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Bedrock mapping 2003 – Simpevarp subarea

Outcrop data, fracture data, modal and geochemical classification of rock types, bedrock map, radiometric dating

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March 2004

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Keywords: AP PS 400-03-056, Bedrock mapping, Observation points, Outcrop data, Fracture data, Modal analysis, Geochemical analysis, Bedrock map, Radiometric dating.

Abstract

This report presents results of bedrock geological investigations that were carried out during 2003 in the Simpevarp subarea. The performed activities comprise bedrock mapping, scan line mapping of fractures, modal and geochemical analysis, radiometric dating and compilation of a bedrock map at the scale 1:10 000.

The Simpevarp subarea is dominated by three rock types: 1) fine-grained dioritoid in the southern part of the Simpevarp peninsula and in the central part of Ävrö as a NE-trending, narrow, winding belt, 2) medium-grained quartz monodiorite in the eastern part of the Simpevarp peninsula, and 3) porphyritic granite to quartz monzodiorite (Ävrö granite) in the northern part of the Simpevarp peninsula and at Hålö and Ävrö. The dominant rock types have overlapping compositional variations, and have beeen distinguished mainly on their different texture and/or grain size. Furthermore, minor bodies to inclusions of diorite to gabbro and medium-grained granite occur. A characteristic feature in the Simpevarp subarea is the frequent occurrence of fine- to medium-grained granite, as well as pegmatite, as dykes, patches and veins.

Contact relationships between the different rock types in the Simpevarp subarea strongly suggest that they are formed more or less synchronously. The latter is confirmed by obtained U-Pb zircon ages of c. 1800 Ma for the quartz monzodiorite and the Ävrö granite, which indicates that they belong to the c. 1800 Ma generation of the 1860-1650 Ma Transscandinavian Igneous Belt.

All rock types in the Simpevarp subarea are more or less structurally well preserved, apart from the local occurrence of a decimetre to a couple of metres wide, low-grade, ductile shear zones. A characteristic phenomenon that affects all rock types is an extensive, inhomogeneous red staining (oxidation/hydrothermal alteration).

Sammanfattning

Denna rapport presenterar resultat av berggrundsgeologiska arbeten utförda under 2003 med syfte att karakterisera berggrunden inom delområde Simpevarp. Arbetena omfattar berggrundskartering, linjekartering av sprickor, modalanalyser och geokemiska analyser av bergarter, åldersdateringar och sammanställning av en berggrundskarta i skala 10 000.

Delområde Simpevarp domineras av följande tre bergarter: 1) finkornig dioritoid i den södra delen av Simpevarpshalvön och i ett smalt, vindlande band genom centrala Ävrö, 2) medelkornig kvartsmonzodiorit i den östra delen av Simpevarpshalvön och 3) porfyrisk granit till kvartsmonzodiorit (Ävrögranit) i den norra delen av Simpevarpshalvön, på Hålö och Ävrö. Bergarterna har överlappande sammansättningsvariationer och har i första hand urskiljts på texturella och kornstorleksmässiga kriterier. Vidare förekommer mindre kroppar till inneslutningar av diorit till gabbro och medelkornig granit. Karakteristiskt för området är den rikliga förekomsten av fin- till medelkornig granit som gångar, körtlar och ådror, samt relativt frekventa pegmatitgångar,- körtlar och -ådror.

Kontaktrelationerna mellan de olika bergarterna inom området och utförda U-Pb-dateringar av kvartsmonzodioriten och Ävrögraniten indikerar att bergarterna är mer eller mindre likåldriga och tillhör den 1800 miljoner år gamla generationen inom det transskandinaviska magmatiska bältet (1860-1650 miljoner år).

Bergarterna är mestadels mer eller mindre strukturellt välbevarade, bortsett från förekomsten av vissa decimeter till några meter breda låggradiga, plastiska skjuvzoner. En inhomogen, men allmänt utbredd sekundär rödfärgning (oxidation/hydrotermalomvandling) är dock karakteristisk för områdets bergarter.

Contents

1 Introduction

This document reports the data gained in connection with bedrock mapping of the Simpevarp subarea, which is one of the activities performed within the initial site investigation at Oskarshamn. The mapping was carried out during the summer 2003 and comprised the Simpevarp peninsula, Hålö and the island of Ävrö. The bedrock mapping aimed to present an updated version of the bedrock map in the scale 1:10 000 that was compiled in connection with the construction of the Äspö Hard Rock Laboratory /Kornfält and Wikman, 1987/.

The following activities were performed within the mapping project:

- Bedrock mapping of existing outcrops.
- Scan line mapping of fractures longer than 100 cm at selected outcrops.
- Sampling and analyses of rocks for geochemical and mineralogical characterization of rock types.
- Sampling of rocks for radiometric dating.
- Compilation of a bedrock map of the Simpevarp subarea at the scale 1:10 000.

The bedrock mapping was carried out in accordance with the activity plan AP PS 400-03-056 (SKB internal controlling document) and the method description for bedrock mapping (SKB MD 132.001, SKB internal controlling document). The fracture mapping was performed according to the scan line technique recommended in the method description for detailed fracture mapping (SKB MD 132.003, SKB MD 132.001, SKB internal controlling document). The geochemical and mineralogical analyses and radiometric datings were performed according to the method descriptions for rock analyses (SKB MD 160.001, SKB MD 132.001, SKB internal controlling document) and age dating of minerals and rocks (SKB MD 132.002, SKB MD 132.001, SKB internal controlling document).

2 Objective and scope

The mapping project aimed to document all outcrops in the Simpevarp subarea in order to present a detailed bedrock map at the scale 1:10 000. Because of the high percentage of outcrops and that many individual outcrops extend over large areas, several observation points were made in many of the outcrops. The outcrop data from the observation points are integrated with geochemical and mineralogical data from sampled rocks and results from the interpretation of airborne geophysical data in order to obtain an integrated data set for the compilation of a bedrock map of the Simpevarp subarea.

The position and orientation of fractures longer than 100 cm were documented at 16 outcrops in the Simpevarp subarea with purpose to get information on fractures, at an intermediate stage between the identified lineaments and the detailed fracture analysis.

The bedrock mapping was for the main part carried out during August and September, and the field activities ceased during October. In total, numerical and descriptive data from 353 observation points have been stored in an outcrop database that has been delivered to SKB.

Furthermore, radiometric dating has been carried out on two rock samples in order to improve our understanding of the age relationships between the magmatic rocks and the geological evolution in the region.

3 Equipment

3.1 Description of equipment

The following equipment was used during the bedrock mapping project:

- Garmin GPS 12.
- Silva compass.
- Instrument to measure magnetic susceptibility (Geoinstruments, Finland; GF Instruments, Czech Republic).
- Camera.
- Brush.
- Magnifying lens.
- Magnet.
- Measuring-tape.
- Sample bags.
- Topographic field map at the scale 1:10 000 generated from orthorectified aerial photographic data, with addition of identified outcrops from the interpretation of infra-red aerial photographs.
- Field notebook with standard observation protocol.
- Various complementary material including pencils, tape, safety equipment etc.

Transport to the field area was carried out with hired cars.

4 Execution

4.1 Preparations

The documentation of previous work what concerns bedrock mapping in the area was completed in connection with the Oskarshamn feasibility study. Key description of the geology of the Simpevarp subarea and the immediate surroundings is the bedrock map at the scale 1:10 000 that was compiled in connection with the pre-investigations for construction of the Äspö Hard Rock Laboratory /Kornfält and Wikman, 1987/. An updated summary of the regional bedrock geology is presented in the Version 0 site descriptive model for Simpevarp /SKB, 2002; see also Andersson et al., 2002/.

The comprehensive and detailed bedrock information that has been generated during the major infrastructure projects in the Simpevarp subarea, i.e. construction of the Oskarshamn nuclear power plant, CLAB and the Äspö Hard Rock Laboratory, have not been evaluated in connection with the bedrock mapping. The structural geological data from the infrastructure projects has been compiled and transferred into digital format by Curtis et al. /2003/, and will be evaluated in the forthcoming 3D modelling.

The boundaries between different rock types in the map by Kornfält and Wikman /1987/ were digitized and subsequently transferred to the field maps used during the bedrock mapping. Outrops that were identified from the interpretation of infrared aerial photographs were transferred to the field maps as well.

4.2 Execution of tests/measurements

The bedrock in the Simpevarp subarea is well exposed and constitutes c. 47 % of the land area. However, moss and lichen cover large parts of the outcrops, except for outcrops along the shore to the Baltic Sea. Accordingly, the percentage of clean and well exposed bedrock surfaces *sensu stricto* are less than 47 %.

Each day mapping was carried out, the geologists visited a fixed point (PP200 at Äspö or BANA at the Simpevarp peninsula) in order to test the drift in the coordinate values (RT 90 2.5 gon V) obtained by the Garmin GPS 12 instrument. The obtained values have been delivered to SKB.

4.2.1 Bedrock mapping

During the bedrock mapping, each observation point was designated an ID-code (PSM-number), and the date and the GPS-coordinates were documented in a standard observation protocol. Mostly, only one observation point is documented in each outcrop. However, if a specific object in an outcrop was regarded as important, an additional observation point was made and documented in the standard protocol. Since many outcrops in the Simpevarp subarea extend over large areas, several observation points are documented in many of the outcrops. However, this does not imply that all parts of the larger outcrops have been visited and mapped in detail, but only that enough information is obtained to compile a bedrock map in the scale 1:10 000.

The descriptive and numerical data that was documented in the standard observation protocol at every observation point include:

1. Object (predominantly outcrop).
2. Rock type (in decreasing order of spatial importance).
3. Occurrence of rock type.
4. Texture.
5. Structure.
6. Grain size (groundmass).
7. Grain size (megacryst).
8. Colour.
9. Key mineral.
10. Occurrence of key mineral.
11. Stratigraphic position.
12. Measurements of mesoscopic structures.
13. Measurements of magnetic susceptibility.
14. Reference sample number.
15. Photograph (how many).
16. Sketch.
17. Comments in free text.

Points 1, 2 and 13 are compulsory for each observation. Documentation of the other points varies and is dependent on the character of the bedrock at the observation point. Comments in free text are made in almost all observation points. If more than one rock type occurs in the outcrop, the rock types are registered in the order of spatial importance, i.e. rock type 1 is dominating etc, and the documentation of points 2-14 is repeated for each rock type. The structural measurements mainly comprise ductile structures, e.g. foliation and ductile shear zones. However, the orientation of some brittle structures, such as certain mesoscopic fracture zones is also documented. Eight measurements of the magnetic susceptibility are registered at each observation point, at least for the dominating rock type (rock type 1).

For planning purposes and as backup, key information for the observation points, principally documented rock types and structural measurements, were plotted on a clean outcrop map at the scale 1:10 000 after every days field work.

4.2.2 Fracture mapping

As a part of the bedrock mapping at Simpevarp 16 outcrops were selected for fracture mapping. The outcrops were chosen to cover the area spatially and geologically. The mapping was conducted along two or several orthogonal scan lines. The scan lines have N-S and E-W direction and the total length of the lines in each direction is ten metres. Only fractures with a trace length of 100 cm or longer were mapped.

The scan lines were located on outcrops where minimal stripping of soil was needed. Generally, these outcrops represent elevated areas in the terrain that contains less altered and fractured rock than what is inferred in topographically lower areas.

On each side of the scan line, 1 metre was uncovered and a measuring tape was lined up along the centre of the stripped surface. As a first step all fractures that should be measured was marked with white chalk. Then each fracture was measured (position along the scan line, strike, dip and number of endings) and scrutinised for fracture infillings and aperture. Fractures that did not cross the scan line were ignored. Fractures that crossed more than one scan line in an outcrop were measured in both scan lines. This was also reported in the comment field for each such fracture. Parallel fractures closer than c. 2 cm apart were considered as one fracture. Fractures that seem to end, but then continues along its course after a short break (shorter than c. 5 cm) were considered as one and the same fracture.

The mapped fractures were generally open or slightly eroded at the surface. Infilling minerals were normally very difficult to identify. For these reasons most fractures have no comment regarding fracture mineralogy or other infilling.

The following information has been documented at the 16 outcrops where orthogonal scan line mapping of fractures longer than 100 cm has been carried out:

- ID-code, line (LSM-number).
- ID-code, outcrop (PSM-number).
- Date.
- Coordinates for the start and end points of the lines
- Line trend.
- Line length.
- Position of crossing line.
- Number of fractures measured along the line.
- Fracture ID-numbers.
- Position of the fractures along the line, measured in metre with two decimals, from south to north (line trend 360^0) and west to east (line trend 90^0), respectively.
- Strike and dip of the fractures.
- Number of visible fracture endings (0, 1 or 2).
- Where relevant, descriptive information in free text format, including the nature of fracture filling.

4.3 Data handling

All the bedrock outcrop data that were registered during the fieldwork has been transferred into an Access database by using a programme developed by the Geological Survey of Sweden (BGDATA, version 1.7.1). Before delivery of the Access file to SKB, questions were designated in the Access file (see 5.2) in order to facilitate future treatment of the stored data in the SICADA database.

The scan line data from the fracture mapping were transferred into an Excel file that has been delivered to SKB and is stored in the SICADA database.

The results of the geochemical analyses of various rock types have been delivered to SKB as Excel files and is stored in the SICADA database.

The modal analyses of selected rock samples have been delivered to SKB and are stored in the SICADA database.

The results of the radiometric dating, i.e. isotope analyses and the obtained ages, have been delivered to the SKB and are stored in the SICADA database.

The Field Note No in SICADA to the various data sets mentioned above can be seen in Table 4-1.

The bedrock map database has been delivered to SKB as ESRI shape files and is stored in SKB GIS database (identity: SGU_SM_GEO_1872, 1873, 1874, 1875, 1876, 1877).

In addition to the above mentioned data sets, geochemical and modal analyses of samples from KSH01, KSH02 and surface reference samples to the mapping of drill cores (Boremap; AP PS 400-02-015) have been used in the characterization of the rocks from the Simpevarp subarea.

Table 4-1. Field Note No in the SICADA database.

Data	Field Note No in SICADA
Outcrop database	202
Fracture mapping	157
Geochemical analyses (surface samples)	157
Modal analyses (surface samples)	78
Geochemical and modal analyses KSH01	94
Geochemical and modal analyses KSH02	164
Geochemical and modal analyses of Boremap reference samples from the surface	34
Radiometric dating (isotope, geochemical and modal analyses of sampled rocks)	78

4.4 Analyses

In order to characterize the bedrock and obtain a correct classification of the rock types in the Simpevarp subarea, 31 representative rock samples were collected during the mapping project for subsequent analytical work, including modal and geochemical analyses and radiometric dating. The following analytical work has been performed:

- 23 modal analyses (point-counting) of thin-sections. In each thin-section 500 points were counted. This was judged to be enough in order to classify the different rock types in a QAPF diagram. The modal analyses were carried out by Mary Ekström at Ekström Mineral AB, Täby.
- 10 geochemical analyses. The analyses comprised major and trace elements, including rare earth elements (REE). The analyses were carried out at Analytica AB, Luleå by the ICP-AES and ICP-QMS analytical methods
- 2 radiometric datings, including both zircon and titanite U-Pb analyses. The isotope analyses were carried out by Per-Olof Persson at the Laboratory of Isotope Geology, Swedish Museum of Natural History, in Stockholm.

Apart from these analyses, geochemical and modal analyses from KSH01, KSH02 and analyses of Boremap reference samples from the surface have been used in order to obtain a characterization of the bedrock and classification of the rock types in the Simpevarp subarea.

All rock samples were carefully selected and prepared. Thus, surfaces that were not fresh were removed, and inhomogeneities and parts that had been subjected to any kind of visible alteration, etc. were avoided.

