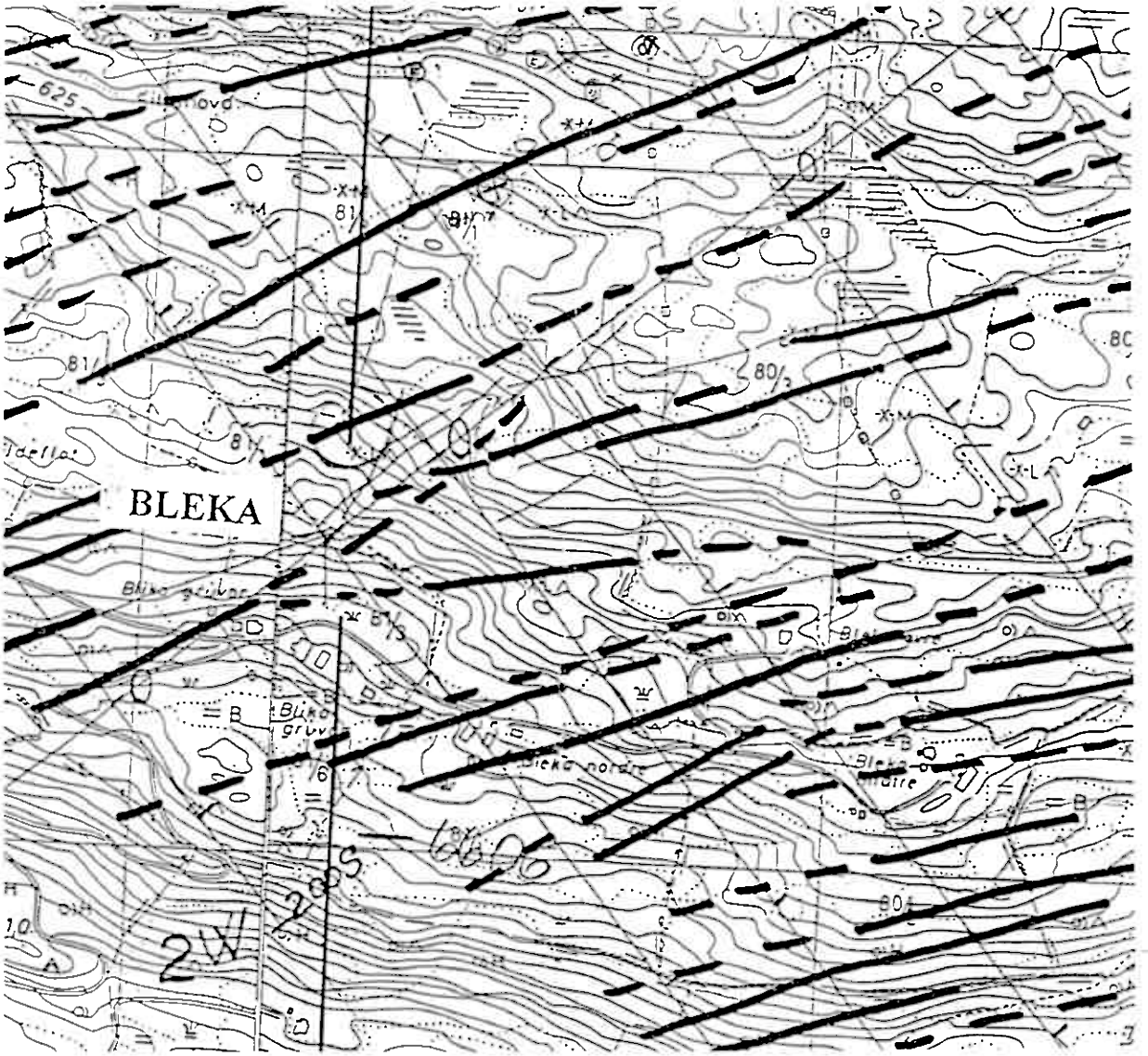
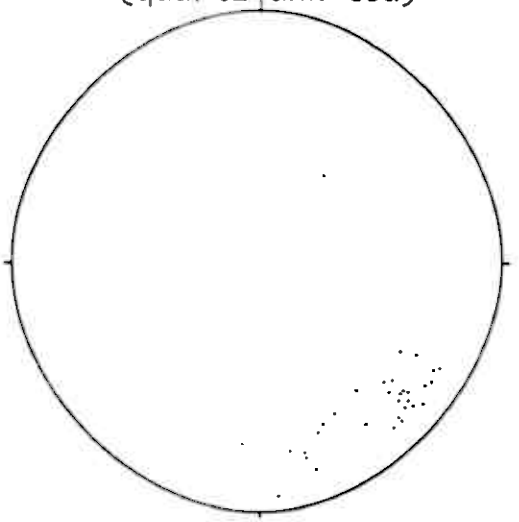


Figure 34. Map detail of the Bleka Gruve- stolle A area.

