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Äspö Hard Rock Laboratory

Evaluation of scaling records for TASA access tunnel

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Chalmers, Göteborg

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Keywords: Tunnel excavation, Scaling, maintenance, Rock support

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

Abstract

This report presents the result of a project accomplished during the summer 2009. It introduces a method to estimate the magnitude, mass distribution and cause of scaled blocks by tunnel mapping and evaluation of scaling data records. These issues are important for understanding the impact of the excavation method on the surrounding rock mass during excavation of the planned underground repository for spent nuclear fuel.

The project includes mapping of the 3120 m drill and blast excavated part of the TASA access tunnel in the Äspö Hard Rock Laboratory (HRL). In addition it includes development of a method for evaluation of the collected material together with scaling data records from the Site Characterization Database (SICADA). An interview has also been held with Erik Gabrielsson, who has been in charge of tunnel maintenance at Äspö for many years.

The mapping focused on to identify size and cause of areas with significant overbreaks in the tunnel roof. By distributing documented scaled volume in a tunnel section on several mapped overbreak areas in the same section it is possible to reconstruct the size of scaled blocks. The observed overbreak areas have been categorized in five different area types, depending on the cause of scaling: two geologically induced, one blast induced, one induced from a combination of geology and blasting and one unable to place in any category.

For the calculated mass distribution the number of observations is declining with increasing block mass. 11% of the total blocks exceeding 400 Kg and 75% of the scaled blocks weights under 200 Kg. Most of the blocks are however lighter with 34% weighting 50 Kg or less.

There is a relation between the mapped area type and the size distribution among the mapped overbreak areas. For example the areas caused by the end of blasting rounds are more frequently appearing then the other types but most of them are small in relation to the others

The impression achieved from the tunnel mapping is that excavation damages primarily are located near the small face in the end of blasting rounds

It may have been possible to reduce the frequency of blasting caused scaling by applying a higher quality class to the excavation works. Reducing the look-out angel and the limit for allowed overbreak may also reduce the frequency of scaled blocks caused by the end of a bottom charge simply because it would generate a more continues geometry.

Sammanfattning

Den här rapporten redovisar resultatet av ett projekt som genomförts under sommaren 2009. Den introducerar en metod för att bestämma förekomst, blockstorlek och orsak till skrotning genom kartering och utvärdering av skrotningsprotokoll. Den här frågeställningen är viktig för att avgöra i vilken utsträckning berget påverkas av den valda drivningsmetoden under byggandet av slutförvaret för använt kärnbränsle.

Projektet omfattar kartering av den sprängda delen av tillfartstunneln TASA i Äspölaboratoriet (3120 meter). Dessutom omfattar det utveckling av en metod för att utvärdera det insamlade materialet och jämföra detta med befintliga skrotningsprotokoll från databasen SICADA. En intervju har också hållits med Erik Gabrielsson, under många år ansvarig för bergunderhåll i Äspölaboratoriet.

Karteringen fokuserade på att bedöma storlek på och orsak till överberg i tunneltaket. Genom att fördela den dokumenterade skrotade volymen på ett antal karterade ytor med överberg, i en viss tunnelsektion, kan de skrotade blocken i samma sektion återskapas. De undersökta ytorna har delats upp i fem olika kategorier beroende på orsaken till skrotning: två geologiska, en spränginducerad, en orsakad av en kombination mellan geologi och sprängning och en kategori för svårbestämda ytor.

Hos den beräknade massfördelningen minskar antalet observationer med ökande blockmassa. 11 % av blocken har en massa som överstiger 400 Kg och 75 % väger under 200 Kg. De flesta blocken är dock mindre än så, 34 % väger 50 Kg eller mindre

Det finns ett samband mellan areakategori och massfördelning hos de karterade ytorna med överberg. Areor orsakade av bottenladdningar är exempelvis vanligare än de andra kategorierna men de orsakade blocken är samtidigt mindre i jämförelse med övriga kategorier.

Det samlade intrycket från karteringen är att drivningsskadorna i första hand återfinns i närheten av övergången från en salva till nästa.

Det hade eventuellt varit möjligt att minska sprängorsakad skrotning genom att använda en högre kvalitetsklass under drivningen. Att minska maximalt tillåtet överberg samt vinkeln, med vilka konturhålen borras, kan också minska frekvensen av block skrotade på grund av bottensalvor eftersom en mer kontinuerlig geometri skapas.

Contents

1 Introduction

During design and excavation of the planned underground repository for spent nuclear fuel it is important, for several reasons, to consider the impact of the excavation method on the surrounding rock mass. Even though drilling and blasting as tunnel excavation method is relatively cheap and flexible, it must be carefully planned and conducted in order to avoid damaging the surrounding rock mass more than necessary.

Examples of these issues are the risk of gravity induced falls-of-ground (FOG) risking to impact vehicles transporting canisters down the access ramp to the underground repository and excavation damage resulting in undesired water bearing fractures in the near field rock mass. This is also a safety issue for the personal working underground.

During the construction and operational phases of the Äspö Hard Rock Laboratory (HRL) comprehensive documentation of the preformed activities in the HRL has been done. These activity records include the rock volumes from maintenance scaling preformed in the HRL during the operational phase. The records have been archived both physically in an ordinary archive and digitally in the Site Characterisation Database (SICADA).

This report introduces a method to estimate the magnitude, mass distribution and cause of scaled blocks by tunnel mapping and evaluation of scaling data records. The mapping has been conducted at Äspö Hard Rock Laboratory, Sweden during June 2009.

1.1 Purpose

The purpose of this report is to estimate the magnitude and mass distribution of loose blocks scaled down from the roof of the TASA access tunnel in the Äspö HRL. For this purpose a method has been developed to reconstruct the distribution of size and locations of the scaled blocks. The records from SICADA, containing scaled volumes, have been used together with tunnel mapping. The mapping focused on to identify areas with significant overbreaks in the tunnel roof. In addition the mapping aimed at estimating the cause of scaling, if structurally controlled or caused by the excavation of the tunnel.

2 Project

This project has been accomplished during the summer 2009. It includes mapping of the 3120 m drill and blast excavated part of the TASA access tunnel. In addition it includes development of a method for evaluation of the collected material together with scaling data records. An interview has also been held with Erik Gabrielsson, who has been in charge of tunnel maintenance at Äspö for many years.

2.1 Scaling data records and data processing

The scaling data have been collected from the Site Characterisation Database (SICADA) and consists of values of scaled rock volume, taken down in specific tunnel sections during the period 1997 to 2008, Appendix I. For most sections it is noted were the scaling was preformed. The tunnel is then divided into right wall, left wall, abutment and roof. From February 2005 the scaled volumes is given in 20 m sections, earlier data is given in irregular sections. For scaling conducted prior to 1997 there are no volumes noted.

The documented volumes were measured after scaling without considering the swelling factor of the material when scaled. Erik Gabrielsson estimates the swelling factor to 20 %.

The processed scaling data for the period 1997 to 2008 is presented in Figure 1. The scaling data have been processed in the following way:

- Volumes given in sections larger than 20 m have been normalised to 20 m sections, i.e., distributed equally in 20 m sections.
- Volumes given in sections smaller than 20 m have not been normalised since that would increase the documented volume.
- Only volumes scaled in the tunnel roof have been used. In records were only the total volume is given 40% is considered to descend from the roof (Gabrielsson personal communication, 2009).

A histogram presenting the volumes scaled down from the TASA roof, sections 0/000 to 3/120, in the period 1997 to 2008 is shown in Figure 1.

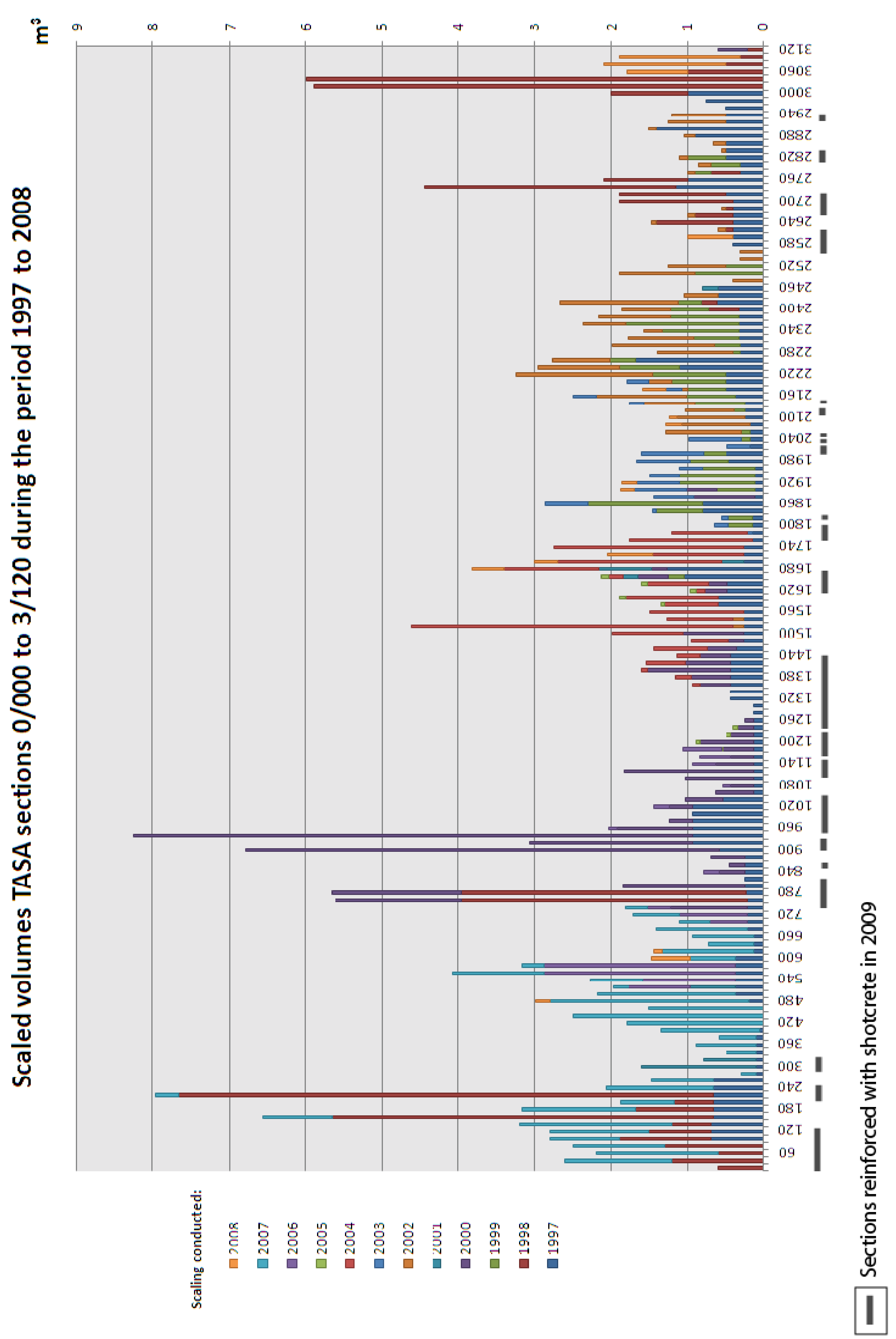


Figure 1. *Scaled volumes originating from the roof and sections with shotcrete TASA sections 0/000 to 3/120.*

2.2 Mapping

Mapping has been conducted in the TASA access tunnel, in sections of 20 meters from the tunnel entrance (chainage 0/000) down to 3/120. The mapping focused on areas with overbreak in the roof. It was assumed that the scaled volumes originated only from the overbreak areas. The areas of interest for this project are those caused by scaling during the operational phase of the Äspö HRL, after the excavation works was completed in 1995.

