

P-09-74

Site investigation SFR

Geological mapping and laser scanning of the lower construction tunnel

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March 2008

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Keywords: P-report SKBDoc id 1226248, Tunnel, Geology, Mapping, Bedrock, Laser scanning, Fractures, Forsmark, Project SFR extension, AP SFR-07-007.

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Abstract

The geology on bare rock surfaces in the lower construction tunnel at SFR has been remapped in 3D, using laser scanned data as template. The mapping is part of an investigation programme for the future expansion of the final repository for radioactive operational waste (SFR).

A large part of the tunnel is covered by shotcrete and thus not available for mapping. There is also a ventilation tube in the roof that prohibits mapping of ca 1 m wide strip in the roof.

Fractures, lithologies, rock contacts, deformation zones and obvious water seepage were mapped. Fractures longer than approximately 2 m and rock occurrences wider than ~0.5 m were included. Both ductile and brittle deformation zones were mapped, down to an approximate width of 0.1 m.

The predominant rock in the tunnel is a fine- to medium-grained metagranite, a probable equivalent to the typically medium-grained metagranite-granodiorite that prevails in the Forsmark tectonic lens on the southwest side of Singö deformation zone. Another common rock type found in the tunnel is pegmatite, especially in the upper and central part. In the order of abundance the following subordinate rock types are found; felsic to intermediate metavolcanic rock, fine to medium grained reddish granite and amphibolite.

The foliation in the tunnel generally strikes in a southeast-northwest direction with a steep dip to the west or east. Towards the lower part of the tunnel, however, the foliation appears to become less steep and dispersed.

Four major fracture sets can be distinguished in the tunnel; a gently dipping, sub-horizontal set, a set with intermediate dip to the south and two sub-vertical sets in the southwest-northeast and southeast-northwest direction, respectively.

Sammanfattning

Blottlagda ytor av berggrunden i Nedre Byggtunneln vid SFR har karterats i 3D, med hjälp av laserskannat underlag. Karteringen av geologin i tunneln ingår som en del i ett brett undersökningssprogram inför kommande planerad utbyggnad av slutförvaret för lågt- och medelaktivt radioaktivt avfall (SFR).

En stor del av tunnelns tak och väggar är täckta av sprutbetong och är därför inte tillgängliga för kartering. Under karteringen fanns också en ventilationstub i drift, vilket döljer ett ungefär 1 m brett band centralt utmed tunnelns tak.

Sprickor, litologier, bergartskontakter, deformationszoner samt tydligt vatteninläckage karterades. Sprickor längre än ca 2 m och bergartsförekomster med större bredd än ~0,5 m inkluderades. Både duktila och spröda deformationszoner karterades, ner till en ungefärlig bredd av 0,1 m.

Den dominerande bergartstypen i tunneln är en fin- till medelkornig metagranit, som utgör en trolig motsvarighet till den vanligen medelkorniga metagranit-granodiorit, som dominerar i Forsmarks tektoniska lins, sydväst om Singölinjens deformationszon. En annan vanlig bergartstyp i tunneln, speciellt i dess övre och mellersta del, är pegmatit. Därefter, i ordningen från mer till mindre vanlig, har även följande bergarter påträffats; felsisk-intermediär metavulkanit, fin-medelkornig röd granit samt amfibolit.

Foliationen i tunneln stryker vanligen i en syostlig-nordvästlig riktning, med en brant stupning. I den nedre delen av tunneln verkar dock foliationens orientering variera mer, men har generellt mer medelbrant stupning.

Fyra huvudsakliga sprickset kan särskiljas; ett flackt liggande set, ett set som stupar medelbrant mot söder, samt två sub-vertikala set, som stryker sydväst-nordöst, respektive sydöst-nordväst.

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1 Introduction

During 2008, SKB initiates an investigation programme for the future expansion of the final repository for radioactive operational waste (SFR). An essential part of the preparations for this work is to update the geological model for the SFR. This necessitates a reassessment of existing geological data from the construction of the SFR, on the basis of the experiences from the preceding site investigation Forsmark.

Most of surfaces in the underground rock excavations at SFR are shotcreted, which prohibits observation of the rock. However, in large parts of the “lower construction tunnel” (NBT) at SFR (Figures 1-1 and 1-2) this is not the case and the rock surface of the walls and roof are partly free to observe. This circumstance made the tunnel suitable for geological mapping, which is reported here. The mapping nomenclature and procedure has been synchronized with that made during the site investigation Forsmark, with respect to lithologies, rock alterations, structures, and other nomenclature.

In order to improve the accuracy of the spatial data, the tunnel was subjected to laser scanning, providing a mapping template that made it possible to register geological features within a few centimetres of their true locations. The mapping is reported as a set of graphical elements in 3D, including a database with a number of attribute related to each graphical element.