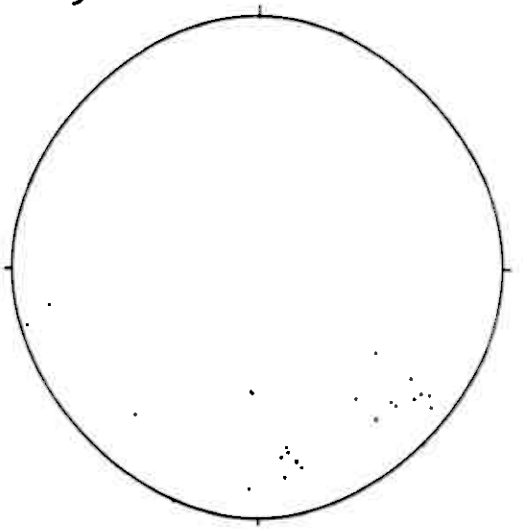
Bleka gruve - stolle A

A) Main vein (quartz-ank-tou)



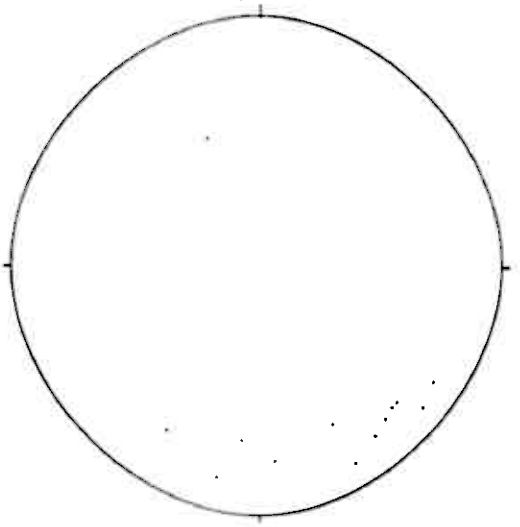
33 Data

B) Ankerite



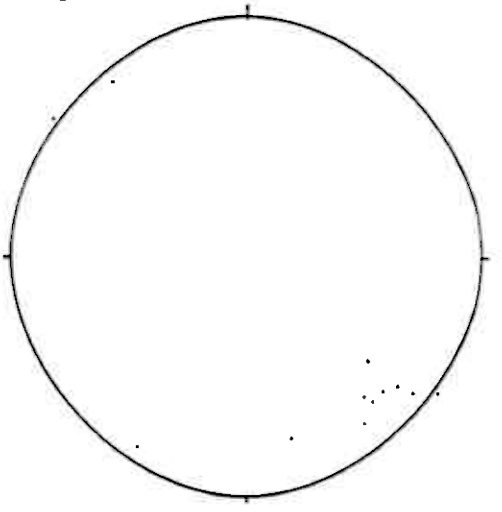
24 Data

C) Minor quartz-veins



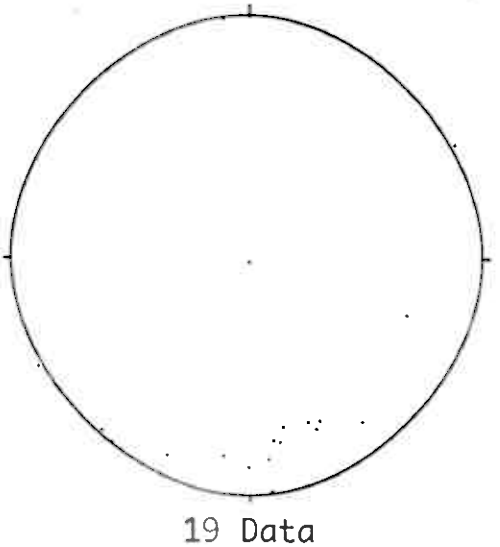
13 Data

D) Quartz-ankerite



11 Data

E) Calcite

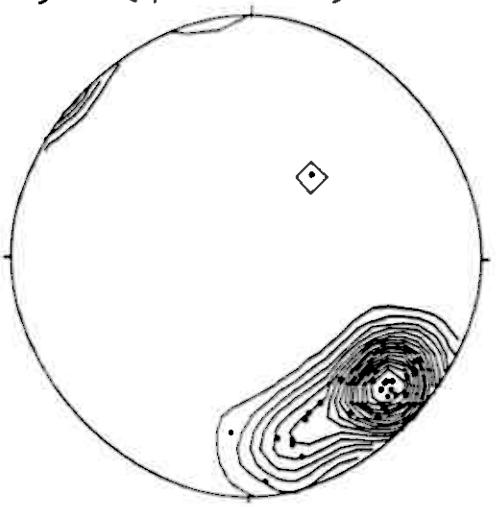


19 Data

Figure 35

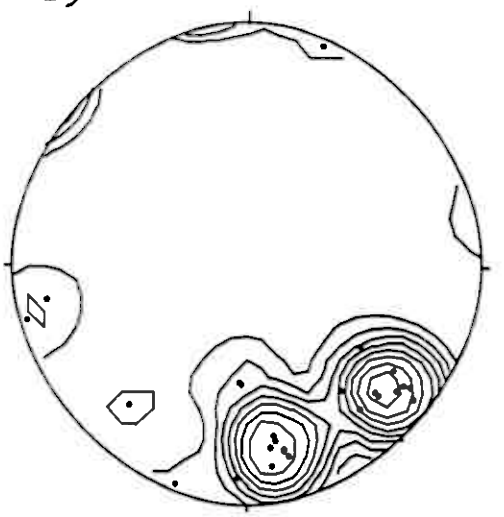
Bleka gruve - stolle A

A) Main vein (qz-ank-tou)