The main reason why overbreak areas were mapped is that it is far easier to visually estimate the area than the height of the damage left after scaling. This together with the possibility to compare the results with documented scaled volumes gives the final results a higher quality than mapping the overbrake volumes.

Only the areas of scaled rock in unreinforced sections have been mapped, while the areas covered with shotcrete or drainage generally are difficult to map.

In addition to scaled overbreak area the estimated cause and location of the scaled area has been noticed. Five area types have been mapped: two geologically induced, one blast induced, one induced from a combination of geology and blasting and one unable to place in any category, Table 1. In most of the mapped sections it has been noted if a mapped area was placed in or near the end of a blasting round, Appendix II. Figure 9 shows the typical geometry of the scaled area types.

Table 1. Mapped overbreak areas: type, cause and location.

Type:	Type of scaled area	Origin	Location
1	Scaled area caused by the bottom charge of the blasting round	Blast induced	Located in the end of the blasting round, near the bottom charge
2	Scaled area caused by a horizontal fracture	Geologically induced	Located anywhere in the blasting round
3	Scaled area caused by multiple fractures intersecting	Geologically induced	Located anywhere in the blasting round
4	Scaled area caused by a combination of geology and blasting	Blast and geologically induced	Located in the end of the blasting round, near the bottom charge
5	Scaled area with unknown cause	Unknown	Located anywhere in the blasting round

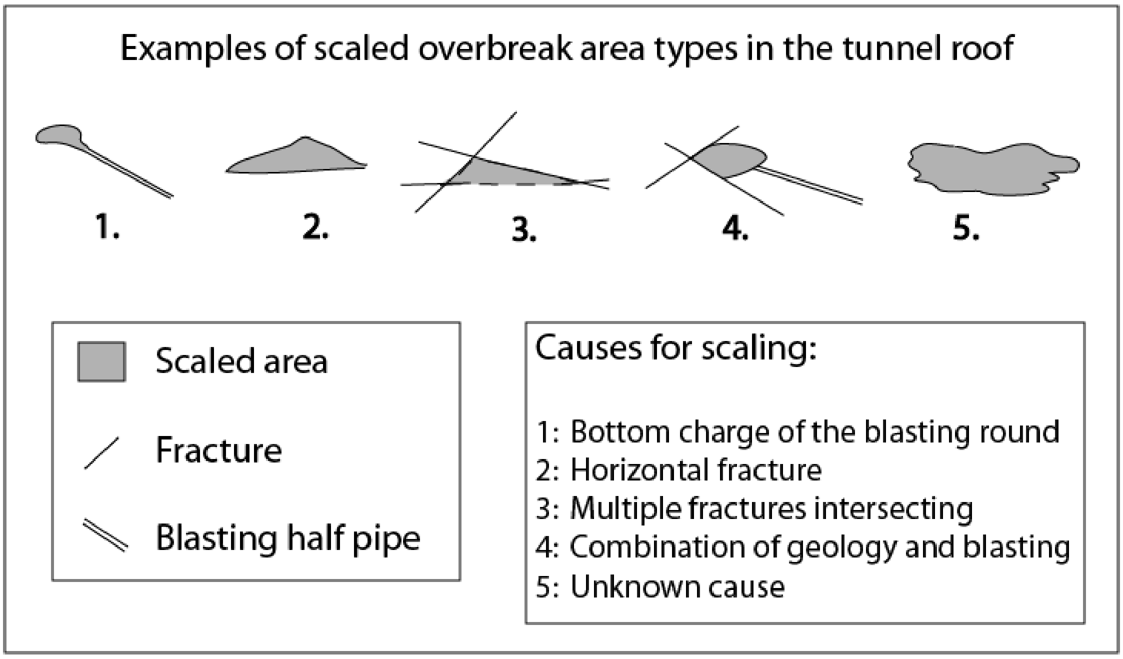


Figure 2. *Examples of scaled area types in the tunnel roof.*

Notes and assumptions related to tunnel mapping:

- Areas smaller than 0,5 m^2 are estimated in intervals of 0,1 m^2, areas 0,5 – 1 m^2 in intervals of 0,25 m^2 and areas larger than 1 m^2 in intervals of 0,5 m^2.
- The areas are estimated by the eye and the marginal of error is therefore at least 15-20%.
- Areas scaled early in the operational phase may in some sections be covered with dirt and harder to map then those from later scaling, were a fresh break is visible.
- It is not possible to separate areas caused by scaling conducted at the time of the excavation from additional scaling preformed in maintenance purpose.

2.3 Method presentation

The method developed for estimation of magnitude, block mass distribution and cause of scaled blocks is based on mapping of scaled overbreak areas in the tunnel roof and documented scaling, conducted in the roof of the TASA tunnel during the period 1997 to 2008.

By distributing documented scaled volume in a tunnel section on several mapped areas in the same section it is possible to reconstruct the blocks taken down, Figure 3.

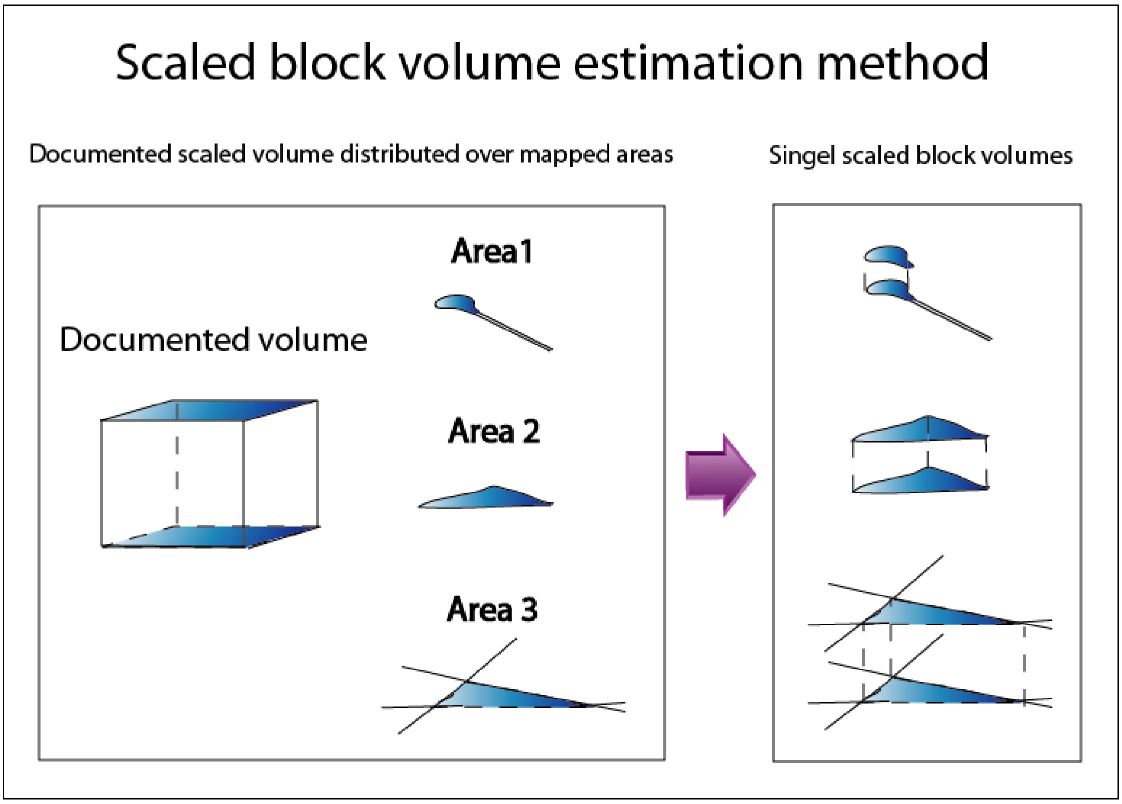


Figure 3. Description of the used method.

When using this method it is assumed that the mapped areas were scaled once a year during the period 1997 to 2008 even if a specific section has been scaled on several occasions during one year. If scaling has been conducted in a specific section in one year, the total documented volume scaled in the section that year is distributed over the mapped areas in the section. The result is one scaled block for each mapped area.

In distributing the documented volume on the mapped areas the block height is considered to be the same for all blocks in a section. In addition the blocks are considered to be symmetrical, se Figure 3.

3 Geological overview and site description

In 1986 SKB decided to construct an underground Hard Rock Laboratory (HRL) in order to perform research in an environment similar to that of the planned deep repository for spent nuclear fuel. The tunnels were excavated in the area of Simpevarp in the north-eastern corner of the municipality of Oskarshamn, Figure 4. During the construction and operating phases of the HRL comprehensive documentation of the preformed activities in the HRL have been done. These activity records have been archived both physically and digitally.

Figure 4. *Geographical location of the Äspö HRL with the tunnel marked in red / Andersson and Söderhäll, 2001/.*

3.1 Geology of the Äspö-area

The major parts of Precambrian bedrock of south-eastern Sweden belong to the so-called Transscandinavian Igneous Belt (TIB) which was formed during intense periods of magmatism during the Svecokarelian orogency. The geology in the Äspö-Simpevarp-Laxemar region is dominated by intrusive rocks of the TIB but the geological development of the region include periods of metamorphosis, resulting in both mineralogical, chemical and structural changes in the bedrock. Figure 5 shows a bedrock map of Äspö.

The dominating rock types found in the Äspö area are listed below. Note that the names for the rock types *Ärvö granit* and *Äspö diorite* are being reworked:

- *Ärvö granit*: a medium grained, equigranular granite to granodiorite, including subordinate quartz monzodiorite.
- *Äspö diorite:* a medium-grained, sparsely to strongly porhyritic intrusive rock that varies in composition between granite and quartz diorite, including tonalitic, granodioritic, quartz monzonitic and quartz monzondioritic varieties.
- A grey, fine-grained, at places slightly porphyritic, intermediate rock.
- Dykes of fine-grained granite and pegmatite are frequently occurring.
- Mafic rocks. These are undifferentiated amphibolites, but most of them are considered to be genetically related to the granitoids and dioritoids of the TIB.

