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DIREKT TOLKNING AV BORRKÄRNOR FÖR BEDÖMNING AV BERGMATERIALETS ANVÄNDNINGSOMRÅDE

- *Pilotstudie, Engelsk Rapport*

Erik Andersson & Sofia Öjerborn

2014-06-05

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CHALMERS

Estimation of Rock Quality in Road Projects from Pre-Study to Aggregate

A comparison of the Los Angeles-coefficient for rock cores and base course

Master of Science Thesis in the Master's Programme Infrastructure and Environmental Engineering

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Department of Civil and Environmental Engineering
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CHALMERS UNIVERSITY OF TECHNOLOGY
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Master's Thesis 2014:38

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Cover:
Rock core drilling by GEO-gruppen at Ale Quarry in February 2014
Photo: Sofia Öjerborn (2014)

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ABSTRACT

The Swedish Transport Administration is currently changing their procurement standards from traditional contracts to design-build contracts. As an effect of this, the contractor will bare a greater monetary risk. In a road or railway project, it is of high priority for the contractor to know the properties of the material available at site. In some current and past Swedish Transport Administration projects it has shown that expected rock quality was not met. The rock material that in the technical specification qualified as good quality rock to be used as base course was after blasting and crushing below the quality limit. The geological properties of rock are determined by gathering samples by either drilling rock cores or collecting material with a sledgehammer. The Los Angeles test determines the rocks resistance to fragmentation and must be below 40 for base course.

The purpose of the report is to evaluate the changes in LA-coefficient from in situ conditions to blasted and crushed rock. The investigation focus on how the rock material is affected by blasting and crushing and to which extent. Furthermore, the study evaluates the process of gathering geological information on beforehand for a road construction. The project aims to find indicators when attention needs to be drawn to the rock quality versus the possible use of the material in a road construction.

To carry out the LA-tests, rock samples have been collected from four different locations in the southern part of Sweden. The result showed that rock cores yields a lower LA-coefficient than cobbles and base course for all locations. It also showed that flaky material most often had a large impact on the LA-coefficient.

The conclusion of the report is that the LA-coefficient obtained from rock cores cannot be equated with the LA-coefficient for the same material after blasting and crushing. Attention should be drawn to LA-coefficients around 30 for rock cores, to be certain not to exceed the limit of 40 for base course.

Key words: Los Angeles, mechanical tests, rock core, base course, cobbles, flakiness index, crushed rock, blasting

Förändring av bergkvalité i vägprojekt från förundersökning till krossat material
En jämförelse av Los Angeles-tal mellan borrkärna och bärlager
Examensarbete inom Infrastructure and Environmental Engineering
ERIK ANDERSSON
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Institutionen för bygg- och miljöteknik
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Väg och trafik
Chalmers tekniska högskola

SAMMANFATTNING

Trafikverkets ambition är att öka andelen totalentreprenader och entreprenader med funktionsansvar de kommande åren och med det kommer branschens entreprenörer ges nya möjligheter med ansvar. I väg- och järnvägsprojekt är det av stor betydelse att känna till egenskaperna av materialet på plats. Det har visat sig i nuvarande och tidigare Trafikverket projekt att förväntad bergkvalitet ej har uppnåtts på plats. Material som enligt förundersökningen klarade kraven för bärlager var efter sprängning och krossning på fel sida kravgränsen. De geologiska egenskaperna hos berg bestäms genom att ta ut borrkärnor eller ta prover med slägghammare. Los Angeles testet bestämmer motstånd mot fragmentering och skall enligt Trafikverket vara under 40 för bärlager.

Syftet med rapporten är att undersöka skillnader i LA-tal från in situ förhållanden till sprängt och krossat berg. Undersökningen fokuserar på hur berget påverkas av sprängning och krossning och till vilken grad. Studien utvärderar metoden för insamling av geologisk data för en förundersökning. Projektets mål är att hitta indikatorer på när uppmärksamhet bör riktas mot bergkvalitet och dess lämplighet att användas i en vägkonstruktion.

För att genomföra LA-tester har bergmaterial insamlats från fyra olika platser i södra Sverige. Resultat från undersökningen visar att borrkärnor ger ett betydligt lägre LA-tal än stenar och bärlager på alla platser. Vidare påvisar undersökningen att flisigt material har en stor påverkan på LA-talet.

Rapportens slutsats är att LA-tal från borrkärnor inte kan likställas med LA-tal för samma material efter att det har genomgått sprängning och krossning. Uppmärksamhet bör riktas mot LA-tal kring 30 för borrkärnor för att vara säker på att inte överstiga kravet på 40 för bärlager.

Nyckelord: Los Angeles, mekaniska tester, borrkärna, bärlager, sten, flisighetsindex, krossat berg, sprängning

Contents

Preface by the authors

This Master's thesis aimed to estimate the rock quality in road projects from pre-study to aggregate. It was carried out at the department of Civil and Environmental engineering, Chalmers University of Technology, in collaboration with Skanska Sverige AB between January 2014 and June 2014. The thesis has been supervised by Jan Englund, Chalmers University of Technology and the examiner was Lars O Ericsson, Professor at the department of GeoEngineering at Chalmers University of Technology.

The project was sponsored by the Development Fund of the Swedish Construction Industry, SBUF, which is gratefully acknowledged. The SBUF report has the project number *12940* and the title "*Direkt tolkning av borrkärnor för bedömning av bergmaterialets användningsområde – pilotstudie"*.

First and foremost, our deepest gratitude goes to our technical supervisors Jan Englund, Chalmers University of Technology and Urban Åkeson, Swedish Transport Administration, for their support and guidance.

We extend our gratitude to our managing supervisor Jan Romell, technical manager at Skanska Sverige AB and the reference group linked to the project. The reference group consisted of Lars Stenlid (Skanska Sverige AB), Bo Ronge (Migmatit AB), Gustaf Magnusson (NCC AB) and Mikael Gustafsson (Skanska Asfalt & Betong AB).

The completion of this thesis would not have been achievable without the following people which we thank gratefully.

- Henrik Nilsson, Project manager at Skanska Sverige AB, for the idea leading to this thesis and hospitality at the Tanum project.
- Madelaine Matsson, Joel Andersson and the rest of the personnel at VTC laboratory in Gunnilse for opening up their laboratory for us.
- Håkan Gustavsson, Production manager Ale & Angered quarry.
- Mikael Löfgren & Jan-Olof Gustafsson at Forserum quarry.

Finally, we wish to express our great appreciation to our opponents, Isa Appelqvist and Sofia Örngren, for their valuable and constructive suggestions during the final completion of this thesis.

Göteborg, June 2014

Erik Andersson

Sofia Öjerborn

Preface by the supervisors

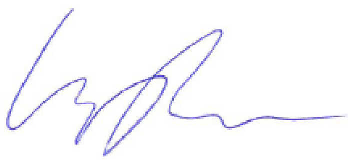
This Master´s thesis describes differences in rock quality in rock mass and produced unbound base layer material. This question is of high importance since the Swedish Transport administration must declare correct properties of the rock material in their tender documents. In some projects, the differences have been too large and the properties of the unbound layer do not pass the requirements. The quality of interest is the resistance to fragmentation determined by using the Los Angeles test. The properties of the rock mass are influenced by mineral content, mineral grain shape, boundary between mineral grains and orientation of mineral grain amongst other. These properties are often not constant in a quarry or in a road cut. The properties of the produced unbound material are influenced by the properties of the rock mass, blasting, crushing, sieving etc., which in turn affect the induced damages and grain shape. The result of a Los Angeles test varies even though the same material is tested each time. All these parameters and variables affect the result of the Los Angeles test. To investigate if there is a difference in crushing resistance between rock mass and produced unbound material, is therefore not an easy task. This investigation must therefore be done in a very structured and careful way.