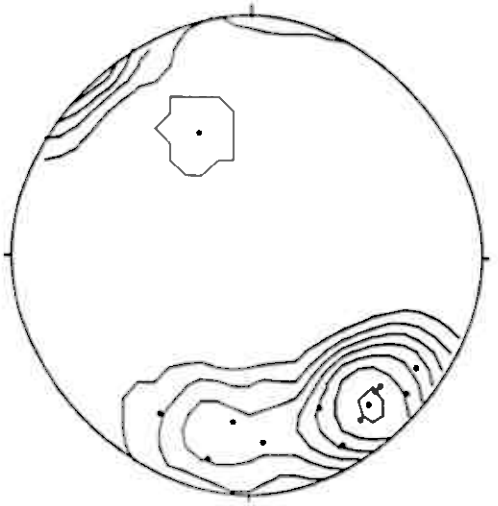
33 Data

B) Ankerite



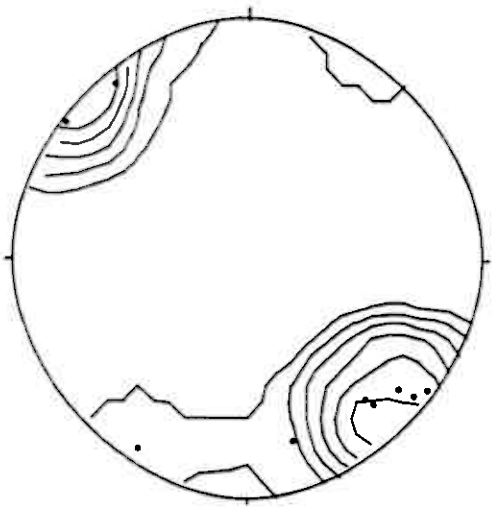
24 Data

C) Minor quartz-veins



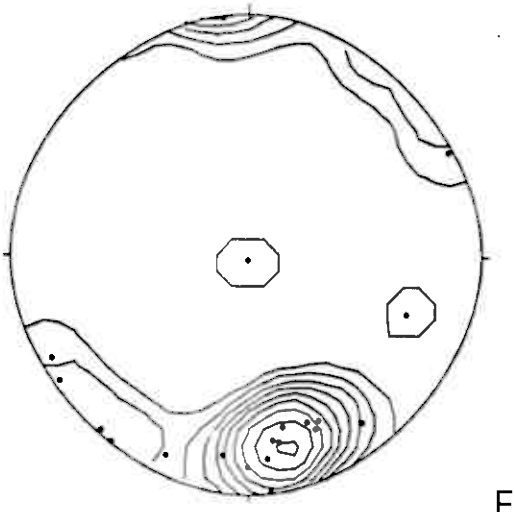
13 Data

D) Quartz-ankerite



8 Data

E) Calcite

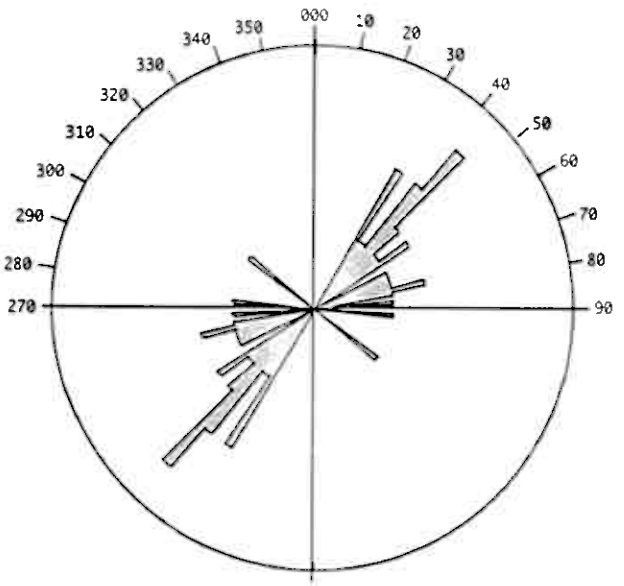


19 Data

Figure 36

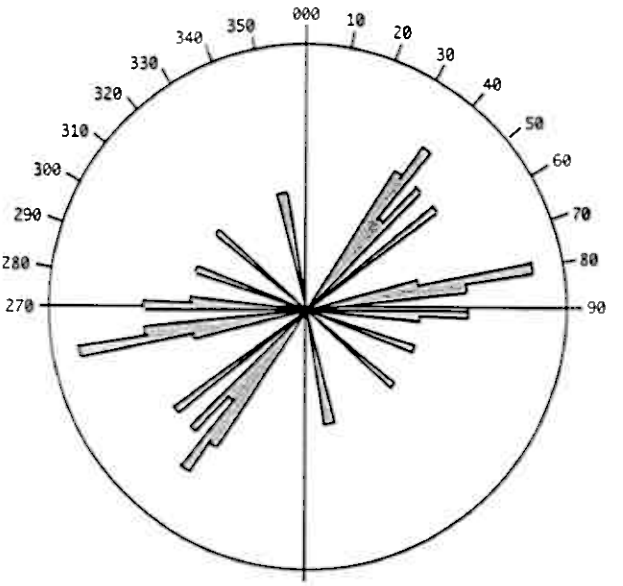
Bleka - stolle A

A) Main vein (qz-tou-ank)