This is one of the activities performed within the investigation programme, preceding the expansion of SFR. The work was carried out in accordance with activity plan AP SFR-07-007. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB’s internal controlling documents.

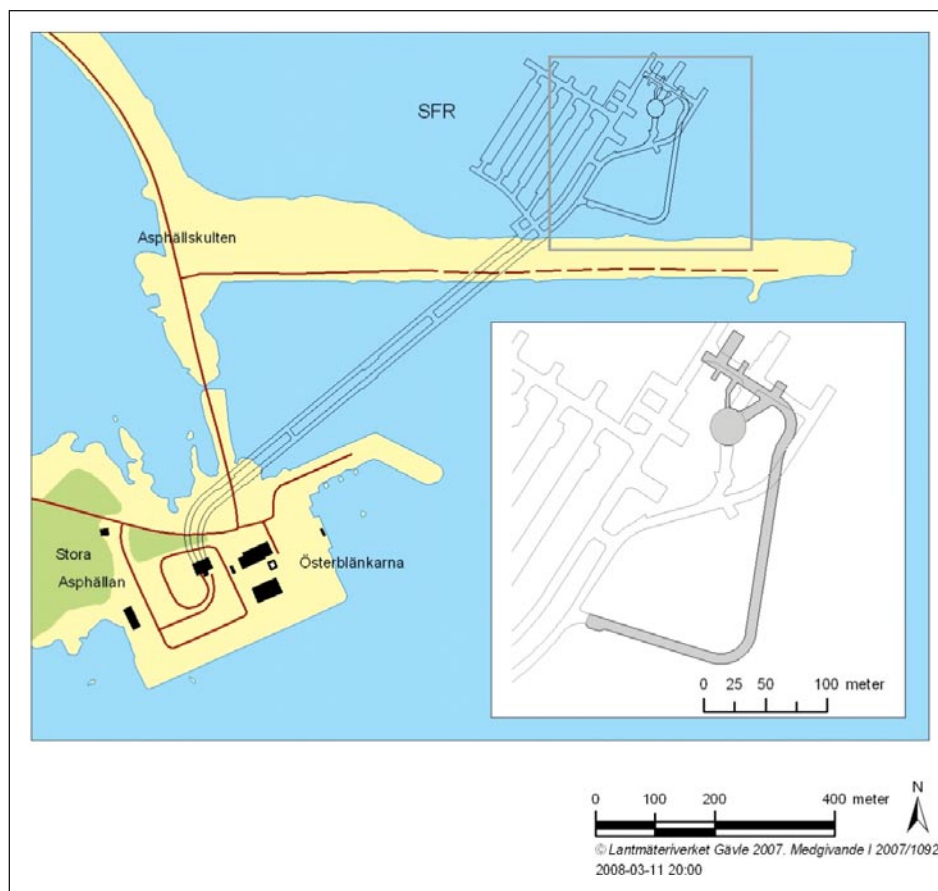


Figure 1-1. Top view of the SFR facility. The lower construction tunnel and the silo are highlighted in the inset figure.

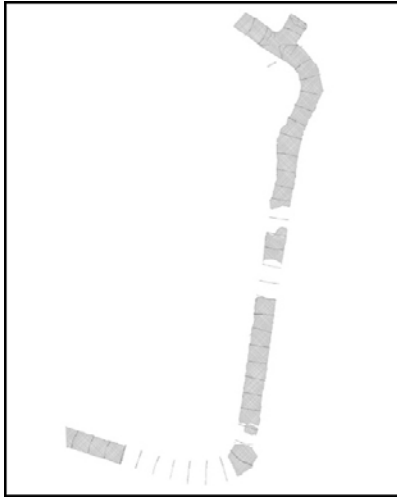


Figure 1-2. Top view over mapped part of the lower construction tunnel. Shotcreted parts of the roof are hatched.

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

Activity plan	Number	Version
Geologisk kartering och laserskanning av nedre byggtunneln	AP SFR-07-007	1.0
Method documents	Number	Version
Instruktion: Regler för bergarters benämningar vid platsundersökningen i Forsmark	SKB MD 132.005	1.0

2 Objective and scope

The NBT (Figure 2-1) has a total length of about 450 m. The scanned part is about 380 m and the mapped part is about 345 m. Typical tunnel dimension is 9x7 m (width x height). The tunnel leans downwards at an angle of about ten degrees, but become almost horizontal in the lowermost parts. Mapping starts at about -95 masl, at chainage 8/050.

The aim of the mapping of the tunnel is to obtain an updated view of the geology, synchronized with nomenclature and procedure of geological mapping in the preceding site investigations for a deep repository at Forsmark. The mapping will be used as input to an updated geological 3D model of SFR.