5 Results

5.1 Outcrop map

The fieldwork in the Simpevarp subarea confirmed that the vast majority of the outcrops that were identified by the interpretation of infrared aerial photographs showed to be exposed bedrock. However, a few of the inferred outcrops proved to be, e.g. block concentrations. Furthermore, some small outcrops that were not recognized during the interpretation of the infra-red aerial photographs were found during the field work. A revised outcrop map has been constructed (Figure 5-1), which, however, mainly is based on the revision performed in connection with the mapping of the Quaternary deposits in the Simpevarp subarea /Rudmark, 2004/. The revised outcrop map, which is extracted from the map of Quaternary deposits, has been delivered to SKB and is stored in the SKB GIS database under Field Note No 246.

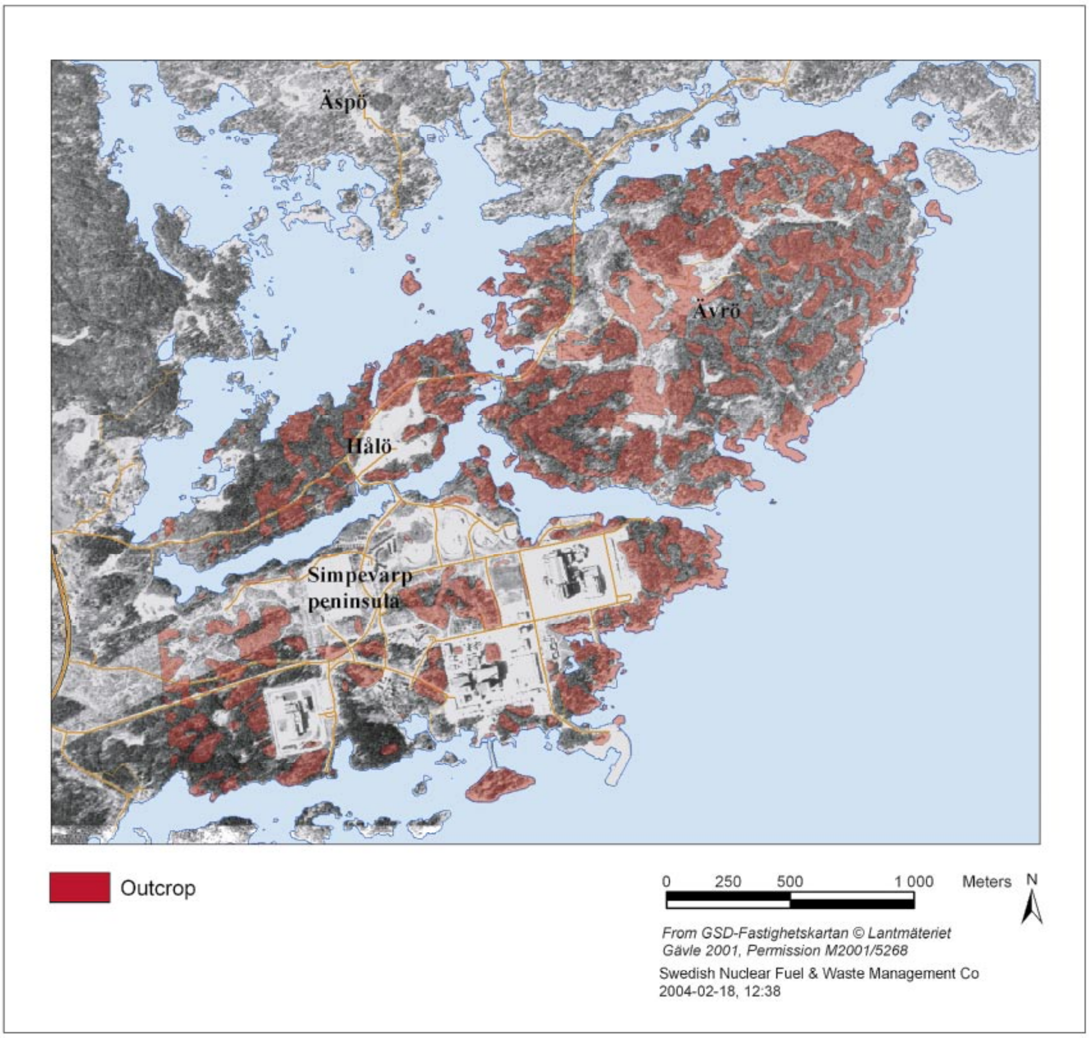

Figure 5-1. Outcrop map of the Simpevarp subarea.

5.2 Outcrop database

The outcrop data from the 353 observation points (Figure 5-2) have been stored in the outcrop database in various data tables as listed in chapter 4.2. In order to facilitate the treatment of the data, the various data has been organized as key questions in the delivered Access file according to the following grouping:

- Outcrop coordinates and date.
- Outcrop rock type, occurrence, stratigraphic position, photographs and samples.
- Outcrop rock type, texture.
- Outcrop rock type, structure.
- Outcrop rock type, groundmass grain size.
- Outcrop rock type, megacryst grain size.
- Outcrop rock type, key minerals.
- Outcrop rock type, structure orientation.
- Outcrop rock type, magnetic susceptibility.
- Observation comment (in free text form).

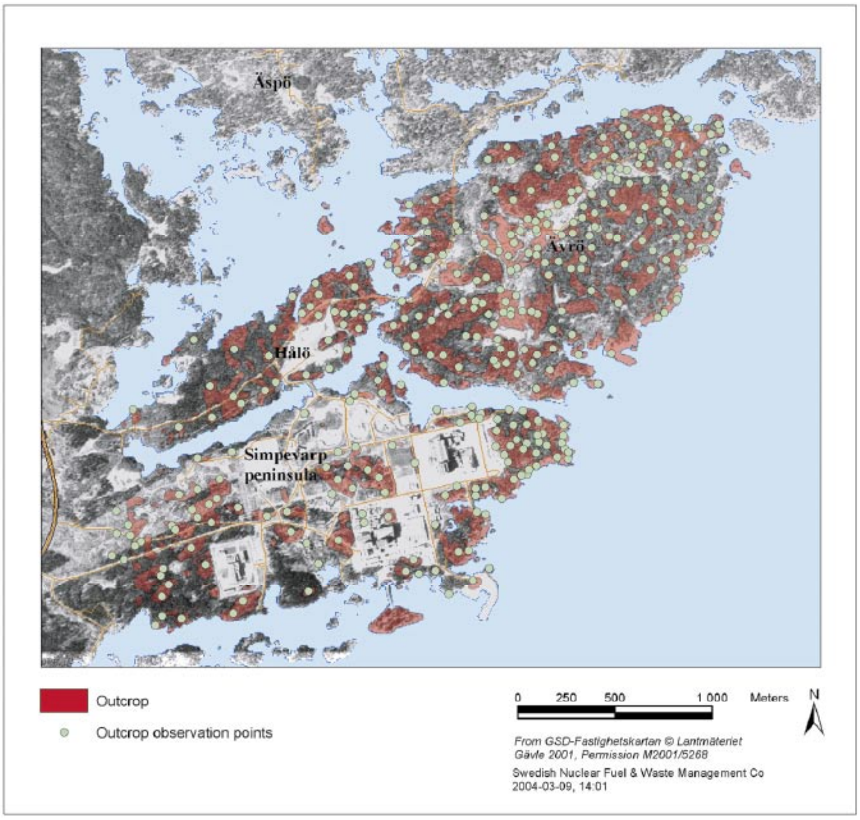

Figure 5-2. *All observation points where outcrop data have been documented.*

5.3 Fracture mapping

The 16 sites where fracture mapping has been carried out can be seen in Figure 5-3. In total 616 fractures have been measured. The average fracture frequency in the 35 scan lines is 1.9 +/-0.8 fractures per metre. It varies from a minimum of 0.60 to a maximum of 3.50 fractures per metre between the lines. A majority of the measured fractures are steeply dipping, although there probably is a bias related to the dominance of horizontal outcrops.

In Figure 5-4, inset rosette diagrams showing fracture frequency for each outcrop is displayed. Only fractures steeper than 45° have been plotted. The dip of all measured fractures can been seen in Figure 5-5. In Table 5-1 to 5-3, fracture frequency from all 16 sites and the sites at Ävrö and the Simpevarp peninsula is reported.

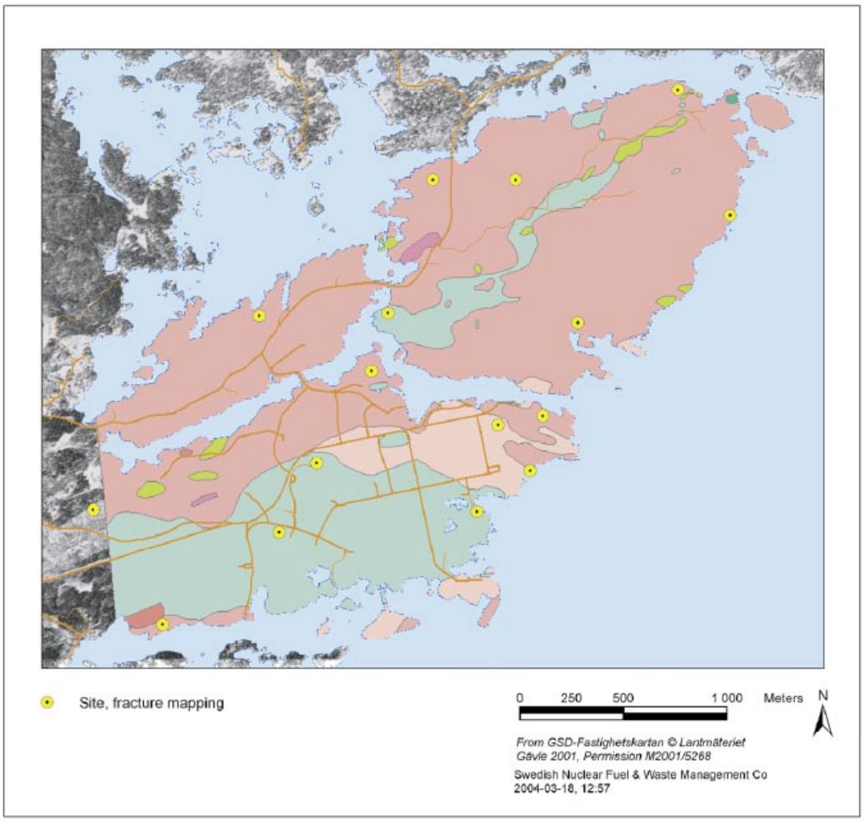

Figure 5-3. *Sites where fracture mapping has been carried out.*

Figure 5-4. Orthophoto with diagrams showing fracture strike and frequency for fractures dipping 45 degrees or more at each outcrop. Note that the frequency scale is different between outcrops.

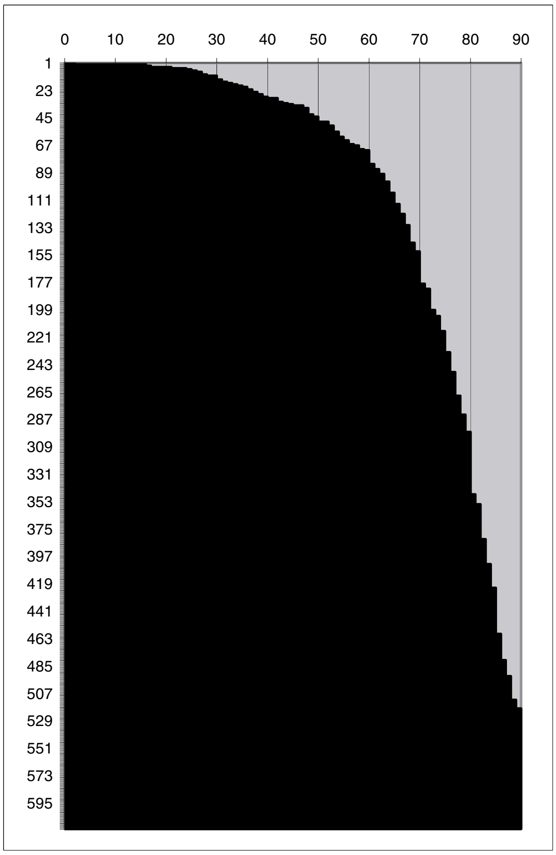

Figure 5-5. The dip of all measured fractures. Note the predominance of steep fractures. Dip in degrees on x-axis and number of fractures on y-axis.

Table 5-1. Fracture frequency (fractures/m) from the 35 lines on the 16 outcrops.

Value	Line direction 360°	Line direction 90°
Number of calculations of fracture frequency	18	17
Maximum value (fractures/m)	3.30	3.50
Minimum value (fractures/m)	0.70	0.60
Mean value (fractures/m)	2.03	1.74
Standard deviation (fractures/m)	0.75	0.89
Median value (fractures/m)	2.10	1.60
Number of fractures measured	330	286

Table 5-2. Fracture frequency (fractures/m) from 6 outcrops at Ävrö, which corresponds to the northeastern part of the Simpevarp subarea.

Value	Line direction 360°	Line direction 90°
Number of calculations of fracture frequency	6	6
Maximum value (fractures/m)	2.60	2.40
Minimum value (fractures/m)	0.70	0.60
Mean value (fractures/m)	2.02	1.53
Standard deviation (fractures/m)	0.71	0.67
Median value (fractures/m)	2.25	1.55
Number of fractures measured	121	92

Table 5-3. Fracture frequency (fractures/m) from 9 outcrops in Simpevarp peninsula.

Value	Line direction 360°	Line direction 90°
Number of calculations of fracture frequency	11	10
Maximum value (fractures/m)	3.30	3.50
Minimum value (fractures/m)	0.80	0.67
Mean value (fractures/m)	2.13	1.87
Standard deviation (fractures/m)	0.76	1.05
Median value (fractures/m)	2.10	1.55
Number of fractures measured	199	177

Fracture orientations have been plotted in five separate stereograms (Appendix A), displaying the variation between different parts and dominant rock types in the Simpevarp subarea.

5.4 Geochemical analyses

Geochemical analyses have been carried out of 31 rock samples from the surface that represent both dominant and subordinate rock types, including 21 reference samples to the Boremap mapping. The latter samples were collected during the autumn 2002 (AP PS 400-02-015, SKB internal controlling document)). The distribution of sample localities in the subarea is displayed in Figure 5-6.

The geochemical classification of the rock types in the TAS classification diagram of Middlemost /1994/ and the classification diagram of Debon and LeFort /1983/ can be seen in Figures 5-7 and 5-8, respectively. The results of the geochemical analyses are stored in the SICADA database. For Field Notes No in SICADA, see Table 4-1.

According to the International Union of Geological Sciences /LeMaitre, 2002/, the classification of rocks should be based on the modal composition. Thus, the above diagrams should not be used strictly for classification purposes, but merely as an indication of the compositional trend of the different rock types.