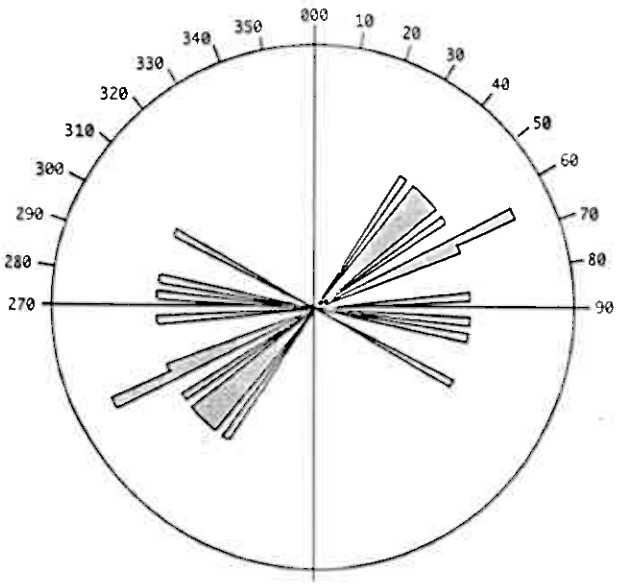
Values: 33 Interval: 3°
Radius: 30%

B) Ankerite



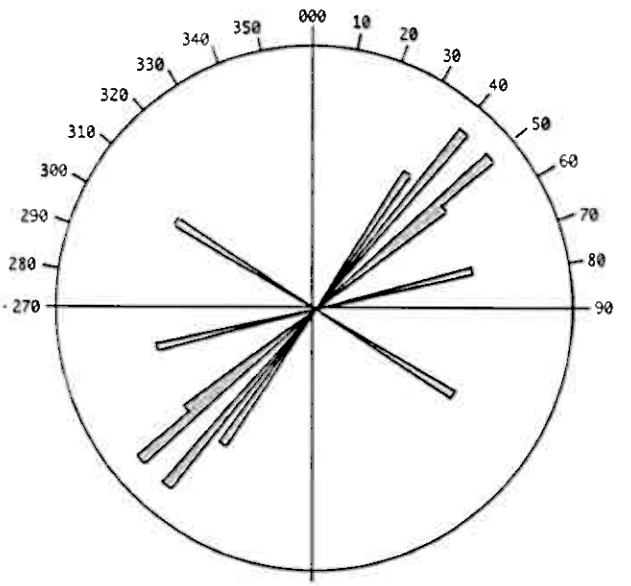
Values: 24 Interval: 3°
Radius: 20%

C) Minor quartz-veins



Values: 13 Interval: 3°
Radius: 20%

D) GrA.qz-ank.data

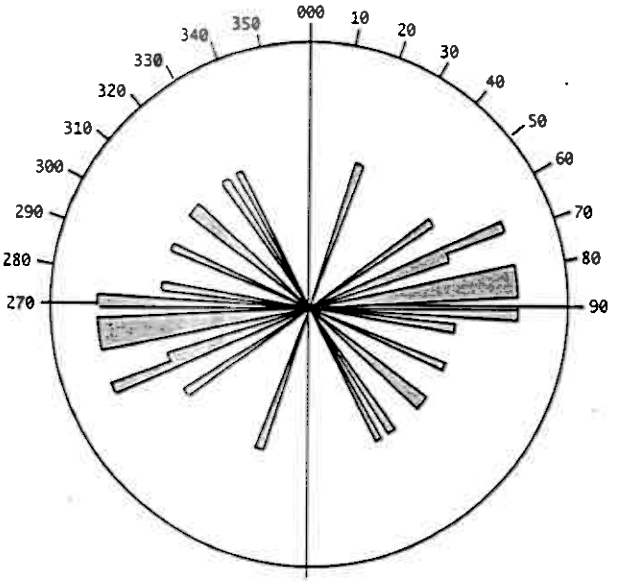


Values: 8 Interval: 3°
Radius: 30%

Figure 37

Bleka - stolle A

E) Calcite



Values: 19 Interval: 3°
Radius: 15%

Figure

VIII) Svervelid

Area location: 900S-10E/200N-4E (see Fig. 39)

Main vein systems: (Figs. 40-42)

- Main quartz (K-) veins: N30°W/69NE
  N59°W/79NE
- Quartz-tourmaline veins: N28°E/67NW
  N6°W/86NE
  N12°E/85SW
  N66°W/73Ne
- Quartz-ankerite: N86°E/75NW
  N3°W/85NE

