P-06-100

Oskarshamn site investigation

The magnetic anisotropy of rocks across two major deformation zones in the Laxemar and Simpevarp area

Håkan Mattsson, GeoVista AB

March 2006

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author and do not necessarily coincide with those of the client.

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Abstract

This report presents the compilation and interpretation of AMS (Anisotropy of Magnetic Susceptibility) data from rock samples collected along two profiles across two major deformation zones; the Äspö shear zone and a large deformation zone in the Simpevarp peninsula.

Deformation zones and their properties are important during the planning and construction of a deep repository for high level radioactive waste. One reason for this is that deformation zones constitute possible zones of weakness in the rock volume, and it is therefore important to find a tool for estimating how far from the deformation zone the rock has been affected by the deformation.

The major aim of this study was to test how far from the zone boundaries it is possible to identify variations in the magnetic properties related to the deformation processes. One important question is: Is it possible to estimate the width of the transition zone of altered rocks outside of the deformation zone center?

The AMS data from the profile across the Äspö shear zone indicate that the dominant ductile deformation of the shear zone was low grade and gave rise to a sinistral sense of movement. Further, the AMS data indicate rotated foliations and variations in the dip of the foliation planes well outside of the shear zone center boundary, in rocks without clear visible signs of ductile deformation. These AMS data indicate the existence of a c. 250 m wide transition zone. The width of the transition zone is similar as the width of the deformation zone it self (c. 300 m at the investigated section).

The interpretation of the AMS data from the southern profile indicates no clear evidence for the existence of a major deformation zone in the bedrock across the Simpevarp peninsula.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av AMS-data (magnetisk susceptibilitetsanisotropi) på bergartsprover insamlade längs två profiler över två större deformationszoner; Äspö skjuvzon och en deformationszon på Simpevarpshalvön.

Inför planering och byggande av ett lager för högaktivt använt kärnbränsle är det viktigt att få ökad kunskap om deformationszoner och deras egenskaper. En orsak är att deformationszoner utgör potentiella svaghetsplan i berggrunden, och därför är det viktigt kunna uppskatta hur långt utanför en deformationszon som berget är påverkat av deformationen.

Huvudmålet med denna studie var att undersöka hur långt utanför en större deformationszon det är möjligt att identifiera variationer i bergets magnetiska egenskaper kopplade till deformationen. En viktig fråga att ställa sig är: Hur bred är övergångszonen med påverkat berg som finns utanför zonens centrum?

AMS-data från profilen över Äspö skjuvzon indikerar att den dominerande deformationen var relativt låggradig och gav upphov till en sinistral rörelse längs zonen. AMS-data indikerar vidare att den magnetiska foliationen roterat moturs, samt ökar i stupning, i ett ca. 250 m brett område utanför den gräns som definierar själva deformationszonen. Bredden på övergångszonen (ca. 250 m) är likvärdig med bredden på deformationszonen i sig (ca. 300 m).

Tolkningen av AMS-data från södra profilen tyder på att det där inte finns någon större deformationszon i berggrunden på Simpevarpshalvön.

Contents

1 Introduction

SKB performs site investigations for localization of a deep repository for high level radioactive waste. The site investigations are performed at two sites, Forsmark and Oskarshamn. This document reports the results gained from the interpretation of measurements of the anisotropy of magnetic susceptibility (AMS) of rocks in two profiles across two domains classified as major deformation zones. The deformation zones are located in Laxemar and at the Simpevarp peninsula, Oskarshamn.

The anisotropy of magnetic susceptibility (AMS) is related to mineral grain shape and crystallographic properties of rocks. The measurements will thus indicate variations in the ductile deformation properties of rocks across the deformation zones. Core samples were collected along two c. east-west oriented profiles across the deformation zones. All individual samples were oriented with reference to the geographical co-ordinate system by use of magnetic and sun compasses. The field work was performed in the autumn 2005 by Håkan Mattsson, GeoVista AB, in cooperation with Torbjörn Bergman, geologist at the Geological Survey of Sweden (SGU). The AMS measurements were performed at the petrophysical laboratory, Luleå University of Technology, and the interpretations were performed by Håkan Mattsson, GeoVista AB.

The interpretation presented in this report is performed by GeoVista AB in accordance with the instructions and guidelines from SKB (activity plan AP PS 400-05-067 and method description MD 230.001, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of the sampling locations, all indicated by their individual identity code. The AMS data and interpreted results are stored in the primary data base SICADA and are traceable by the activity plan number.

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	Number	Version
Insamling av orienterade bergartsprover och mätning av magnetisk susceptibilitetsanisotropi över Äspö skjuvzon.	AP PS 400-05-067	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för mätning av bergartes petrofysiska egenskaper.	SKB MD 230.001	2.0

Figure 1-1. *Locations of the sampling sites (red dot) and their identity code respectively.*

2 Objective and scope

Deformation zones and their properties are important during the planning and construction of a deep repository for high level radioactive waste. One reason for this is that deformation zones constitute possible zones of weakness in the rock volume. SKB defines a deformation zone (ductile as well as brittle) by a central core of heavily deformed rock, and an outer transition zone with a lower degree of deformation /1/ (Figure 2-1). The degree of deformation decreases perpendicularly away from the core boundary. Beyond the transition zone there is fresh rock. The width of the transition zone is important for the design of the deep repository, since this width is one of the parameters that, determines how close to the deformation zone it is possible to put the canisters containing the radioactive waste. Thus, it is important to be able to estimate how far from the core of the deformation zone the rock has been affected by the deformation processes.

Deformation zones are generally divided into brittle and ductile zones, and also a combination of these, such as brittle-ductile (mainly brittle) and ductile-brittle (mainly ductile). The scope of this investigation is to use the magnetic susceptibility and its anisotropy as a tool for estimating variations in the ductile deformation properties of the rocks along two profiles across two rock domains classified as large deformation zones. Up to now the geometries of these zones are mainly based on geological field mapping and airborne geophysical data.

The major aim is to test how far from the zone boundaries it is possible to identify variations in the magnetic properties related to the deformation processes. AMS is very sensitive even to weak ductile deformation and may detect rock deformation not visible by the eye.

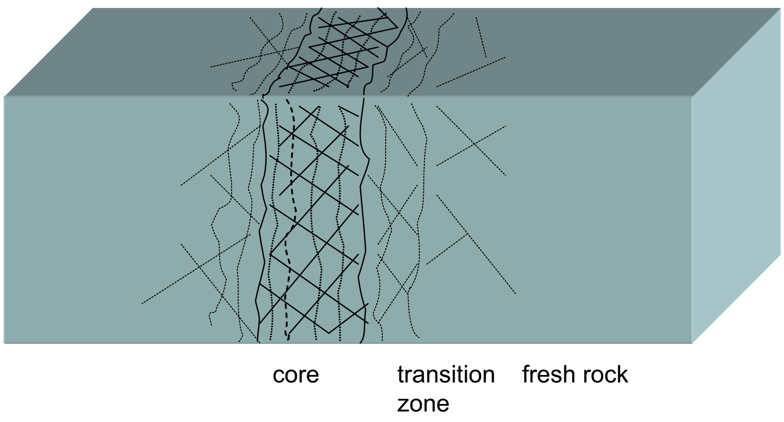

Figure 2-1. *Principle sketch of the SKB definition of a deformation zone (modified after Munier et al. /1/).*

3 Equipment

3.1 Description of equipment for analyses of AMS data

The software used for the interpretation are Anisoft (AGICO Inc.) used for analyses of anisotropy data, Grapher v5 (Golden Software) and MapInfo v.7.0 (MapInfo Corporation), mainly used for plotting and some statistical analyses.

4 Geology

A general description of the geological setting of the entire site investigation area is presented in the report describing the geological bedrock mapping program /2/. All sampling locations were geologically characterized by geologist Torbjörn Bergman (see the text beneath the stereogram figures in Appendix 1).

4.1 Geological decription of the northern profile

The northern profile of sampling sites (id-codes PSM007585–PSM007605, Figure 4-1) transverses an area dominated by Ävrö granite, and crosscuts a major deformation zone, generally is referred to as "Äspö shear zone". Äspö shear zone is not one single deformation zone. It defines rather a belt with a high concentration of low-grade ductile to brittle-ductile shear zones and an increased fracturing and red staining. The rock type at all sampling locations, except for the single locality PSM007597, is classified as Ävrö granite; mainly with a granitic to granodioritic composition. The rock type at PSM007597 is classified as a brittle-ductile mylonite with strong foliation oriented at c. 040°/85°. This mylonite is located within the Äspö shear zone, close to its western boundary.

__Figure 4-1.__ Sampling locations plotted on the geological map from the feasibility study of Oskarshamn /3/. Dark pink = Ävrö granite, light pink = quartz monzodiorite. The boundaries of the domains classified as deformation zones are indicated with blue lines.

All sampling locations located west of the mylonite at the locality PSM007597, PSM007585–PSM007596, are situated in a rock domain of supposedly fresh and not deformed Ävrö granite. At the sites PSM007585–PSM7594 there are no visual indications in the outcrops of ductile deformation, increased fracturing or alteration. However, the rocks of the two sites PSM007595 and PSM007596, that are located outside of the deformation zone, but closest to the mylonite, show increased fracturing and red staining. There is also a weak foliation at PSM007596 oriented at c. 070°/85°. The two sampling locations are located close to a fracture zone oriented at c. N070°E, which most likely indicates a younger reactivation of the Äspö shear zone. It is possible that the red staining is a result of the brittle deformation indicated by the fracture zone. However, it is important to note that the weak foliation indicated in the outcrop (sub-parallel to the plane of the fracture zone) deviates from the orientation of the magnetic foliation (see Appendix 1, picture "7596FOL").

In all outcrops sampled within the deformation zone domain (PSM007597–PSM007602) the rocks show red staining and increased fracturing. The fractures are generally sealed with epidote. At two locations (PSM007599 and PSM007601) a weak foliation is also noted. The orientation of the foliation is 070°/75° (PSM007599) and 068°/90° (PSM007601).