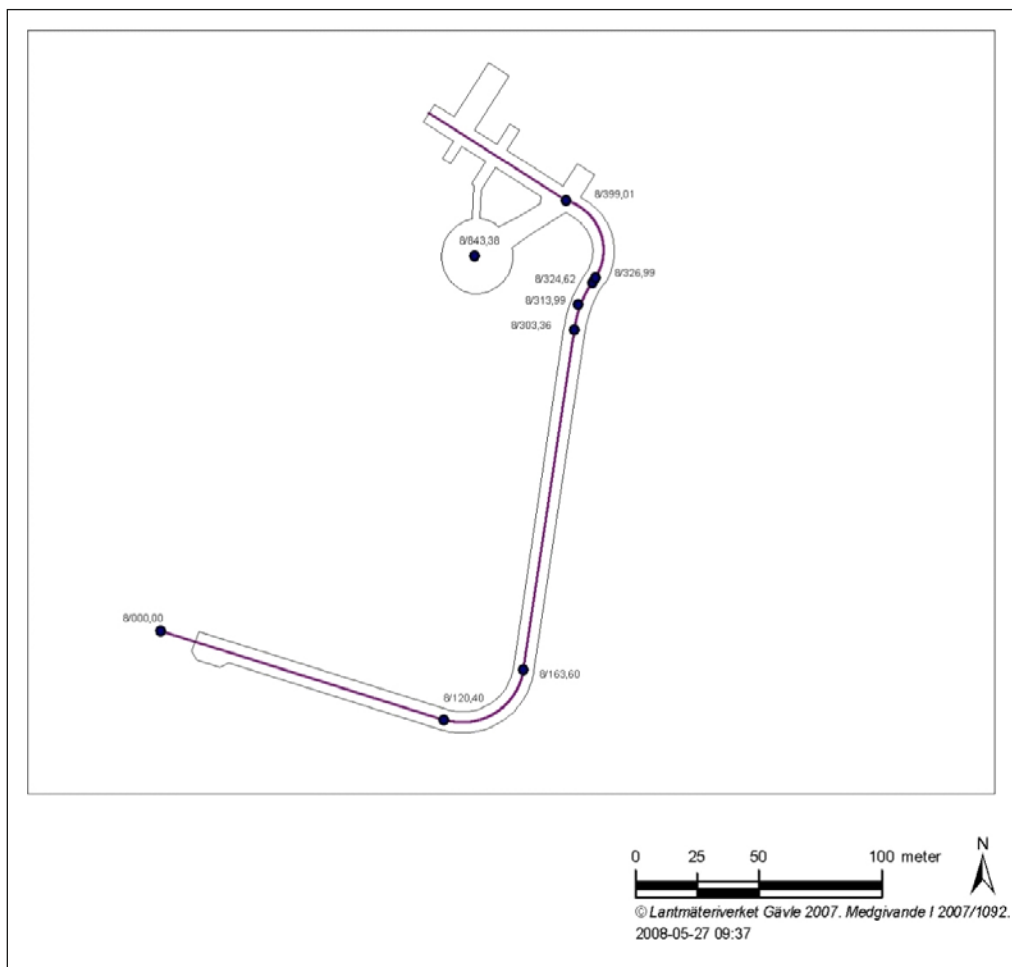


Figure 2-1. The lower construction tunnel with length sectioning.

3 Equipment

3.1 Description of equipment/interpretation tools

The scanner equipment used was of the type Faro Photon 80, and to handle the data the software Faro Scene® and Faro Scout® was utilized. For the purpose of illumination, 2 carriages with fluorescent lamp fittings (9x2, 220 V) was utilized.

During the geological mapping a rugged PC was used (General Dynamics, Gobook XR-1), containing the software Faro Scout®, background images from the scanning, subdivided into three separate image files (left wall, roof, and right wall), and a spreadsheet database (Access®) to collect the geological information.

To make database connection between the graphical objects and their attributes (the character of mapped objects), an application in Microstation® (see below) was used.

4 Execution

4.1 General

The walls in the tunnel are to a large extent free of shotcrete and available for geological mapping. Most parts of the roof are, however, covered with shotcrete. At several places this cover extends downwards to cover parts, or even the full height of the walls. There are also several installations that in part inhibit the mapping, especially the ventilation tube in the roof.

Prior to the laser scanning and mapping, the tunnel was first scaled for loose rock boulders and then cleansed from dirt etc with the help of high-pressurised water.

4.2 Laser scanning

The laser scanning was performed according with the procedure in the activity plan (AP SFR-07-007, see also /Berlin and Hardenby 2008/). Reference bolts were mounted in the wall, at relative distances of 10 m between each, along both sides of the tunnel. These bolts were positioned in absolute terms by measuring with in reference to available fix points, in total ca 10 fix points.

Before the scanning, spheres were attached to the bolts (see Figure 4-1). These spheres were registered in the scanning data, and used to rectify the scans to each other and to the RT90 coordinate system.