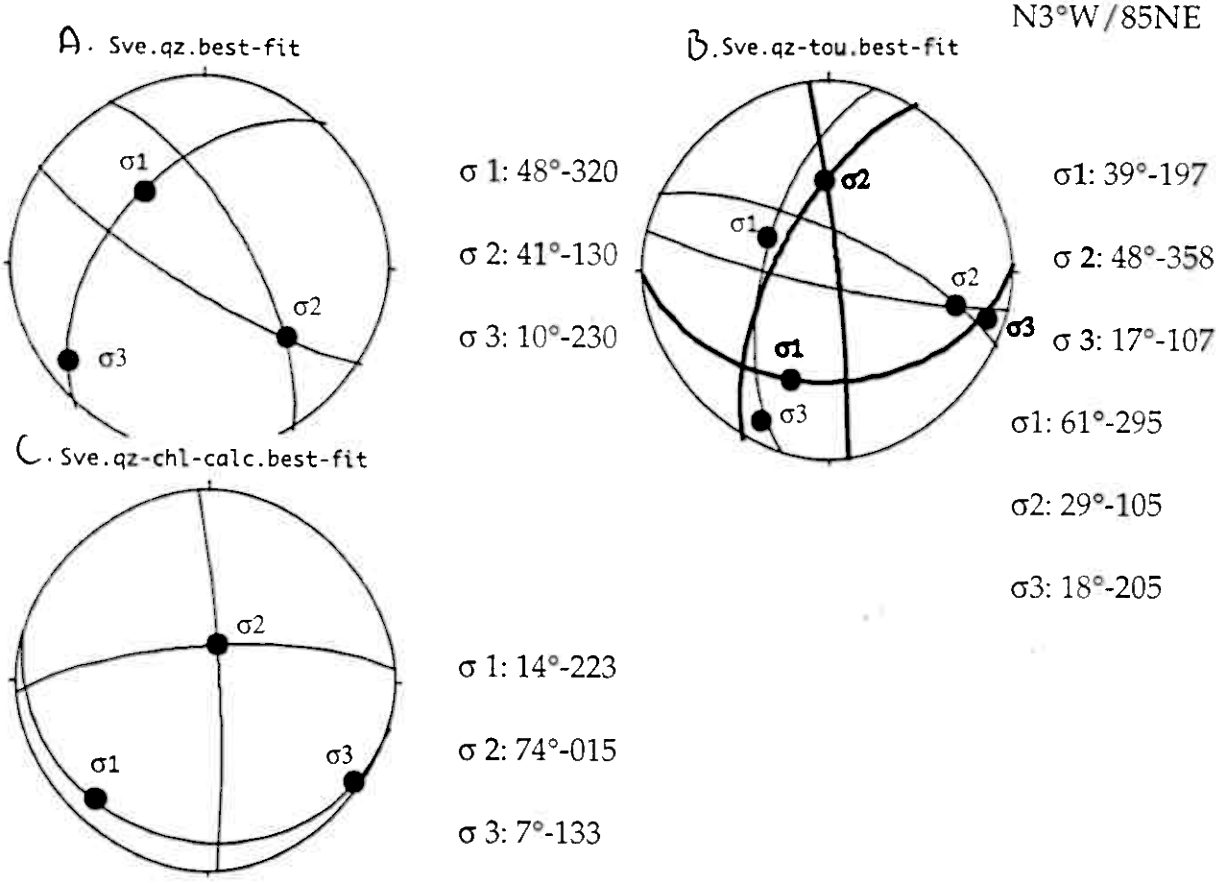


Figure 43. Note the the two perpendicular sets of quartz-tourmaline veins indicating changing stress-directions.

Relay zones:

Quartz relay zone: 40° towards 130.