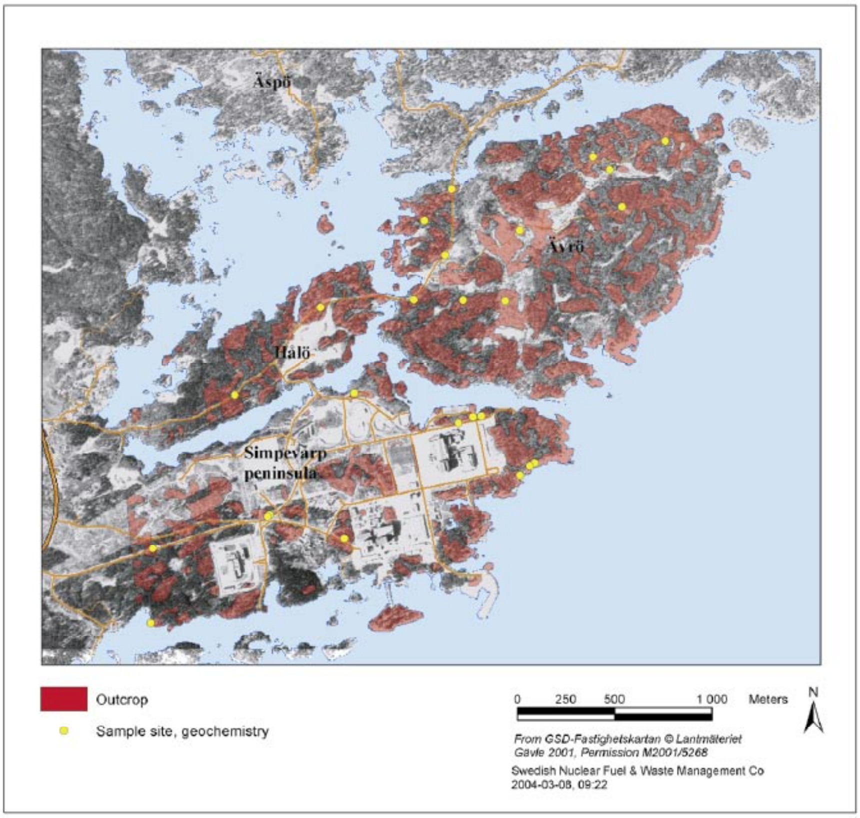

Figure 5-6. *Sites where rocks have been sampled for geochemical analyses.*

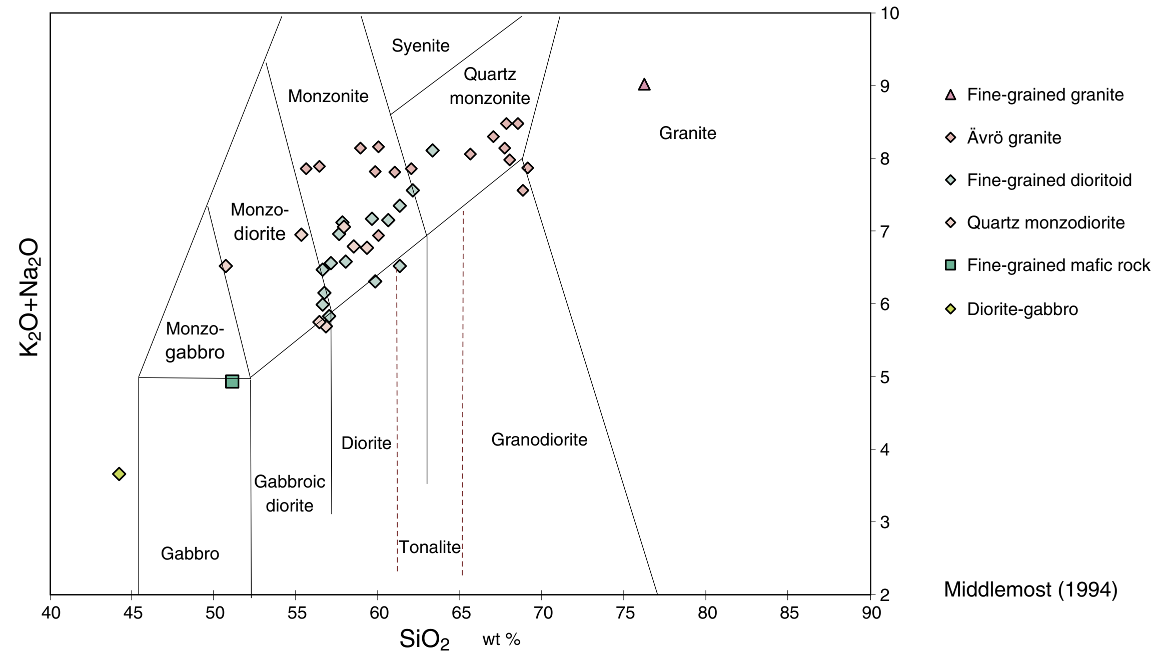

Figure 5-7. *Geochemical classification of rocks from the Simpevarp subarea according to Middlemost /1994/. In the diagram, analyses from KSH01 and KSH02 are also included.*

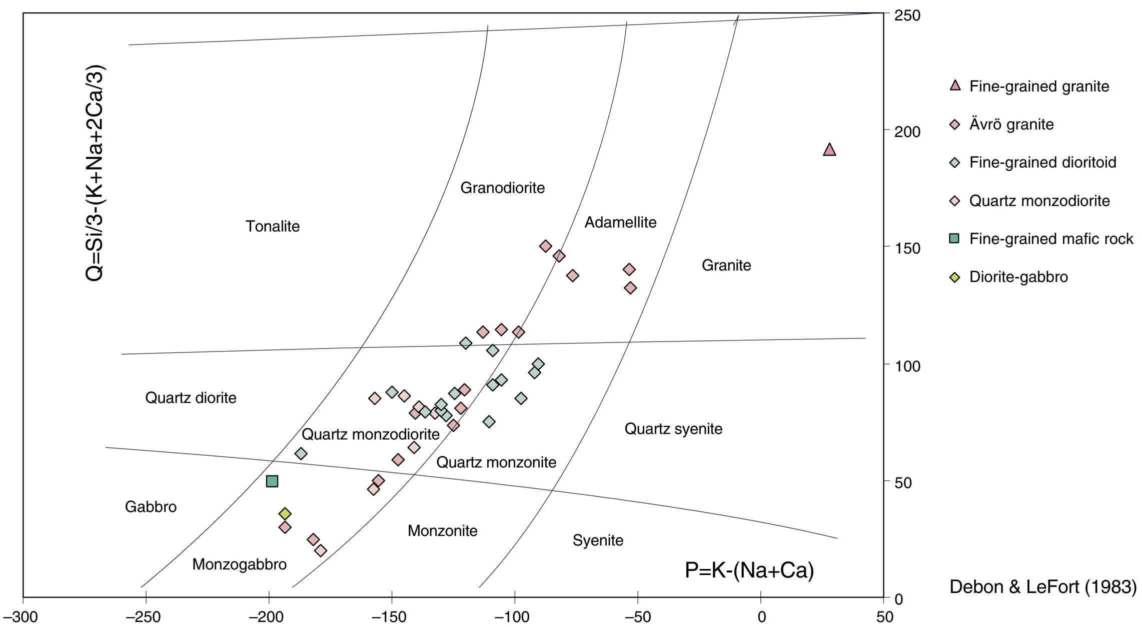

Figure 5-8. *Geochemical classification of rocks in the Simpevarp subarea according to Debon and Le Fort /1983/. In the diagram, analyses from KSH01 and KSH02 are also included.*

5.5 Modal analyses

Modal analyses have been carried out on 23 rocks that were sampled during the bedrock mapping. In addition, 23 modal analyses exist from the Boremap reference samples. The sample sites is displayed in Figure 5-9. In the QAPF modal classification diagram /Streckeisen, 1976, 1978/ in Figure 5-10, 8 modal analyses from KSH01, 9 from KSH02 and 5 from KSH03 are also included. Thus, 68 modal analyses in total are displayed in the QAPF-diagram, and the compositional variation of the various rock types is displayed. The results of the modal analyses are stored in the SICADA database. For Field Notes No in SICADA, see Table 4-1.

The QAPF modal classification of individual rock types is displayed in the Appendix B.

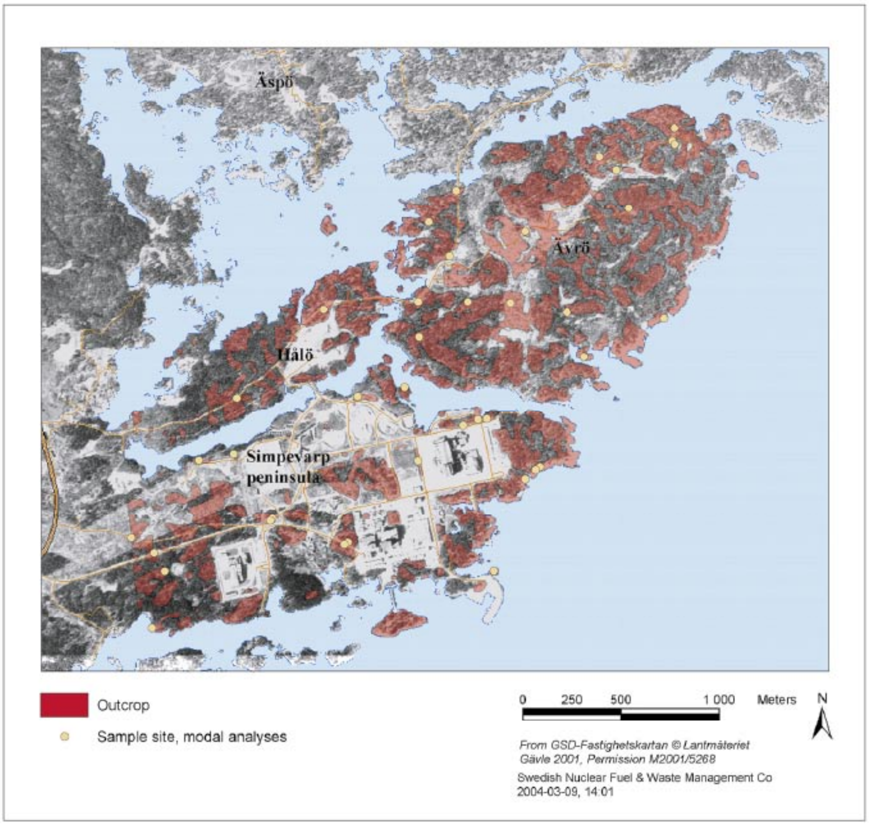

Figure 5-9. *Sites where rocks have been sampled for modal analyses.*

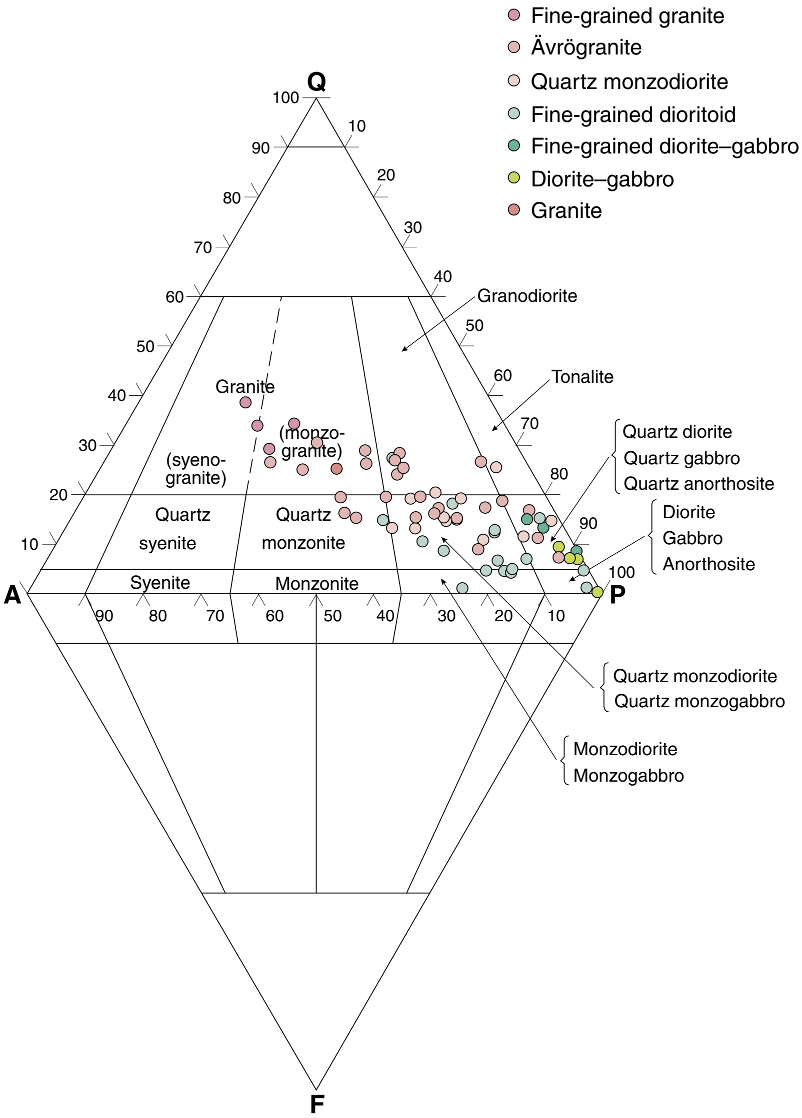

Figure 5-10. *QAPF modal classification of analyzed rock types in the Simpevarp subarea. Analyzed samples from KSH01, KSH02 and KSH03 are also included in the diagram.*

5.6 Bedrock map

As a result of the bedrock mapping that was carried out in the Simpevarp subarea during 2003, an updated bedrock map has been compiled at the scale 1:10 000 /cf. Kornfält and Wikman, 1987/. Due to overlapping magnetic susceptibility values for the dominant rock types (Figure 5-11), the magnetic anomaly map has been of limited value what concerns the delimitation of the dominant rock types. The bedrock map is displayed in a reduced scale in Figure 5-12.

5.6.1 Rock types

As is evident from Figure 5-12, the Simpevarp subarea is dominated by three rock types:

- Fine-grained dioritoid (intermediate magmatic rock).
- Ävrö granite (granite to quartz monzodiorite), generally porphyritic.
- Quartz monzodiorite (quartz monzonite to monzodiorite), equigranular to weakly porphyritic.

As can be seen in the geochemical and QAPF classification diagrams (see above), the dominant rock types in the Simpevarp subarea display similar and overlapping compositional variations. Therefore, the most important criteria in distinguishing between the different rock types are texture and grain size:

- Dioritoid: fine-grained, unequigranular (megacryst-bearing).
- Ävrö granite: medium-grained and porphyritic to varying degree.
- Quartz monzodiorite: medium-grained, equigranular.

The fine-grained dioritoid dominates the southern part of the Simpevarp peninsula, and occupies the central part of Ävrö island as a NE-trending, narrow, winding belt. Furthermore, it occurs as minor bodies and inclusions (Figures 5-12 and 5-13) in the Ävrö granite and the quartz monzodiorite. The fine-grained dioritoid is grey and commonly unequigranular with up to 3 mm large (exceptionally 5 mm) megacrysts of hornblende and plagioclase (see Figure 5-14). Locally, megacrysts of pyroxene and biotite also occur. However, the pyroxene is generally more or less altered to hornblende. Thus, most of the hornblende megacrysts are inferred to be secondary after pyroxene.