This is what Erik Andersson and Sofia Öjerborn have accomplished in their Master's thesis. They have shown great enthusiasm for the task and worked highly independent which resulted in an explanation why there is a difference between rock mass and produced unbound material. It has been a true pleasure to supervise you in this work and we wish you all the best in the future!

Göteborg, June 2014

Jan Englund

Main supervisor, Chalmers



Urban Åkeson

Assisting supervisor, Trafikverket

Notations

Roman letters

A_N	Nordic ball mill-coefficient
D	Largest grain size
d	Smallest grain size
E	Young's modulus
E_1	Spacing distance
FI	Flakiness index
Gc	Surface energy per unit area that is required to create the crack surface
K	Bench height
L_A	Los Angeles-coefficient
M_1	Original dry mass
M_2	Dry mass of material larger than 2 mm after abrasion
M_{DE}	Micro-Deval-coefficient
M_{final}	Mass of remaining material on sieve 1,6 mm
$M_{original}$	Original sample mass
n	Material-specific constant
V_1	Burden distance
v_p	Pore volume in percent

Greek letters

α	Dimension of limiting flaw
β	Actual compressive strength
β_0	Compressive strength of the material without porosity
θ	Material-specific constant
ρ_p	Pre-dried particle density
σ_t	Critical tensile stress

Abbreviations

ATB	General technical description (Allmän teknisk beskrivning)
BC	Base course
DB	Design-build
DBM	Design-build-maintain
CSS	Closed side setting
FI	Flakiness index
KBH	Core bore hole (Kärnborrhål)
LA	Los Angeles
MD	Micro-Deval
OCC	Open side setting
RC	Rock core
Skanska	Skanska Sverige AB/Skanska Asfalt och Betong AB
VTC	Road engineering centre (Vägtekniskt Centrum)

Glossary

Aggregate impact value	-	Sprödhetstal
Bench face	-	Pallfront
Burden distance	-	Försättning
Cobble	-	Sten i fraktionen 64 till 256 mm
Decoupling	-	Frikoppling
Equigranular rock	-	Magmatisk bergart med mineralkorn av samma storlek
Gyratory crusher	-	Spindelkross
Homeoblastic rock	-	Metamorf bergart med mineralkorn av samma storlek
Mica	-	Glimmer
Nordic ball mill	-	Kulkvarn
Spacing distance	-	Hålavstånd
Subdrilling	-	Underborrning
Swedish abrasion value	-	Slipvärdesmetoden

1 INTRODUCTION

The Swedish Transport Administration has an ambition of changing their standard contract form from traditional contracts to design-build (DB) contracts and design-build-maintain (DBM) contracts (SOU, 2012). For contracts ranging from 25 million SEK to 500 million SEK the amount of DB contracts are to be increased from 20% in 2012 to 40% in 2014. At 2018, the goal is to have a steady rate of approximately 50% of the contracts as DB or DBM. By changing toward DB contracts, Swedish Transport Administration is handing over the interpretation of the pre-study data and design to the contractor. DB contracts offer more flexibility to the contractor to build more innovate and thus lowering the cost by finding smarter solutions and building techniques, while bearing a greater risk.

In a road or railway construction project, it is of high priority for the contractor to know the properties of the materials available at site. During the tendering process, economic benefits for the contractor and client can be identified if the material excavated at site can be used during the construction. The ambition of Swedish Transport Administration to change the contract form to DB and DBM means the contractor is responsible for interpreting the material at site. This gives the contractor a greater liberty and a possibility of more effectively using the resources at site, leading to lower costs and a reduced impact on the environment. When the contractor owns the responsibility for the evaluation of materials, possibilities for earning and risks of losing money will be created for the contractor.

1.1 Background

As of today, traditional contracts are the most common type of contract (SOU, 2012). If traditional contracts are used, Swedish Transport Administration is responsible to provide the contractor with geological information. In some current and past Swedish Transport Administration projects it has shown that expected rock quality was not met[1]. The rock material that in the technical specification qualified as good quality rock to be used as base course was after blasting and crushing below the quality limit and did not meet the criteria for base course.

The geological properties of the rock are determined by gathering samples by either drilling rock cores or collecting material with sledgehammer[2]. The samples are thereafter tested at a laboratory regarding resistance to fragmentation, strength and geometry, amongst other properties evaluated. The Los Angeles (LA) test determines the rocks resistance to fragmentation and is a standard test method for aggregates. It has shown that LA-test result for sampled rock not always is consistent with the LA-test result obtained after blasting and crushing.

Therefore, due to the uncertainties regarding expected rock quality at site, more knowledge of how the LA-test result changes due to blasting and crushing must be obtained. Knowledge of the geology is crucial for the contractor to carry the risk they will be given in a design-build and design-build-maintain contract.

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[1] Åkeson, Urban; Trafikverket. 2014. Start meeting January 27th.
[2] Ibid.

1.2 Purpose

This thesis evaluates the changes in the LA-coefficient from in situ conditions to blasted and crushed rock. The investigation focus on how the rock material is affected by crushing and blasting and to which extent. Furthermore, the process of gathering mechanical properties of the rock on beforehand for a road construction is evaluated.

The purpose of the project is to find indicators when attention needs to be drawn to the rock quality versus the possible use of the material in a road construction. The thesis targets the following research questions:

- Do differences occur between expected and received LA-coefficient?
- Does the grain shape affect the resistance to fragmentation?

1.3 Hypothesis

The test results from the investigation are believed to show that the crushing resistance is lowered after blasting and crushing of the rock. It is also likely that base course samples will show a poorer Los Angeles-coefficient than cobbles. In which extent the crushing resistance is lowered is hard to determine on beforehand. The flakiness of the samples is expected to affect the overall resistance to fragmentation, with a flaky material having poorer technical qualities.

1.4 Method

To gain knowledge of how the crushing resistance changes from in situ conditions to blasted and crushed rock, mechanical tests are carried out at four different locations with different rock types. Drilled cores are taken from the four locations and are thereafter tested for crushing resistance by the LA-method in the VTC laboratory in Gunnilse, according to standard testing methods. After the rock cores have been drilled, the rock is blasted and thereafter crushed according to normal procedure at site. Thereafter, the crushed material is tested for crushing resistance by the LA-method. The blasted and crushed rock is both base course (0 to 32 mm) and cobbles (64 to 256 mm). The cobbles correspond to sledgehammer samples, although that they are blasted. The samples are analysed and compared to the rock cores in order to identify possible indicators that affect the crushing resistance.