Quartz-chlorite: 75° towards 015

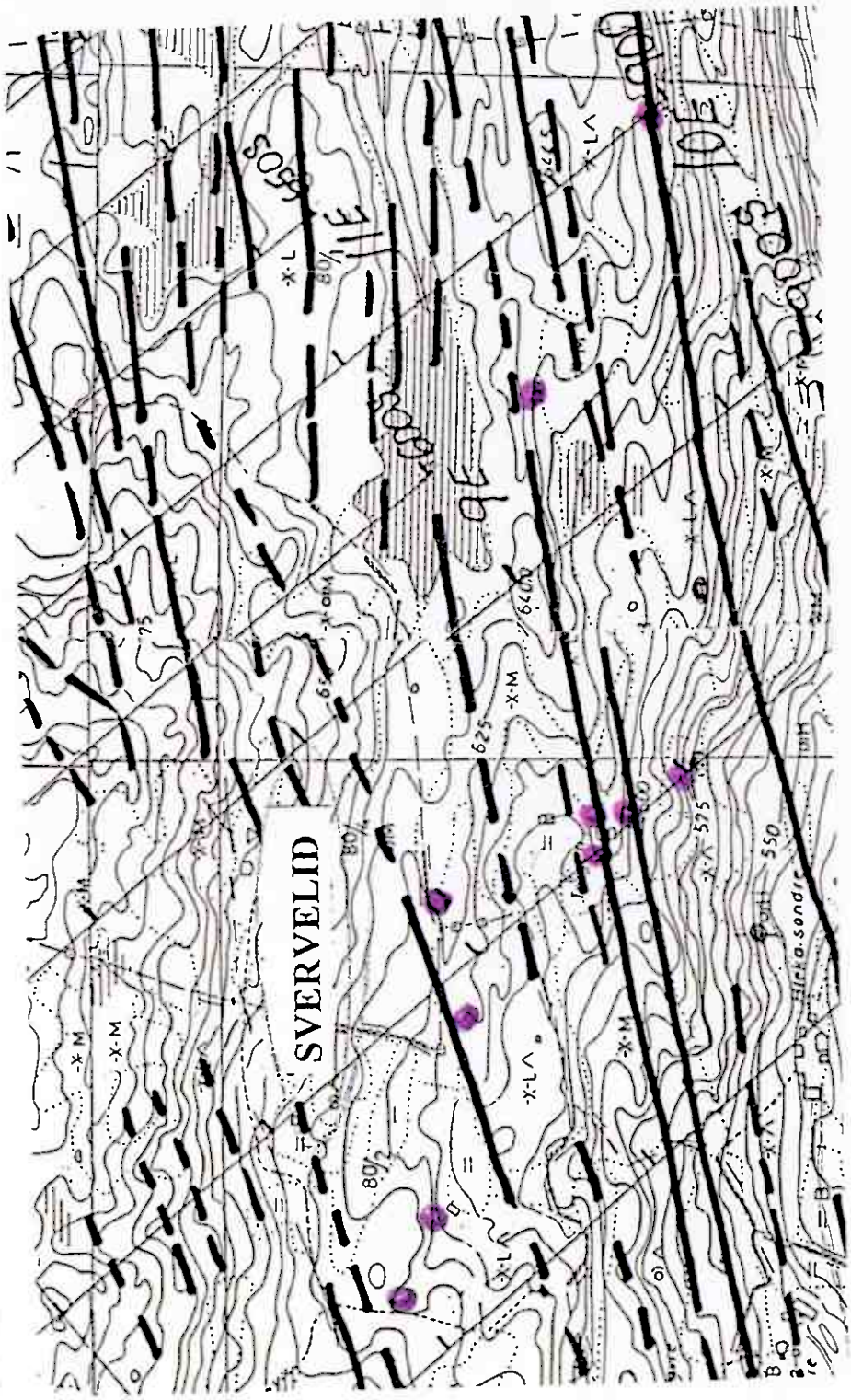


Figure 39. Map detail of the Svervelid area east of Bleka gruve.

Svervelid

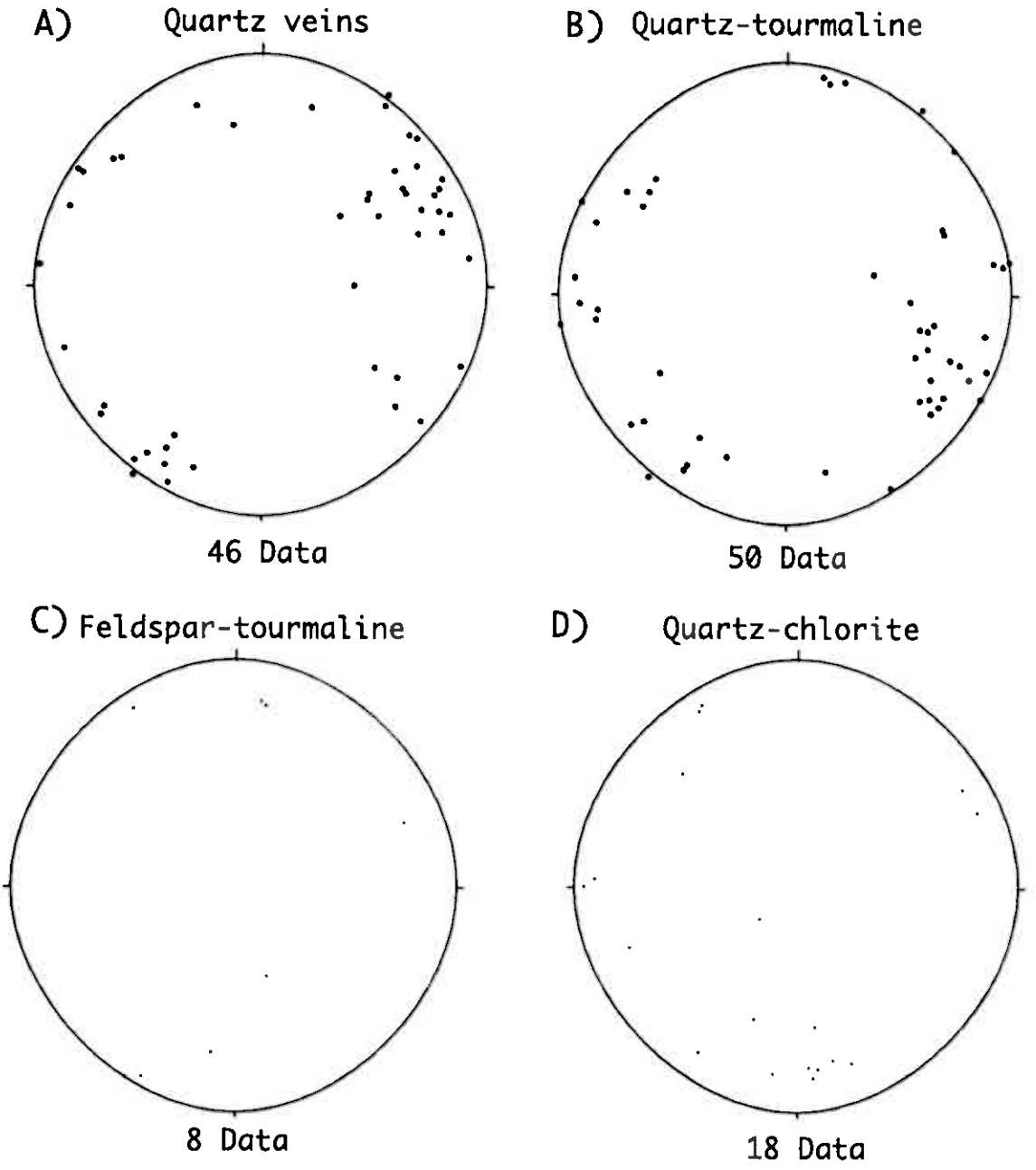
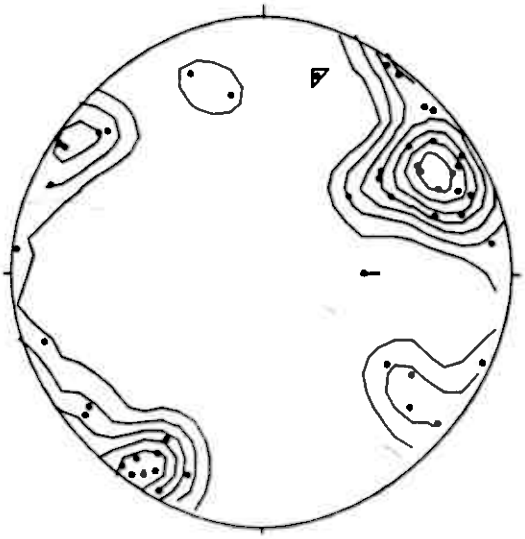