To the east of the deformation zone samples were collected at three outcrops, PSM007603, PSM007604 and PSM007605. There are no indications of ductile deformation in these outcrops, but there is red staining of the rock at the sites PSM007603 and PSM007605.

4.2 Geological decription of the southern profile

The bedrock geology along the southern profile (id-codes PSM007606–PSM007617, Figure 4-1) is more heterogenic compared to the northern profile. The rock at the site PSM007606 is Ävrö granite with a foliation oriented c. 086°/90° and with red staining. At PSM007607 there is a ductile mylonite with strong foliation in c. 054°/80°. The rock at PSM007608 is granite to granodiorite, most likely Ävrö granite, without any signs of ductile deformation or alteration. The following sampling site, PSM007609, is a mylonite with a ductile deformation foliation oriented at c. 256°/70°. The sites PSM007610, PSM007611 and PSM007612 (foliation at c. 060°/85°) comprise quartz monzodiorite . At the remaining five site locations, PSM007613–PSM007617, the rock is classified as fine-grained dioritoid without any signs of ductile deformation. However, dark color in combination with the fine grain size of this rock type makes structural features difficult to identify in outcrop scale. The sites PSM007616 and PSM007617 are both located fairly close to distinct topographic lineaments.

The geological heterogeneity of the southern profile makes the interpretations of the AMS data, and also structural geological analyses, much more difficult to perform than if there would have been only one single rock type. Different rock types vary in competence, and will thus have responded differently to the affecting deformation processes. Different rock types also have different magnetic mineralogy, which may affect the results of the AMS measurements significantly; especially regarding the degree of anisotropy and the shape of the anisotropy ellipsoids.

5 Execution

5.1 Collection of samples

Two drill cores were collected at each sampling location, Figure 5-1. Each drill core is c. 8 cm long with a diameter of 25 mm. The strike and dip direction of each core was measured using the technique from traditional paleomagnetic sampling. The co-ordinates in the RT90 system were collected with a portable GPS instrument. All data were stored in a field diary.

Each sampling location was given a site code “PSM00XXXX” (id-code) followed by a rock type number (rock_no). The rock type number is followed by a specimen number (s_code), which separates the different drill cores (samples) selected at each sample location.

The selection of sampling locations was performed in co-operation with the geologist Carl-Henric Wahlgren (Geological Survey of Sweden) and the sampling was performed in co-operation with the geologist Torbjörn Bergman (Geological Survey of Sweden).

a)

b)

Figure 5-1. *a) Petrophysical sampling by use of water cooled drill machine. b) Orientation of drill core by use of sun compass.*

5.2 Measurements and data handling

Preparations of the drill cores were performed by a technician at the laboratory of the Division of Applied Geophysics, Luleå University of Technology, according to the standard techniques used for example, in the preparation of samples for paleomagnetic analyses. Sun-strike directions of the drill cores were calculated at GeoVista AB by use of the DOS-software "sun.exe" (in-house software, Luleå University of Technology) and all orientation information was stored in a Microsoft Excel file.

Three 22 mm long specimens were cut off from each drill core, thus totally six specimens for each sampling location. AMS measurements were performed on all six specimens, and the results were stored in data files sorted with reference to each sampling location.

5.3 Analyses and interpretations

The magnetic anisotropy of rock forming minerals basically originates from two sources, the grain shape and the crystallographic structure /4/. Magnetite is ferrimagnetic and carries strong shape anisotropy, whereas pyrrhotite and hematite are governed by crystalline anisotropy due to their antiferromagnetic origin. Paramagnetic minerals (e.g. biotite, hornblende) and diamagnetic minerals (e.g. quartz, feldspars) are also carriers of magnetocrystalline anisotropy. The orientation of the anisotropy of magnetic susceptibility coincides with the crystallographic axes for most rock forming minerals, so it is therefore possible to directly transfer "magnetic directions" to "tectonic directions" (foliation and lineation) measured in the field. Since magnetite carries a very high magnetic susceptibility in comparison to most other rock forming minerals, only a small portion present in a rock tends to dominate the magnetic properties, including the anisotropy. However, for example for "non-magnetic" granites the magnetic anisotropy is mainly governed by biotite and other paramagnetic minerals.

The AMS measurements were performed on six specimens per rock object (site), which produced six data readings per object. The six measurements allow a calculation of mean directions of the principal AMS axes (site mean directions) and corresponding "site mean values" of the degree of anisotropy (P), degree of lineation (L), degree of foliation (F) and ellipsoid shape (T). When calculating the site mean values of the anisotropy parameters, the orientation of the principal anisotropy directions of each specimen is taken into account. Vector addition is applied to the three susceptibility axes of the six specimens from the site, which results in a "site mean ellipsoid". The site mean values of the anisotropy parameters thus give information of the site as a whole and are not just "simple" average values. According to statistical demands at least six measurements (specimens) are required for estimating uncertainty regions (95% confidence ellipses of the mean) of the calculated mean directions. The uncertainty regions indicate how well the mean direction is determined statistically.

5.4 Nonconformities

No nonconformities are reported.

6 Results

6.1 Northern profile – Äspö shear zone

6.1.1 AMS parameters

In Figure 6-1 the magnetic susceptibility is plotted versus the easting co-ordinate of each sampling location respectively. The average magnetic susceptibility of fresh Ävrö granite, which is c. $1,660 \times 10^{-5}$ SI /5/, is indicated by a full drawn horizontal line in the diagram. Outside of the deformation zone a majority of the data point plot above the average susceptibility, and within the zone the result is vice versa. This indicates that the deformation has led to a destruction or alteration of magnetite, and it explains why the zone comes out as a distinct low magnetic region in the helicopter borne magnetic data. Looking at the distribution of the data, it appears as if the magnetic susceptibility slowly decreases, when approaching the western boundary from the west, starting at c. 1,549,700 m. However, the indicated decrease is hardly significant since there is a fairly wide distribution of the volume susceptibility.

The degree of magnetic anisotropy (P) can under certain conditions be used as an indicator of the degree of rock deformation. However, one important requirement is that the magnetic mineralogy must not be altered, and this is unfortunately the case for the rocks in this investigation. A test shows that there is a linear relation between the degree of anisotropy and the logarithm of the volume susceptibility. An attempt to correct for this linear dependent of "P" is presented in Figure 6-2, which displays the P-parameter normalized with reference to the logarithm of the volume susceptibility, and plotted with reference to the easting co-ordinate of the sample locations.

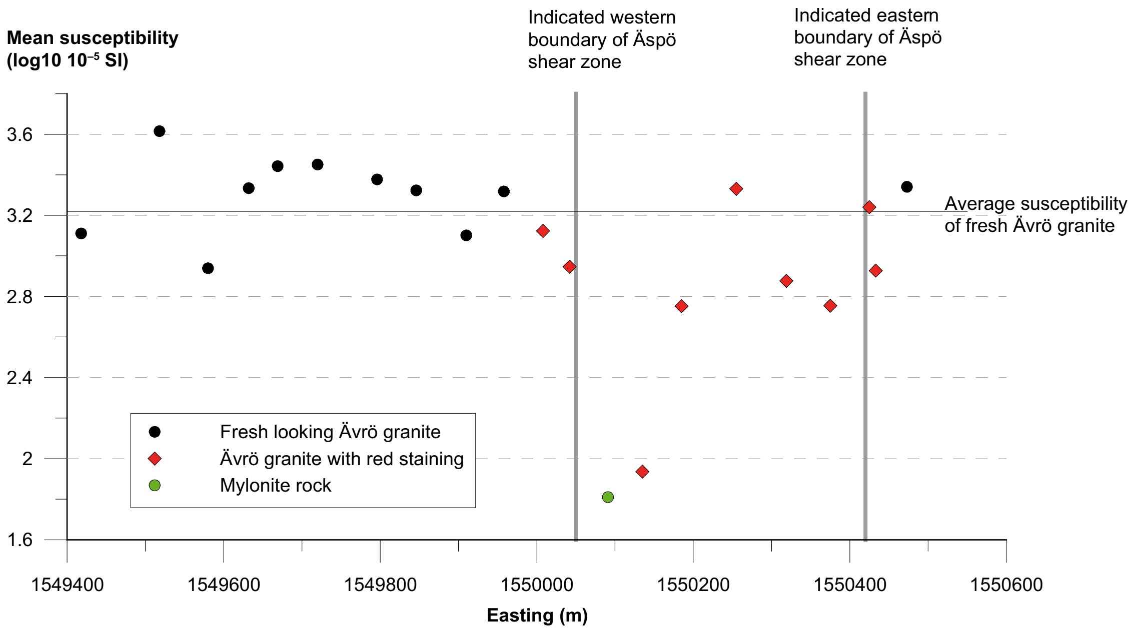

Figure 6-1. *Magnetic susceptibility (site mean values) along the northern profile. The data are plotted with reference to the easting co-ordinate of each sample location respectively.*