/ Berglund et al, 2003/

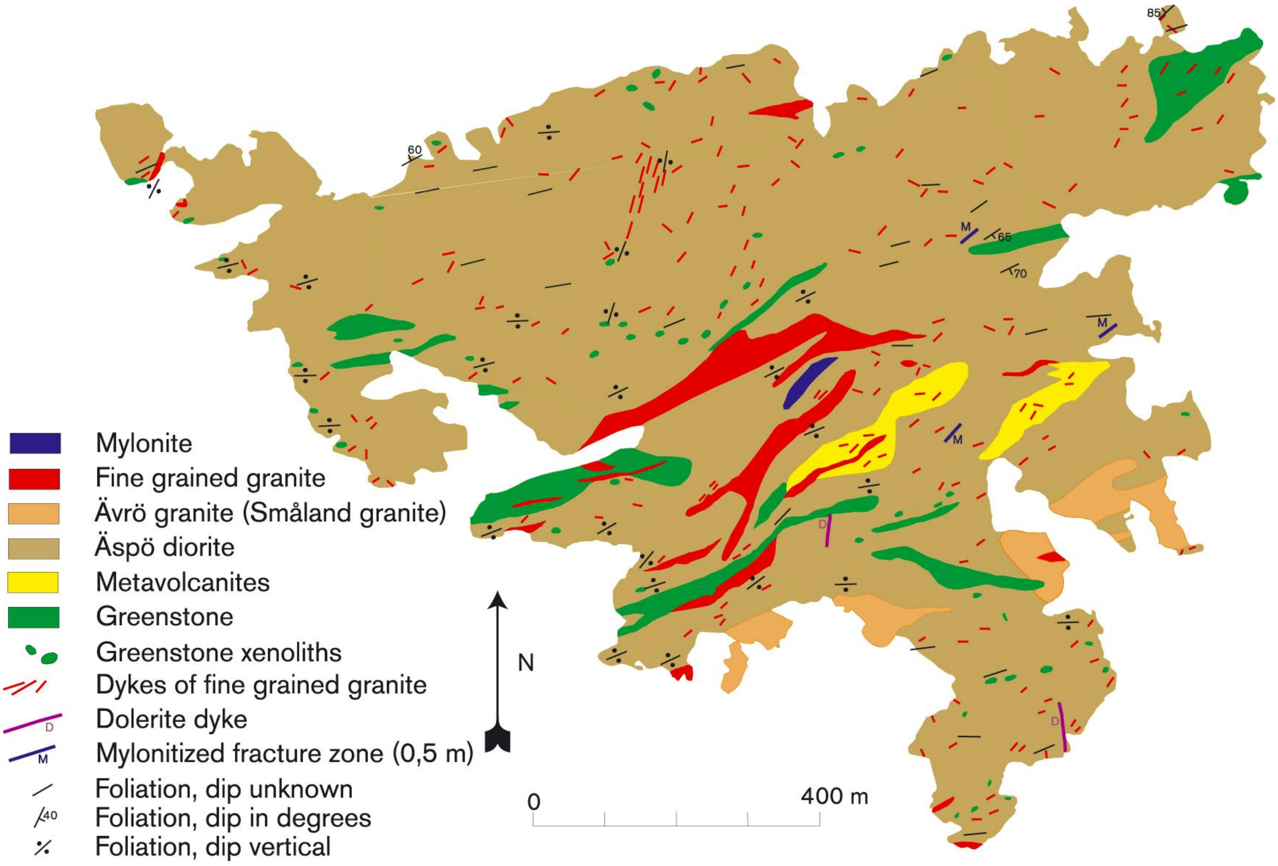


Figure 5. *Bedrock map of Äspö / Berglund et al, 2003/ (modified from /Kornfält and* Wikman, 1988/).

There are several deformation zones of both regional and local scale located in the Äspö area. Two nearly orthogonal tectonic structures are dominating, one trending North-South and the other East-West. The extension of these two tectonic structures is larger than 10 km. Five of the fracture zones in the area are located near the Laboratory, three with East-west trending and two trending North-East/ Andersson and Söderhäll, 2001/. Figure 6 shows the location of the deformation zones in relation to the laboratory. Thickness and dip/strike of the deformation zones shown in Figure 6 are presented in Table 2.

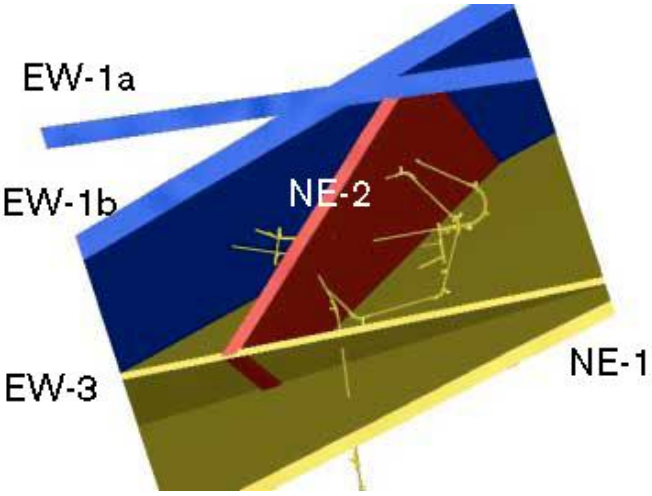


Figure 6. *Top view of larger deformation zones near the HRL, the tunnel is shown in planar view. / Andersson and Söderhäll, 2001/ (modified).*

Table 2: Thickness and dip/strike of the deformation zones presented in Figure 6. Note that all strike directions are given by in the äspö96 co-ordinate system in which north is 12 degrees west of the magnetic north / Andersson and Söderhäll, 2001/.

Deformation zone	**thickness**	**Dip/stike**
EW-1a	50 m	082/90°
EW-1b	50 m	060/75 °
EW-3	7 to 13 m	079/079 °
NE-1	60 m	243/70 °
NE-2	1 to 5 m	033/76 °

The rock mass in the Äspö HRL has been classified using the RMR-system (Rock Mass Rating). The RMR-system describes the rock mass by parameters for strength of rock material, RQD-value, spacing of discontinuities, conditions of continuities and the inflow of water to the tunnel. Each parameter is associated with a number of points, depending on the parameter. The sum of all points describes the rock mass in the form of a RMR-value. Finally the RMR-value is adjusted for the fracture orientation. The RMR-value varies between 0 and 100, with RMR > 60 classified as good rock, RMR 40 – 60 as fair rock and RMR < 40 as poor rock /Carlsson and Christiansson , 2007/.

Figure 7 shows RMR values for parts of the TASA access tunnel together with some of the deformation zones intersecting the tunnel. For a description of the RMR-values in Figure 7, see Table 3.

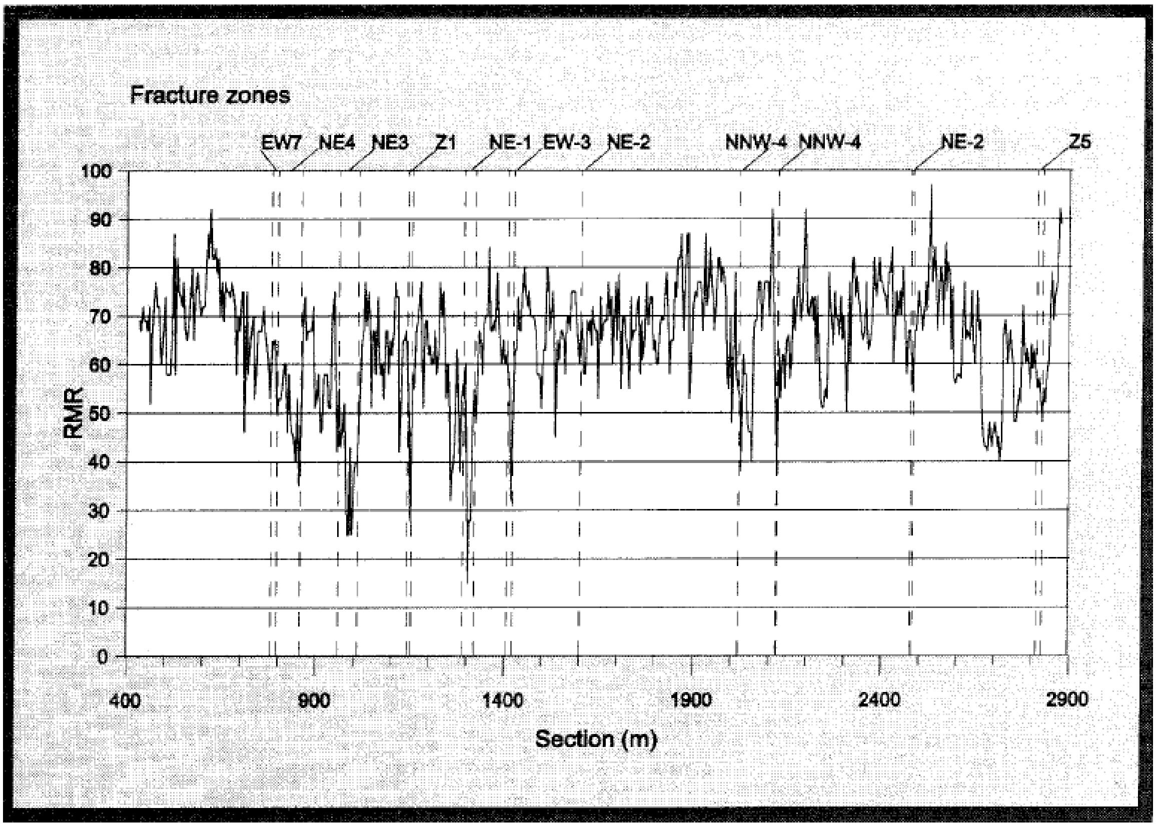


Figure 7. *RMR values along TASA sections 0/400 to 2/900 / Stanfors , Olsson and Stille, 1997/.*

Table 3. Description of RMR-values /Stille and Olsson 1990/.

Rock Class	RMR-value	Description
A	>72	Competent rock of Smålands granite or diorite, sparsely fractured, RQD 90–100, distance between fractures 1–3 m. Existing fractures are closed. The rock mass is dry or minor inflow of water may occur, < 25 l/min and 10 m. Fracture orientation is favourable for the tunnel orientation.
B	60–72	Granite or diorite with a higher fracture frequency than Rock class A, RQD 50–90, distance between fractures 0.3–1.0 m. Competent greenstone/metavolcanics or finegrained granite with RQD > 75. Existing fractures are closed and rough. Minor inflow of water, < 25 l/min and 10 m. There is also some Rock class A but with unfavourable fracture orientation.
C	40–60	Granite with a high fracture frequency, RQD 50–75, distance between fractures 5–50 cm. Fracture surfaces are planar-undulating and occasionally altered. Inflow of water 25–125 l/min and 10 m. Highly fractured diorite, RQD < 25, distance between fractures 5–30 cm. Closed fractures with unaltered fracture surfaces. Minor inflow of water. Fine-grained granite, RQD 50–75, 0.3–1.0 spacing between fractures. Inflow of water under moderate pressure, 25–125 l/min and 10 m. Greenstone, RQD 60–95 with 0.3–1.0 spacing between fractures. Unaltered fracture surfaces, surface staining only. Minor inflow of water, occasional outwash of open fractures.
D	< 40	Minor fracture zones with RQD < 50, 5–30 cm spacing between fractures. Zones are < 5 m wide and are intersected by the tunnel at a sharp angle. Fracture surfaces are planar-undulating and altered. Fractures are occasionally filled with clay minerals. Inflow of water under moderate pressure, 25–125 l/min and 10 m.
E	< 40	Zones with highly fractured granite or mylonite. Zones are > 4 m wide and are intersected by the tunnel at a sharp angle. Fracture surfaces are altered. Inflow of water 25–125 l/min and 10 m

The orientation of fractures located outside deformations zones are shown in Figure 8. The left Schmidt plot shows all fracture orientations and the right one shows the orientation of water bearing fractures. Each red dot shows the tangential point of a plane representing the fracture orientation. The normal to the orientation plane, starting in the centre of the hemisphere intersects the tangential point.