Four locations have been chosen to be investigated;

- Ale Quarry. Gneiss. Skanska
- Angered Quarry. Gneiss. Skanska
- Tanum road project E6. Bohus granite and gneiss. Skanska
- Forserum Quarry. Dolerite. Skanska

The effect of the geometry of the grains is analysed by investigating the flakiness index on all rock samples. To further evaluate the quality properties and to justify the LA-test result, Micro-Deval tests has been carried out on selected samples.

1.5 Limitations

The project does only involve rock material from four locations. Therefore, the results only apply to these locations and places with similar geological conditions. Only two in-situ samples from each location are evaluated and compared with blasted and crushed material. For Tanum, three in-situ rock samples are collected. The flakiness index has been measured by a method that has been created especially for this thesis and is not the standard procedure for measuring flakiness index.

1.6 Disposition

Chapter 2 is initiated by providing a presentation of relevant theory. Mechanical tests are described, followed by a brief description of blasting and crushing. Thereafter, factors that affect rock properties will be presented.

Chapter 3 describes the locations chosen for this study from a geological perspective in a case study. The regional geology is presented followed by a closer description of the local geology at Ale, Angered, Tanum and Forserum respectively. Last, a presentation of the rock core mapping is made.

Chapter 4 presents the methodology. First, the method for rock core drilling is explained followed by the blasting process. The method for preparation of rock samples, including crushing and sieving is then described. Last, the method for tests with Los Angeles, Micro-Deval and modified flakiness index tests is described.

Chapter 5 shows the results from the Los Angeles and the Micro-Deval tests. Furthermore, the results from the modified flakiness index test are presented.

Chapter 6 analyses the results by comparing the result with different properties of the material, such as flakiness and location. Furthermore, different relations are plotted to see if any correlations can be found.

Chapter 7 provides a discussion regarding the methodology, the result and the analysis. Additionally, sources of errors and suggestions of further studies are discussed.

Chapter 8 answers the purpose, the research questions and summarizes the findings in a conclusion.

References are given in Chapter 9 followed by the appendices.

2 THEORY AND LITERATURE REVIEW

Chapter two deals firstly with a theory review on mechanical test on aggregates including Los Angeles-, Micro-Deval- and Nordic ball mill tests. Further, test on geometric properties with Flakiness index are described. A theory review regarding blasting and crushing will be presented followed by information about factors that affect rock properties. Nordic ball mill tests are included in the literature review because its relationship with Micro-Deval is very strong.

2.1 Mechanical tests on aggregates

A road pavement consists of multiple layers, bound (bituminous) and unbound, see Figure 2.1. The layers distribute the load from traffic and the stress and strain are reduced with depth (Saarenketo & Scullion, 2000). Depending on the traffic volume and the layer referred to, the quality requirements for aggregates varies (SGU, 2006).

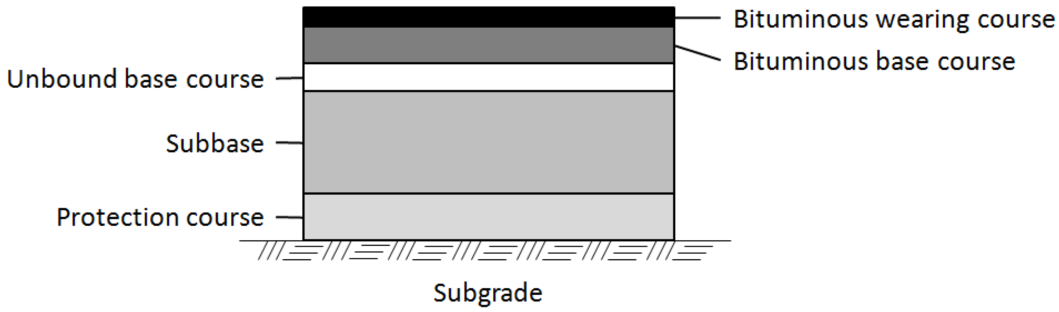

Figure 2.1 Schematic picture of a road pavement, modified (Vägverket, 2004).

Mechanical analysis of aggregates such as Los Angeles-, Micro-Deval- and Nordic ball mill- tests are the most commonly used quality tests in Sweden (Hellman, et al., 2013). The aggregate impact value were until 2004 the method used for determining the resistance to fragmentation in Sweden (Viman & Broms, 2005). In conjunction with the coordination of standards for Europe, the impact value was replaced by the Los Angeles testing method. The Nordic ball mill method is from 2004 replaced by the Micro-Deval method for determining the resistance to wear on aggregates, except for tests on the wearing course (Viman & Broms, 2005). The two tests have similar testing procedures, but a difference is the missing shelves in the Micro-Deval drum compared to the drum in the Nordic ball mill test.

The different layers are tested with different combinations of the above mentioned mechanical analyses on aggregates. Tests on bituminous bound layers include Micro-Deval-, Los Angeles- and Nordic ball mill tests on aggregates (Trafikverket, 2011b). The unbound base course is tested with Micro-Deval- and Los Angeles tests and the subbase is tested with the Micro-Deval test (Trafikverket, 2011a). Additionally tests measuring for example flakiness index and crushed surface ratio among others are also a part of the requirement Swedish Transport Administration impose on aggregates.

2.1.1 Los Angeles test SS-EN 1097-2

The Los Angeles test was developed in Los Angeles in 1916 (Stenlid, 1996). It became a standardized method in the US in 1939 and came to Europe after the Second World War. Differences in equipment together with differences in evaluation methods were observed when the method was introduced in the European countries. A

European Standard for Los Angeles test and evaluation has since then been established and adapted in Sweden. It was introduced in ATB VÄG in 2004 and is referred to as SS-EN 1097-2 (Swedish Standards Institute, 2014a; Viman & Broms, 2005).

The Los Angeles test was developed to determine the resistance to fragmentation. It is an important parameter to measure because the aggregates must be able to resist crushing, wearing and abrasion during construction and tolerate load from traffic without breaking (SGU, 2010a).

In Figure 2.2 an explanatory image of a Los Angeles machine can be seen. The test equipment consists of:

- A large drum (cylinder) with a shelf
- Steel balls (11 spherical balls, 400-445 grams each)
- Sample of rock material (5000 g)

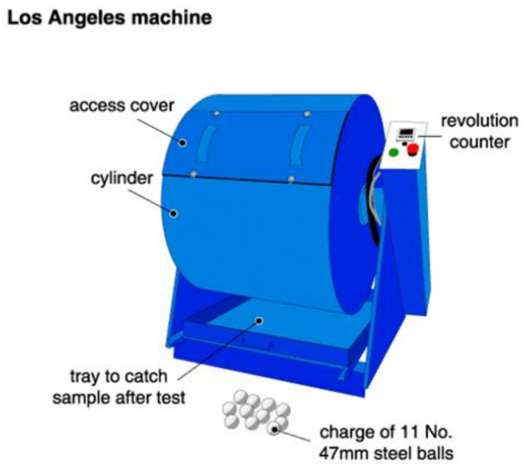

Figure 2.2 Los Angeles-drum (Northstone, n.d.).

To test rock samples with the Los Angeles-method it needs to be crushed and sieved to receive a 10-14 mm fraction for analyse in a LA-drum (Swedish Standards Institute, 2010). The 10-14 mm fraction consists of two fractions, 10-11,2 mm and 11,2-14 mm. The weight proportion of 11,2-14 mm and 10-11,2 mm must be between 60:40 and 70:30 with a total weight of 5000 gram.