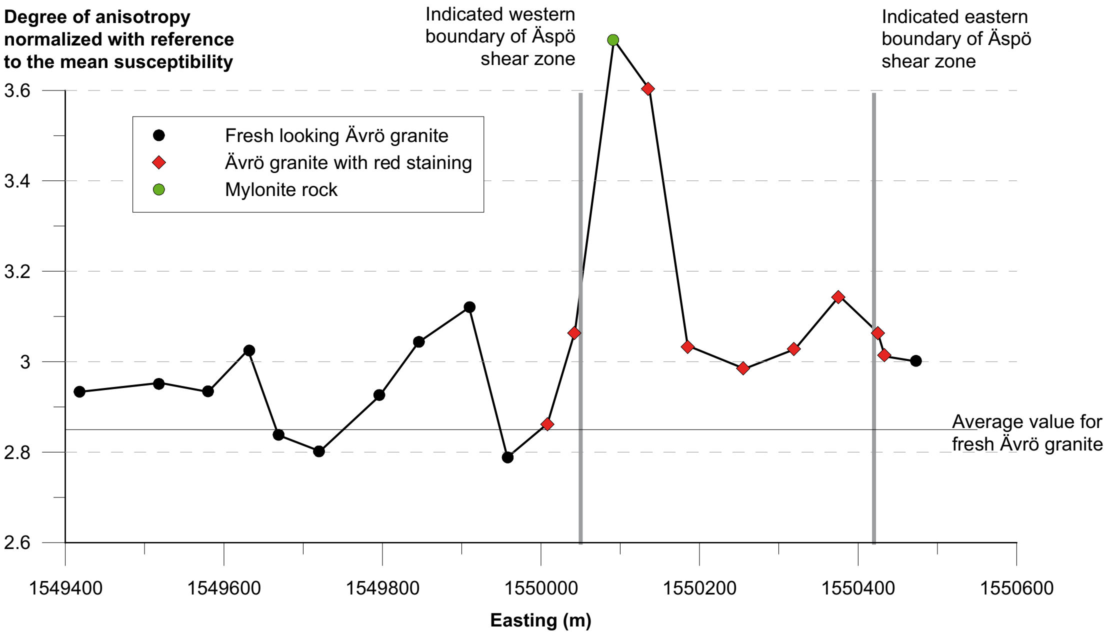

Figure 6-2. *Degree of magnetic anisotropy normalized with the mean susceptibility (site mean values) along the northern profile. The data are plotted with reference to the easting co-ordinate of each sample location respectively.*

The horizontal line in Figure 6-2 shows the average value for fresh Ävrö granite. For a majority of the sample locations the "corrected" degree of anisotropy plots above the average value for fresh Ävrö granite. At two locations within the deformation zone (a mylonite and the location closest to the east of the mylonite) there are significant peaks in the "corrected" degree of anisotropy. The peaks are mainly caused by the low magnetic susceptibility of the rocks at these two locations (see Figure 6-1). The normalized degree of anisotropy is slightly higher within the deformation zone as compared to outside of the zone boundaries, but the difference is not statistically significant.

The degree of foliation (Figure 6-3) indicates variations in the flattening of the ellipsoid shape. The foliation variations along the northern profile show a clear anomaly when crossing the deformation zone. The anomaly starts (going from west to east) c. 100–150 m west of the western boundary of the Äspö shear zone, which indicates that the deformation has affected rocks without visual signs of ductile deformation. However, the anomaly is negative, which indicates that the ellipsoid becomes less flattened in areas of deformation. The same phenomenon is shown also when plotting the degree of lineation in the same way. Normally one would expect increased degrees of foliation and lineation within the deformation zone. One reason for the "inverse" structural fabric most likely corresponds to the variations in magnetic mineralogy as indicated by the volume susceptibility and the red staining of the rock samples within the deformation zone. However, at one sample location with clearly decreased degree of foliation the rock does not show any red staining and the volume susceptibility is high.

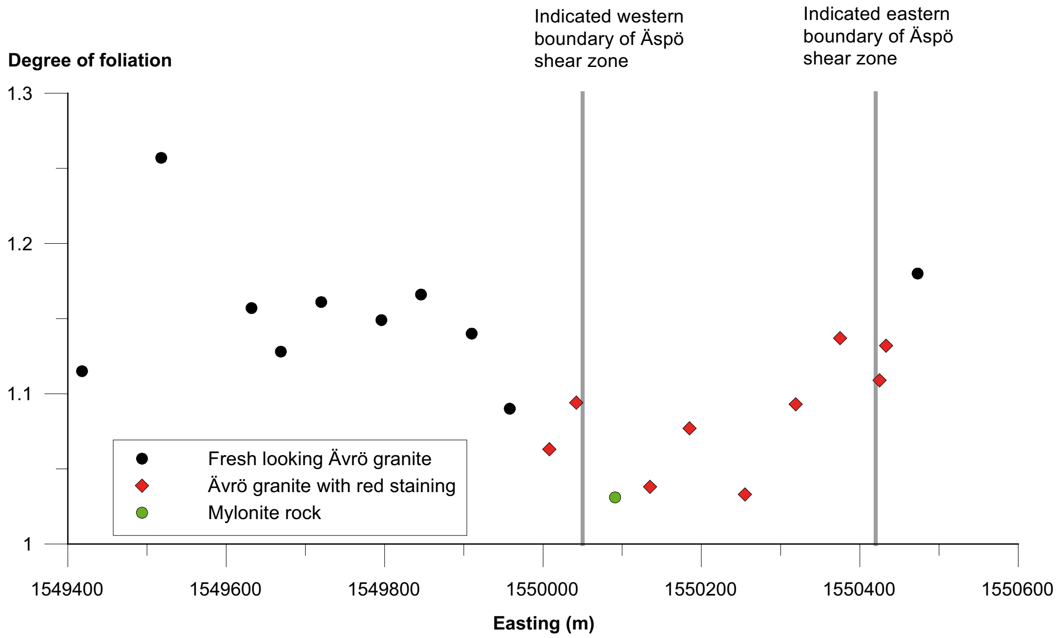

Figure 6-3. *Degree of magnetic foliation (flattening) along the northern profile. The data are plotted with reference to the easting co-ordinate of each sample location respectively.*

6.1.2 The orientation of AMS fabrics

The strike and dip of the magnetic foliations along the northern profile are presented in Figure 6-4. The six sites located most far west show west-striking (or WNW-striking) planes of foliation, and moderate dips. To the east of the hatched line in Figure 6-4, but outside of the deformation zone, there is a counter clockwise rotation of the foliation planes and the dip becomes c. 20° steeper compared to the previous sites. Within the deformation zone there is a general increase in the counter clockwise rotation and the dip becomes even steeper (c. 10°). East of the deformation zone there is a decrease in the counter clockwise rotation and the dip becomes shallower. The rotations of the foliations in combination with the systematic dip variations indicate that the rocks have suffered from sinistral shearing and compression.

The orientation of the magnetic foliation of fresh Ävrö granite from sites collected in the entire site investigation area (presented in /5/) shows that the major direction of orientation of the magnetic foliation planes is west-northwest strike and moderate dip, which agrees well with the six sampling locations situated farthest to the west in Figure 6-4.

When looking at the same data in stereographic diagrams (Figure 6-5) the rotational pattern becomes even clearer. There is significant increase in the dip of the planes of foliation but there is also measurable counter clockwise rotation.

The AMS data presented in the Figures 6-4 and 6-5 indicate that the bedrock is affected by the deformation as far as 250–300 m outside of the western boundary of the deformation zone.

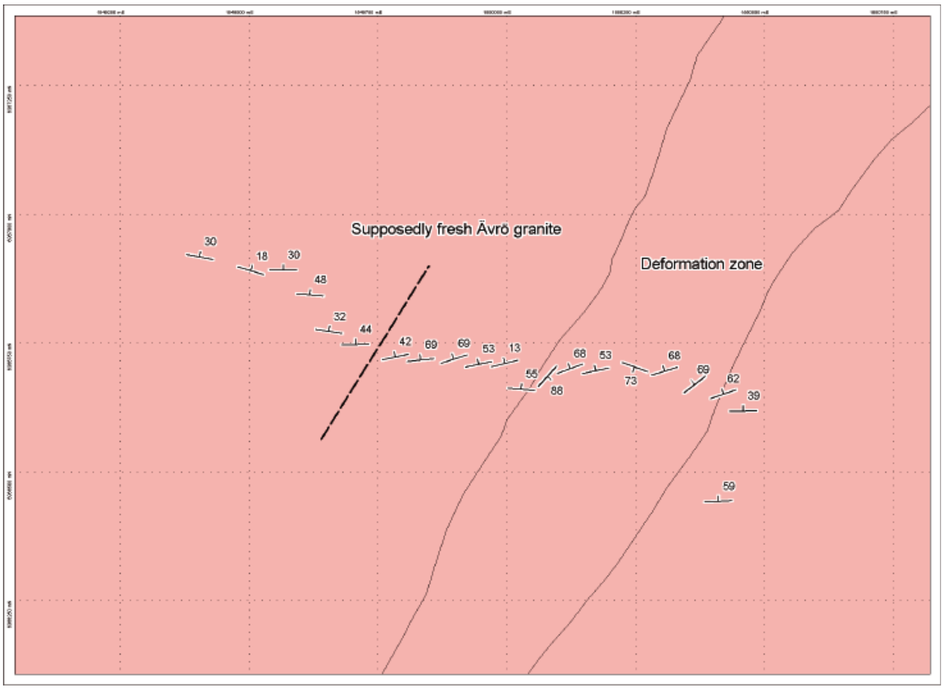

Figure 6-4. The orientation (strike and dip) of the magnetic foliation. The hatched line shows an interpreted boarder that indicates a change in the fabric orientation in the fresh Ävrö granite c. 250 m west of the western boundary of the Äspö shear zone.