The system consists of a laser scanner and a digital camera. The system is described in the activity plan (AP SFR-07-007).

To facilitate the geological mapping, the scanning cloud is subdivided into three parts: the left side, roof, and right side of the tunnel. The collected scanning cloud contains overlaps of at least 2 m of the consecutive individual scans, in order to reveal as much as possible of hidden pockets in the tunnel walls.

4.3 Geological mapping

All kind of mapping involves some sort of simplification of the nature, in order to give an understandable graphical view of the character, extension and relations of different features, such as the geology in a tunnel. It is important that the conditions for how these simplifications are made.

Table 4-1 summarizes the different kinds of geological features and utilized cut-off levels. The figures given represent the length measured on the rock surfaces whereas the width is the orthogonal width. These are not definite figures and objects below the cut-offs may have been registered if they are considered to be of particular interest.

Table 4-1. Employed cut-off levels.

Object	Cut-off level
Fractures (length)	> 2 m, if not specific characters, water-bearing or a fracture system that warrant documentation of shorter objects
Rock occurrences (length/width)	> 3 m/> 0.5 m, if not a system of dykes or other specific characters
Deformation zones (brittle-ductile to ductile and cataclastic) (width)	> 1 dm if intersecting the full tunnel perimeter, else >3–5 dm
Alterations	Distinct areas >2 m Ø. Around fractures > 0.5 dm

The mapping was performed in 3D on the prepared image templates, covering the exposed parts of the tunnel. During mapping, a database with attributes according to Appendix 1 was successively completed contemporaneously with the mapping.

In addition to the standardized parameterization of registered objects that are found in the database tables, there is also a remark field. Both information regarding lithological, mineralogical and structural features may be found here.

The procedure for the mapping in the tunnel was as follows. The first step was to localise the object (e.g. fracture, rock boundary, etc) on the tunnel face and decide whether it should be included in the mapping or not. If included, the next step would be to locate it in the image on the PC screen. In a third the step a line is drawn along the object as it appeared on the screen. By doing so, coordinates for the object are being collected by the software for later export to CAD. The line was drawn with a pen directly on the touch screen on the PC (Figure 4-1). This was done either by “click-move-click”, or by “freehand”. The latter alternative collects coordinates continuously, whereas the former only collects where you point on the screen. For fractures, normally the “click-move-click”-technique was used, whereas contacts between rocks normally were sampled by drawing a continuous line. Both methods of sampling are sensitive to the exact location on the image and when a large topography exists over short distances in the image the resultant line will often be a jumpy curve.

A common situation is that there are several fractures running sub-parallel to each other. Where the distance between such fractures is less than 3-4 decimetre (i.e. too close to be represented by separate lines for scalar reasons), they are represented by one, single line in the graphics. The number of fractures a line represents is noted in the database.

Another common case is to find “stepping” fractures or fractures oriented “en echelon”. In such cases it is the length of the structure as a whole that is considered, when it comes to cut-off level. Hence, even if individual fractures in the structure are shorter than the cut-off level, the structure as a whole may be represented in the mapping as a single line, the character being noted in the remark field in the database.