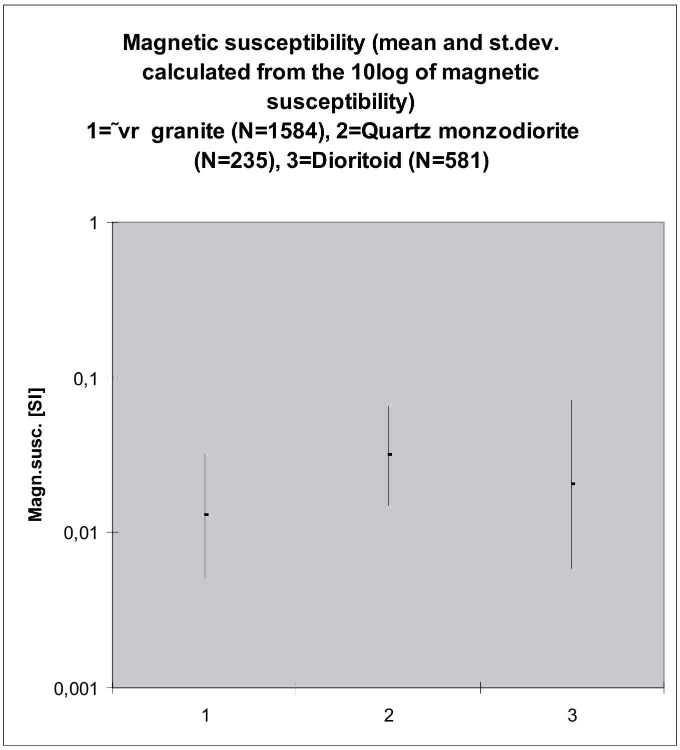

Figure 5-11. *Magnetic susceptibility of the dominant rock types. Based on field measurements during bedrock mapping.*

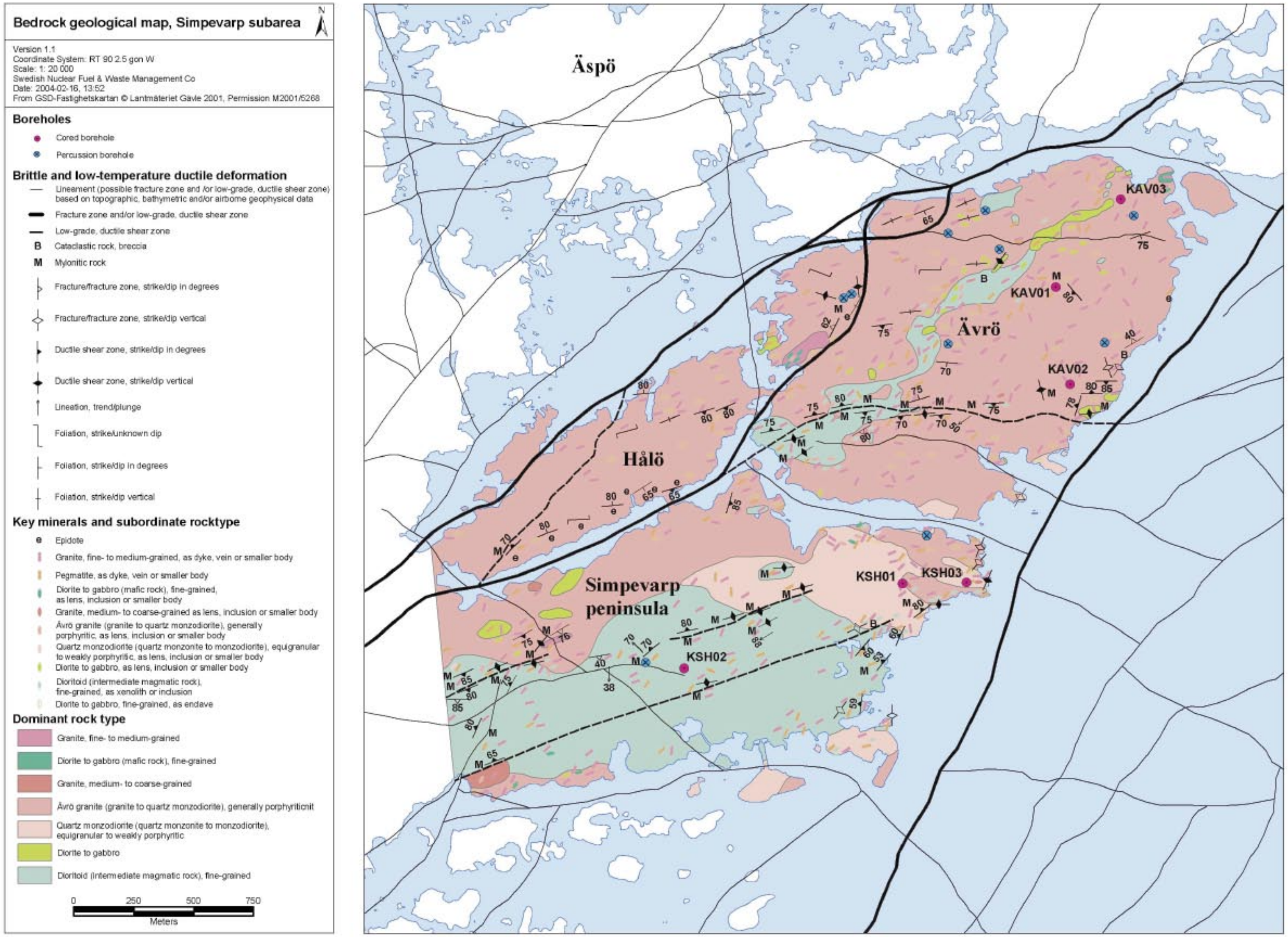

Figure 5-12. *Bedrock map of the Simpevarp subarea. The linked lineaments are extracted from Triumf /2004/.*

Figure 5-13. *Inclusion of fine-grained dioritoid in quartz monzodiorite.*

Figure 5-14. *Fine-grained dioritoid with megacrysts of hornblende (dark grains) and plagioclase (white to light grey grains).*

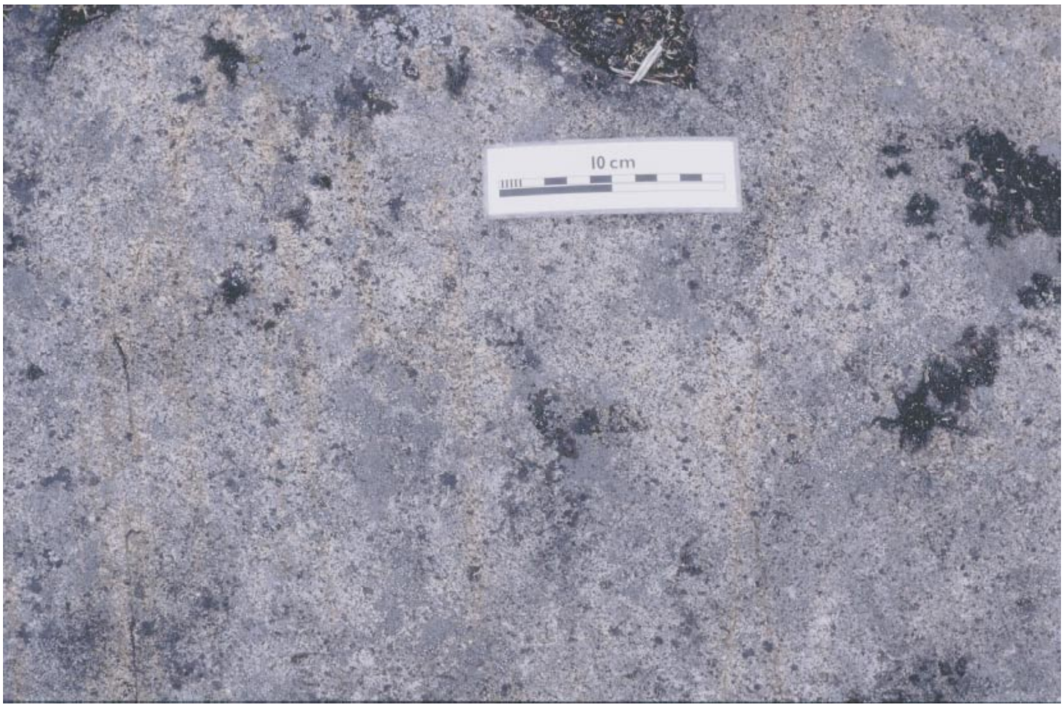

Figure 5-15. *Inhomogeneously coarsened, fine-grained dioritoid.*

A characteristic feature in the fine-grained dioritoid is an inhomogeneous coarsening in cm-m scale (Figure 5-15). It appears as diffusely delimited vein-like aggregates and patches. The coarsening makes the fine-grained dioritoid resemble the quartz monzodiorite, and consequently, these two rock types are occasionally difficult to distinguish from each other. In such cases, the overall impression is the basis for the judgement whether the rock should be classified as a dioritoid or quartz monzodiorite.

The contacts between the dioritoid and the country rocks are usually gradual, but locally the contact is sharp (Figure 5-16).

The quartz monzodiorite mainly occurs in the eastern part of the Simpevarp peninsula and neighbouring parts in southernmost Ävrö (see Figure 5-12). It is grey to reddish grey, medium-grained, commonly equigranular (Figure 5-16) and has a relatively restricted compositional range (see Figures 5-7, 5-8 and 5-10), which is similar to that of the fine-grained dioritoid. Transitional varieties between typical quartz monzodiorite and fine-grained dioritoid occur, which further strengthens the close relationship between these two rock types.

Ävrö granite is a collective name for a suite of more or less porphyritic rocks that vary in composition from quartz monzodiorite to granite, including quartz dioritic, granodioritic and quartz monzonitic varieties (see Figures 5-7, 5-8 and 5-10). It is the dominating rock type in the northern part of the Simpevarp peninsula, Hålö and Ävrö. The Ävrö granite is reddish grey to greyish red, medium-grained and the phenocrysts are usually 1-2 cm in size but scattered larger phenocrysts do occur (Figure 5-17). A characteristic feature in the Ävrö granite is the occurrence of scattered cm to 0.5 m large enclaves of intermediate to mafic composition (Figure 5-18).

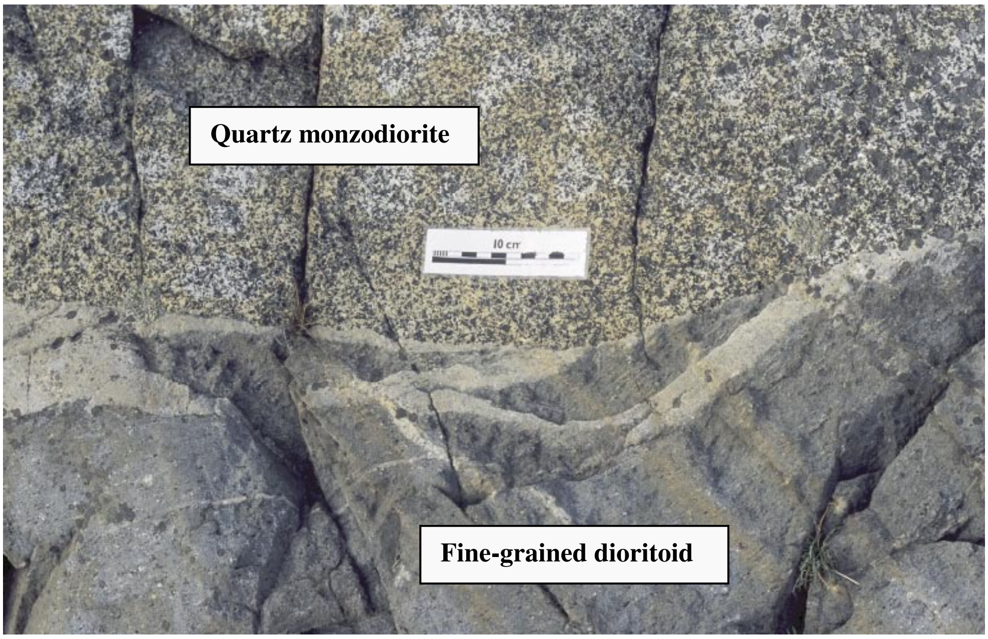

Figure 5-16. *Contact between fine-grained dioritoid and quartz monzodiorite.*

Figure 5-17. *Sparsely porphyritic Ävrö granite.*

Figure 5-18. *Enclave in Ävrö granite. Note the red staining along the sealed fracture.*

In the easternmost part of the Simpevarp peninsula, the quartz monzodiorite is intimately mixed and mingled with the Ävrö granite. This is also evident in the cored borehole KSH01. Gradual contact relationships are characteristic and strongly indicate that the quartz monzodiorite and the Ävrö granite formed more or less synchronously.

Diorite to gabbro occur as scattered, minor bodies (Figure 5-12). They usually display mixing and mingling relationships with the country rock. Furthermore, red to greyish red, medium- to coarse-grained granite occur, both as minor bodies in the western part of the subarea, but also as diffusely delimited small occurrences in the Ävrö granite (Figure 5-12).

A characteristic feature in the Simpevarp subarea is the frequent occurrence of fine- to medium- grained granite, usually as dykes but also as veins and minor bodies (Figures 5-12 and 5-19). Locally, a fine-grained intermediate to mafic rock (diorite to gabbro) occurs as sheets, dykes or minor bodies. Generally, it is net-veined by fine-grained granite, and, thus, they constitute composite intrusions (dykes).

Pegmatite is also frequently occurring (Figures 5-12 and 5-19), and pegmatite cross-cutting granitic dykes and vice versa is observed. Consequently, at least two generations of fine- to medium-grained granite as well as pegmatite occur in the area. However, they are all interpreted to belong to the waning stages of the igneous activity that formed the majority of the rocks in the region.

The QAPF modal classification of individual rock types is displayed in Appendix B.

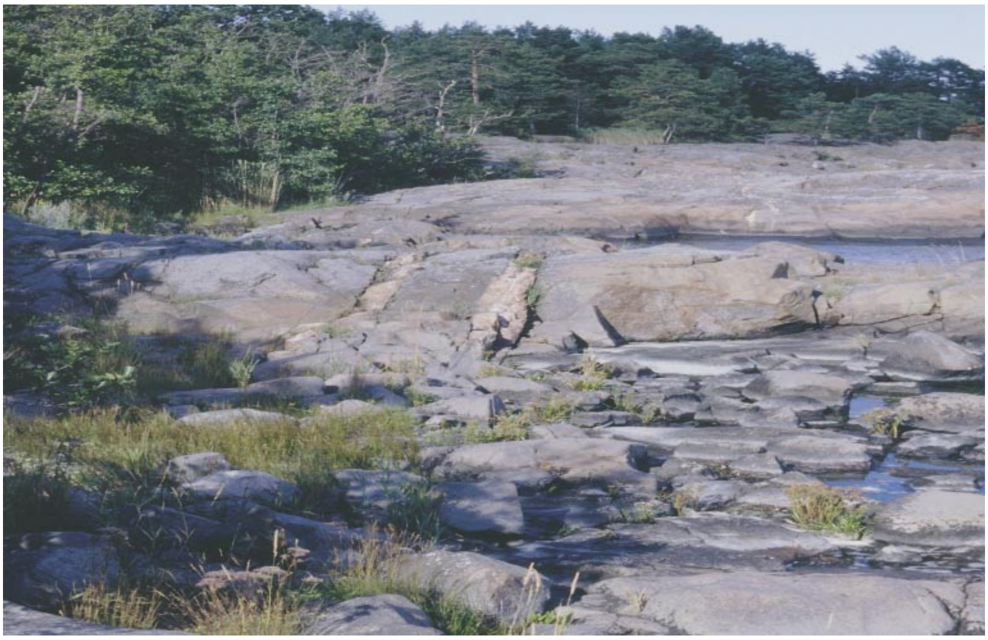

Figure 5-19. *Dykes of fine- to medium-grained granite and pegmatite.*

5.6.2 Structures

The rocks in the Simpevarp subarea are generally well-preserved and more or less isotropic, but, locally, a weak foliation is developed. However, mesoscopic low-grade shear zones of the same character as the Äspö shear zone are documented in several outcrops. The width varies between a decimetre and several metres and the shear zones are characterized by strong protomylonitic to mylonitic foliation (Figures 5-20 and 5-21). The dip is subvertical to vertical and the majority of the observed shear zones have E-W to NE strike. Kinematic indications suggest that they are characterized by a sinistral strike-slip and a south-side-up dip-slip component. The alignment of some of the observed shear zones implies that they form part of one and the same zone of local major character (see Figure 5-12).

Linked lineaments /Triumf, 2004/ that have been delivered to SKB are also shown in the bedrock map (Figure 5-12). Some of these lineaments are known to constitute deformation zones /cf. SKB, 2002/, but, based on available information, only those lineaments that encompass the Simpevarp subarea have been upgraded to fracture zones and/or low-grade ductile shear zones in the present compilation of the bedrock map.