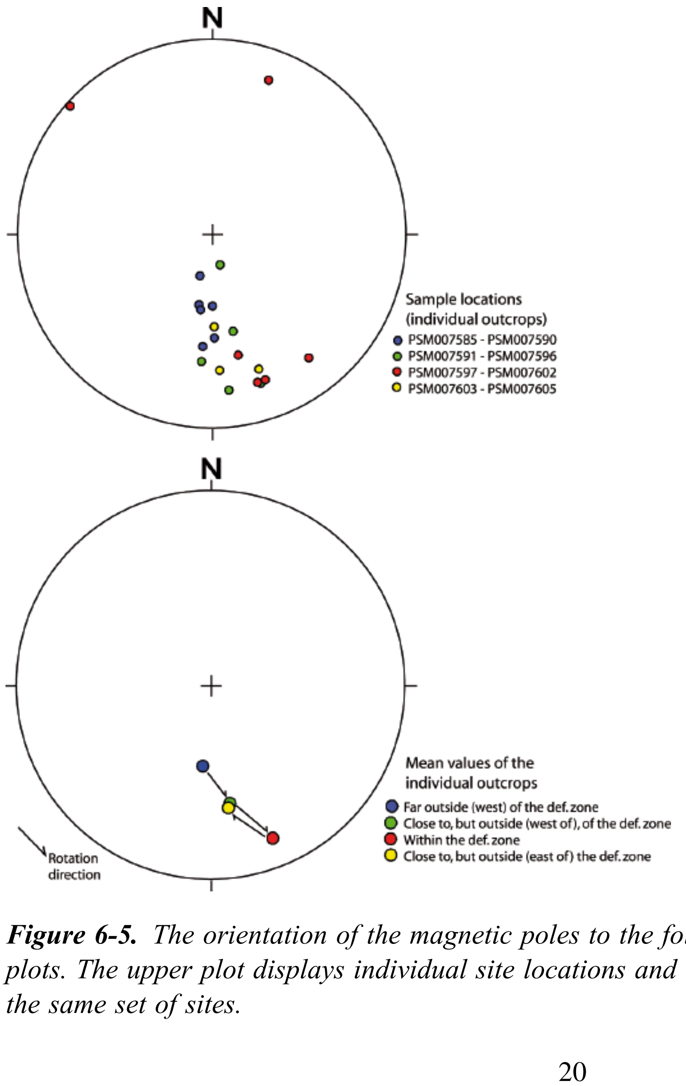

Figure 6-5. The orientation of the magnetic poles to the foliation plotted in equal area projection plots. The upper plot displays individual site locations and the lower plots displays mean values of the same set of sites.

In Figure 6-6 below strike and dip of the magnetic lineation (maximum strain) is presented for the northern profile. In contrast to the foliation data there are no clear indications of influence from the deformation of the rock in the sampling locations outside of the zone boundaries. The lineations generally strike east or west and have shallow or moderate dips, which is subparallel with magnetic lineation data reported for fresh Ävrö granite in the Laxemar area. Within the deformation zone, at some locations, the lineations are rotated and also display steeper dips.

In the equal area projection plot (Figure 6-7) there is an indication that the lineations from the sample locations situated farthest west of the deformation zone (blue dots) tend to strike eastward, and at the other sites the lineations mainly strike westward.

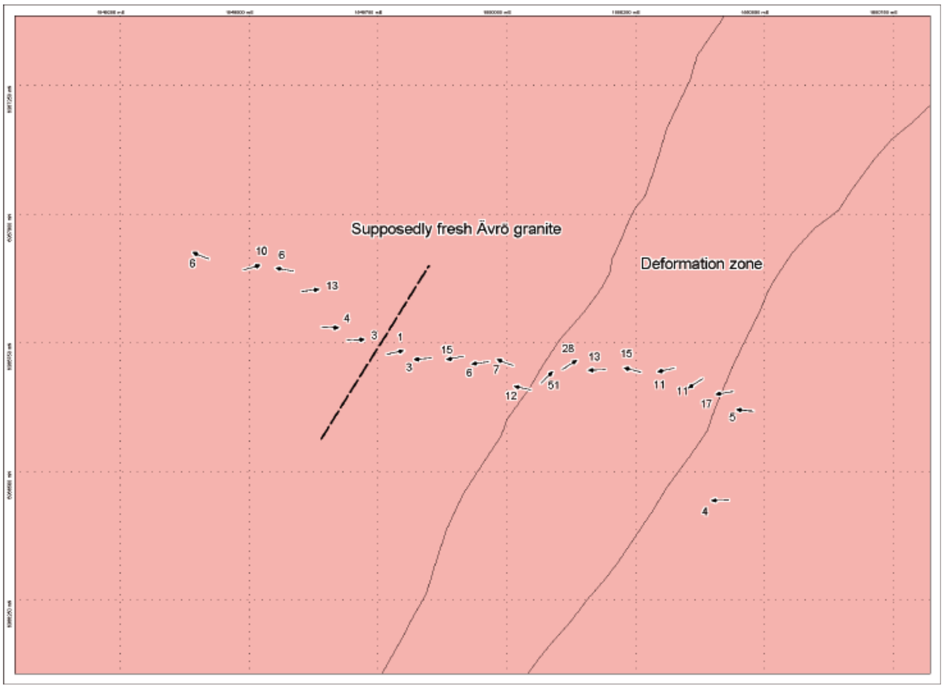

Figure 6-6. *The orientation (strike and dip) of the magnetic lineation. The hatched line shows an interpreted boarder that indicates a change in the fabric orientation in the fresh Ävrö granite c. 250 m west of the western boundary of the Äspö shear zone.*

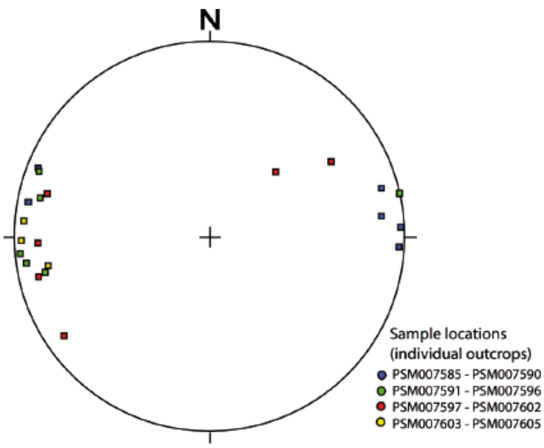

Figure 6-7. *The orientation of the magnetic lineation at individual site locations plotted in an equal area projection plot.*

6.2 Southern profile – Simpevarp peninsula

6.2.1 AMS parameters

In Figure 6-8 the magnetic susceptibility is plotted versus a distance line which is approximately perpendicular to the trend of the deformation zone. The two mylonites within the deformation zone and one quartz monzodiorite show very low magnetic susceptibility, but at all other sample locations the bedrock has a fairly high magnetic susceptibility. There seems to be no correlation between deformation of the rocks and variations in the magnetic susceptibility.

In the same way as for the northern profile a plot of the degree of anisotropy versus the volume susceptibility shows that there is a linear relation between the degree of anisotropy and the logarithm of the volume susceptibility. An attempt to correct for this linear dependent of "P" is presented in Figure 6-9, which displays the P-parameter, normalized with reference to the logarithm of the volume susceptibility, and plotted with reference to the distance from the deformation zone for each sampling location respectively. The data appears to be greatly affected by variations in the volume susceptibility even after the normalization, and there is no clear correlation between the deformation zone boundaries and the corrected degree of anisotropy.

Neither the variations in the degree of the foliation across the deformation zone (Figure 6-10) nor the degree of the lineation, show any anomalies that seem to correlate with the deformation zone boundaries.

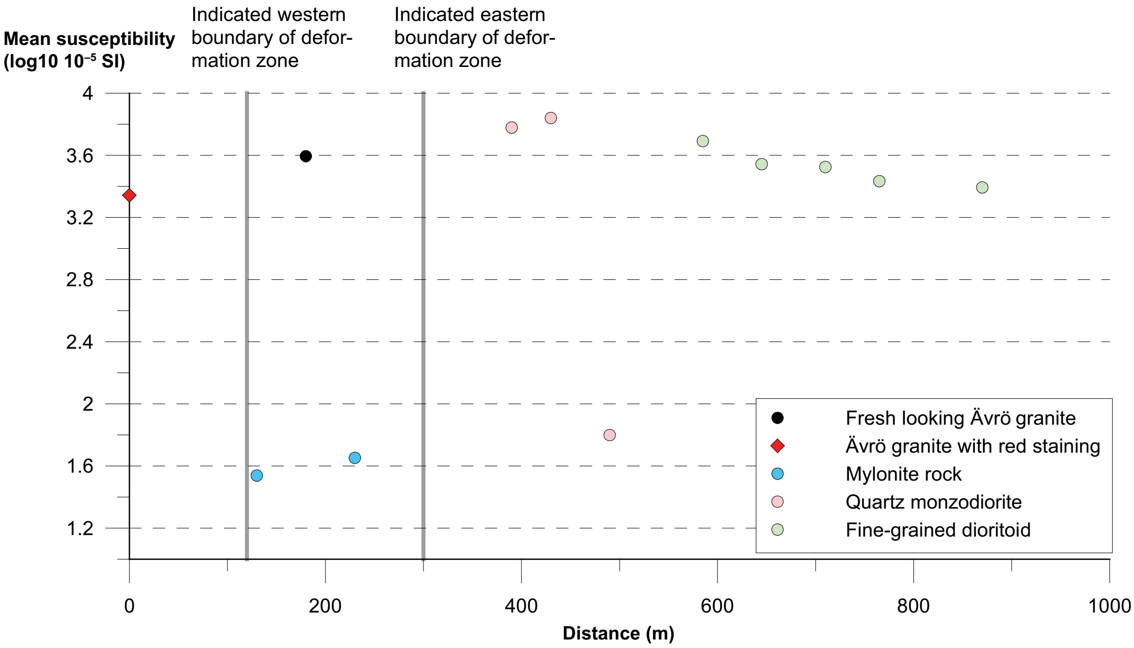

Figure 6-8. *Magnetic susceptibility (site mean values) along the southern profile. The data are plotted with reference to the estimated distance orthogonal to the strike of the deformation zone. The site location PSM007618 is not included.*