Figure 40

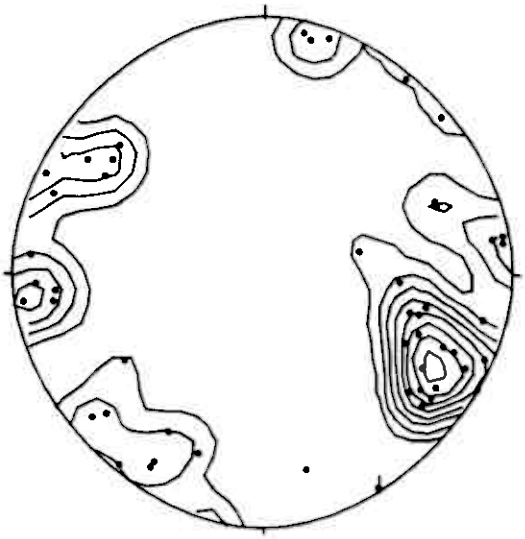
Svervelid

A) Quartz veins



46 Data

B) Quartz-tourmaline

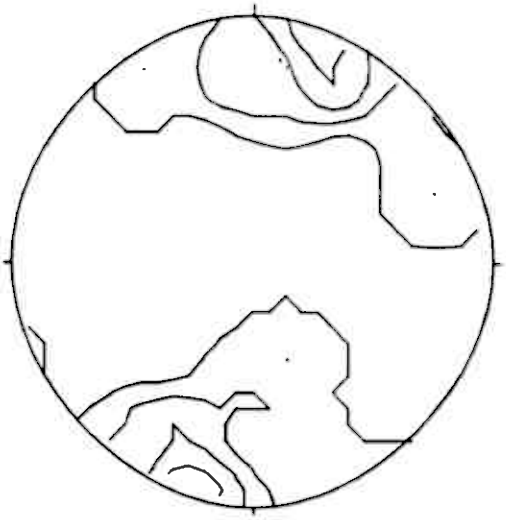


50 Data

C) Quartz-chlorite-calcite

18 Data

D) Feldspar-tourmaline

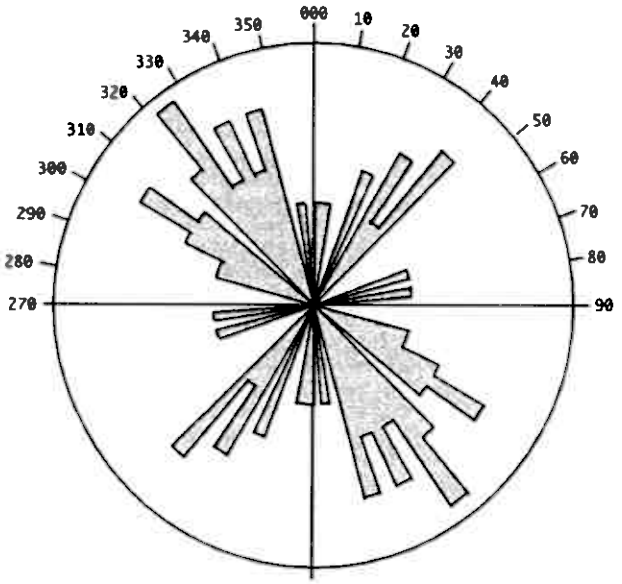


8 data

Figure 41

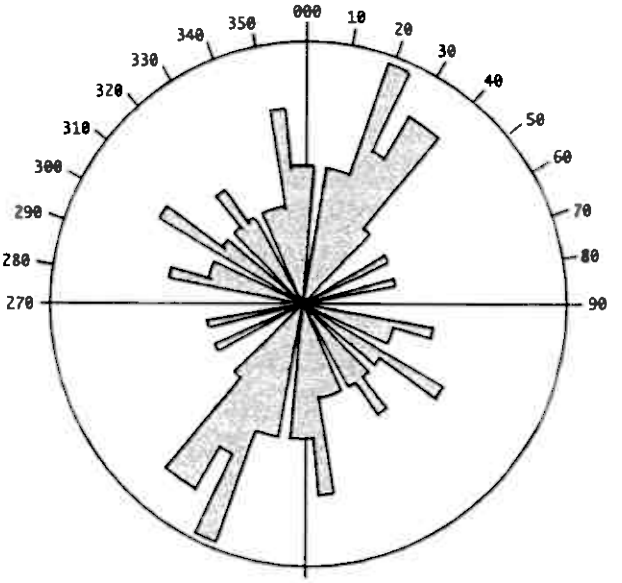
Svervelid

A) Quartz veins



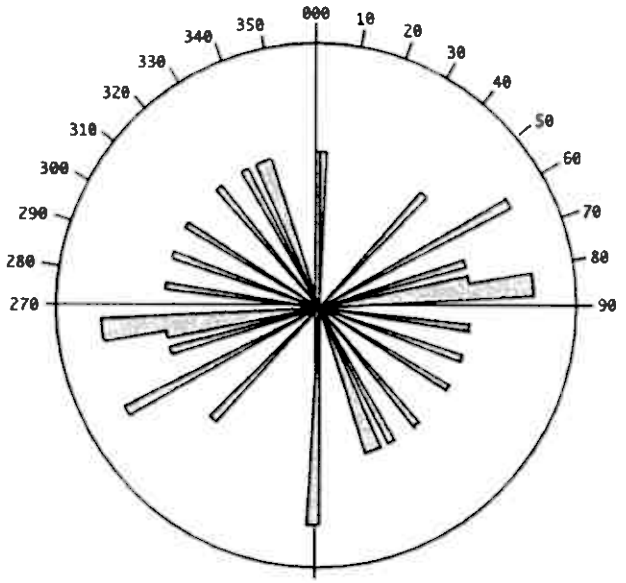
Values: 46 Interval: 8°
Radius: 10

B) Quartz-tourmaline



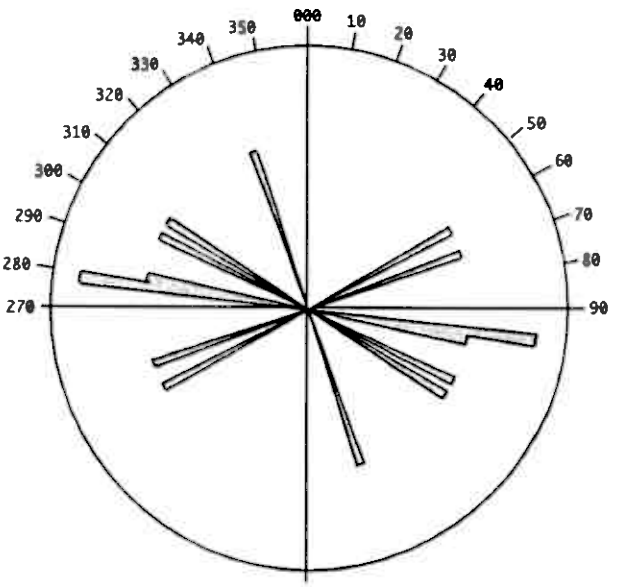
Values: 50 Interval: 8°
Radius: 10

C) Quartz-chlorite-calcite



Values: 18 Interval: 3°
Radius: 15%

D) Feldspar-tourmaline



Values: 8 Interval: 3°
Radius: 30%

Figure 42

Discussion

The structural data as well as the internal structures of the Bleka veins (quartz and otherwise) provide a record of both variable displacement and stress regimes during the development of the quartz vein system.

The quartz veins (including qz-tourmaline, qz-ankerite etc) display a variety of internal textures, from the thick, dry, buck quartz veins to the complex sheared and laminated quartz-tourmaline veins seen both in outcrops and within the mine adits. Many of these laminated (coarsely or finely) veins will be interbanded with dilational joints with massive white coarse-grained quartz. These are several examples where veins have started out with brecciating only to deform by brittle-ductile shearing. These hybrid veins are found in many relay zones in the Bleka area.