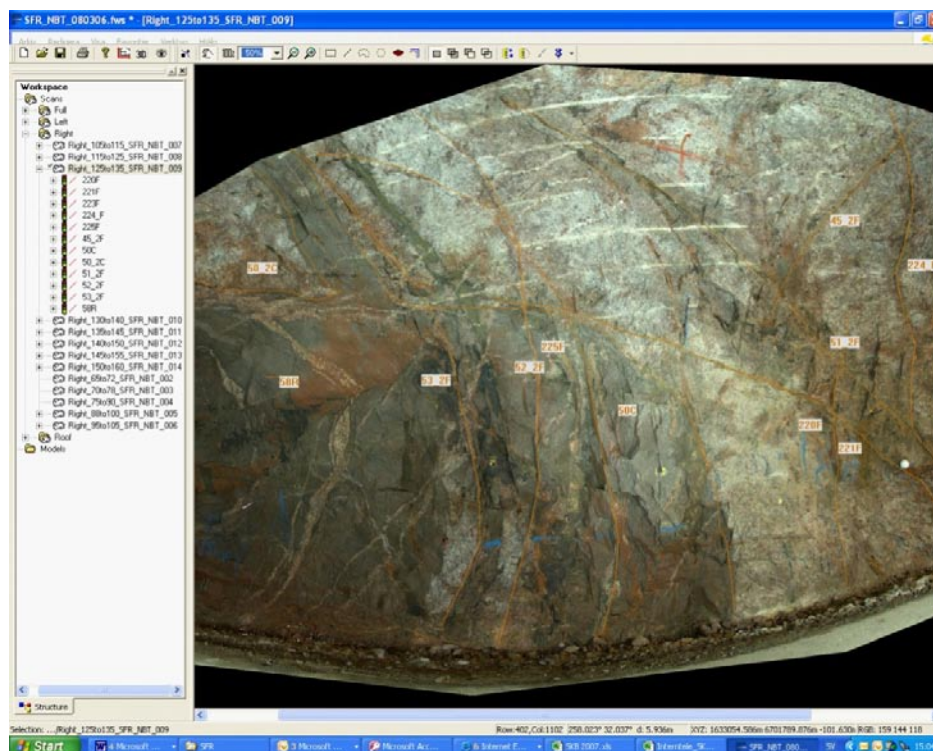


Figure 4-1. Screen dump from the PC used in the tunnel for mapping, showing the FaroScout software with the colour template view with some geological features mapped. Note the mounted sphere (white dot) to the right, used for rectification.

Table 4-1. Employed cut-off levels.

Object type	Level in dgn-file	Colour (RGB)
DeformationZone	Deformation zones	255,0,255
Fracture	Fractures and water	255,127,0
RockType	Rocks and rock boundaries	0,0,255
RockContact	Rocks and rock boundaries	0,0,255
Water	Fractures and water	255,127,0

In both the cases described above, the number of fractures in a mapped object and their average spacing is estimated and documented in the database. It should thus be noted that the length of individual fractures in a registered object may be shorter than the mapped line and their spacing may vary as well.

4.4 Data handling and quality routines

The database was initially stored on the local computer, with a separate backup after each mapping episode on the SKB server.

Mapped polylines in Faro Scout were first exported to the local PC hard drive, with a separate backup after each mapping episode on the SKB server.

The polylines were imported to Microstation after the tunnel mapping was finished. The lines were edited in order to clean the data from overlap that were created by mapping on several, partly overlapping images. The file was after correction stored in a mapping file. All lines were then colour coded by object type according to Table 4-2) and placed at separate graphical levels, in order to simplify the handling of different geologic features.

The database was finally checked and errors corrected.

4.5 Nonconformities

Rock contacts were drawn as lines. Normally these boundaries end towards a shotcreted surface or to some other superficial cover. For this reason there are few places in the tunnel where the full extension of rock contacts across the tunnel perimeter is mapped.

Since the tunnel was grouted during production and has been in operation for two decades, the seepage of water should not in any way be expected to reflect the situation of the intact rock. Water seepage has only been registered when it comes from a distinct spot, fracture or area. "Damp" has not been registered at all.

Some fracture filling minerals are more conspicuous than other. For example, the distinct red staining shown by sub-microscopic hematite reveals extremely low concentrations of the mineral. Diluted hydrochloric acid for identification of calcite was not used, so calcite had to be macroscopically visible to be detected. Clay minerals can be expected to have been eroded and probably some other minerals as well.

Much of the artificial cover of the rock, outside shotcreted areas, was not possible to remove during cleaning of the surface by high-pressurised water. There are different kinds of substances that have cemented to the wall and partly cover it. This makes the interpretation of the geology difficult at places.

The ability to identify, and the precision in location of a specific object to be registered, is dependent on many parameters. The most important ones are the visible contrast of the object to the surrounding geology in the photographic image, but also its location in relation to the scanner as well as the quality of the image.

The quality of the colour image used as a template for mapping varies. Generally it is good enough to spatially locate objects within 1-2 decimetres. The image quality is dependent upon the rock face location in relation to the scanner, with the best quality being right in front of the scanner and the least good quality in an intermediate position between two scanner locations. Since the average distance between two scan positions is about 8 m, a fracture in the wall at such location will be viewed at an angle of less than 45 degrees to the tunnel wall. As an effect of the irregular shape of the rock surface, there will be areas that are hidden to the scanner which the laser beam and camera will not register. Another important aspect for image quality is the amount of light used at exposure and how much light the rock reflects. The light used in this case was especially designed for the project and resulted in higher degree of illumination than previously used in tunnel scans by ATS AB.

5 Results

5.1 Lithology

The major part of SFR (including NBT) is located northeast of the regional Singö deformation zone, which separates the Forsmark tectonic lens from the SFR area. According to previous geological data SFR is located in a high-strain belt adjacent to the Singö deformation zone, in rock consisting of intermediate metavolcanic rocks, together with pegmatitic granite and locally fine- to medium-grained granite (e.g. /SKB 2005/).