Even if a few fracture orientations are predominating there is a scatter of orientations. The water bearing fractures are however more commonly oriented in the northwest direction. There is also variations in fracture orientation and frequency in different tunnel sections / Berglund et al, 2003/.

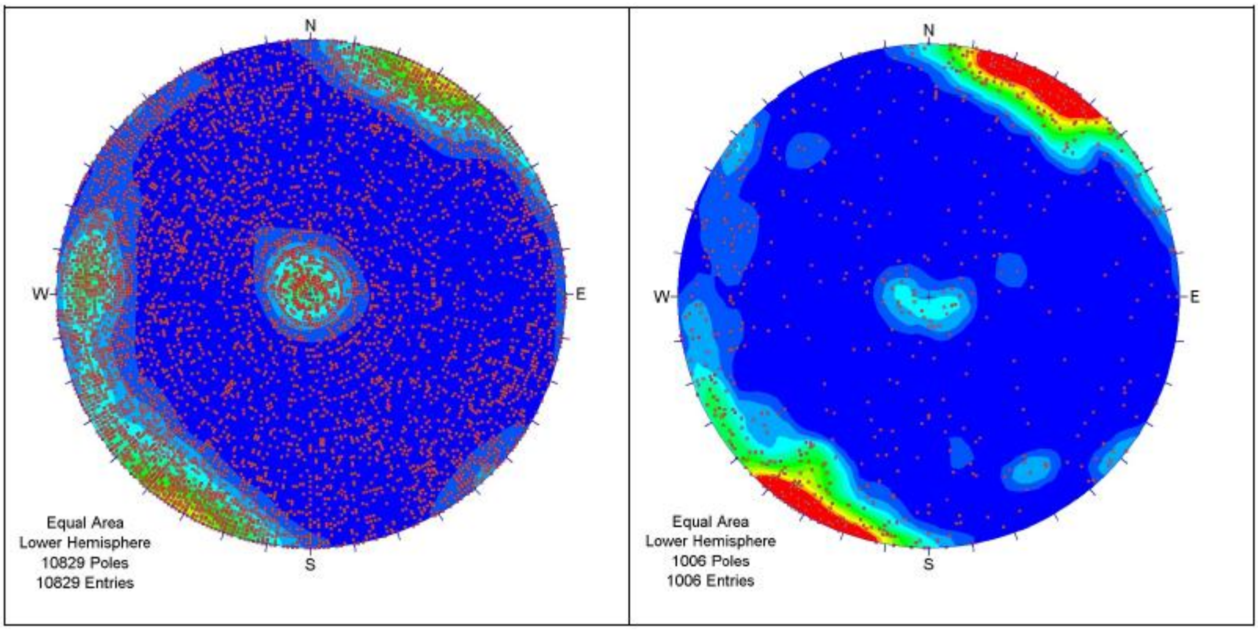


Figure 8. *Schmidt plot of fracture orientations at the Äspö HRL with contour intervals at 1 %. Several measures can have the same direction. Fractures mapped in fracture zones are not included in the figure / Berglund et al, 2003/.*

3.2 The Äspö HRL

The Äspö HRL consists of an underground and a surface part. The underground part is a tunnel, beginning at the Simpevarp peninsula near the Oskarshamn nuclear power plant. The tunnel continues to the southern part of the Äspö island where it takes the form of a hexagonal spiral down to a depth of 450 m (Figure 9), from where the tunnel continues 400 m. A hoist shaft and two ventilation shafts connect the underground part of the laboratory with the surface part, where office, storage and research facilities are located / Berglund et al, 2003 /.

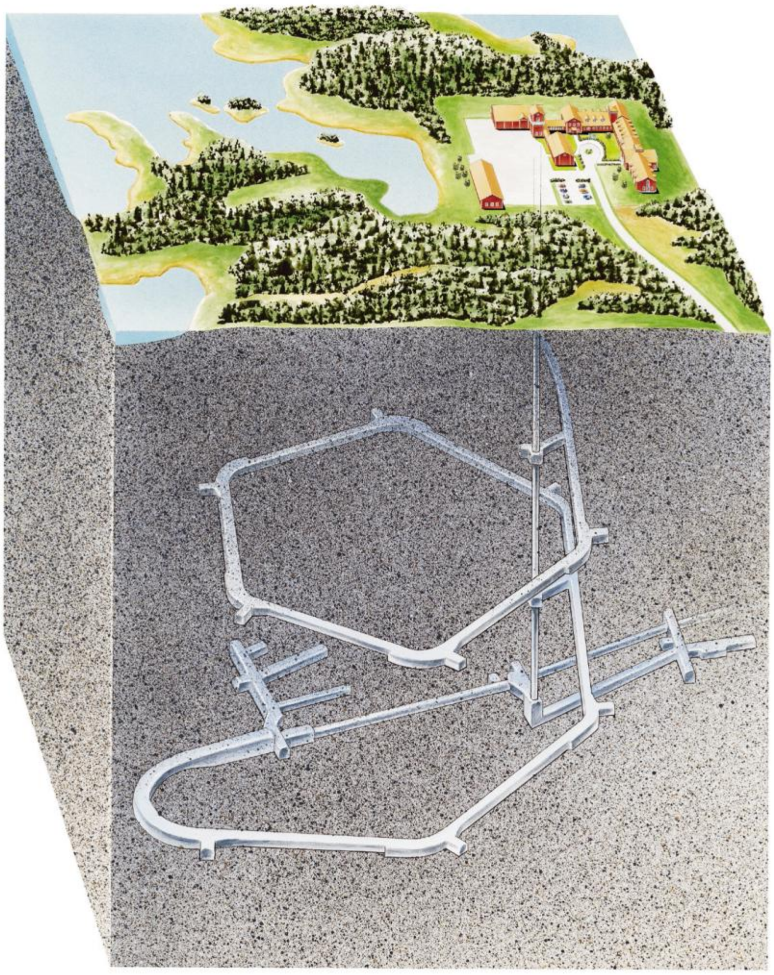


Figure 9. *Overview of the surface and underground parts of the Äspö HRL / Berglund et al, 2003/.*

3.2.1 Tunnel design and support

The design work started in 1989 and the tunnels were excavated during the period 1990 to 1995. There was a flexible approach from the start, allowing adjustments to be made as knowledge increased about the rock mass conditions once the excavation work proceeded. The tunnel is designed for transport and work vehicles with height of 3, 5 m and width of 3 m. The chosen cross sectional area is 25 m^2 down to a depth of 340 m and the tunnel width is 5 m. The access ramp is then narrowed by 0, 2 m due to less rack for installation except for the curves of the hexagonal spiral of the access ramp were the tunnel is widened to 8 m and has a cross sectional area of 42 m^2 (Figure 10) / Andersson and Söderhäll, 2001/, /Carlsson and Christiansson, 2007/.

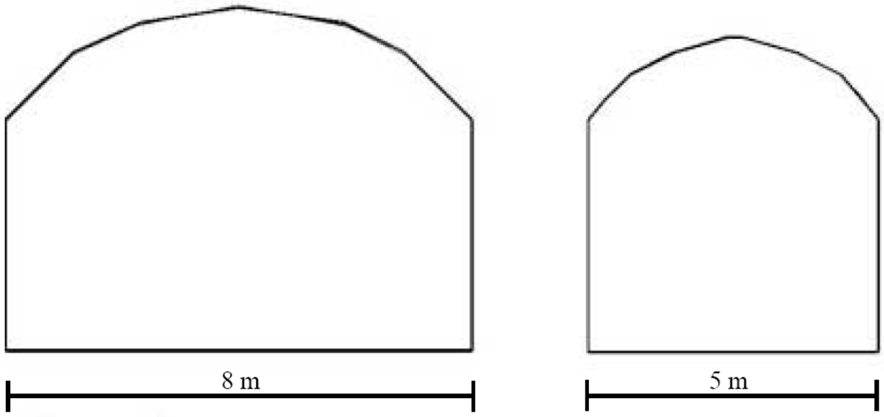


Figure 10. *Cross section of the tunnel profile for the legs of the access ramp (right) and the curves of the access ramp (left) / Andersson and Söderhäll, 2001/.*

Turning niches are placed orthogonal to the tunnel heading in the curves and 20 m is used for curve radius in the access ramp. Approximately 3200 m of the 3600 m long tunnel have been excavated by conventional drill and blast technique using two drilling rigs, on computerized fitted whit 18-ft feed (Tamrock DATA Maxi) and on conventional with three booms fitted with 16-ft (also a Tamrock rig).The rest is excavated using a Ø 5 Tunnel Boring Machine (TBM) model Jarva Mk15 manufactured by Robbins Europe. /Andersson and Söderhäll, 2001/, /Carlsson and Christiansson, 2007/.

Ordinary tunnel support and grouting technology has been used during construction. However in order to be able go back and study exposed rock surfaces and hydrogeology, support and grouting was preformed to a limited extent. /Andersson and Söderhäll, 2001/, /Carlsson and Christiansson, 2007/.

3.2.2 Blasting technique used in the TASA access ramp

A typical blast hole pattern of a drill and blast driven tunnel includes contour holes, stoping holes and a parallel hole cut or large hole cut, normally placed in the lower centre of the face. The cut consists of one or several empty holes surrounded by a few charged holes, Figure 11. Figure 12 shows a typical blast hole pattern with its firing sequence noted next to the holes. The contour holes are divided into floor holes, roof holes and wall holes in the figure. The firing sequence must be designed so that every hole has free breakage. That is achieved by first detonating the cut, then the stoping holes and at last the contour holes/ Olofsson, 2002/.

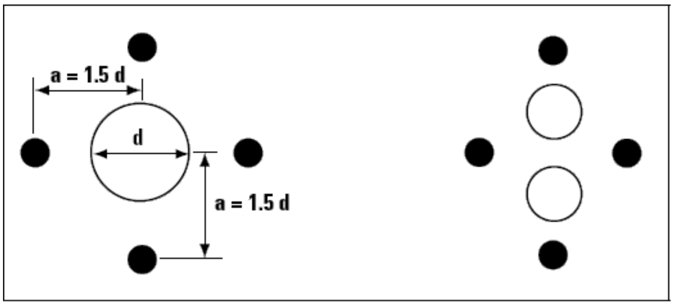


Figure 11. *Example of two typical large hole cut designs/ Olofsson, 2002/.*

To create more stable rock surfaces, with less extent Excavation Damage Zone (EDZ) in underground facilities "smooth" blasting technique have been developed. For smooth blasting a special type of small diameter light explosive is used in the contour holes / Olofsson, 2002/.