Figure 5-20. *Dm-wide, low-grade ductile shear zone in Ävrö granite.*

Figure 5-21. *Low-grade ductile shear zone in fine-grained dioritoid (west of CLAB).*

5.6.3 Alteration

A characteristic phenomenon in the Simpevarp subarea is an extensive, inhomogeneous, red staining (oxidation) of the bedrock (Figures 5-22 and 5-23). The red staining might at least partly have obliterated the primary magnetization of the dominant rock types and caused an inhomogeneouos oxidation. The latter is inferred to be the main cause for the overlapping magnetic susceptibility values recorded for the dominant rock types (see Figure 5-11). The red staining is caused by hydrothermal processes of secondary nature, and is principally concentrated along fractures. However, in many places the red staining has affected also the rock volumes in between mesoscopic fractures. Numerous, small-scale, sealed fractures occur in these rock volumes, and presumably these fractures acted as channels for the penetrating hydrothermal fluids. The most common mineral infilling that can be identified macroscopically in mesoscopic fractures is epidote, but quartz, calcite and chlorite are also observed. A white to greyish white, fine-grained infilling is common in fractures that are spatially related to the red staining. This infilling is supposed to be dominated by prehnite (Figure 5-22). The mineral infilling in fractures has not been marked on the bedrock map of editorial reasons. What concerns the documentation of mineral infilling in sealed fractures, the reader is referred to the outcrop database.

The red staining alteration process has been studied in the drillcore from KSH01A and B /Drake et al., 2004; cf. Eliasson, 1993/, but the study will be extended in an ongoing project (Tullborg, in progress). The first results from KSH01A and B indicates several generations of alteration and mineral infilling, starting during ductile conditions and continuing during successively more brittle conditions.

Along the southern shore of Hålö, the Ävrö granite displays an increased content of epidote in the groundmass (Figure 5-12), locally also chlorite, and a reddish staining. This is indicative of a hydrothermal alteration that presumably is related to the deformation zone between Hålö and the Simpevarp peninsula.

Even though the rock types in the Simpevarp subarea are structurally relatively well-preserved, many of the rocks have suffered from a low-grade, metamorphic alteration. This alteration is difficult to discover in handspecimen, but under the microscope a more or less strong sericitization and/or saussuritization of plagioclase is common and also an incipient to more or less thorough chloritization of biotite.

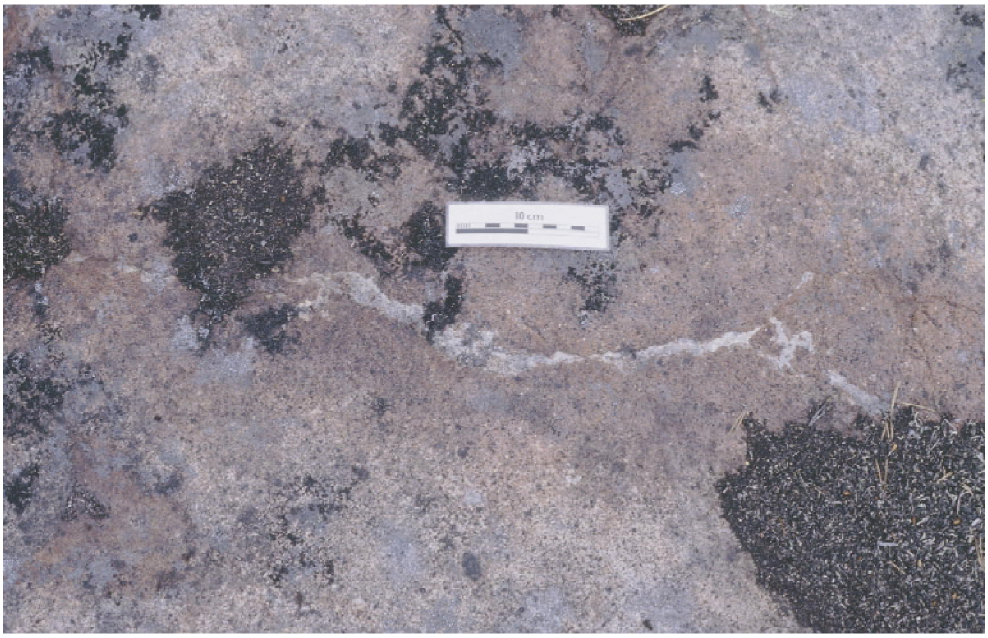

Figure 5-22. *Red staining along a sealed fracture in fine-grained dioritoid. The mineral infilling is supposedly dominated by prehnite.*

Figure 5-23. *Red staining in Ävrö granite.*

5.7 Radiometric dating

In connection with the bedrock mapping, the Ävrö granite and the quartz monzodiorite were sampled for U-Pb zircon and titanite dating. The Ävrö granite was sampled at the stripped outcrop at the site for the cored borehole KAV01, and the quartz monzodiorite was sampled in a roadcut north of the OIII reactor, in the eastern part of the Simpevarp peninsula.

Zircon and titanite was analyzed in both samples. The Ävrö granite yielded an upper intercept zircon and titanite age of 1800±4 Ma, and the quartz monzodiorite yielded an upper intercept zircon age of 1802±4 Ma and a slightly younger titanite upper intercept age of 1793±4 Ma (Figure 5-24). The obtained ages are in good agreement with earlier reported ages for intrusive rocks in the neighbouring region (Table 5-4). Included in the table are also the Götemar type of granite intrusions which, however, are distinctly younger.

For description of the analyzed zircons and titanites, see Appendix C.

The results of the isotope analyses and the obtained ages have been delivered to the SKB and are stored in the SICADA database. For field note in SICADA, see Table 4-1.

Table 5-4. Radiometric ages for intrusive rocks in the Simpevarp region.

Rock type	Northing	Easting	Depth	U-Pb zircon age	Reference
Fine-grained granite	6367111.8	1551572.7	-124.8	1794 + 16/-12 Ma	Kornfält et al. (1997), Wikman & Kornfält(1995)
Fine-grained granite	6367985.2	1551588.6	-395.7	1808 + 33/-30 Ma	Kornfält et al. (1997), Wikman & Kornfält(1995)
Äspö diorite	6367669.2	1551455.3	-318.4	1804 ± 3 Ma	Kornfält et al. (1997), Wikman & Kornfält(1995)
Uthammar granite	636207	154827		1441 + 5/-3 Ma	Åhäll (2001)
Jungfru granite	63473	12590		1441 ± 2 Ma	Åhäll (2001)
Götemar granite	637280	154980		1452 +11/-9 Ma	Åhäll (2001)
Gersebo granite	637310	155148		1803 ± 7 Ma	Åhäll (2001)
Virbo granite	6353848	1543959		1790 Ma	Bergman et al. (2000)
Quartz monzodiorite	6366200	1552295		1802±4 Ma	This study
Quartz monzodiorite	6366200	1552295		1793±4 Ma (titanite)	This study
Ävrö granite	6367281	1553063		1800±4 Ma (zircon+titanite)	This study

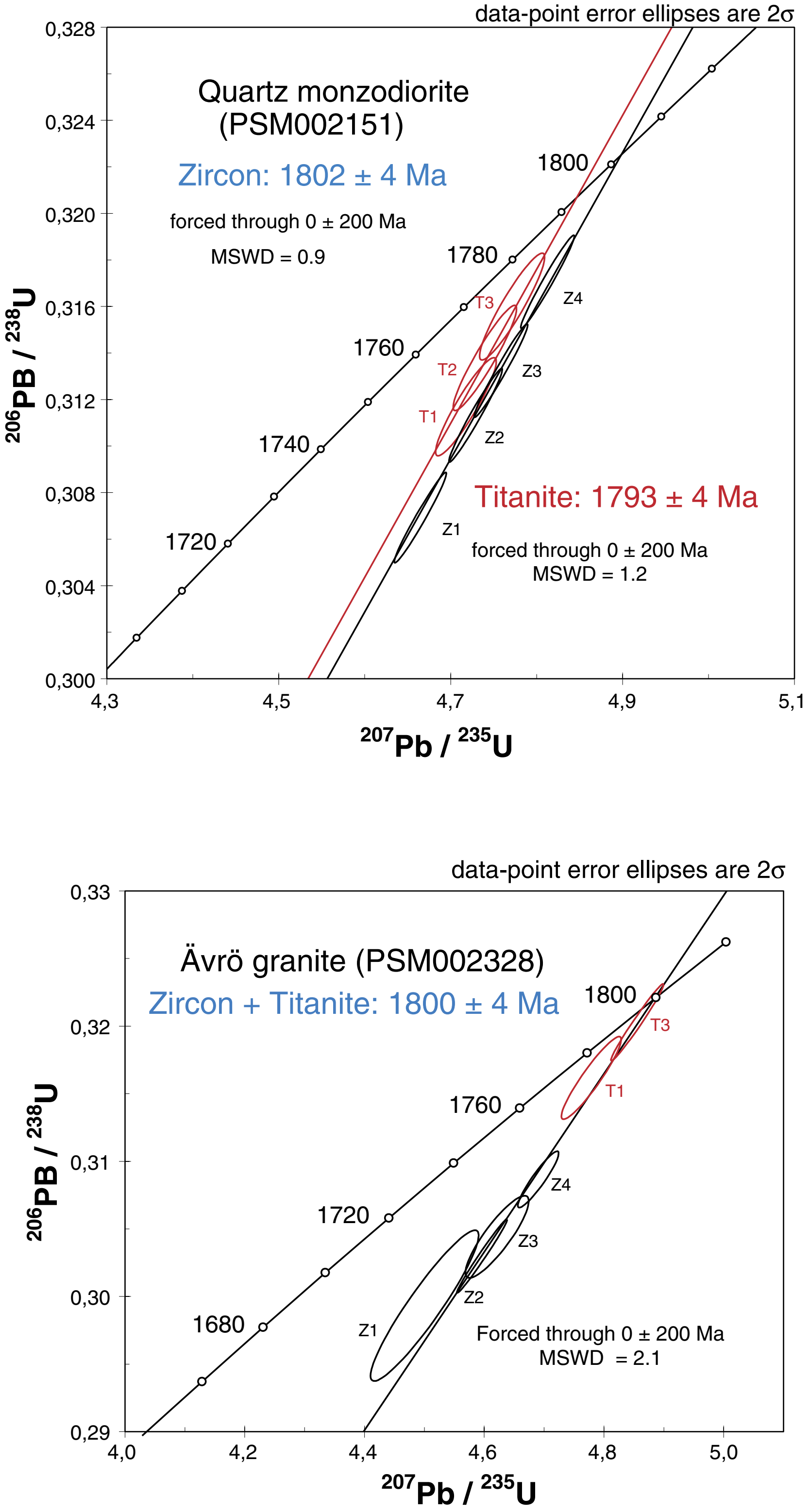

Figure 5-24. *Concordia diagrams for the quartz monzodiorite and the Ävrö granite.*

5.8 Discussion

In the outcrop database, most of the information is of descriptive character and is based on an interpretation of what the geologist can see in the outcrop. This is in contrast to e.g. results of the geochemical analyses, structural measurements in the outcrop, measurements of the magnetic susceptibility, and the geophysical data that is generated by the airborne measurements. In connection with the compilation of the bedrock map, all the different data sets are evaluated together and integrated in order to generate a bedrock map. The latter is a 2D-model of the bedrock at the Earths surface.

The fine-grained dioritoid has traditionally been classified as a volcanic rock of dacitic to andesitic composition (SKB, 2002 and references therein). However, except for being fine-grained, no characteristic criteria that the rock should be of volcanic origin were found during the bedrock mapping. An alternative interpretation is that the rock constitutes a high-level intrusion that subsequently was intruded by its parent magma, which is represented by the neighbouring quartz monzodiorite in the country rock. The characteristic, inhomogeneous coarsening in the fine-grained dioritoid is inferred to be a late-magmatic phenomenon, presumably due to a thermal input during the emplacement of the quartz monzodiorite and possibly also the Ävrö granite. The uncertainty in the interpretation of the origin of the fine-grained dioritoid is the primary cause to the present more neutral classification as a dioritoid. However, this does not exclude that the rock might be of volcanic origin.

The mixing and mingling relationships and diffuse contacts between the dominant rock types in the Simpevarp subarea strongly indicate that the latter are formed more or less synchronously. This is confirmed by the obtained ages for the quartz monzodiorite and the Ävrö granite. However, based on field relationships, the following chronostratigraphy can be established for the dominant and subordinate rock types:

- Fine- to medium-grained granite and pegmatite. Youngest
- Fine-grained to mafic rock.
- Medium- to coarse-grained granite.
- Ävrö granite.
- Quartz monzodiorite.
- Diorite to gabbro.
- Fine-grained dioritoid. Oldest

The occurrence of low-grade-ductile shear zones in the Simpevarp subarea implies that ductile deformation was active after, and possibly also during the emplacement of the magmatic rocks. In Figure 5-25 it is evident that the area east of the Äspö shear zone is characterized by a more banded magnetic anomaly pattern than the area west of the Äspö shear zone. The banded anomaly pattern east of the Äspö shear zone is inferred to reflect a higher frequence of spaced, low-grade ductile shear zones in this area. Based on field observations and the magnetic anomaly pattern, a possible working model at the present stage is that the Simpevarp subarea forms part of a low-grade ductile shear belt.

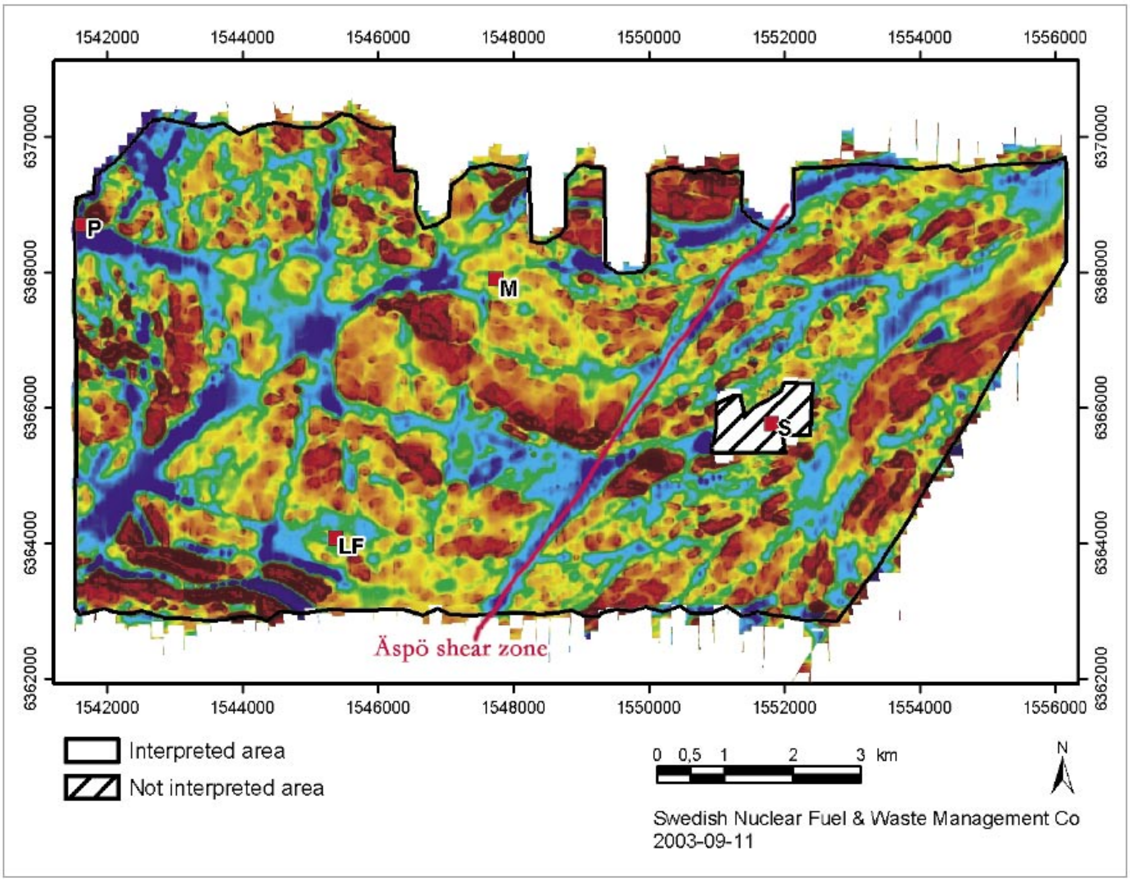

Figure 5-25. *Map of the total magnetic field after reduction to the pole and subtraction of the field from an upward continuation of 250 m /Triumf et al., 2002/. S=Simpevarp, M=Mederhult, LF=Lilla Fjälltorpet, P=Plittorp.*

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Appendix A

Fracture mapping

The fracture orientation is displayed in Figures A-1 – A-6. In Figure A-1 all fractures from the 16 outcrops (35 lines) have been plotted, including those where the dip has been estimated. The difference from the distribution of fracture orientation when these fractures are omitted is only marginal. The fractures also have been subdivided in different ways. In Figure A-2, A-3 and A-4 the fracture orientation in the three dominant rock types have been separated and in Figure A-5 and A-6 the outcrops at the Ävrö Island and Simpevarp peninsula, respectively, have been plotted. The single outcrop at Hålö was left out since it is judged that data from a single outcrop is not enough to be statistically representative for the Hålö part of the subarea. The bedrock at Ävrö is dominated by Ävrö granite (granite to quartz monzodiorite), whereas the Simpevarp peninsula is dominated by fine-grained dioritoid (southern part), quartz monzodiorite (eastern part) and Ävrö granite (northern part).