The material is washed and dried in an oven before the steel balls and the material is added to the drum. The material is lifted with the shelf and then falls freely in 500 revolutions in the LA-drum. The material is then washed, sieved and dried. The material larger than 1,6 mm is weighted.

The proportion of material smaller than 1,6 mm generated by the drum define the LA-coefficient and is calculated as shown in Equation (1) (Pavement Interactive, 2011).

$$L_A = \left(\frac{M_{original} - M_{final}}{M_{original}}\right) \times 100, \text{ where} \quad (1)$$

$M_{original}$ is the original sample mass (5000 gram) and M_{final} is the remaining mass of material in sieve 1,6 mm measured in gram. A high LA-coefficient corresponds to low resistance to fragmentation i.e. poor technical qualities.

2.1.2 LA-limits for a road

According to Trafikverket (2011a) the resistance to fragmentation with the Los Angeles method cannot exceed 40 for aggregates in the unbound base layer. The limit has been set by the Swedish Transport Administration based on empirical tests and experience[3]. For declared material at least one control of LA-coefficient per project and quarry or per 40 000 m^2 must be performed (Trafikverket, 2011a). Undeclared material is controlled once per 10 000 m^2 or once per project and quarry.

The wearing course must be able to withstand higher loads than the base course and the subbase. Therefore, the LA-coefficient limit for aggregates in bound layers is maximum 25 (Trafikverket, 2011b).

2.1.3 Micro-Deval SS-EN 1097-1

The Micro-Deval method was developed in France in the 1960s to determine the resistance to wear (Stenlid, 2000). It was introduced in ATB VÄG in 2004 and the standard for the testing procedure is referred to as SS-EN 1097-1 (Viman & Broms, 2005). The testing equipment consists of a cylinder, steel balls (5kg), water (2,5kg) and the rock sample (500g). A Micro-Deval machine can be seen in Figure 2.3.

Figure 2.3 The Micro-Deval testing machine with four cylinders (Jet Materials, 2014).

Particles with 10-14 mm size fraction are needed to determine the Micro-Deval-coefficient (Swedish Standards Institute, 2011). In similarity with the Los Angeles test, the weight proportion of 11,2-14 mm and 10-11,2 mm must be between 60:40 and 70:30. The total mass of each sample shall be 500 gram.

A washed and dried sample is placed in a drum along with 5000 grams of steel balls and 2,5 litre of water. The test procedure includes 12 000 revolutions in the drum. The sample is then washed, dried and sieved in a 1,6 mm sieve.

The proportion of generated material smaller than 1,6 mm define the Micro-Deval-coefficient and can be calculated using Equation (2).

$$M_{DE} = \left(\frac{M_{original} - M_{final}}{M_{original}}\right) \times 100, \text{ where} \qquad (2)$$

$M_{original}$ is the original sample mass (500 gram) and M_{final} is the remaining mass of material in sieve 1,6 mm measured in gram. A high Micro-Deval-coefficient corresponds to low resistance to wear, i.e. poor technical qualities.

[3] Åkeson, Urban; Trafikverket. 2014. Start meeting January 27th.

2.1.4 Micro-Deval limits for a road

The limits for Micro-Deval coefficient, i.e. resistance to wear, are 20 both for aggregates in the subbase and in the base course (Trafikverket, 2011a). If the road is not trafficked during the construction, a coefficient of maximum 25 is allowed for the base course. The Micro-Deval-coefficient for declared material needs to be controlled once per 30 000 m^2 or at least two times per project and quarry. Undeclared material is controlled once per 10 000 m^2 or once per project and quarry.

In the bound layers the maximum value of the Micro-Deval coefficient is 15 due to the higher loads it needs to carry compared to the unbound layers (Trafikverket, 2011b).

2.1.5 Nordic ball mill SS-EN 1097-9

The Nordic ball mill test determines the resistance to wear by abrasion from studded tires (Swedish Standards Institute, 2014b). The test used previously, Swedish abrasion value, was replaced by Nordic test values after its introduction in VÄG 94 (Stenlid, 2000).

The Nordic test sample shall consist of 35±1 % of fraction 14-16 mm and 65±1 % of fraction 11,2-14 mm (Swedish Standards Institute, 2014b). The original dry mass is defined as in Equation (3) and to calculate the Nordic abrasion value Equation (4) can be used.

$$M_1 = \frac{1000\rho_p}{2{,}65} \pm 5 \quad (3)$$

$$A_N = 100\, {}^{(M_1 - M_2)}/_{M_1}, \text{ where} \quad (4)$$

M_1 is the original dry mass of the sample in grams and M_2 is the dry mass of material greater than 2 mm, obtained after abrasion, in grams. ρ_p is the pre-dried particle density in Mg/m^3. A high Nordic abrasion value corresponds to low resistance to wear by abrasion from studded tires, i.e. poor technical qualities.

The Nordic method is similar to the Micro-Deval method but is only used for tests on aggregates in wearing courses (Viman & Broms, 2005). However, the relationship between Nordic ball mill tests and Micro-Deval tests is strong and a correlation coefficient of 0.97 can be obtained, see Figure 2.4 (Stenlid, 2000).

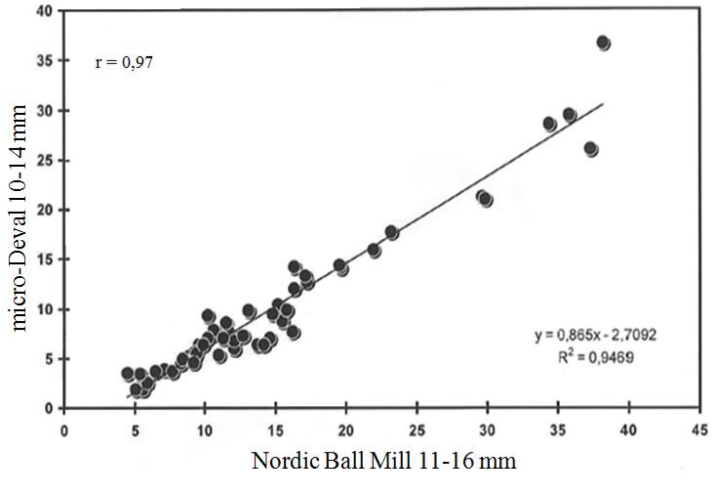

Figure 2.4 Relationship between Micro-Deval and Nordic ball mill tests (Stenlid, 2000).

2.2 Flakiness index

The flakiness index is a parameter for measuring the geometry of aggregates (Viman & Broms, 2005). The grain shape of aggregates is determined by the flakiness index and expresses the relationship between the width and the thickness of the grains. There are demands on uniform dimensions of aggregates because a high proportion of flaky aggregates degrade the bearing capacity of the road structure (SGU, 2006).

To receive the flakiness index, the flaky particles are separated from the sample fraction d-D (for example 10-16 mm), obtained with a sieve with square mesh. The fraction d-D is screened in a sieve with grids with a distance of D/2 (Viman & Broms, 2005). The flakiness index (FI) is expressed as the mass of the flaky particles as a percentage of the total sample mass, see Figure 2.5 (Humboldt, 2009). The red line represents the grain size and the blue line represents the thickness of the grains. The flakiness index is further presented by Equation (5).