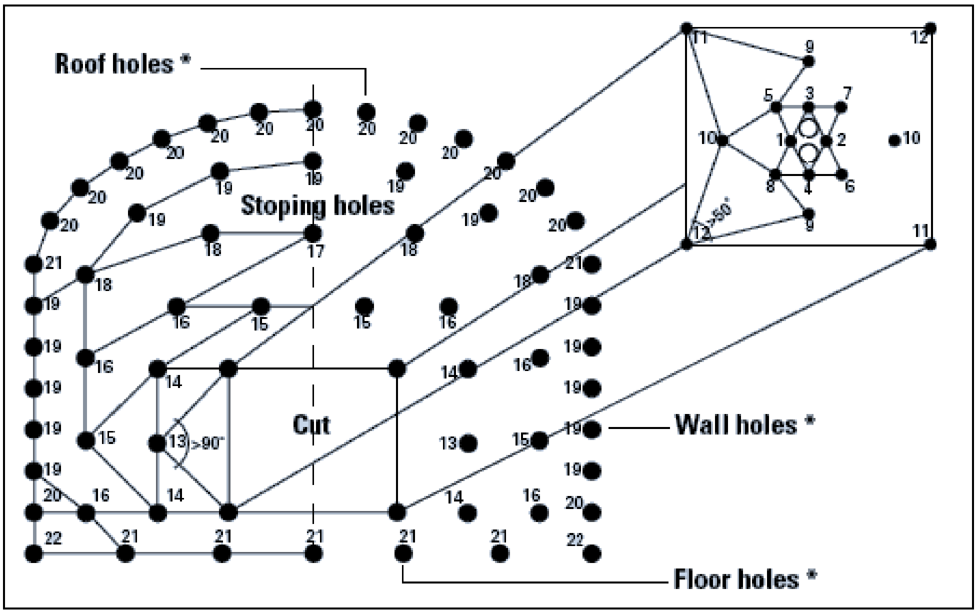


Figure 12. *Firing sequence of a typical blast hole pattern (*contour holes) / Olofsson, 2002/.*

When constructing a tunnel with conventional drill and blast technique the excavated profile is bound to deviate from the theoretical tunnel contour due to space needed by the drilling rig. To keep the tunnel profile the contour holes are drilled whit a certain look-out angel, resulting in a small face in the end of the blasting rounds, Figure 13 /AB Svensk byggtjänst, 1998/. Swedish quality classes for tunnel geometry deviation from the theoretical tunnel contour and drill hole deviation from the theoretical contour are described in Table 4.

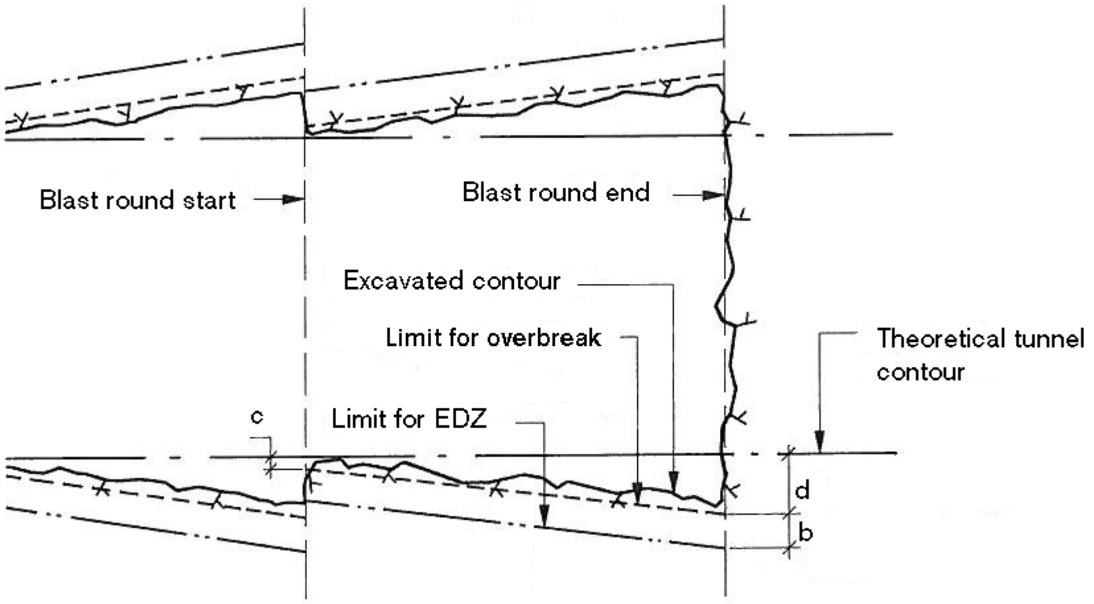


Figure 13. *Plan of a tunnel section excvated with drill and blast techniqe / AB Svensk byggtjänst, 1998/ (modified).*

Table 4. Quality classes in tunnel excavation with drill and blast technique /AB Svensk byggtjänst, 1998/.

Quality class	Maximum mean value of c and d (Figure 13).	Maximum deviation between a single drill hole in wall or roof and the theoretical tunnel contour	Maximum deviation between a single drill hole in the tunnel floor and the theoretical tunnel contour
1	0,3 m	0,7 m	0,8 m
2	0,35 m	0,8 m	0,9 m
3	0,40 m	0,9 m	1,0 m

There are five quality classes for tunnel excavation described in Swedish publication *Anläggnings AMA* concerning maximum extension of the Excavation Damage Zone (EDZ). These quality classes are generally identical to those in earlier publications, used for the excavation of the Äspö HRL. Quality class 1 is to be considered as “smooth blasting”. These classes are used in conventional tunnel excavation in Sweden (Table 5).

Table 5. Quality classes for maximum Excavation Damage Zone (EDZ) /AB Svensk byggtjänst, 1998/.

Quality class	Maximum value of Excavation Damage Zone (EDZ), (b value in Figure 13)
1	0, 2 m
2	0, 3 m
3	0,5 m
4	1,1 m
5	-

The excavation of TASA access tunnel were at first conducted according to quality class 2, Table 5, with the modification that the maximum deviation between a single drill hole in the tunnel floor and the theoretical tunnel contour was set to 0,6. This Quality class however turned out to be expensive to maintain and was therefore changed to 0, 5 m limit for EDZ (b value) and 1, 5 m for Maximum deviation between a single drill hole in the tunnel floor and the theoretical tunnel contour /Carlsson and Christiansson, 2007/. As seen in Table 4 and Table 5, this is a less ambitious aim for the blasting works conducted.

In Swedish civil engineering projects a table has been used for the estimation of the extension of the EDZ depending on the mass and type of explosives used. The table is based on several blasting tests on granite gneiss in road tunnels in the Gothenburg area were new fractures were mapped in core bore holes after blasting. Olsson and Ouchterlony 2003 claims that the table although it has been improved several times lacks a number of important parameters, such as blast hole pattern, scatter in initiation, coupling ratio and effect of charge length. It also lacks a clear definition of damage.

Research conducted by SveBeFo has pointed out that the concentration of the end charge and contour hole spacing are two important parameters affecting the extension of the EDZ. /Olsson and Ouchterlony 2003/.

4 Results

The block mass for each individual block is calculated using the total rock volume taken down in a section in on year, divided by the total area scaled from the tunnel roof in the same section. The volume/area relation for the section is then multiplied by each individual area, resulting in the volumes of each individual block. The individual block mass is calculated by multiplying the volume with the density of the rock mass. The rock mass density used is ρ= 2700 [kg/m^3]. The block mass is also corrected for the assumed 20% swelling factor of the documented scaled material, i.e. multiplied by a factor 0, 8.

The used formula:

Block mass [Kg] = (Scaled volume [m^3]/ Total mapped area [m^2])*Individual mapped area [m^2] * ρ [Kg/m^3]*0, 8

4.1 Block mass distribution

The block mass distribution of all scaled blocks in the TASA access ramp is shown together with mean and median, in Figure 14.

The number of observations is declining with increasing block mass, with 11% of the total blocks exceeding 400 Kg and 75% of the scaled blocks weights under 200 Kg, as seen in Figure 15. The mass distribution among the larger blocks, > 400 Kg is presented in Figure 16.

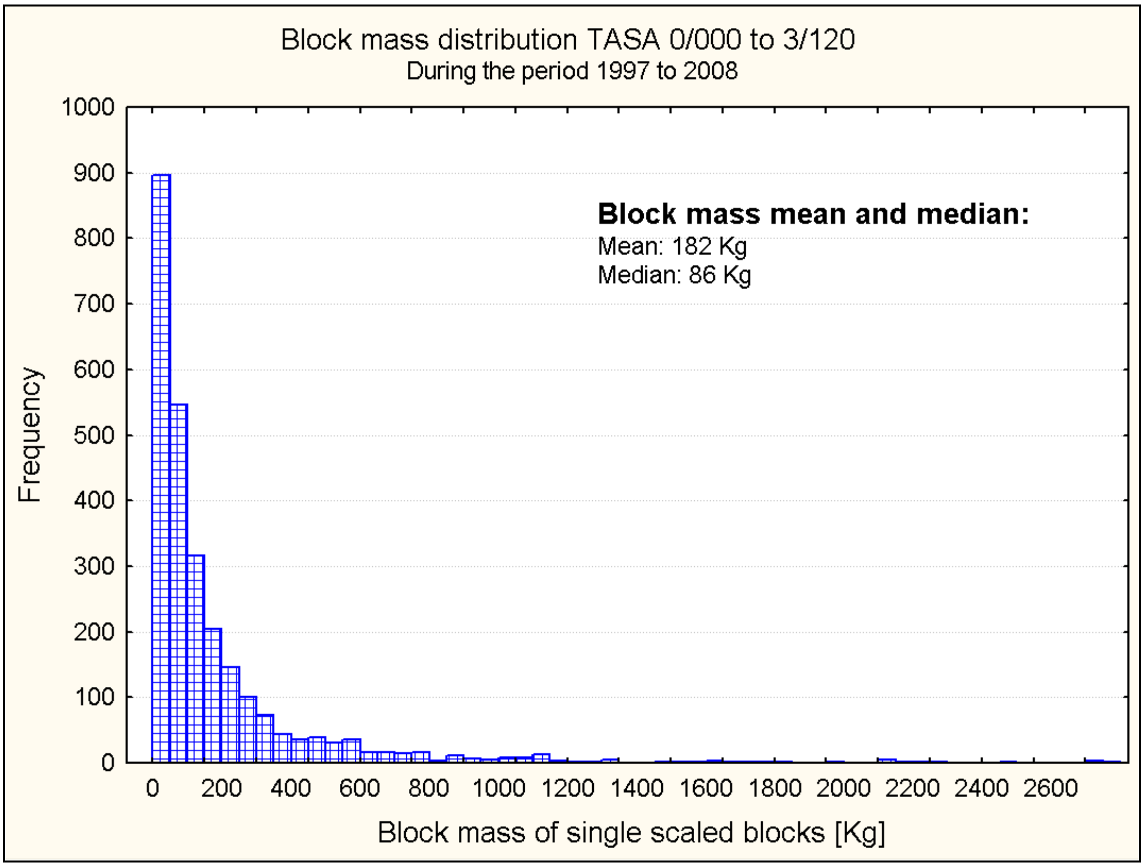


Figure 14. *Block mass distribution for the TASA tunnel, sections 0/000 to 3/120.*