Several localities have produced good indications of changing stress directions during vein emplacement. There is evidence for a near 90° swing in the compression direction in a few places e.g. in Svervelid (page 42 Fig. 43b). Here two conjugate sets of quartz-tourmaline composition have a 90° difference in their $\sigma 1$ direction. In other localities there are evidence such as stylolites forming within the main quartz veins (see Fig 44 below)

Figure 44. Close up of main-vein at Komplikationsklippan showing formation of what appears to be stylolites within the vein system. This would suggest that there has been a change in the compression direction and what used to be $\sigma 3$ direction has changed to $\sigma 1$. There are also signs of shortened and buckled veins in this area.

At Komplicationsklippan (page 7 Fig. A & B), the direction of σ_1 appear to initially have rotated by 10-20° between the earlier higher T event and the later reactivational event. The Riedel shears appear to utilise/reactivate one set of the conjugate vein system and introducing a new set which cross-cuts the other conjugate sets by 10-15°. Locally this value may be higher.

In other areasit is also visible how the quartz veins are utilising previously existing systems e.g. Fig. 45 below.

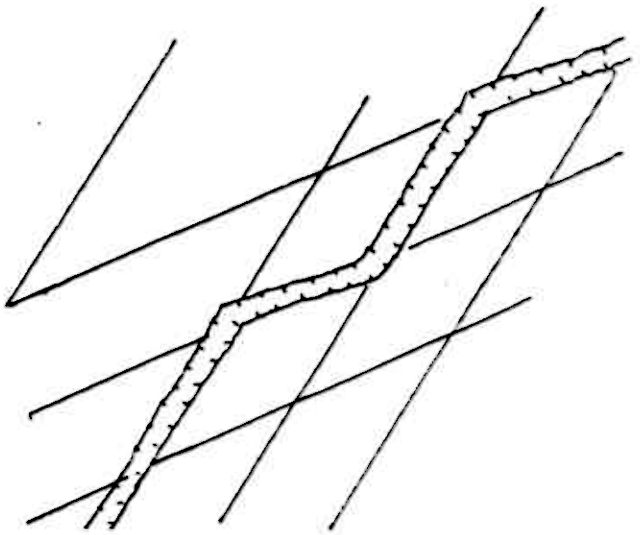


Figure 45. Here the quartz veins are intruding a conjugate set of tourmaline veins.

It is also visible in many localities the change between syntaxial intrusions i.e. the veins are dilating from the centre and the fluids react with the wall-rock once, and antitaxial where the veins break open continuously along the vein wall-rock contact and new fluids are introduced to the contact zone. continuously. These data are important to the understanding of the sytem and the mineralisations and should be studied more.