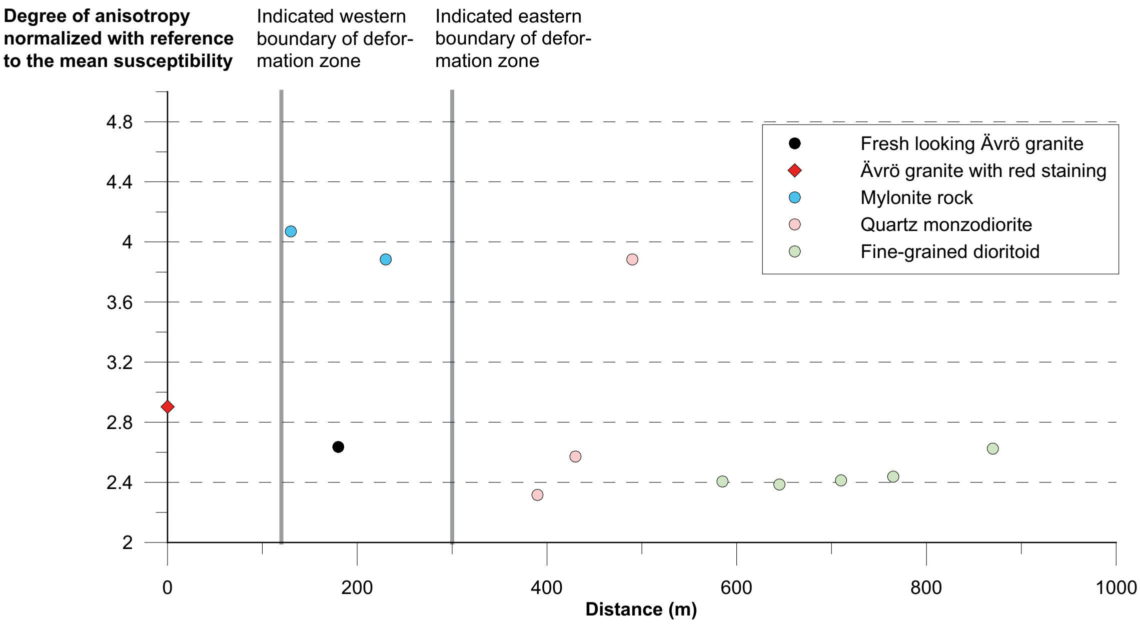

***Figure 6-9.** Degree of magnetic anisotropy normalized with the mean susceptibility (site mean values) along the southern profile. The data are plotted with reference to the estimated distance orthogonal to the strike of the deformation zone. The site location PSM007618 is not included.*

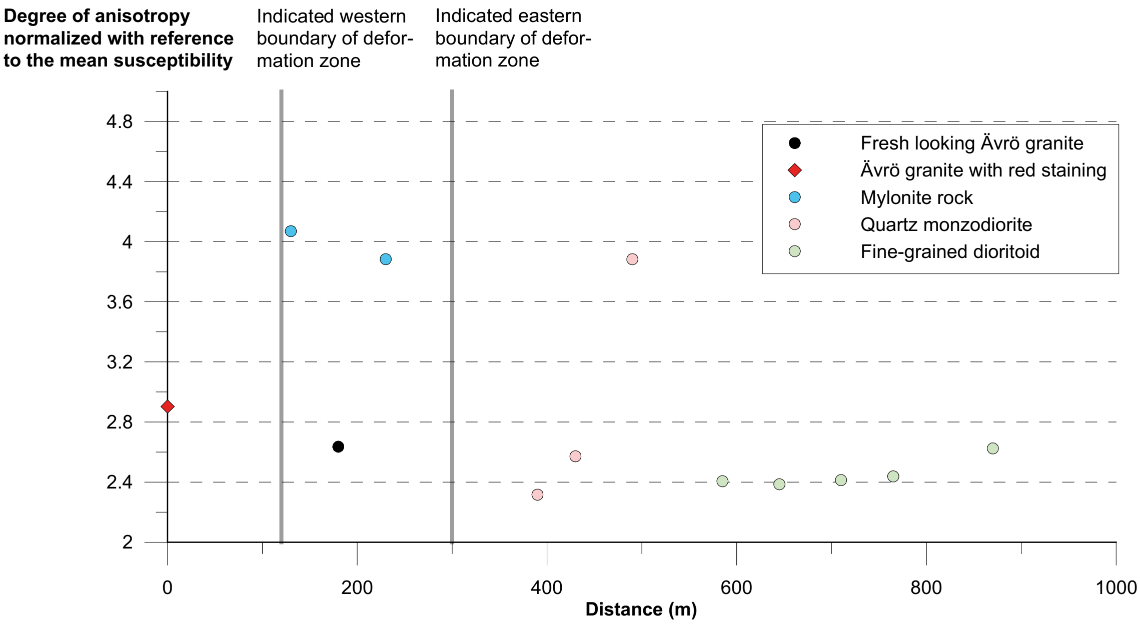

***Figure 6-10.** Degree of foliation along the southern profile. The data are plotted with reference to the estimated distance orthogonal to the strike of the deformation zone. The site location PSM007618 is not included.*

6.2.2 The orientation of AMS fabrics

Strike and dip of the magnetic foliation and magnetic lineation along the southern profile are plotted on the geological map from the feasibility study of Oskarshamn in Figure 6-11 /3/. For a majority of the site locations the plane of the magnetic foliation strikes westward and dips moderate to steep to the north. There is a tendency of decreasing dips towards southeast. At the site location PSM007618 the magnetic foliation strikes in the southeast

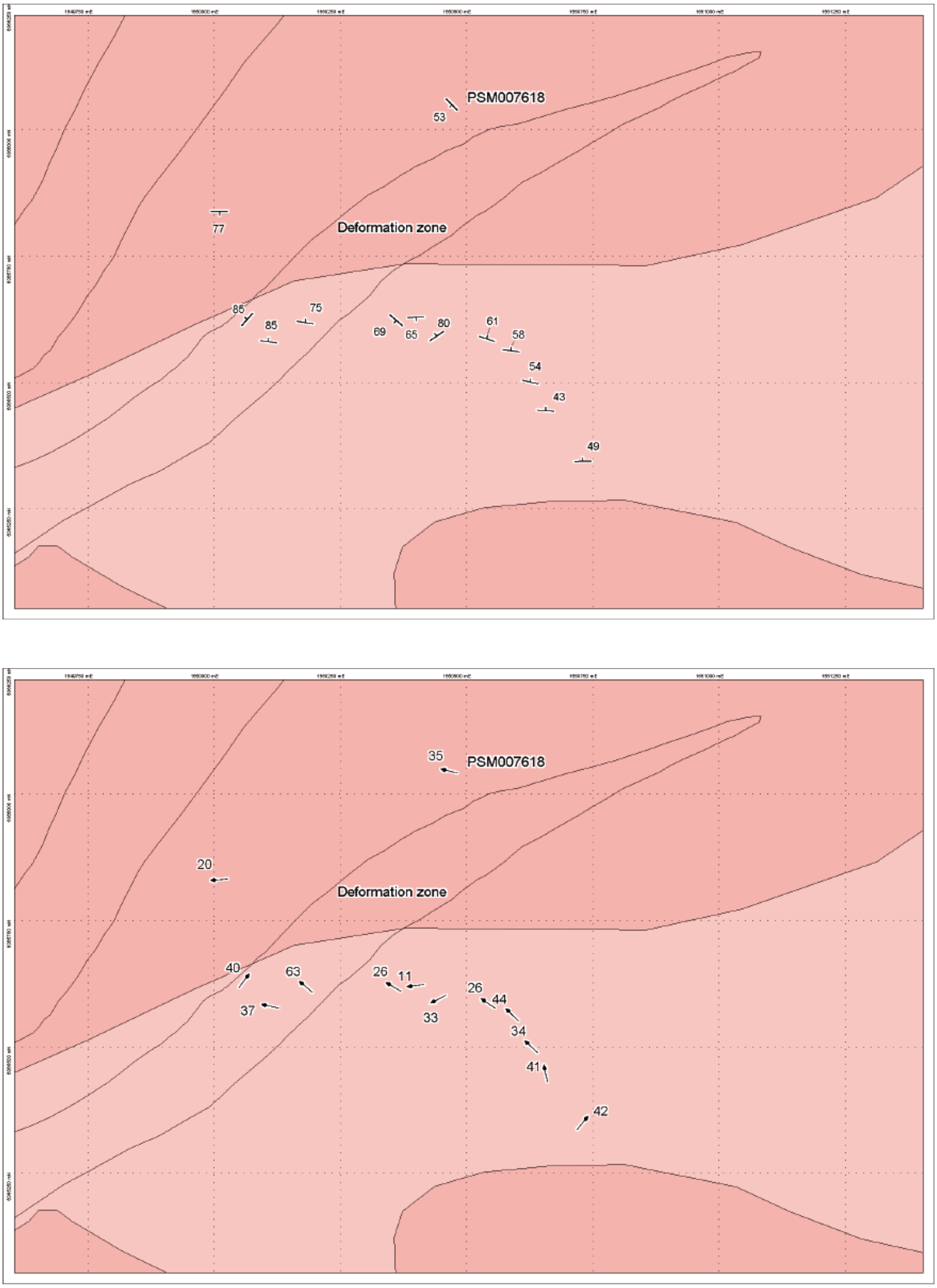

Figure 6-11. *The orientation (strike and dip) of the magnetic foliation (upper plot) and the magnetic lineation (lower plot).*

directions, which clearly deviates from the general orientation pattern; but also note that the foliation at the location PSM007610, which is in direct vicinity of the eastern boundary of the deformation zone, has a similarly deviating orientation of the foliation (Figure 6-12, upper plot). It also important to point out that the one of the mylonites within the deformation zone (PSM007609) has a foliation that strikes WNW, which is almost perpendicular to the strike of the deformation zone and subparallel to the general trend of the foliation orientations along the profile.

The magnetic lineations are scattered but show a mean strike direction to northwest with moderate dip (Figure 6-12, lower plot). This mean direction is subparallel with the average direction of the magnetic lineation reported for a number of fresh rock types sampled all over the Laxemar area /5/. Two site locations show significantly deviating lineation directions, oriented at northeast, and these are a mylonite at PSM007607 (within the deformation zone) and a fine-grained dioritoid PSM007617 (located farthest to the east in the profile).