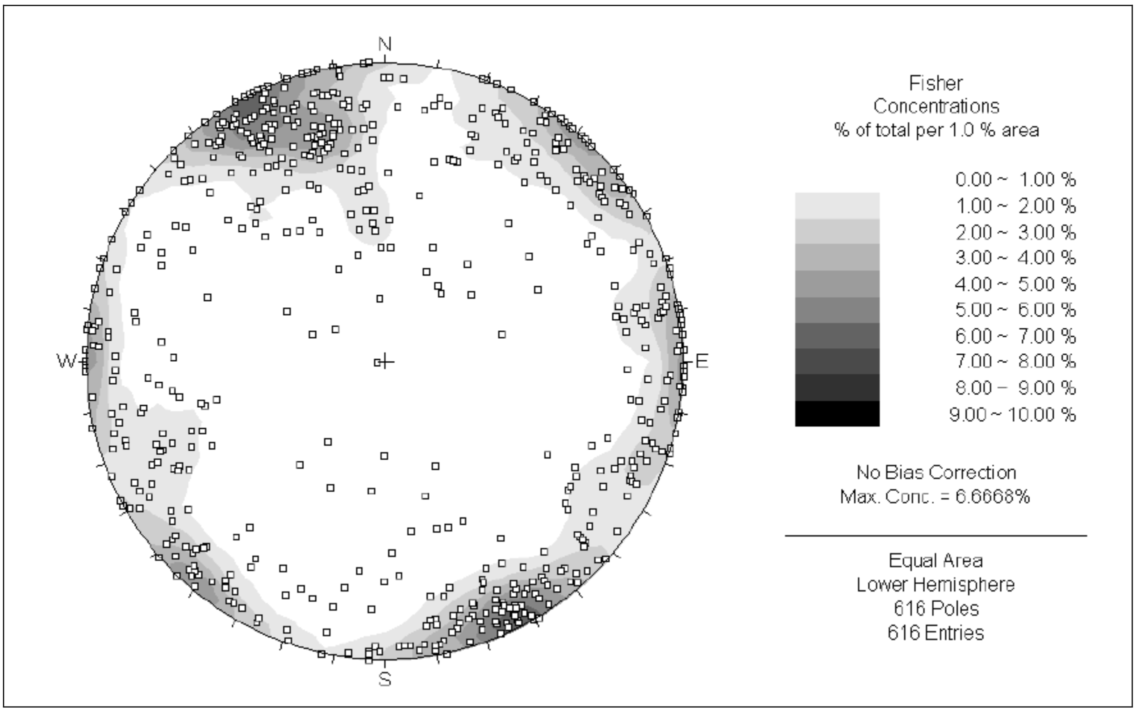


Figure A-1 *Fracture orientation for all fractures*

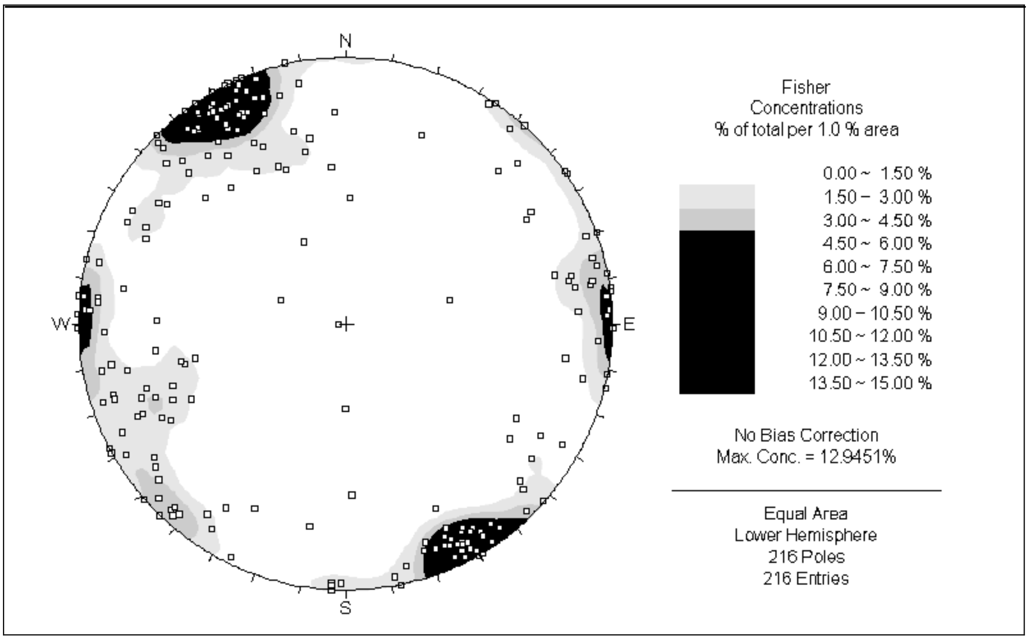


Figure A-2 *Fracture orientation in fine-grained dioritoid*

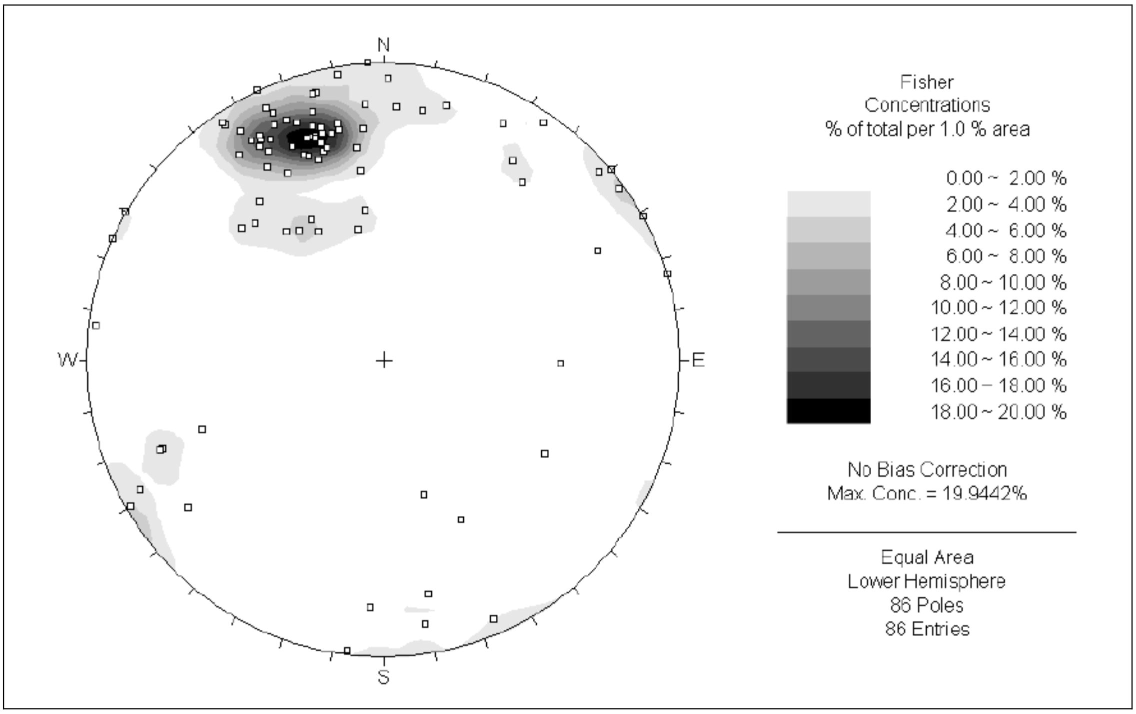


Figure A-3 *Fracture orientation in quartz monzodiorite*

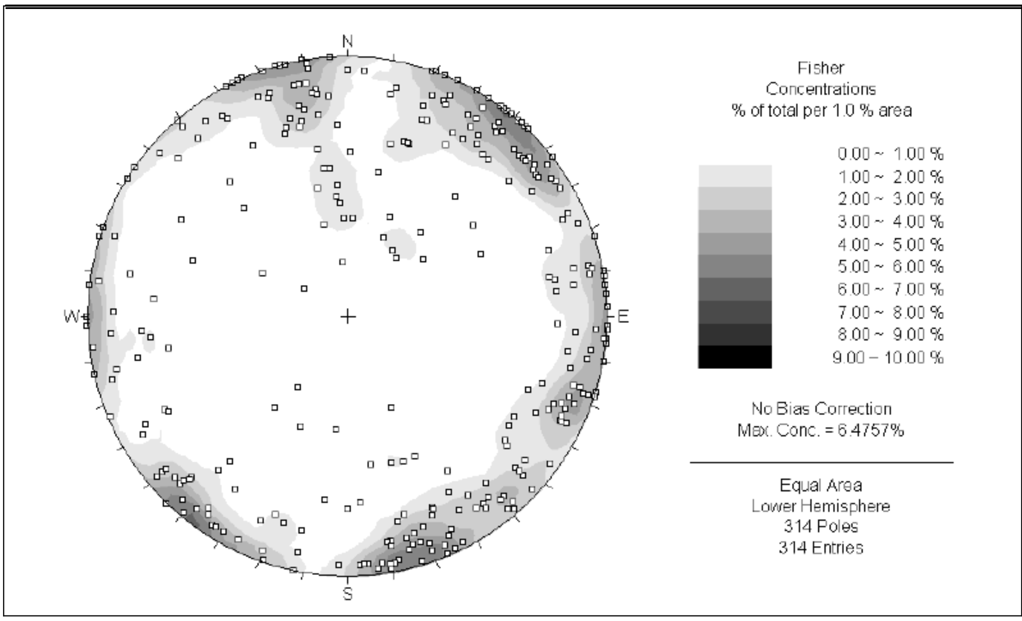


Figure A-4 *Fracture orientation in Ävrö granite*

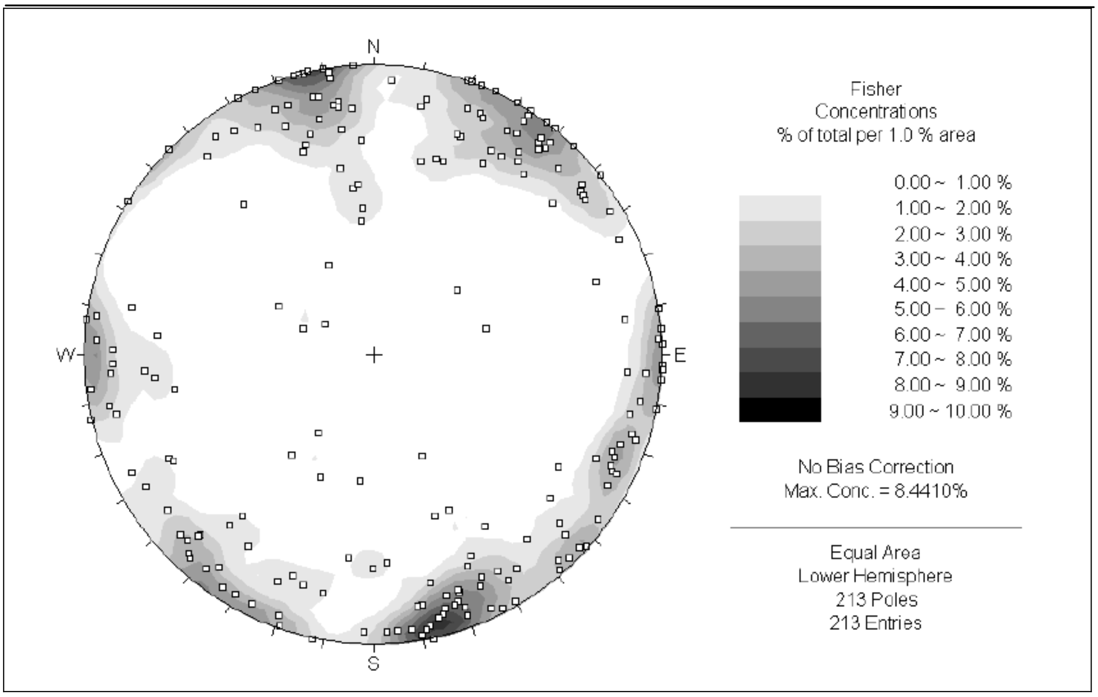


Figure A-5 *Fracture orientation on the Ävrö Island.*

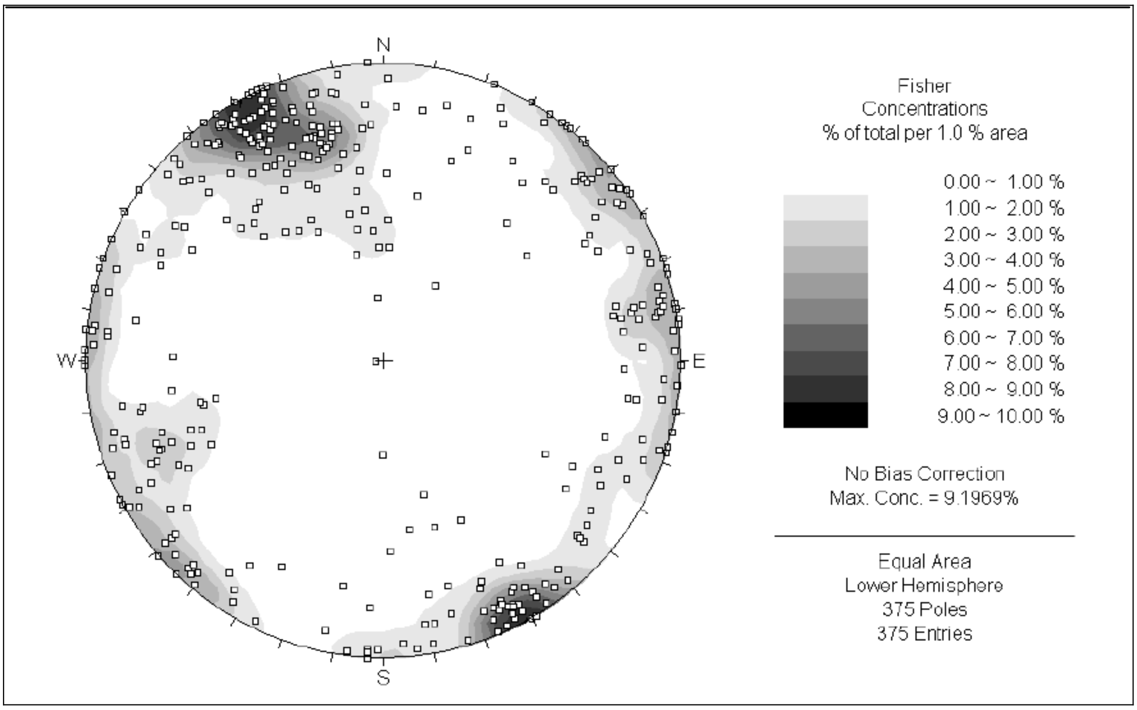
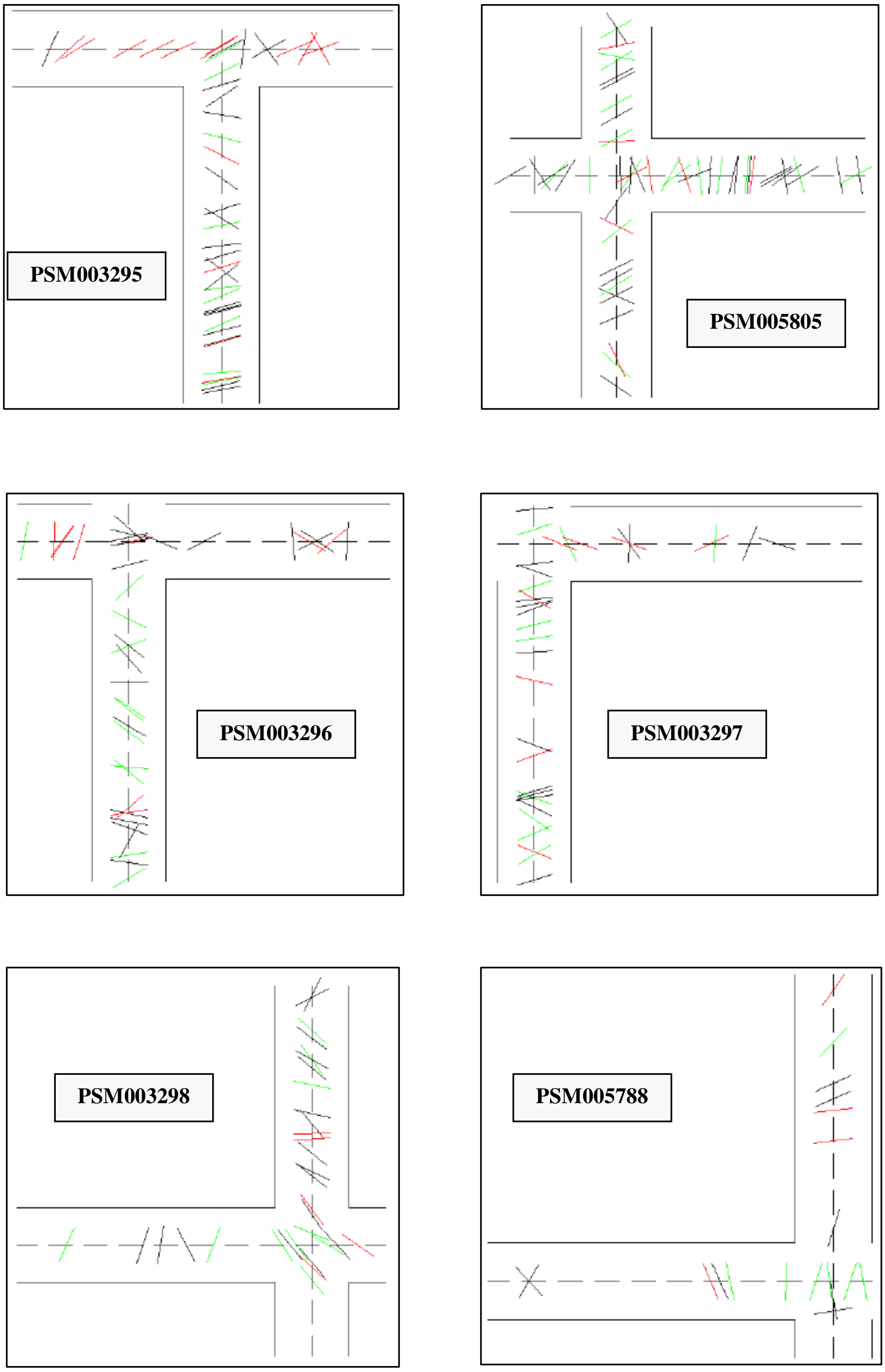
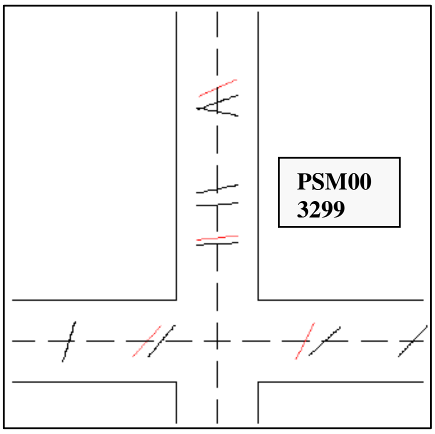


Figure A-6 *Fracture orientation on the Simpevarp peninsula.*

On the following pages, sketch maps of the mapped fractures at each outcrop are shown (Figure A-7).

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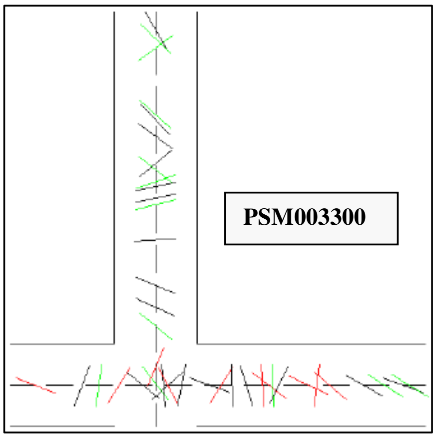
3299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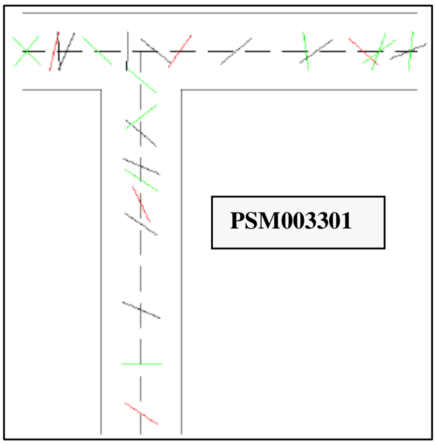
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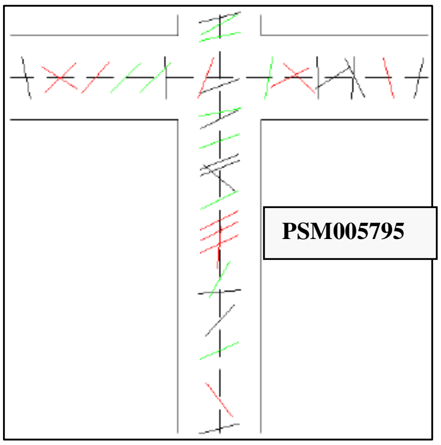