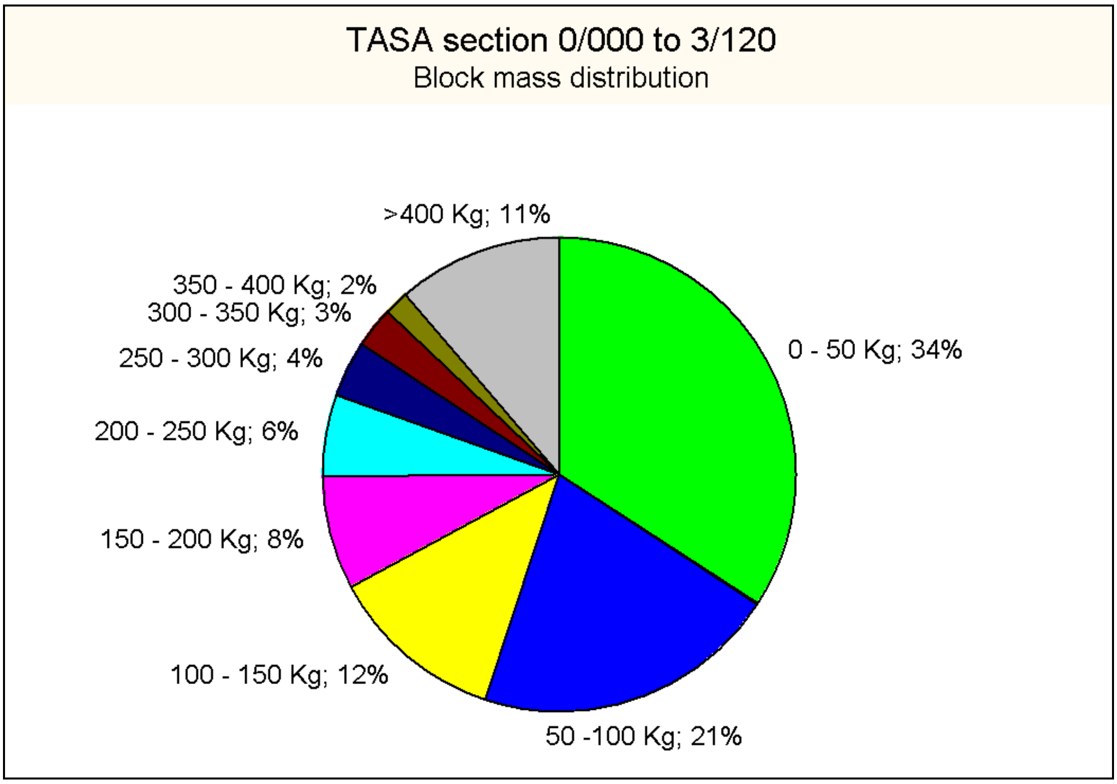


Figure 15. *Pie diagram over block mass distribution of the TASA tunnel, sections 0/000 to 3/120.*

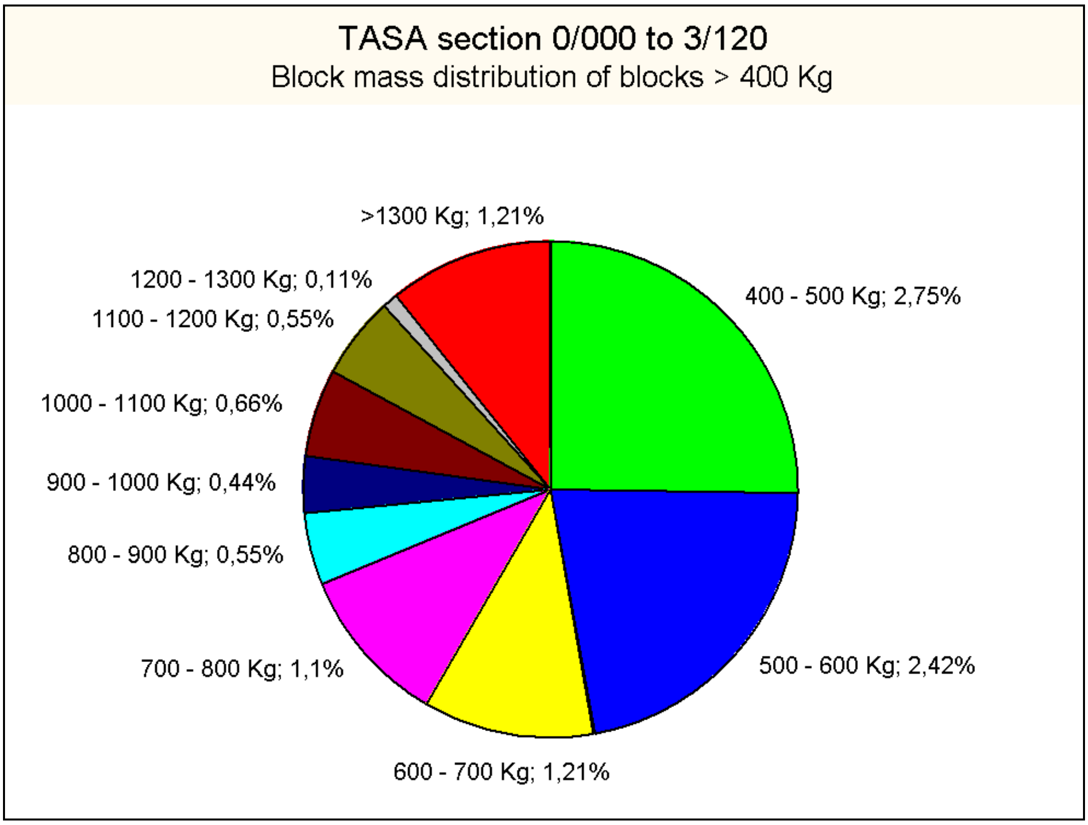


Figure 16. *Pie diagram over the mass distribution of larger blocks, >400 Kg*

The largest block estimated with this method has a mass of 4008 Kg. This is however an exception since only a few blocks of the large sample have a mass exceeding 1000 Kg, as seen in Figure 16.

Figure 17 shows the mean and median block mass in each mapped section of the TASA access ramp together with RMR-value and location of fracture zones. The block mass values presented for each section are the mean and median of the means and medians of scaling conducted in a section each year in the period 1997 to 2008, i.e. the mean and median are calculated separately. This gives an idea of the block mass distribution of the annual scaling in different parts of the tunnel.

The number of mapped overbreak areas in each section is shown in Figure 18. The trend is that more areas have been mapped in first part of the tunnel, in the sections 0/000 to 1/000, and in the last part from approximately 2/500. Note that sections with no mapped areas and therefore displaying mean and median values equal to zero are all reinforced by shotcrete. Those sections may still have been subjected to early scaling, even though it is not possible to study them.

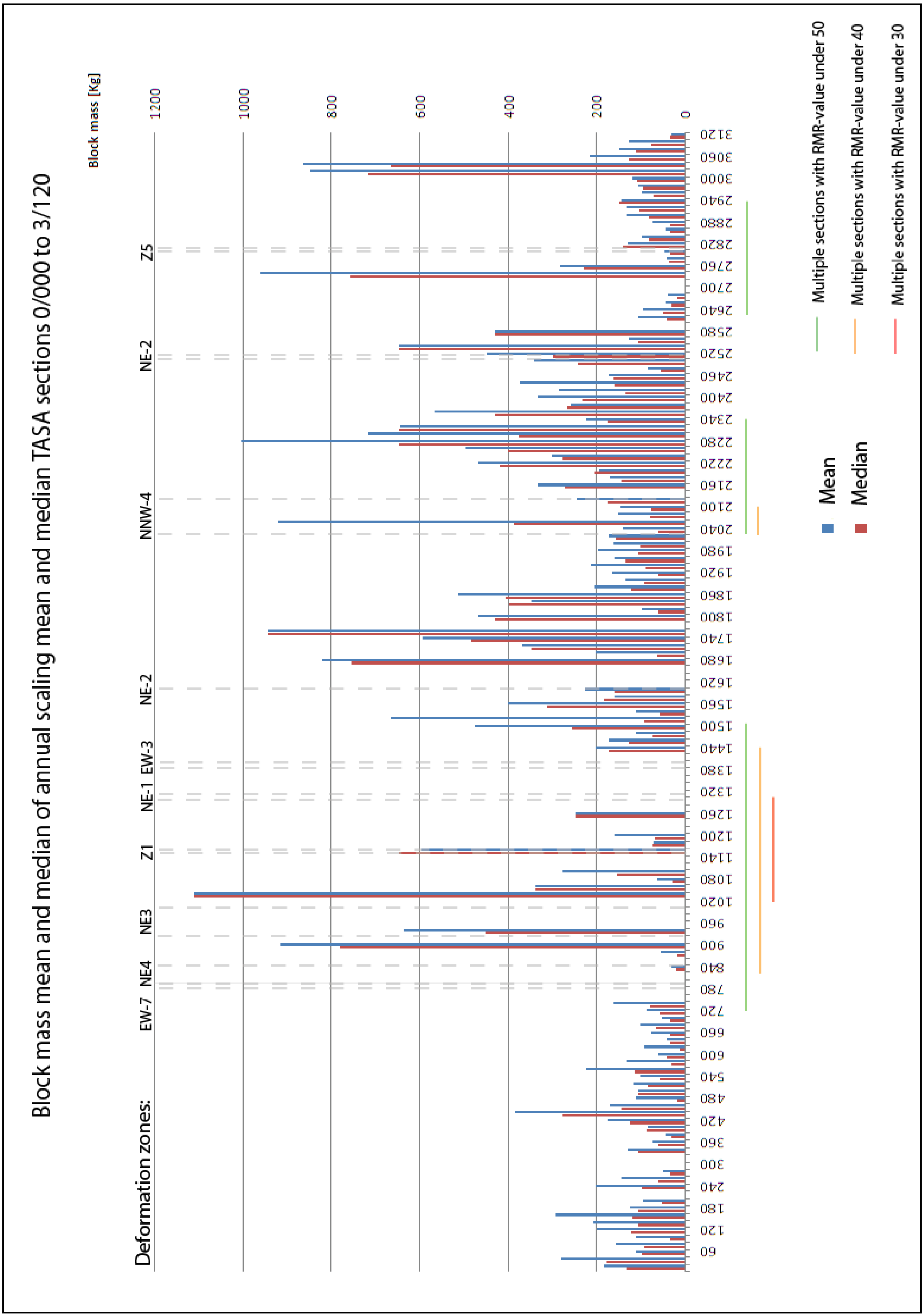


Figure 17. *Block mass mean and median of annual scaling mean and median together with RMR-value and location of fracture zones. TASA sections 0/000 to 3/120.*