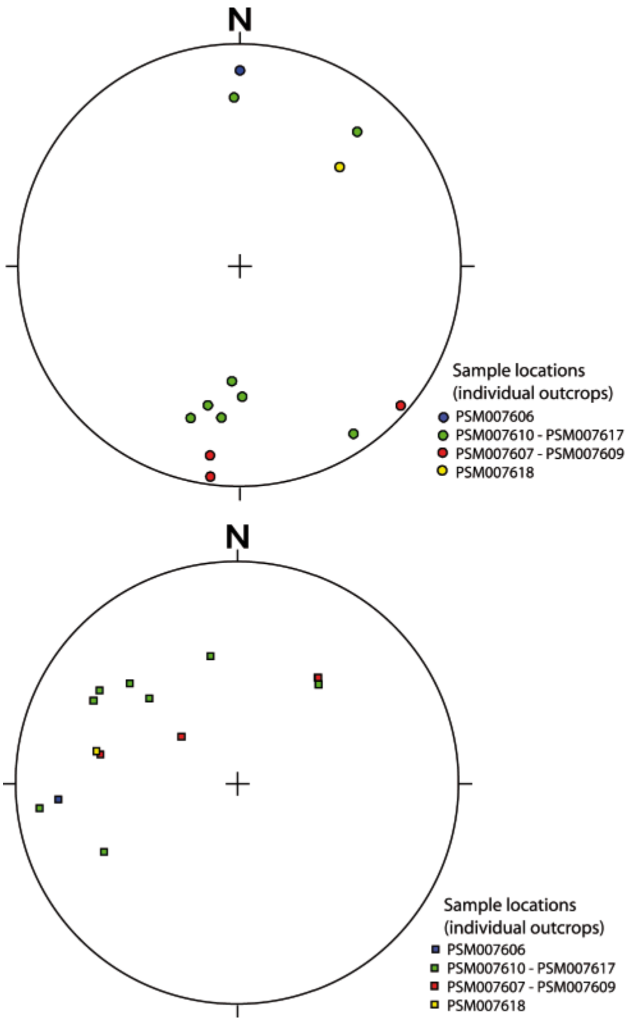

Figure 6-12. *The orientation of the poles to the magnetic foliation (upper plot) and the magnetic lineation (lower plot) at individual site locations plotted in equal area projection diagrams.*

7 Discussion

The oriented AMS data from the northern profile across the Äspö shear zone are of high quality and indicate a structural fabric that varies distinctly with distance from the deformation zone. Far west of the deformation zone the AMS fabric is identical with the primary fabric reported for fresh Ävrö granite in the Laxemar area /5/. In a c. 250 m wide transition zone outside of the deformation zone center, there is a clearly detectable counter clockwise rotation of the magnetic foliations, and there is also an increase in the dip of foliation planes. Within the zone center there is a general increase in the counter clockwise rotation and the dip generally becomes even steeper.

The magnetic foliaion fabric variations fit well to the expected fabric of a ductile deformation zone with sinistral sense of movement (Figure 7-1). The fact that the magnetic lineations show little evidence of the deformation process, apart from the mylonite at PSM007597 and the neighboring site PSM007598, most likely indicates that the degree of deformation was low. This assumption is supported by the geological observations in outcrops within the deformation zone that indicate that the mylonite is brittle-ductile (thus mainly brittle) and that surrounding rocks mainly carry only weak foliation.

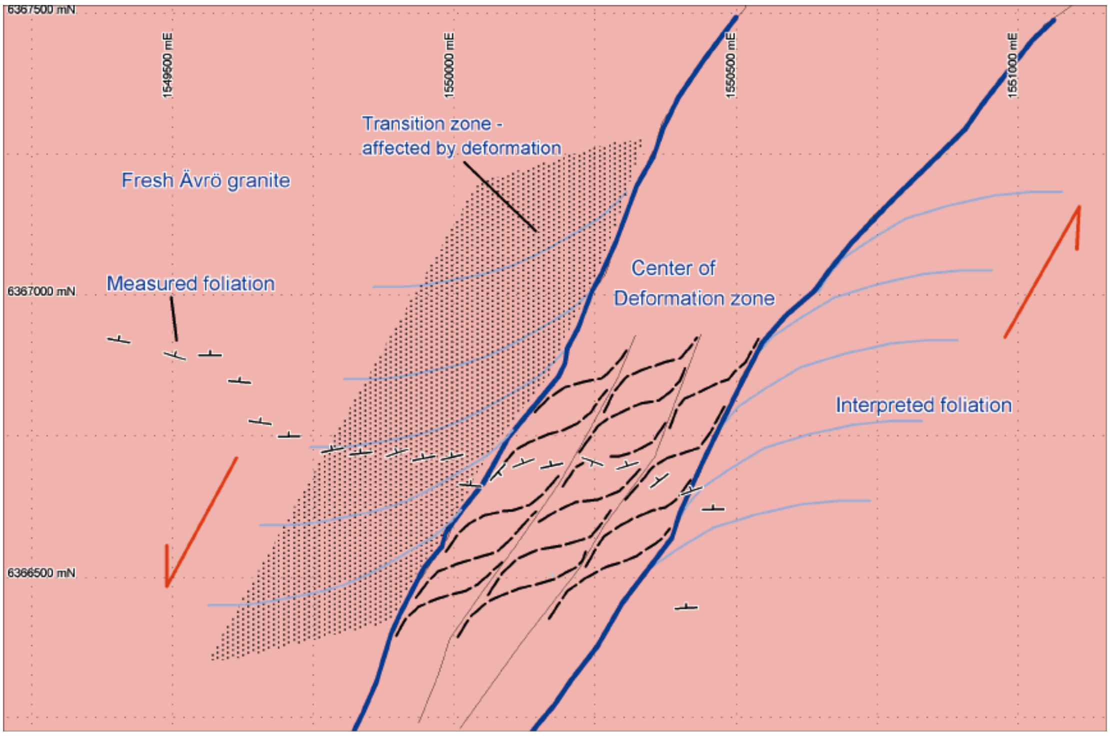

Figure 7-1. *Example of possible interpretation of the AMS data from the northern profile across the Äspö shear zone.*

The AMS data from the southern profile show very little agreement with the deformation zone geometry as indicated in, for example Figure 6-11. Only one single mylonite (PSM007607) carries a magnetic foliation that is parallel with the indicated zone boundary. A majority of the rocks at the investigated sample locations show magnetic fabrics that coincide with the general fabric of the entire region as reported in /5/. The sampled rocks show little evidence of having been affected by ductile deformation, though it must be emphasized that the dark color in combination with the fine grain size of the fine-grained dioritoid makes it very difficult to detect structures in this rock type. The number of site locations within the suggested deformation zone center (three) is also a bit low to make a safe interpretation. However, the interpretation of the AMS data from the southern profile is that there are no clear indications of the existence of a major deformation zone in the bedrock.

In conclusion, this investigation indicates that the dominant ductile deformation of the Äspö shear zone was low grade and gave rise to a sinsitral sense of movement. Further, the AMS data indicate rotated foliations well outside of the shear zone boundary, in rocks without clear visible signs of ductile deformation. These AMS data indicate the existence of a transition zone of similar width (c. 250 m) as the deformation zone center, which is c.. 300 m at the investigated section.

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/2/ **Wahlgren C-H, Bergman T, Persson Nilsson K, Eliasson T, Ahl M, Ekström M.** Bedrock map of the Laxemar subarea and surroundings. Description of rock types, modal and geochemical analyses, including the cored boreholes KLX03, KSH03 and KAV01. Oskarshamn site investigation. SKB P-05-180. Svensk Kärnbränslehantering AB.

/3/ **Bergman T, Johansson R, Linden A H, Lindgren J, Rudmark L, Wahlgren C-H, Isaksson H, Lindroos H, 1998.** Förstudie Oskarshamn – Jordarter, bergarter och deformationszoner. SKB R-98-56. Svensk Kärnbränslehantering AB.

/4/ **Tarling D, Hrouda H, 1993.** The magnetic anisotropy of rocks. Chapman & Hall, New York.

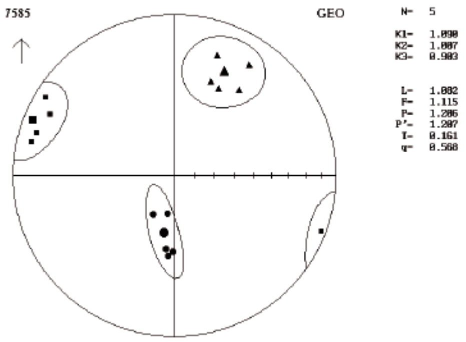
/5/ **Mattsson H, Thunehed H, Triumf C A.** Compilation of petrophysical data from rock samples and in situ gamma-ray spectrometry measurements Stage2 – 2004 (including 2002). SKB P-04-294. Svensk Kärnbränslehantering AB.

Appendix 1

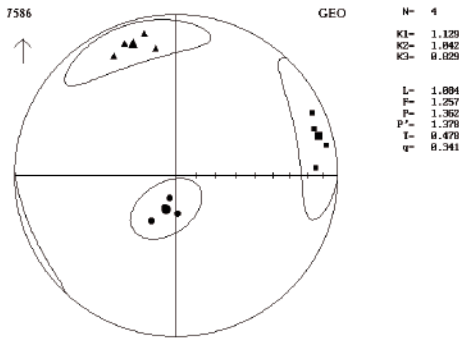
Equal area stereograms of AMS data and geological comments for all individual site locations.

Square = $K_{maximum}$, triangle = $K_{intermediate}$, Dot = $K_{minimum}$

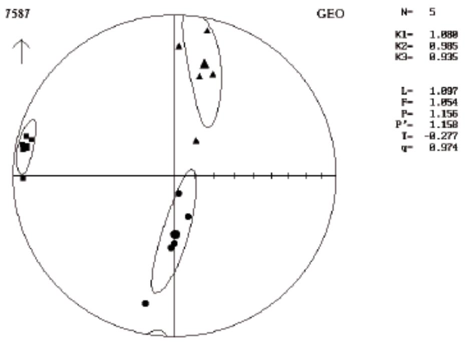
Great circles denote tectonic foliation measured in outcrops.