However, felsic to intermediate metavolcanic rocks (103076) are a subordinate component in NBT. The predominant rock is a fine- to medium-grained metagranite, which appears to be an equivalent to the typically medium-grained metagranite-granodiorite (101057) that prevails in the Forsmark tectonic lens. The metagranite exists in all mapped parts of the tunnel, but is most common in the central and lower part. The distinction between this rock type and the rock types of inferred volcanic origin are generally difficult to make, partly because of tectonic overprinting. The main criteria used to separate these rock types are: (1) the presence of a compositional banding, (2) the mica content, (3) the typical 'domain texture' exhibited by the metagranite and (4) grain size. The mentioned 'domain texture' is recognized as slightly elongated aggregates (domains) of feldspar and quartz surrounded by more mica-rich domains, a result of tectonic and metamorphic overprinting /Petersson et al. 2004/.

Another volumetrically important rock type in the lower construction tunnel is pegmatitic granite (101061). The most extensive occurrences, in the mapped part of the tunnel, are found in upper part starting at about chainage 8/060 and ending at about 8/130. The pegmatitic granite is generally not foliated, but dykes emanating from the main body are intensely folded together with the surrounding, less brittle metagranite. Internally, however, the pegmatitic granite lack, or exhibits only a vague foliation, also in these dykes. The pegmatite seems to be genetically associated with a rather homogeneous, reddish, medium-grained metagranite, interpreted as a rock type variety belonging to sub-code 111058. This type of granite occurs at several locations in the tunnel, typically in association with pegmatites. Normally it show less intense foliation than the fine to medium-grained metagranite (101057), but locally the difference is minor.

Amphibolites (102017) occur sporadically throughout the tunnel. Generally they occur as bands or dyke-like bodies. None of these exceeds 1 m in width. Extensions and contacts of all these occurrences are more or less parallel with the tectonic fabric, as well as their internal foliation. Normally the internal foliation is more strongly developed than in the surrounding rock.

5.2 Ductile deformation (foliation)

The principal rock in the tunnel (fine-medium grained granite-granodiorite, 101057) shows a foliation of generally medium intensity. Locally it also shows a more intense, strong foliation, at places aligned with a gneissosity. The measures of the foliation have been plotted in Figure 5-1, with colour coding for illustration of variation towards depth in the tunnel. It can be seen that the foliation seems to disperse and become somewhat more gently dipping towards the lowermost part of the tunnel.

Table 5-1. Sections used during mapping.

IDSection	StartSection	EndSection
1	8/050	8/105
2	8/105	8/150
3	8/150	8/215
4	8/215	8/300
5	8/300	8/395

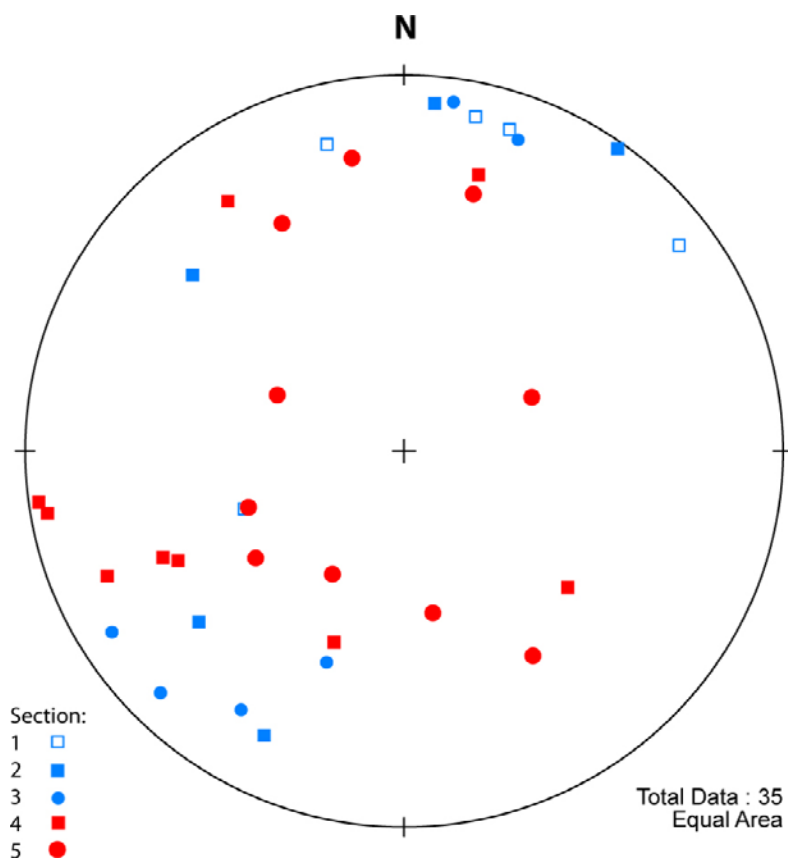


Figure 5-1. Foliation orientation as measured during mapping of the tunnel, from top (section 1) to bottom part (section 5). Stereographic plot of poles to foliation planes in lower hemisphere.