$FI = 100 \times \left(\frac{M_1}{M_2}\right)$, where (5)

M_1 is the mass of the sample and M_2 is the mass of the flaky particles that have passed through a grid sieve with a grid distance of D/2, measured in grams.

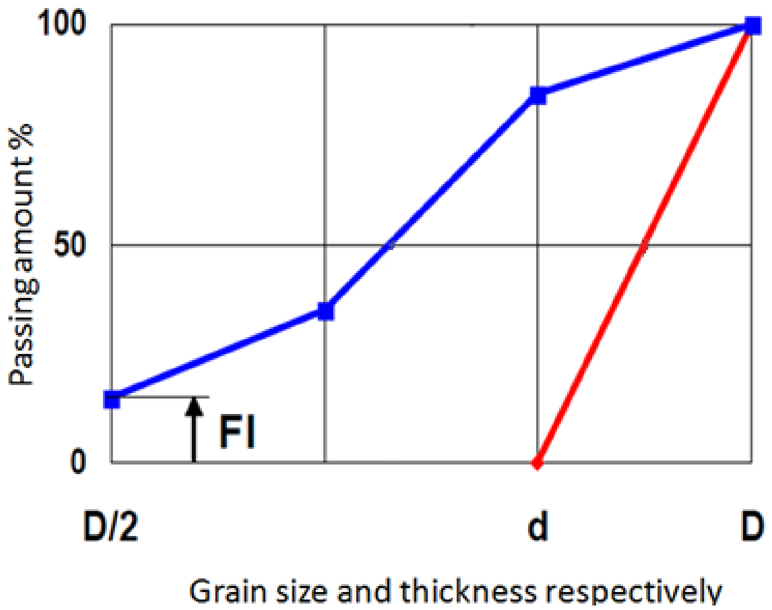

Figure 2.5 *Definition of flakiness index, FI. The red line represents the grain sizes with square mesh and the blue line represents the thickness of the grains with grid sieving, modified (Viman & Broms, 2005).*

A grid sieve and a sieve with square mesh can be seen in Figure 2.6. Grid sieves are used for determination of flakiness index and sieves with square mesh are used for determination of for example the grain size distribution.

Figure 2.6 Grid sieve used for determination of flakiness index to the left and a square mesh sieve to the right (Haver & Boecker, 2014; Chinawire-mesh, 2014).

High loads and heavy traffic on roads can make weak flaky aggregates to break (SGU, 2006). It is therefore favourably to have a low flakiness index to maintain the bearing capacity of the road.

Rock type and crushing technique affects the geometric properties of the aggregates i.e. the flakiness index (SGU, 2006). A more foliated rock will result in more flaky aggregates[4]. A rising amount of flaky aggregates i.e. a higher flakiness index give an increasing LA-coefficient (poorer technical qualities) (Stenlid, 2002). Conversely, a higher number of crushing steps and edge abrasion will lower the amount of flaky aggregates and increase the quality.

2.3 Blasting

Aggregates are natural sand and gravel or crushed rock produced by blasting, either in a quarry, when excavating a tunnel or rock cuttings. The proportion of natural sand and gravel is decreasing, and the use of crushed rock corresponds to over 80 percent of the aggregate used today (SGU, 2014). Over half of the production of aggregates is used in road construction.

There are different approaches of blasting in tunnels, quarries and cuttings. Quarries apply bench blasting, which means that there are two free surfaces. In tunnel blasting, there is only one free surface for blasting (Bergsäker AB, 2009). Another difference between bench blasting and tunnel blasting is that the explosive consumption is higher for tunnel blasting than for bench blasting, because of the higher stresses in the rock beneath the surface. In rock cuttings, a type of bench blasting called contour blasting is applied (Olsson, et al., 2014).

In road construction blasting, it is important to keep the remaining rock as intact as possible (Olsson, et al., 2014). At the same time it is important to receive good rock fragmentation. Although, Jern (2001), Hellman et al (2011) and Loorents (2006) states that blasting creates micro cracks and reduces the overall rock strength. Blast damage can hence be described as micro crack growth (Jern, 2004).

The blasting procedure can be divided into two main steps; the stress wave and the gas expansion (Jern, 2004). The stress wave initiates new cracks in the rock and the gas expansion propagates and expands existing cracks. The damaged zone due to blasting, with higher frequency of fractures, can amount in several meters but is dependent on the geology at site (Jern, 2001). The crack propagation is also influenced by several blast-technical aspects such as type of explosive, charge

[4] Åkeson, Urban; Trafikverket. 2014. E-mail conversation April 14th.

concentration, degree of coupling, burden and spacing distance, initiation time and water in boreholes (Olsson, et al., 2014). Blast parameters and bench geometry can be seen in Figure 2.7.

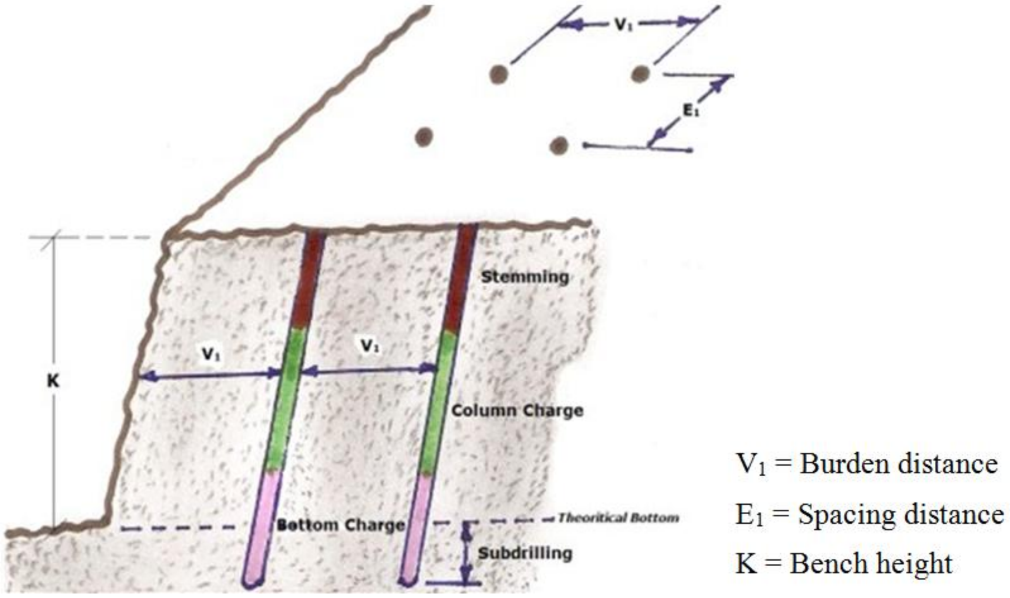

Figure 2.7 Illustrative figure over bench blasting geometry and parameters (Helal, 2011).

2.4 Crushing

The rock fragmentation and the properties of the rock are affected by the blast and crushing procedure (Stenlid, 1996). The number of crushing steps and kind of crusher affects the resistance to fragmentation and the grain shape. This results in a reduced flakiness index when the number of crushing steps increases (Räisänen, et al., 2006).