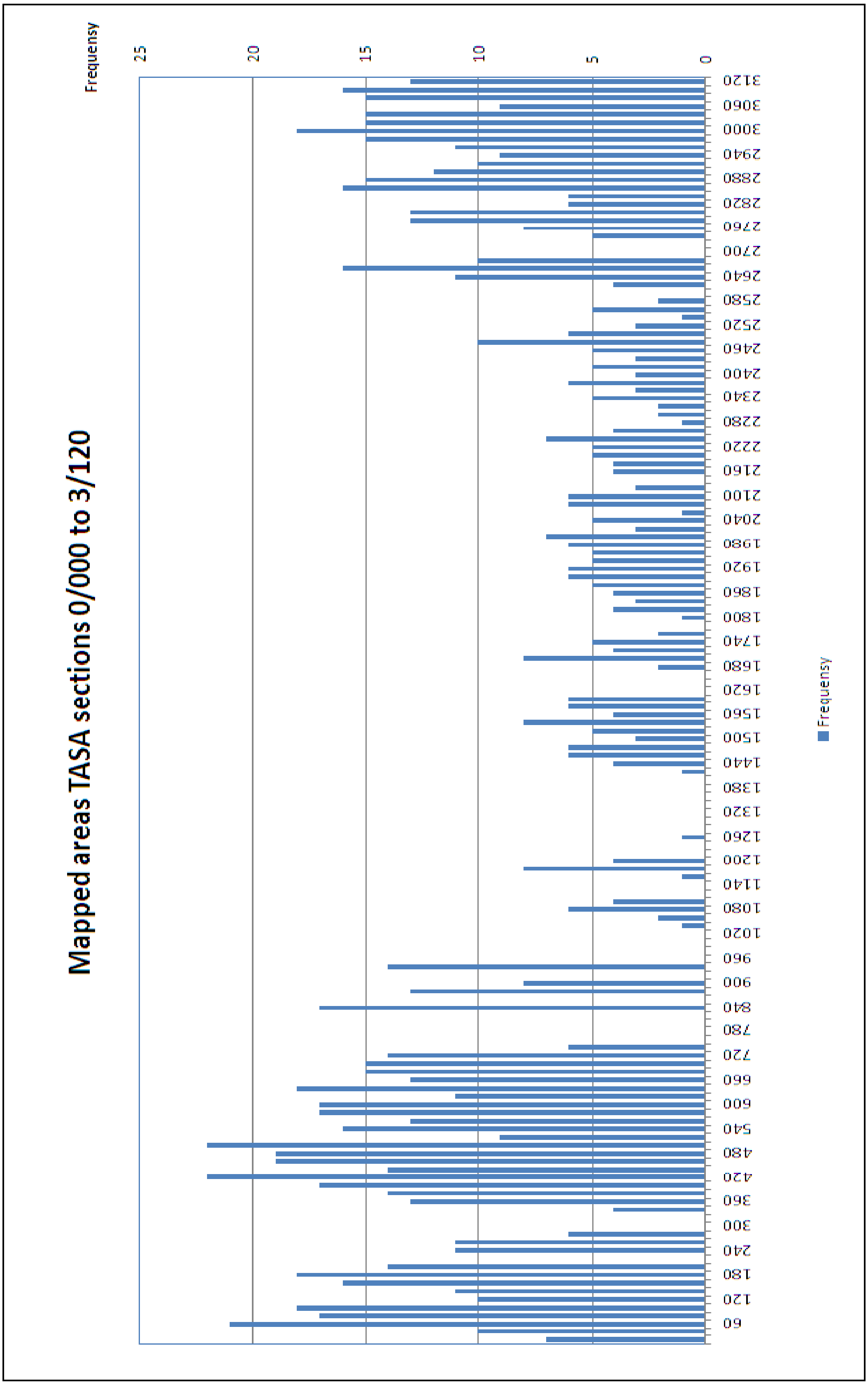


Figure 18. *Mapped overbreak areas. TASA sections 0/000 to 3/120.*

4.2 Location of excavation damage

The impression achieved from the tunnel mapping is that excavation damages primarily are located near the small face in the end of blasting rounds. In addition many of the small niches excavated orthogonally in the curves of the TASA access ramp are constructed with a demanding geometry. Those intersections require continues scaling and reinforcement works, some of them have been reinforced with shotcrete.

4.3 Scaled overbreak area types

The distribution of causes for scaling in the TASA access ramp is shown in Figure 19. With totally 54 %, the blast induced scaling causes are the most common. Scaling caused by a bottom charge is the single dominating area type. 4% of the mapped areas did not fit into any category and was therefore given the area type “unknown”. Figure 20 -22 shows the scaling causes in different parts of the tunnel.

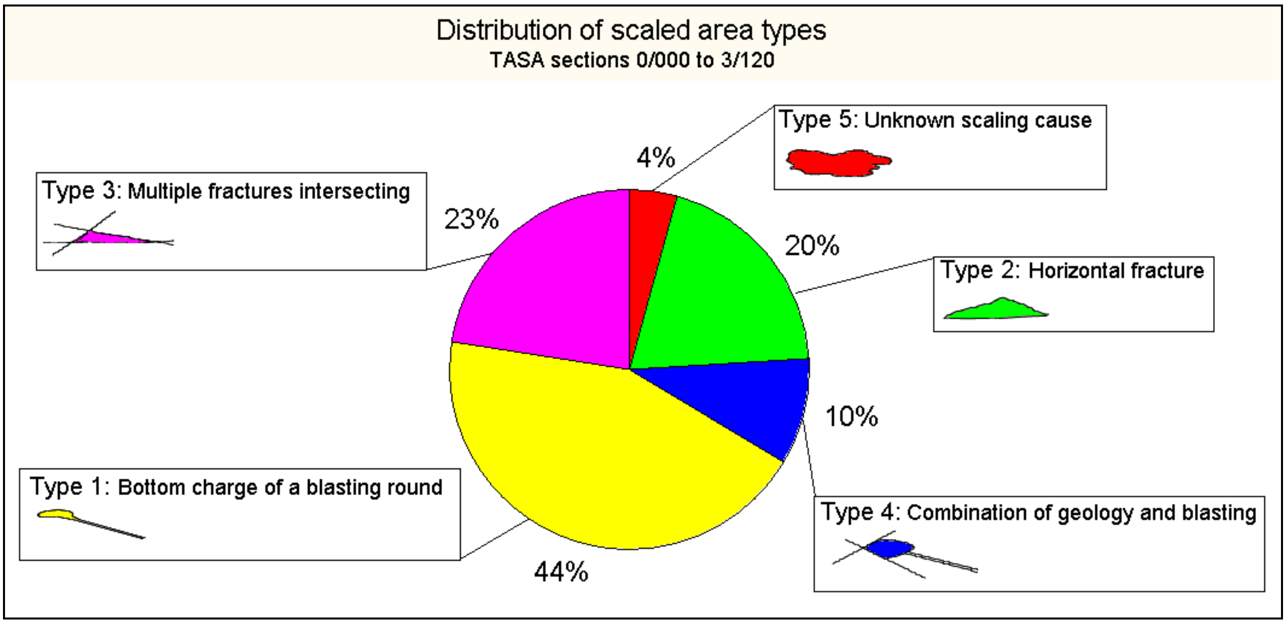
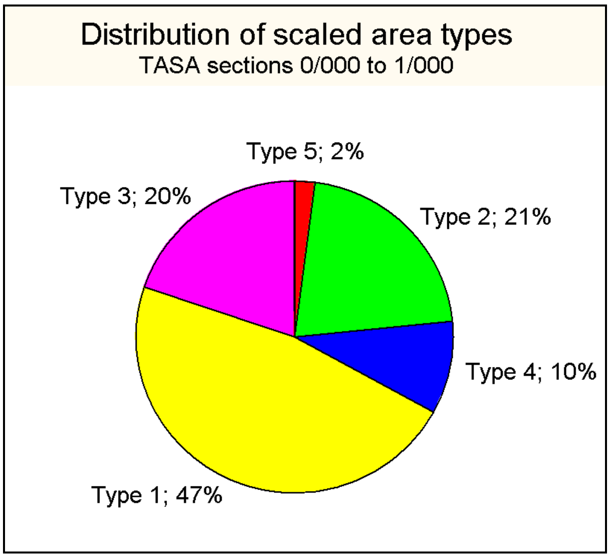


Figure 19. Distribution of the scaled area types.



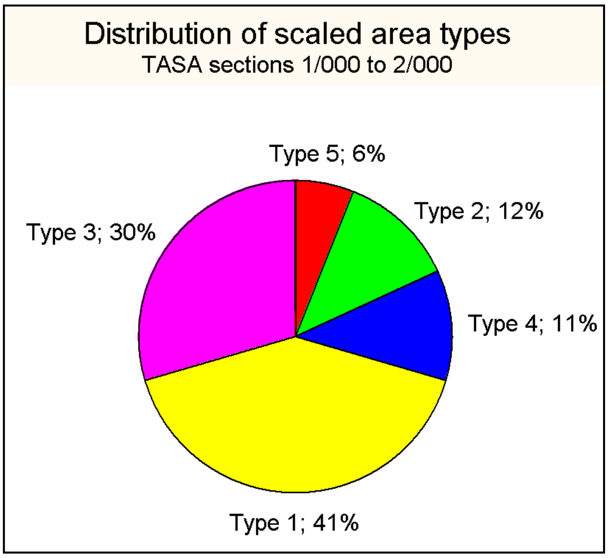


Figure 21. *Scaled area types 0/000 to 1/000.*

Figure 20. *Scaled area types 1/000 to 2/000.*

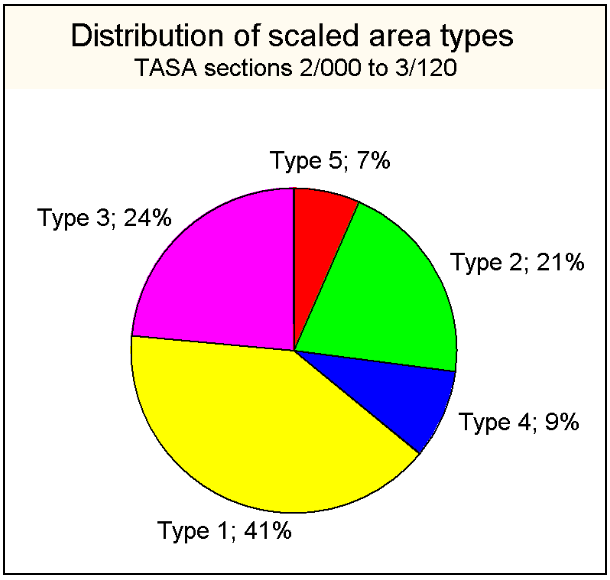


Figure 22. *Scaled area types 2/000 to 3/120.*

4.4 Relation between mapped area size and scaling cause

There is a relation between the mapped area type and the size distribution among the mapped overbreak areas (Figure 23). For example the areas of type 1 (end of blasting round) are more frequently appearing then the other types but most of them are small in relation to the others. Each overbreak area type except type 2 (horizontal fracture) has a characteristic declining distribution even though the rate of decrease is different between them. The distribution of area type 4 (combination of geology and blast damage) for example is decreasing linearly while the distributions of type 1 (end of the blasting round) and type 3 (multiply fractures intersecting) are exponentially decreasing. Area type 2 (horizontal fracture) has a higher frequency in the interval 0, 5 to 1 m^2 indicating that this area type is generally larger than the others.