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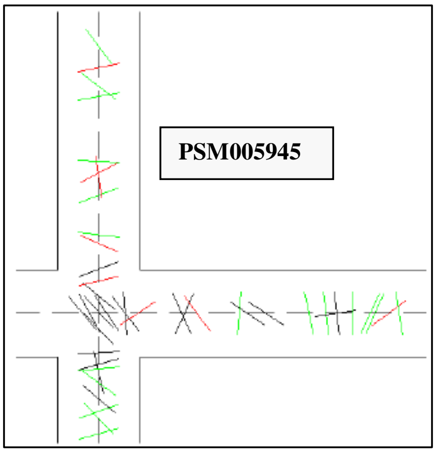
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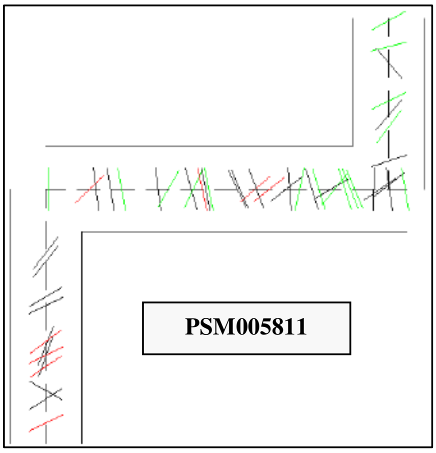
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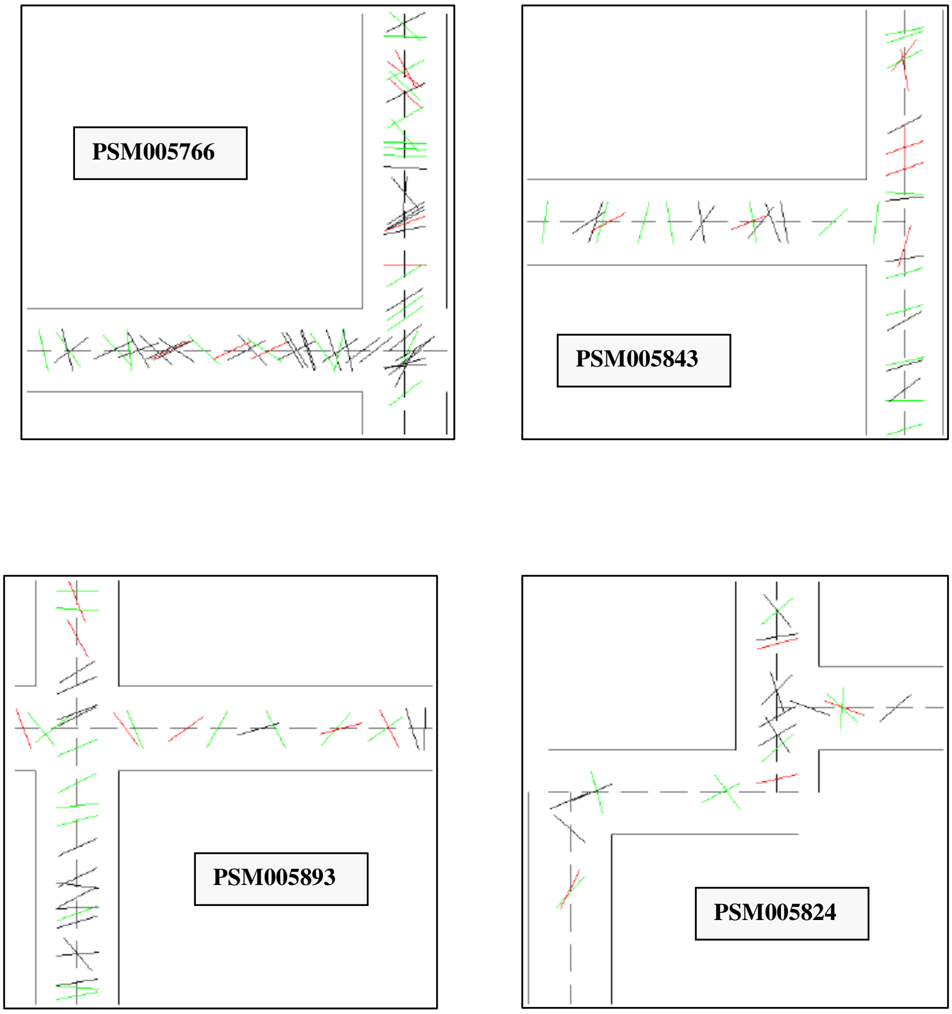


Figure A-7. *Sketches over each outcrop. The PSM-number denotes the IDcode for the outcrop as found in SICADA and the sketches illustrate the scan lines, the excavated areas and the individual fractures at each locality. North corresponds to up on the figure and each fracture is oriented with a correct strike, but with fictive length, fixed to 1 metre. The fractures are colour coded according to the number of fracture endings. Green designates 0 endings (the fracture continues beyond the excavated area on both sides), black is 1 ending and red is 2 endings.*

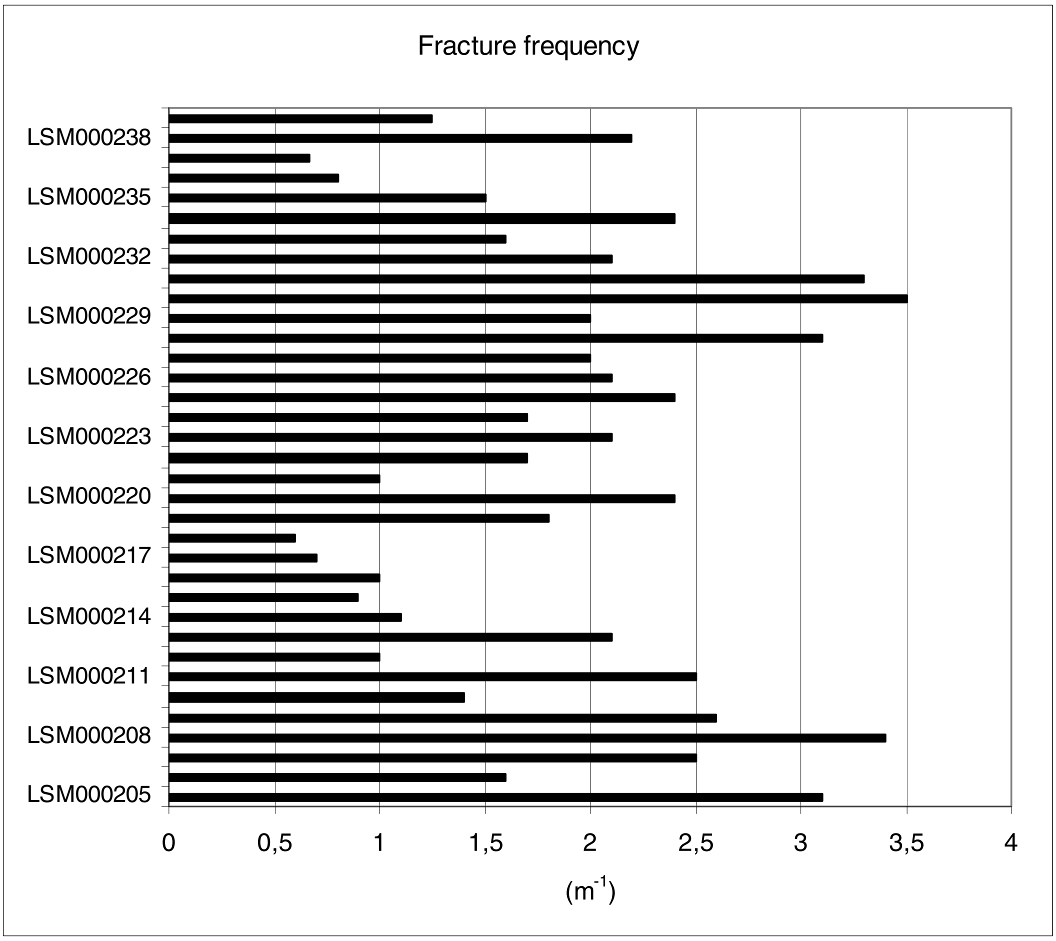


Figure A-8. *Fracture frequence for each scan line.*

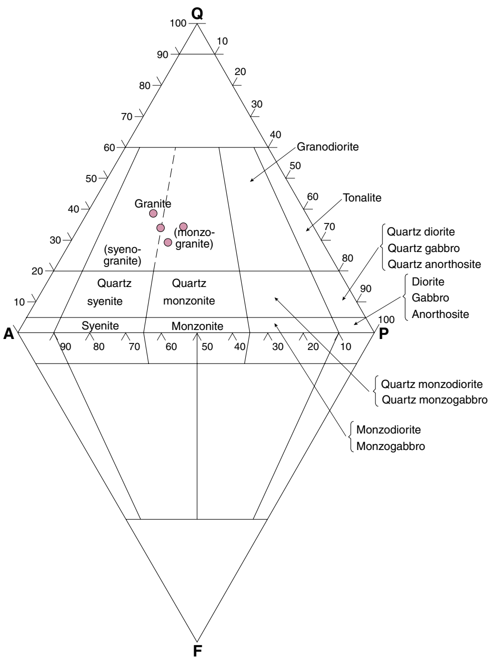
Table A-1. Fracture frequency for each scan line