There are mainly two kinds of crushers present in the quarry and laboratory environment[5]; jaw crusher and cone crusher. The difference between the crushers is according to Evertsson[6] that the jaw crusher causes cracks between the points of contact and an unfavourable grain shape while the cone crusher crushes aggregates "stone against stone" and creates smoother edges. Schematic images of a jaw crusher and a cone crusher can be seen in Figure 2.8.

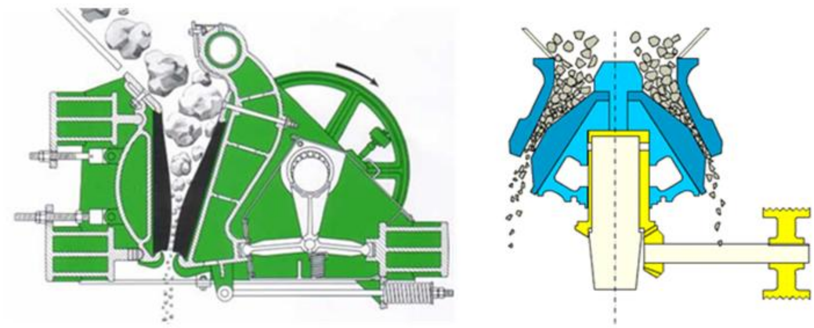

Figure 2.8 Jaw crusher to the left and cone crusher to the right (Pennsylvania Crusher, 2014; Aggregate Design Corporation, 2014).

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[5] Evertsson, Magnus; Professor in Machine Elements, Chalmers University of Technology. 2014. Meeting April 16th.
[6] Ibid.

The principle of a jaw crusher is that one moveable and one stationary jaw crush the material by compression (Pennsylvania Crusher, 2014). In a cone crusher, two conical surfaces, a lower mantle moving in a rotary pattern and concave liners above, crush the material (Aggregate Design Corporation, 2014).

In quarries, it is common to have a jaw crusher as primary crusher and cone crushers as secondary and tertiary crushers (Aggregate Design Corporation, 2014). Gyratory crushers can also be present in quarries. A gyratory crusher is closely related to the cone crusher[7]. It is mainly used as a primary crusher where it can replace the jaw crusher due to its larger capacity. Alternatively, the gyratory crusher can be used in the secondary crushing stage (Bengtsson, 2009).

In Figure 2.9, the changes in relative strength during the process stages can be seen[8]. There is a loss in relative strength after blasting. Thereafter, if the crushing process is good, the relative strength is improved for every crushing stage. Equally large differences cannot be seen with a bad crushing process.

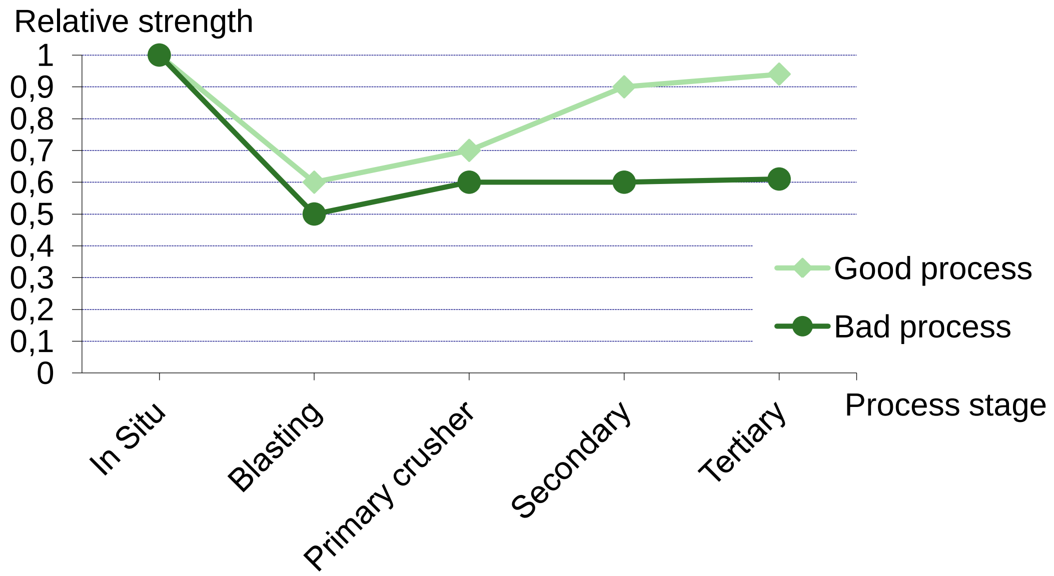

Figure 2.9 *The change in relative strength from in situ to blasting and primary, secondary and tertiary crusher. The figure shows good and bad crushing processes[9].*

The size of the feed, i.e. the distance between the crushing plates, can be described with CSS (closed side setting) or OSS (Open side setting), where CSS describes the shortest distance between plates and OSS the distance when the plates are furthest away from each other (Bengtsson, 2009). In cone crushers and gyratory crushers the best particle shape is generated to grains close to or equal to the CSS value. Furthermore, the shape of the particles deteriorates with an increased feed size.

[7] Evertsson, Magnus; Professor in Machine Elements, Chalmers University of Technology. 2014. E-mail conversation May 8th.
[8] Evertsson, Magnus; Professor in Machine Elements, Chalmers University of Technology. 2014. Meeting April 16th.
[9] Ibid.

2.5 Factors affecting rock properties

An estimation of the rocks technical properties can be obtained by studying the intrinsic properties such as mineralogical composition, grain size and shape, foliation, cracks and porosity (Lindqvist, et al., 2007). The intrinsic properties of the rock can be determined by conducting a petrography analysis. The intrinsic properties relate to one another and it is usually the weakest factor that limits the rocks resistance of degradation and fragmentation (Hellman, et al., 2011). The difference between different rock types, even within the same rock type, can be vast. The properties that are evaluated during a petrography analysis are presented below.

2.5.1 Mineralogy

A rock consists of minerals that are jointed together (Hellman, et al., 2011). The properties of the individual minerals that make up the rock such as hardness, crystal form, density and cleavage, are limiting factors for the technical properties of the rock (Lindqvist, et al., 2007). These individual properties of the minerals are important, but they alone do not provide enough information for determine the technical properties of the rock (Hellman, et al., 2011). The most important factors of a mineral to decide the technical properties of the rock are the hardness and cleavage.

The hardness of the mineral contributes to the compressive strength of the rock and resistance against wearing and fragmentation (Hellman, et al., 2011). Most minerals have one or many cleavage planes where the minerals are easier to break. These weaker planes in individual minerals may have a negative impact on the rocks overall strength, which seems to be greater with larger grain size. According to Hellman et al (2011), the most extreme cases are when mica minerals are present, since they are fully cleavable in one direction. A rock type containing mica mineral therefore decreases its strength. On the other hand, Lindqvist et al (2007) states that the influence of micas is strongly dependent on their size and orientation. The latter is also verified by SGU (2006), which states that micas are a reinforcing mineral having a damping effect. Small, randomly oriented micas may increase the fracture toughness and act like reinforcement (Lindqvist, et al., 2007). Larger single mica grains or large aggregates of mica grains may provide a path for crack propagation and may therefore weaken the rock. However, it has been proved that the concentration of mica itself has a very limited effect (Åkesson, 2004).