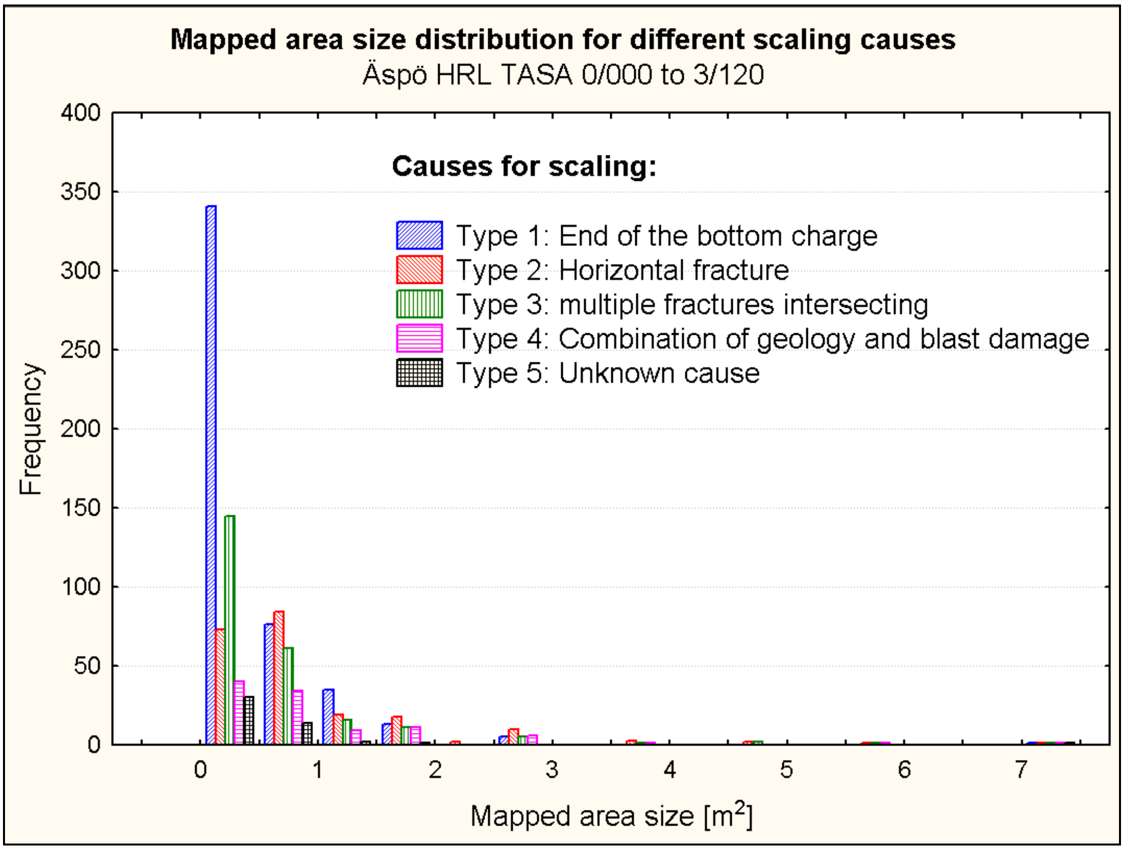


Figure 23. Overbreak area size distribution for different scaling causes.

5 Discussion

5.1 Block mass distribution

The calculated mean and median block mass, 182 Kg and 86 Kg, seems to be realistic values for single blocks scaled down, especially considering there may be an overestimation due to uncertainties in the method. One of the most important assumptions leading to an overestimation of the block mass is that a mapped area is assumed to be subjected to scaling one a year. In reality however the same area can be scaled several times in one year. It is also possible that more than one block was scaled from a mapped overbreak area at one occasion. Considering this, the calculated mass distribution of the largest blocks is probably overestimated.

It seems to be a correspondence between the calculated block mass distribution and RMR values for the TASA tunnel (Figure 7). For example the sections between 0/700 and 1/500 which are not covered with shotcrete have relative low RMR values and high estimated block mass mean and median (Figure 17). The block mass mean and median are also relative high in the other sections with low RMR, for example around 2/000 and 2/700. The sections with RMR-value higher than 50 have generally lower block mass values, except in the sections 1/600 to 1/800.

An explanation of the relative low frequency of mapped areas between approximately 1/000 and 2/000 could be that recently scaling has only been preformed to a limited extent in those sections and the areas are covered with layers of sediment or dust and are more difficult to map. Using the same argument the block mass distribution should be most accurate in the sections scaled in recent years, for example 0/000 to 0/700 and 2/000 to 2/400, scaled in 2007 and 2008. For recent years the scaling data documentation are also considerably better conducted.

The obvious alternative to this method for future scaling documentation is to document the volume, type and location of each individual block taken down. The best way to ensure high quality of this documentation is to have an engineering geologist on the site when scaling is conducted.

5.2 Distribution of overbreak area types

The results suggest that more than every second block scaled down is the result of damage caused by the excavation. Area type 1 is the most frequently occurring but Type 2, 3 and 5 may in many chases also be the result of damage caused by blasting. In the first part of the tunnel, 0/000 to 1/000, there is a higher frequency of the first type of scaled area suggesting excavation damages are more widespread in this part. The frequency of scaling caused by blasting in the other two thirds of the tunnel is approximately 50 %.

According to the ambition in drill hole deviation and extension of EDZ during excavation of the TASA access tunnel it may have been possible to reduce the frequency of blasting caused scaling by applying a higher quality class to the excavation works. Reducing the look-out angel and the limit for allowed overbreak may also reduce the frequency of scaled blocks of type 1(caused by the end of a bottom charge) simply because it would generate a more continues geometry.

To determine the actual rate of mapped areas originating from excavation damage further studies are required. A way to do this could be to note the location of all areas mapped. If the scaled area is located in or near the end of a blasting round it could be caused by the excavations.

It would be interesting to apply this method on other civil engineering projects were excavation is conducted using various blasting designs. Applying the method in a different geological environment would also be interesting.

6 Conclusions

6.1 Uncertainties and deviation in the results

The method presented is a fast and cheap alternative for a reconstruction of the blocks taken down during tunnel scaling and the results seems to be realistic. In this particular case there are several uncertainties affecting the final results:

- It is not known how accurate the given volumes in the scaling data records are. Considering it is an estimation the quality of the documentation may differ between sections and scaling occasions.

- There is no way of knowing the exact 20 meter section of the scaled volumes, given in larger sections during the earlier scaling campaigns. More accurate documentation would distribute the normalised volumes.

- The volume given by the scaling data records does not consider the increased bulk density of the scaled material when collected after scaling. Although the swelling factor of the scaled material were estimated to 20% this have never been measured and documented.

- The mapped areas are estimated by the eye and are therefore subjected to a marginal of error of at least 15-20%. A more accurate but demanding method would be to measure the areas, for example with laser scanning.

- This method treats all areas as the results annual scaling, i.e. scaled once pro year. A mapped area may have been subject to scaling multiple times in the same year, this may lead to an overestimation of the block mass of single blocks.

- It is hard to tell whether a mapped area is a consequence of scaling preformed during excavation or in maintenance purpose during the operational phase. A part of the mapped areas may origin from the time of the excavation and because the scaling records only contain the scaling preformed in the operational phase this can lead to an underestimation of the block mass. Blast induced overbreak areas are obviously caused by the excavation but have most likely been subjected to later scaling, to what degree is unknown.

- For maintenance scaling conducted prior to 1997 there are no volumes noted in the scaling records, even though it is noted that scaling was conducted. The real block mass may therefore differ from the calculated in some sections.

- It is possible that documented volumes in some sections have been scaled down in areas without overbreak.

6.2 Causes for scaling

The results suggest that at least 50 % of the total blocks scaled down origins from damage caused by the excavation. There is a high frequency of those block types although the blocks are usually small compared to other types. Blocks of the other types may as well origin from excavation damage, to what degree is not known.

It is clear that many sections with low RMR-value have been reinforced with shotcrete, Figure 24. If those sections were left unreinforced with the roof visible for mapping the results may have been different. Additional shotcrete may reduce future scaling of larger blocks since there is a relation between low RMR-value and high scaled block mass.

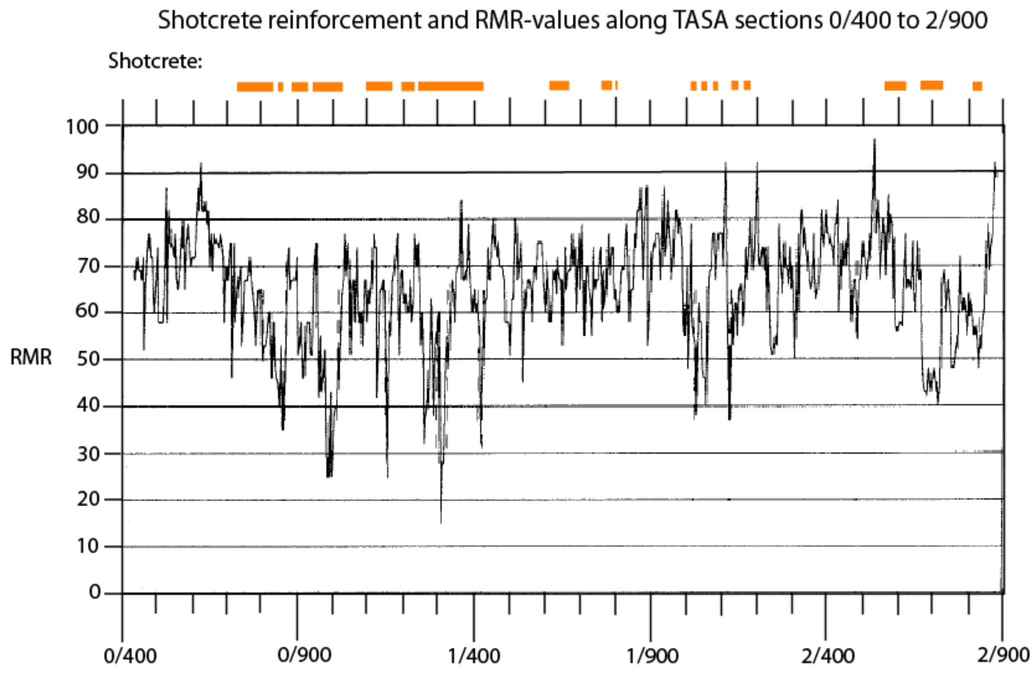


Figure 24. *Shotcrete and RMR-values TASA sections 0/400 to 2/900.*

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