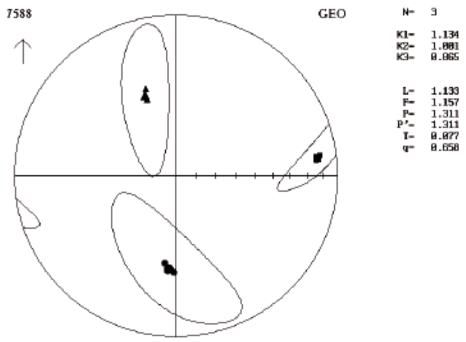
Ävrö granite. No visual indications of ductile deformation. Inhomogeneous locality with large occurrences of fine-grained diorite to gabbro.



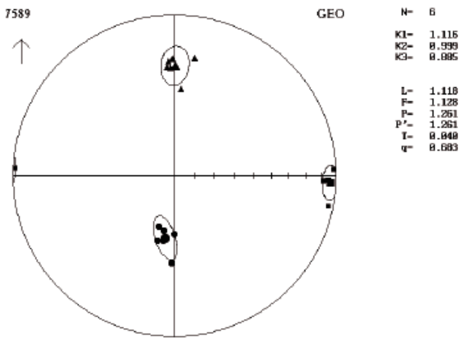
Ävrö granite. No visual indications of ductile deformation.



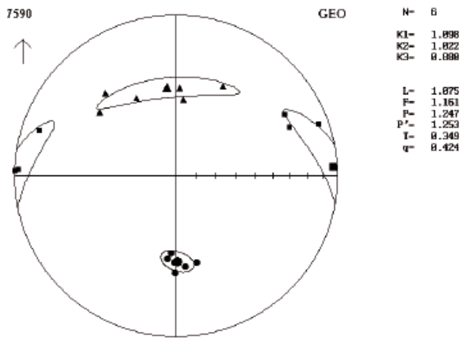
Ävrö granite. No visual indications of ductile deformation.



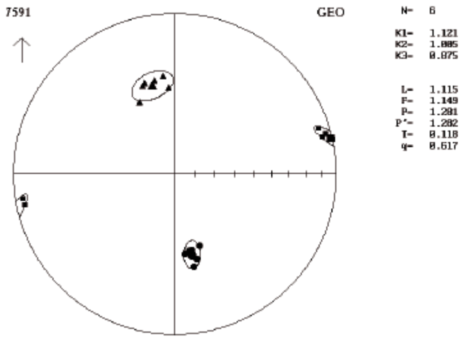
Ävrö granite. No visual indications of ductile deformation.



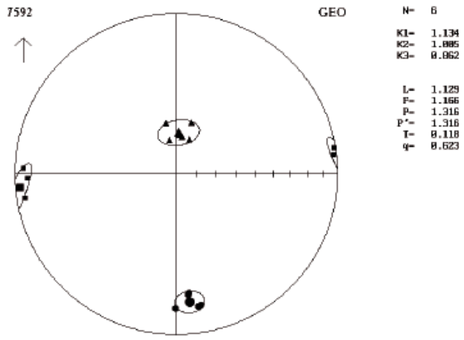
Ävrö granite. No visual indications of ductile deformation.



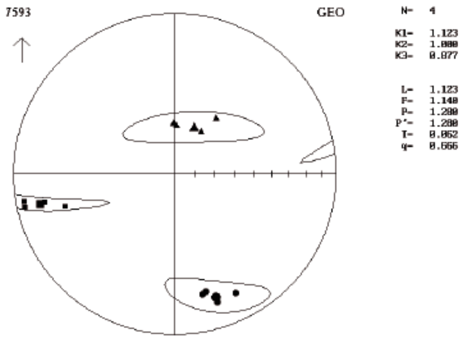
Ävrö granite. No visual indications of ductile deformation.



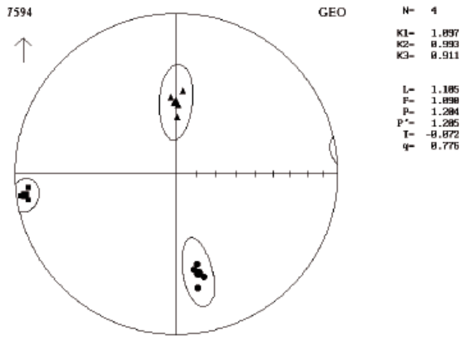
Ävrö granite. No visual indications of ductile deformation.



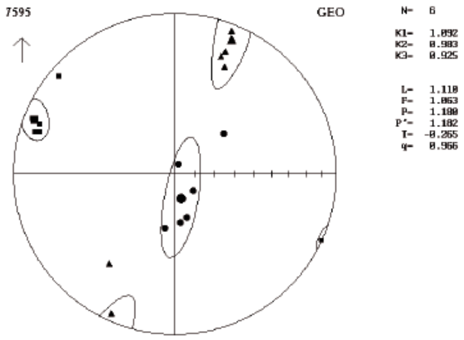
Ävrö granite. No visual indications of ductile deformation.



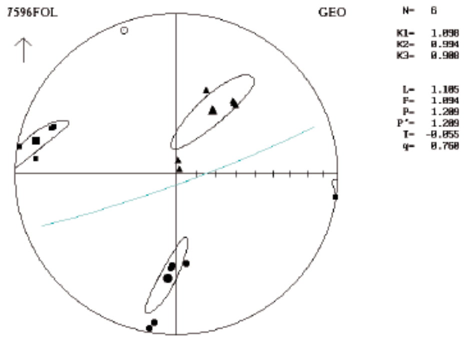
Ävrö granite. No visual indications of ductile deformation.



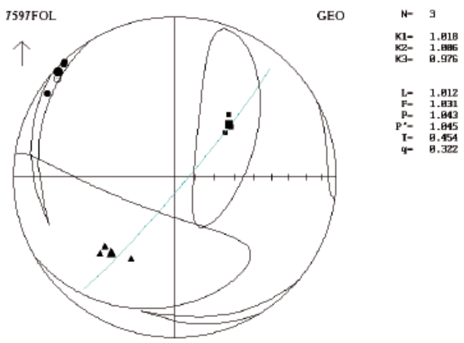
Ävrö granite. No visual indications of ductile deformation.



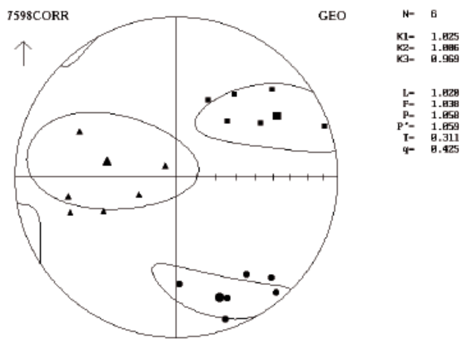
Ävrö granite. No visual indications of ductile deformation. However, intense red staining and occurrences of fractures filled with epidote. Locality situated close to lineament.



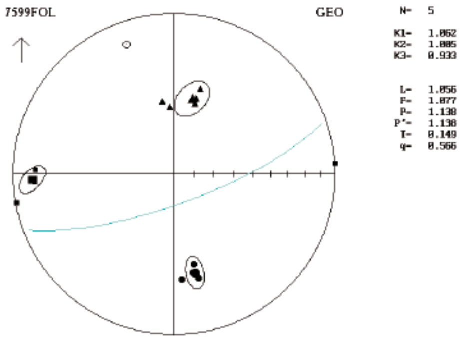
Ävrö granite. Weak foliation 070°/85°. Increased fracturing and red staining.



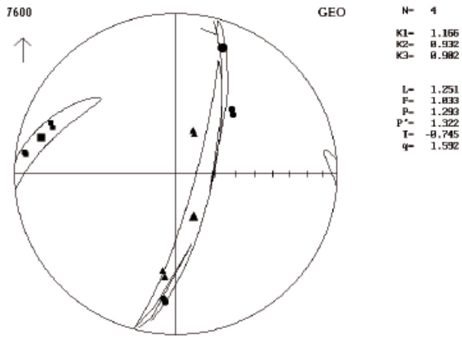
Brittle-ductile mylonite. Strong foliation 040°/85°.



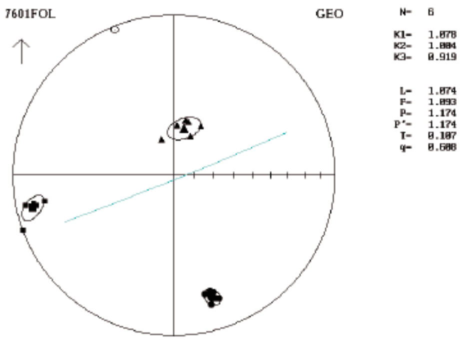
Ävrö granite. No visual indications of ductile deformation. Red staining and occurrences of fractures filled with epidote.



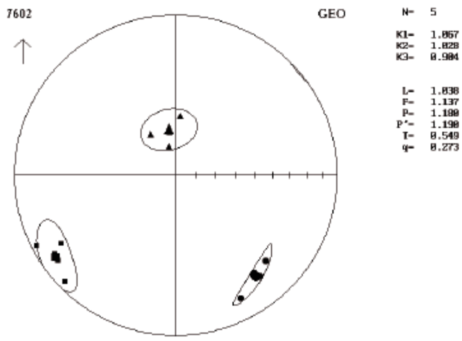
Ävrö granite. Weak foliation 070°/75°. Red staining and occurrences of fractures filled with epidote.



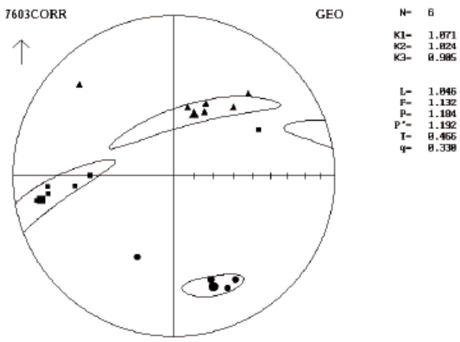
Ävrö granite (medium grained, sparsely porphyritic, granite to granodiorite). No indications of ductile deformation. Red staining.