Quartz is one of the minerals that lack a specific cleavage plane (Hellman, et al., 2011). The lack of a specific cleavage plane together with the hardness of quartz and its ability to recrystallize and form complex grain boundary shapes is the most important factors why rock types containing quartz usually have a good resistance to fragmentation.

2.5.2 Grain size

The grain size is a very important factor when to determine the mechanical properties of the rock (Hellman, et al., 2011). It is well known that finer grained rocks of the same type gains a higher strength and it has been proved that the compressive strength of granites increases with an increase of the specific surface (Lindqvist, et al., 2007). An exception is a fine-grained rock with a distinct foliation that causes weakness planes. The strength is not solely determined by the grain size, the grain size distribution is important as well. A large size range yields a higher strength and better resistance to fragmentation and wear compared to a more equigranular or homeoblastic rock. It has shown that rocks consisting of both coarse- and finer-grain in a matrix have a beneficial effect on the strength of the rock (Hellman, et al., 2011). This is due to that the properties of the finer-grained mineral seem to be dominating those of the courser-grained mineral.

2.5.3 Grain and grain boundary shape

The grain and grain boundary shape has a large impact of the brittleness and the resistance of wearing of the rock (Hellman, et al., 2011). The more complex the grain shape and grain boundary geometry is the stronger the boundaries become (Lindqvist, et al., 2007). According to Åkeson et al (2003) the strength and resistance to mechanical fragmentation increases when the shapes of the grains are going from straight surfaces and boundaries to more irregular grain shapes and grain boundaries. An increased complexity in the grain shape and grain boundary geometry forces the cracks to go through the minerals instead of along the boundaries (Hellman, et al., 2011). This makes the rock stronger compared to rocks with less complex grain shape geometry and straight boundaries where cracks can form along the boundaries. When cracks can form along the boundaries it makes the rock less resistant to mechanical fragmentation. In Figure 2.10, two granites with the same grain size but different grain boundary shape can be seen.

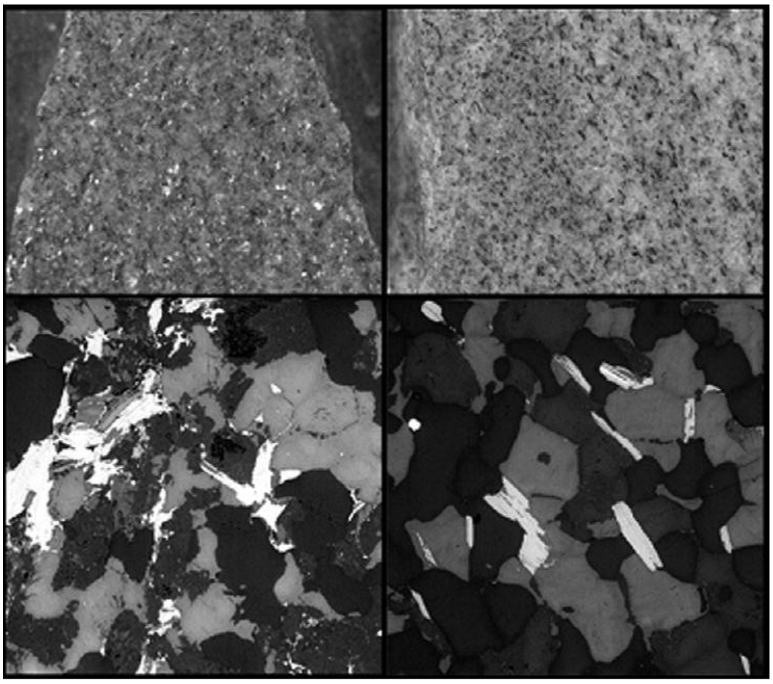

Figure 2.10 *Two granites with the same grain size but different grain boundary shapes. The more complex boundary shape on the granite to the left will give it a higher resistance to fragmentation (Åkesson, 2004).*

2.5.4 Foliation

Foliation is defined as a parallel structure within the rock (Hellman, et al., 2011). The properties of a rock with an oriented parallel structure differ from rocks with a randomly oriented structure (Lindqvist, et al., 2007). The orientation can be divided into two different types; shape-preferred orientation and lattice-preferred orientation. Shape-preferred orientation is when the orientation of the mineral grains is based on the shape of the mineral grains. Lattice-preferred orientation on the other hand, is when the orientation is based on the atomic lattice of the different mineral grains. A foliated rock mass defined by shape-preferred orientation usually represents weaker planes in the rock. A foliation defined by micas or clay mineral has a strong influence on the mechanical properties of the rock. When micas or clay are present, the rock normally becomes very weak in a specific plane and therefore the resistance to fragmentation is lowered. As mentioned earlier, randomly oriented micas does not necessarily have a weakening effect on the rock. The lattice-preferred orientation might have a substantial effect for minerals with strong anisotropy of slip planes, such as micas and feldspars.

On the other hand, some of the metamorphic rock types with foliation have recrystallized and in that process developed more complex grain boundary geometry (Hellman, et al., 2011). These rock types have a good resistance to fragmentation and strong mechanical properties. Investigations of foliated rock types in the Baltic shield show that the foliation has led to more complex boundaries and therefore the foliation has increased the strength of the rock.

2.5.5 Micro cracks

Blasting, crushing and other activities that deform the rock such as pressure discharge, thermal contraction and tectonic movements in the crust creates micro cracks (Hellman, et al., 2011). The resistance to fragmentation is highly affected by the occurrence and amount of micro cracks. Micro cracks are cracks with a size equal to or smaller than the grain size. There are two different types of micro cracks; intergranular and transgranular. An intergranular crack is a fracture that takes place along the grain boundary of the rock. A transgranular crack is a fracture that follows the edges of lattices rather than the grain boundaries, ignoring the grains in the individual lattices.

Crack propagation generally takes place more easily along long straight surfaces such as grain boundaries or cleavage planes (Hellman, et al., 2011). The presence of micro cracks is critical for the rocks resistance to fragmentation. The strength or resistance to fragmentation of a rock is related to the presence of discontinuities, limiting flaws, where cracks that may result in failure can be initiated (Lindqvist, et al., 2007). A limiting flaw can be a grain or phase boundary, a pore or a pre-existing crack. The size of the flaws is the main factor when determine their influence, and when studying the tensile stress, it can be expressed generally as Equation (6).

$$\sigma_t = \theta\sqrt{\frac{EGc}{\alpha}}\text{, where} \qquad (6)$$

σ_t = Critical tensile stress
θ = Material-specific constant
α = Dimension of the limiting flaw
E = Young’s modulus
Gc = Surface energy per unit area that is required to create the crack surface

This equation provides an understanding of how the critical tensile stress is calculated, but is not intended to be used for calculations within the report. It is common that propagated cracks heal and crystallize new minerals (Hellman, et al., 2011). These cracks are normally filled with calcite, chlorite, quartz and epidote. The healed cracks might make up weaker parts of the rock and might cause new crack propagation to take place.