5.3 Faulting and deformation zones

Occurrences of local zones of higher strain are found frequently in the tunnel. There are altogether 17 occurrences registered as deformation zones. Most of these are brittle or brittle-ductile. Only one is strictly ductile. 15 of the deformation zones are 0.6 m wide or less.

A common characteristic of the amphibolitic bands in the tunnel is that they show a higher strain than the surrounding rock. Since these bands normally are short and do not penetrate the full tunnel perimeter, they are not registered as deformation zones. The deformation mode changes dramatically across rock boundaries, especially around pegmatite boundaries. Hence, severe ductile deformation is common close to the larger pegmatite bodies, but only in the surrounding rock. The pegmatite itself may either have been affected by more extensive brittle deformation or have been left macroscopically unaffected by the deformation. One exceptional example of this is found at chainage 8/265 where the only strictly ductile deformation zone has been registered. The zone is about 1 m wide and is located in a metagranite (101057) next to an extensive pegmatite. It also affects narrow pegmatitic bands that are only slightly deformed just next to the deformation zone, but isoclinally folded within the zone (Figure 5-2). The zone itself has a strongly developed axial planar foliation parallel to the zone boundary, but discordant to the foliation in the surrounding metagranite and perpendicular to the general strike of the folded pegmatite dyke outside the zone.

The classification of brittle deformation structures as a zone, rather than a group of individual fractures has been made according to the following criteria:

1. the fracture frequency is distinctly higher than that of the surrounding rock,
2. the structure has a high length/width ratio and
3. the structure is continuous through a large portion of the tunnel perimeter.

Most brittle zones are regarded as minor, and their zone character may well be of rather local extent.

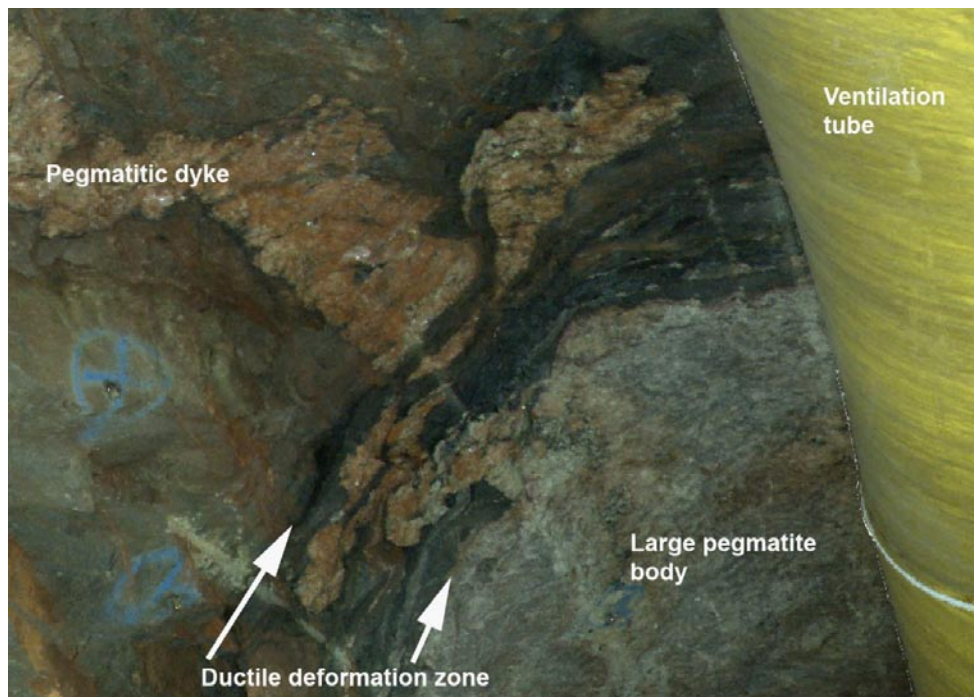


Figure 5-2. Ductile deformation zone along the contact to a pegmatite. Note the isoclinal folding of the pegmatitic dyke in the deformation zone.

The width of the brittle deformation zones varies between 0.1 and 0.6 m, with the exception of a deformation zone close to chainage 8/120, where a zone of 1.5 m width has been recorded. This zone is continuous across the visible parts of tunnel perimeter, from the left wall to the right wall. It has an orientation of 240/85, but contains three different sets of fractures, of which the most dominant is sub-parallel to the zone orientation.

Indications of faulting are common also in fractures in the form of slickenlines that are frequently found in the tunnel. In total 66 fractures have been noted to have slickenlines, with a measure of trend and plunge in the database. 59 of them have a dip of 45 degrees or less, with a majority located on steep fractures oriented in a southwest-northeast direction. No systematic kinematic analysis has been performed on these measurements, but based on their geometries alone it may be concluded that there is a dominant strike slip component along these fracture planes.