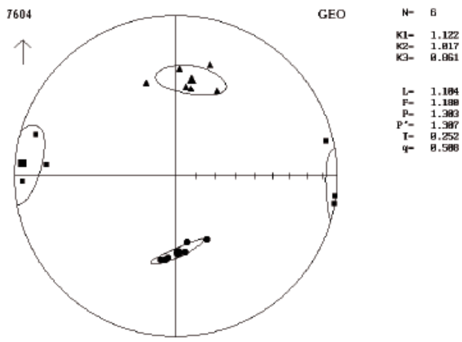
Ävrö granite (granite to granodiorite). Weak foliation 068°/90°. Red staining.



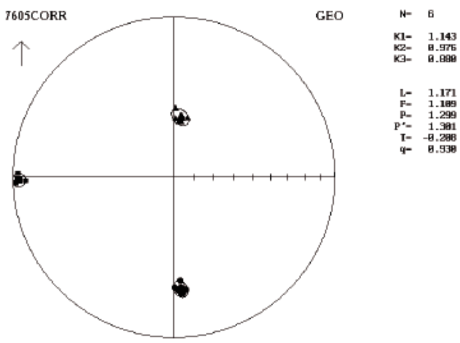
Ävrö granite (granodiorite). No indications of ductile deformation. Red staining, indications of alteration.



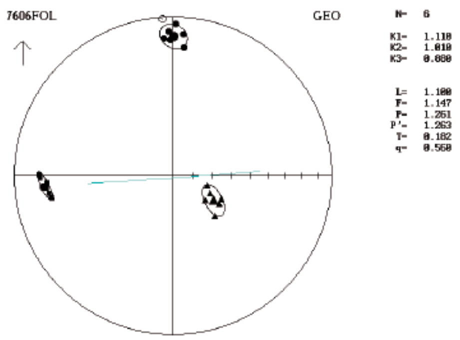
Ävrö granite (granite to granodiorite). No indications of ductile deformation. Red staining.



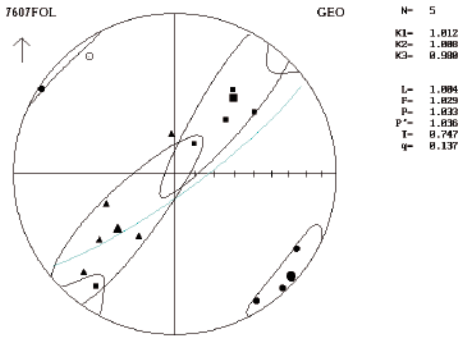
Ävrö granite (granite) fresh! No indications of ductile deformation.



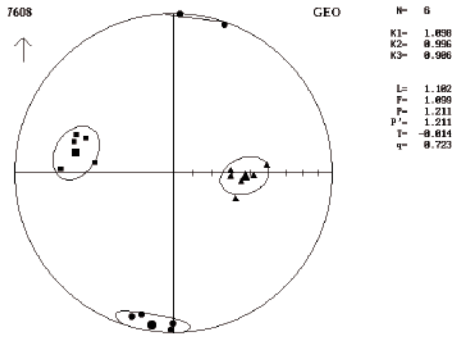
Ävrö granite (granite). No indications of ductile deformation. Weak red staining.



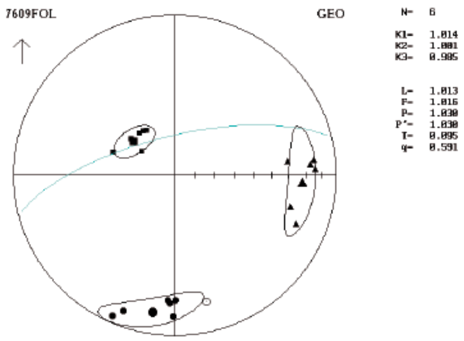
Ävrö granite (granite to granodiorite). Weak foliation 086°/90°. Red staining.



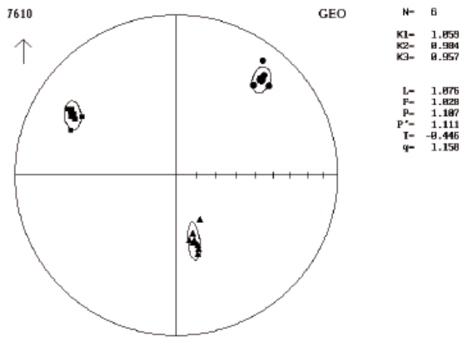
Mylonite. Strong foliation 054°/80°.



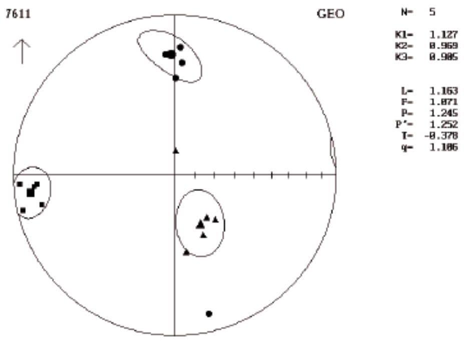
Granite to granodiorite (porphyritic), rock type = ? No indications of ductile deformation.



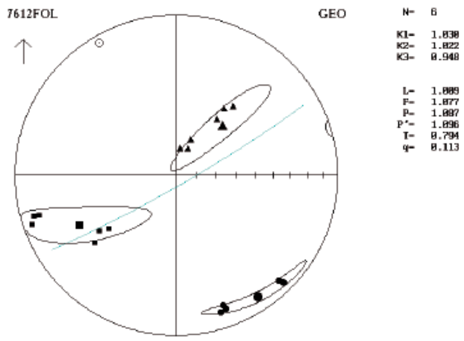
Mylonite. Strong foliation 256°/70°.



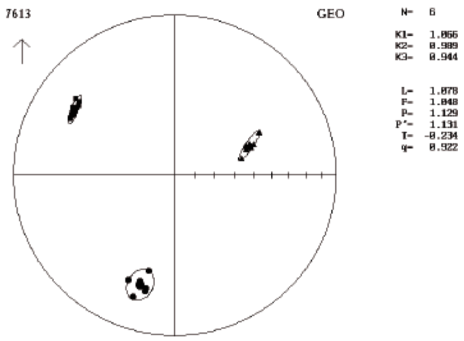
Quartz monzodiorite. No indications of ductile deformation.



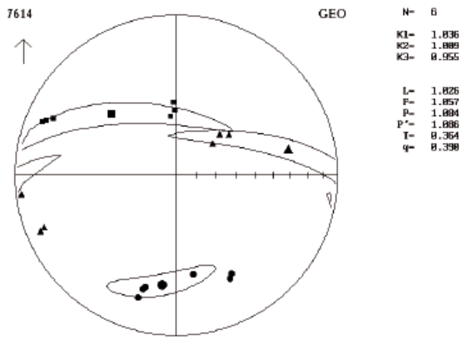
Quartz monzodiorite. No indications of ductile deformation.



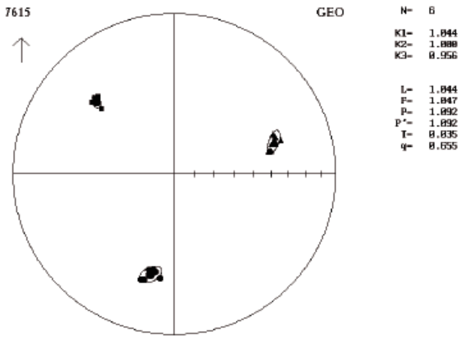
Quartz monzodiorite. Foliation 060°/85°.



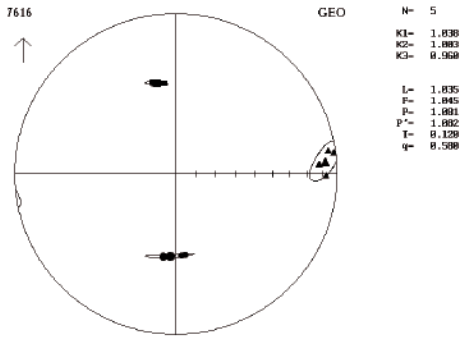
Fine-grained dioritoid. No indications of ductile deformation. The locality is situated only 15 m from mylonite with foliation 060°/90°.



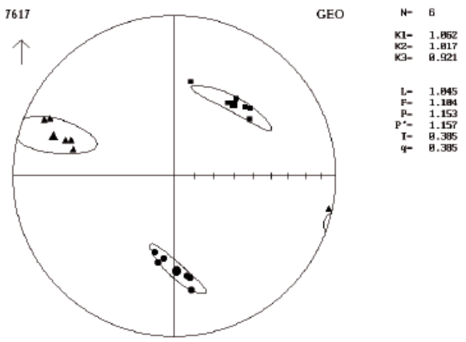
Fine-grained dioritoid. No indications of ductile deformation.



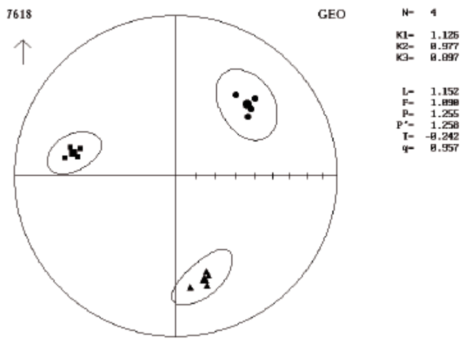
Fine-grained dioritoid. No indications of ductile deformation.



Fine-grained dioritoid. No indications of ductile deformation. Close to minor lineament.



Fine-grained dioritoid. No indications of ductile deformation. Close to major lineament.



Fine-grained dioritoid. No indications of ductile deformation.