Idcode	Length of line, in metres	No. of fractures	Frequency (m^{-1})
LSM000205	10	31	3.1
LSM000206	10	16	1.6
LSM000207	10	25	2.5
LSM000208	10	34	3.4
LSM000209	10	26	2.6
LSM000210	10	14	1.4
LSM000211	10	25	2.5
LSM000212	10	10	1
LSM000213	10	21	2.1
LSM000214	10	11	1.1
LSM000215	10	9	0.9
LSM000216	10	10	1
LSM000217	10	7	0.7
LSM000218	10	6	0.6
LSM000219	10	18	1.8
LSM000220	10	24	2.4
LSM000221	10	10	1
LSM000222	10	17	1.7
LSM000223	10	21	2.1
LSM000224	10	17	1.7
LSM000225	10	24	2.4
LSM000226	10	21	2.1
LSM000227	6	12	2
LSM000228	10	31	3.1
LSM000229	4	8	2
LSM000230	10	35	3.5
LSM000231	10	33	3.3
LSM000232	10	21	2.1
LSM000233	10	16	1.6
LSM000234	10	24	2.4
LSM000235	10	15	1.5
LSM000236	5	4	0.8
LSM000237	6	4	0.67
LSM000238	5	11	2.2
LSM000239	4	5	1.25
Total	320	616	1.93

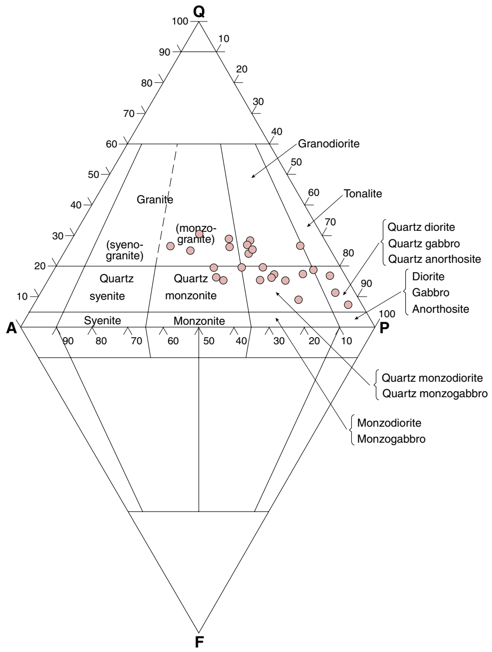
Appendix B

The QAPF modal classification of individual rock types is displayed below.

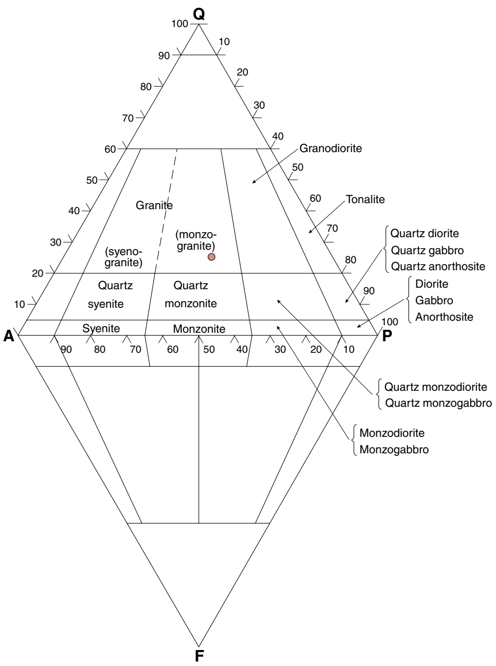
Fine-to medium-grained granite



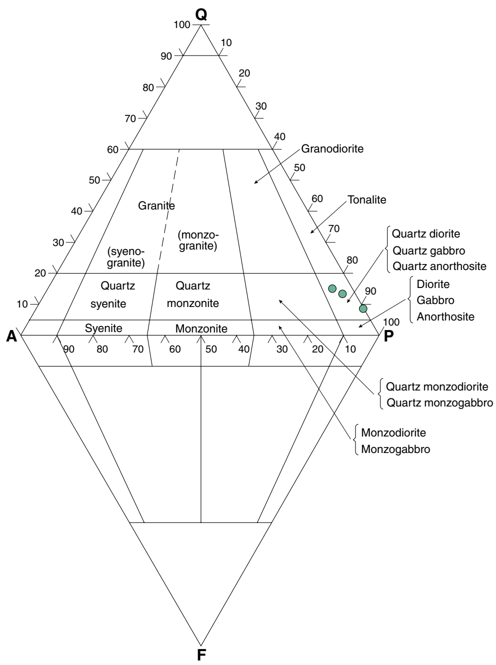
Ävrö granite



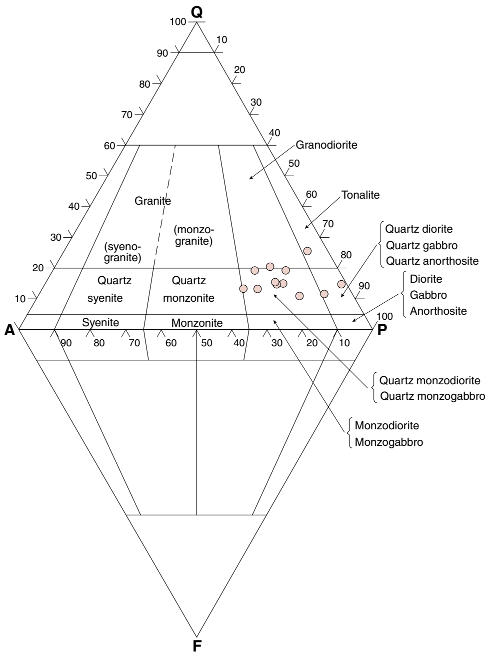
Granite



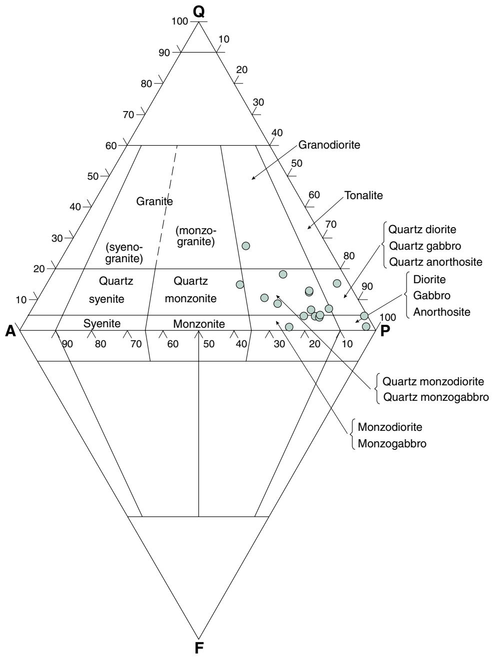
Fine-grained mafic rock



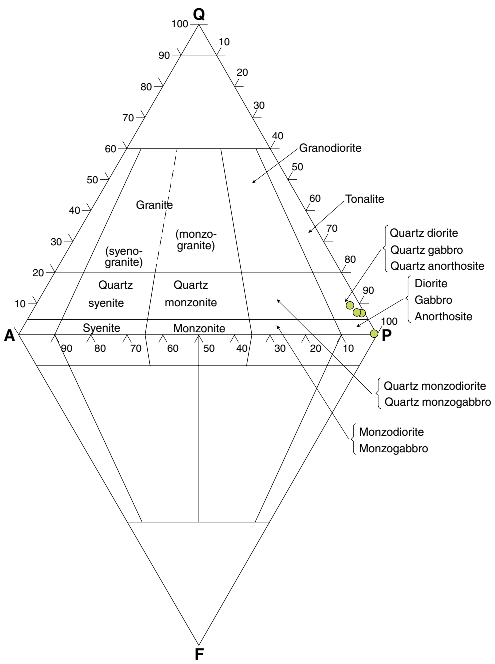
Quartz monzodiorite



Fine-grained dioritoid



Diorite to gabbro



Appendix C

Radiometric dating

Quartz monzodiorite (PSM002151)

Zircon

The zircons are poor in quality. Their colour is pink or brown. Virtually all are metamict. Some are euhedral or subhedral but the majority are rounded, anhedral or fragmented. Many grains are tabular.

Analysed fractions:

The crystals that were selected and abraded were rather large and of relatively good quality. They contain cracks but are not metamict. About half of them are elongated. They are generally slightly rounded. It is possible that this is due to the presence of numerous small crystal faces, which is difficult to determine under the stereo microscope.

Z 1 3 crystals. Clear, pale brown. Good quality. Two of them display weak zonation. Abraded.
Z 2 3 crystals. They have sparse cracks and show zonation. Abraded.
Z 3 3 crystals. Clear, colourless, andhedral and tabular. They are presumably fragments of larger grains. Not abraded.
Z 4 4 crystals. They have the same appearance as the previous fraction. Not abraded.

Titanite

T 1 9 crystals. Light brown to medium brown. Transparent. Anhedral or fragmented. Crack-free. Not abraded.

T 2 8 crystals. Light brown. They are clear but contain cracks. Anhedral or fragmented. Not abraded.

T 3 5 crystals. Medium brown. They are more turbid than fraction 1 and 2 and show cracks. Anhedral or fragmented. Crack-free. Not abraded.

The zircons are slightly discordant and define a discordia with intercept ages of –150 and 1800 Ma. Due to the negative lower intercept, the discordia has intstead been anchored at 0 Ma with a chosen uncertainty of ±200 Ma. The upper intercept is then 1802 ± 4 Ma.

The titanites are also slightly discordant and plot closely together, somewhat to the left of the zircons. If a lower intercept of 0 ± 200 Ma is assumed, the upper intercept becomes 1793 ± 4 Ma.

The most plausible interpretation is that the zircon gives the intrusion age of the quartz monzodiorite whereas the titanite age represents a cooling age. It is rather common for plutonics that titanite yields a somewhat younger age than zircon due to the lower blocking temperature of the former.

Ävrö granite (PSM002328)

Zircon

The zircons constitute a heterogeneous population. The colour varies from colourless to grey or yellowish brown. The length/width ratio is 1-5. Some grains are euhedral whereas others are rounded. Some of the rounded ones have small crystal faces with high indices. Cores and overgrowths are common but such grains were avoided when selecting grains for analysis. The quality is generally poor and very few grains are clear. All analysed crystals were abraded.

Analysed fractions:

Z 1 5 crystals. From sieve fraction <74 µm. Good quality. Some have sparse cracks and inclusions.

Z 2 3 crystals. From sieve fraction. >74 µm. They are clear and of good quality. They have magmatic zonation but no visible cores or overgrowths.

Z 3 1 crystal. From sieve fraction. >74 µm. Equant. Clear. Good quality.

Z 4 1 crystal. From sieve fraction. >74 µm. Somewhat poorer quality than the previous one. Some inclusions can be seen.

Titanite

The titanites are various shades of brown. They are anhedral or fragmented. No abrasion was carried out.

T 1 8 crystals. Light brown. They are transparent with only small turbid domains.

T 2 5 crystals. Dark brown. They are clear but contain some small cracks. Some grains have thin rims of grey material, possibly leucoxene.

T 3 7 crystals. Light brown. They are transparent in reflected light but slightly turbid in transmitted light.

Three of the zircon fractions plot on a straight line but closely together. The fourth fraction (Z 1) plots aside and has a younger $^{207}Pb/^{206}Pb$ age. The zircons in this fraction are smaller than the others. Two of the titanite fractions fall on the same discordia as the three zircon fractions and one of them is concordant. Fraction T 2, which consists of darker grains, is strongly reversely discordant and is not shown in the diagram. Its $^{207}Pb/^{206}Pb$ age is older and the chemical composition differs from the other titanite fractions. The U content is higher, the $^{206}Pb/^{204}Pb$ lower and the ^{208}Pb portion higher in comparison. The latter parameter indicates a higher Th/U ratio. The presence of possible leucoxen rims is indicative of alteration. The discordia in the diagram is calculated using the fractions Z2, Z3, Z4, T1 and T3. A regression analysis yields intercept ages of 1796 ± 9 and –164 ± 480. Because of the negative lower intercept it is preferable to assume a zero lower intercept and an arbitrary uncertainty of ±200 Ma. The upper intercept then becomes 1800 ± 4 Ma. In this sample titanite and zircon yield the same age, possibly due to rapid cooling.

Table C-1. U-Pb data

Analysis No.	Weight (µg)	No. of crystals	U (ppm)	Pb tot. (ppm)	Common Pb (ppm)	$^{206}Pb/^{204}Pb$ [a]	^{206}Pb - ^{207}Pb - ^{208}Pb Radiog. (atom %)[b]	$^{206}Pb/^{238}U$ [b]	$^{207}Pb/^{235}U$ [b]	$^{207}Pb/^{206}Pb$ age (Ma)
PSM002151		**Quartz monzodiorite**								
Zr 1	3.3	3	203.1	66.1	0.06	9277	81.2 - 8.9 - 9.9	0.3068±16	4.663±25	1803±2
Zr 2	4.7	3	204.5	67.7	0.36	4952	81.3 - 9.0 - 9.7	0.3113±16	4.728±26	1802±2
Zr 3	4.4	3	262.7	88.5	0.08	9650	80.1 - 8.8 - 11.1	0.3132±17	4.757±26	1802±2
Zr 4	6.4	4	230.6	76.6	0.02	20728	82.1 - 9.0 - 8.9	0.3170±16	4.811±25	1801±2
Ti 1	12.0	9	68.2	38.6	1.89	620	50.0 - 5.5 - 44.5	0.3117±17	4.718±29	1796±4
Ti 2	13.3	8	85.2	38.4	2.12	703	63.5 - 6.9 - 29.6	0.3138±18	4.740±30	1792±4
Ti 3	16.7	5	89.6	52.9	2.06	774	48.1 - 5.3 - 4.6	0.3160±19	4.772±31	1791±5
PSM002328		**Ävrö granite**								
Zr 1	2.1	5	228.3	76.4	0.36	3239	77.4 - 8.4 - 14.2	0.2993±46	4.500±70	1784±6
Zr 2	4.4	3	195.7	64.2	0.04	7607	79.5 - 8.7 - 11.8	0.3030±22	4.597±34	1800±2
Zr 3	5.6	1	77.2	25.9	0.74	1298	80.3 - 8.8 - 10.9	0.3044±25	4.622±43	1801±8
Zr 4	8.1	1	83.4	29.0	0.11	4469	76.7 - 8.4 - 14.9	0.3087±17	4.690±28	1803±4
Ti 1	17.6	8	146.8	57.8	2.65	992	72.5 - 7.9 - 19.6	0.3162±25	4.779±41	1793±6
Ti 2	13.5	5	284.1	156.5	20.62	295	63.4 - 7.1 - 29.5	0.3520±21	5.401±37	1821±6
Ti 3	19.2	7	174.0	69.2	3.25	980	72.8 - 8.0 - 19.2	0.3203±23	4.856±36	1799±3

a) corrected for mass fractionation (0.1% per a.m.u) and spike. b) corrected for mass fractionation, spike, blank and common Pb.