Fractures that are oriented 'en echelon' are common. However, normally the asymmetrical shape of these structures is not consistent along the whole structure. In this case the structure is mapped as 'system' rather than 'en echelon'. When a consistent structure has been recorded, the indicated sense of rotation of the structure is often noted in the remark field in the database.

5.4 Alteration

In the mapped part of the tunnel the rock only display a faint to weak alteration. The most common alteration is oxidation localised around fractures. However, although common (registered in 244 fractures), it is generally restricted to a few centimetres around the fractures. It should also be noted that what is mapped as oxidation actually is a red staining of the rock, which elsewhere in Forsmark have been shown to be sub-microscopic hematite. There is also a longer section of weak to moderate oxidation in the lower part of NBT, between chainage 8/345 and 8/365.

Another type of alteration that is rather frequent around fracture planes is laumontitization. It has been noticed adjacent to 21 fractures, preferentially those having a steep southwest-northeast direction.

5.5 Fracture characteristics

As presented in Figure 5-3, at least four rather distinctive sets of fractures can be distinguished. One sub-horizontal set, one set dipping 40–60° degrees south and two steep sets; Striking southwest-northeast and southeast-northwest. These steep sets may possibly be subdivided further. No distinction has been made between ‘broken’ (parted) and ‘unbroken’ (sealed) fractures, or open and sealed fractures. However, apertures have been noted when observed, but these are rare. Water seepage indicates fracture aperture, as well as grout-filled fractures. A distinction of fractures between ‘broken’ and ‘unbroken’ is difficult, however, considering that it is the ‘in situ’ rock situation that is of interest and it can be difficult to evaluate whether a fracture has been parted because of the blasting of the tunnel or not. Apart from this, a fracture normally changes character along its path in the tunnel and may locally be sealed and locally open.

Although there are local variations of fracture frequencies in mapped parts of the tunnel, the variability is limited, outside deformation zones, except for a section in the first bend of the tunnel, at around chainage 8/140, especially in the right wall. Here, the lithology is in fact more heterogeneous than elsewhere in the tunnel, with frequently occurring pegmatite bands, occurrences of fine- to medium-grained granite (111058) and a gneissic appearance of the metagranite (101057), with bands and slices of amphibolite. The metagranite, in this section of the tunnel, has a moderate to strong foliation parallel to the gneissosity, along which the rock locally has fractured.

Of the 482 fractures, all but three have some kind of fracture infilling. Most frequently occurring fracture minerals are calcite and chlorite, followed by laumontite. These minerals seem to be present in all fracture sets except for the sub-horizontal set, that appear to lack laumontite.

Other fracture infillings, of which none occurs in more than about 1% of the total fractures, include adularia, epidote, asphaltite, sericite, muscovite, quartz, hematite prehnite, biotite, amphibole, clay minerals, cataclastic rock, fault gouge and unknown minerals.

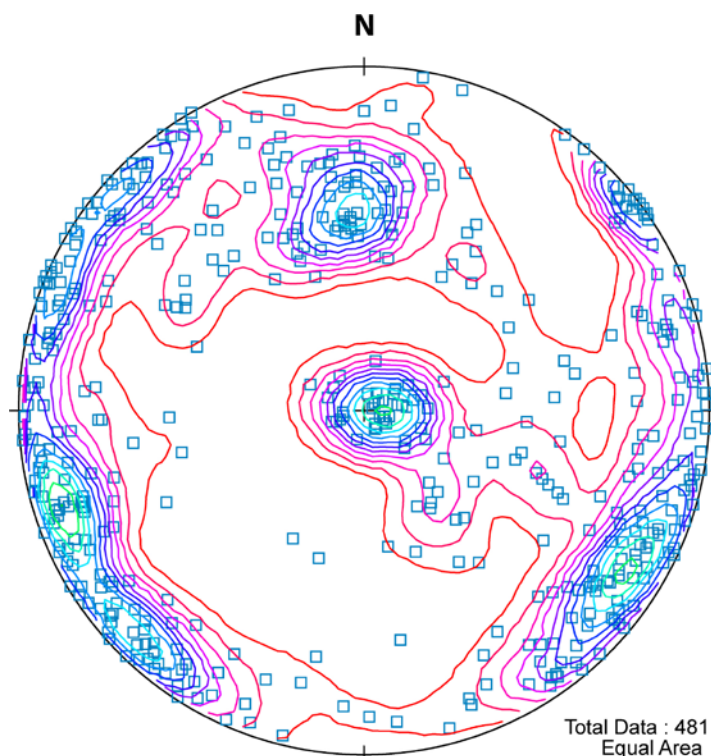


Figure 5-3. Stereographic projection of all fractures registered and measured in the tunnel. All measures are made using a field compass. ‘N’ represents magnetic north and contours are Kamb contouring /Vollmer 1995/, with 2 sigma intervals.

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Database structure and attribute names