2.5.6 Porosity

The porosity is generally very low in crystalline Swedish bedrock, not often above 0,5% of the total volume (Hellman, et al., 2011). Sedimentary rock, like sandstone, usually has a higher porosity than crystalline rock. A rock with high porosity might decrease the quality of the bitumen bound layers of a road, since the bitumen is consumed by the voids of the rock. An increase in porosity generally yields a loss in rock strength. The relation between total porosity and compressive strength can be expressed as Equation (7) (Lindqvist, et al., 2007):

$$\beta = \beta_0 \left(1 - v_p\right)^n \text{, where} \qquad (7)$$

β = Actual compressive strength
β_0 = Compressive strength of the material without porosity
v_p = Pore volume in percent
n = Material-specific constant

This equation provides an understanding of the relationship between compressive strength and porosity but is not intended to be used for calculations within the report. Pores can both facilitate crack propagation as well as trap a propagating crack.

3 CASE STUDY

The locations chosen for this study, Ale, Angered, Tanum and Forserum, will in this chapter be presented more closely regarding both the regional and local geology. The locations have been chosen due to the different types of rock and geology they represent, where Forserum is having the best quality rock, followed by Ale, Angered and at last Tanum with the poorest rock quality regarding LA-testing and fragmentation. The locations and rock type at each location are presented in Figure 3.1.

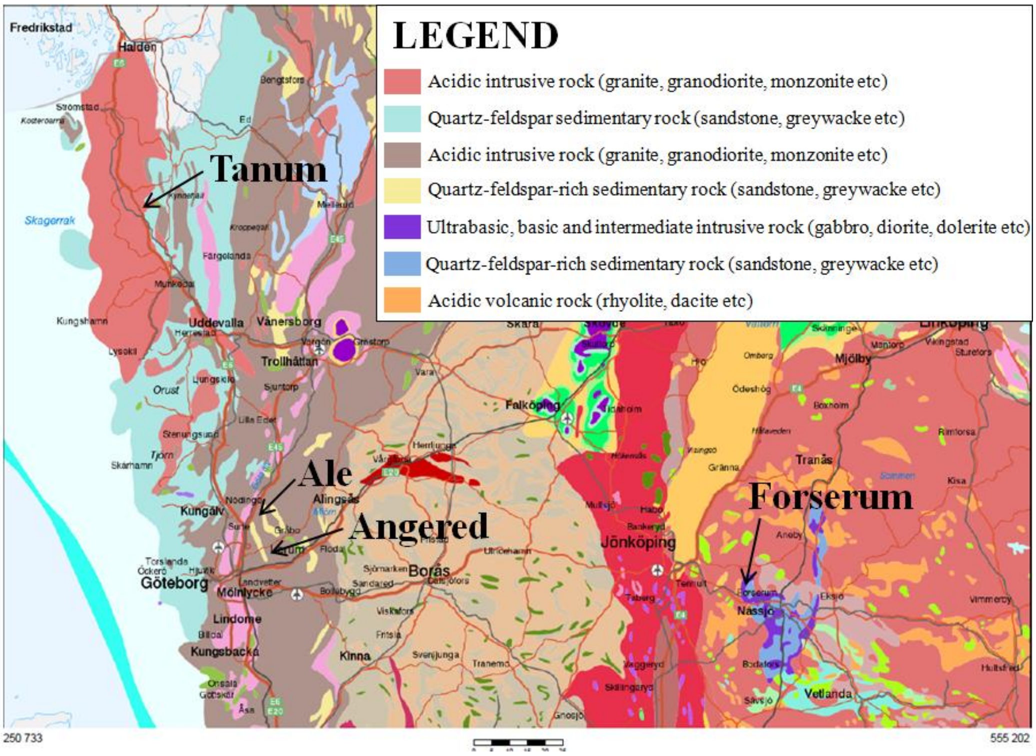

Figure 3.1 *Bedrock map of the south-west parts of Sweden, modified (SGU, 2010b).*

3.1 Regional geology

A large part of the bedrock in south-western Sweden consists of different types of gneiss (Antal, et al., 1999). The bedrock is mainly between 1,700 and 1,550 million years old and was metamorphosed during the Sveconorwegian orogeny, which occurred about 1,100 - 900 million years ago. This province is called the South-western gneiss province and sometimes also the Sveconorwegian province, from the time most of it was formed. The region has been intruded by several generations of granite since the metamorphose 1,100 - 900 million years ago (Johansson, 2014). The youngest of these granites are the Bohus granite which is located in the north-western part of the province, in northern Bohuslän.

The south-eastern part of Sweden is a part of the Trans-Scandinavian igneous belt, ranging from Småland, through Värmland and up to western Dalarna (Johansson, 2014). The Trans-Scandinavian belt consists of relatively undeformed granites and volcanic porphyries, aging from 1,800 to 1,650 million years old. Late Precambrian sedimentary rock can be found at several locations within this province, superimposing the older igneous rock (Gierup, et al., 1999). Similarly, mafic intrusive rock such as dolerite and diabase is frequently found within the province.

3.2 Ale

The quarry in Ale is owned by Skanska and has been active since the year of 1998. The total aggregate production in Ale was 314 000 tonnes in 2013[10]. Each blast corresponds to approximately 50 000 tonnes produced aggregates, which means there are around 6 blasts each year. Tests on produced base course are made every year. The LA-coefficient for base course in 2013 was 24. In Figure 3.2, the quarry in Ale can be seen where the location for the drill and blast is highlighted.

Figure 3.2 Photo of Ale quarry © Lantmäteriet [i2012/1099].

3.2.1 Local geology

Four different rock types are present in Ale quarry[11]. They are all different variations of gneiss, containing different levels of the main minerals k-feldspar, quartz and mica. Bands rich in granular minerals such as k-feldspar and quartz exist throughout the quarry. The bands can be up to several meters in width, cutting through the quarry. The two main rock types in Ale are granitic gneiss and augen-bearing gneiss (Stølen & Göransson, 2012). The content of mica is also relatively high compared with other gneisses in the south-western parts of Sweden. A bedrock map over the area can be seen in Appendix A.

3.2.2 Rock core mapping

The rock cores from Ale consist almost solely out of gneiss. However, the gneiss is heterogeneous in its appearance, as can be seen in Appendix B. The gneiss is mostly dark and fine grained, but contains a high number of dykes of pegmatite, rich in k-feldspar and quartz. Red gneiss is also present in the three bore holes, representing one of the wider bands in the quarry. The red gneiss is fine grained as well.

[10] Gustavsson, Håkan; Production Manager, Skanska Asfalt och Betong AB. 2014. E-mail conversation April 23th.
[11] Gustafsson, Mikael; Geologist, Skanska Asfalt och Betong AB. 2014. Meeting May 8th.

3.3 Angered

Angeredskrossen is a quarry owned by Skanska and was established in the end of the 1960s. In 2013, the aggregate production amounted in 496 000 tonnes[12]. Around ten blasts are performed in Angered each year with approximately 50 000 tonnes of aggregates produced each time. The total amount extracted in Angered is estimated to approximately 14 million tonnes[13]. The LA-coefficient for produced base course was 34 in the yearly measurements 2013. Compared to measurements earlier years, this is a high LA-coefficient[14]. The quarry in Angered can be seen in Figure 3.3 where the location for the drill and blast is highlighted.

Figure 3.3 Photo of Angered quarry[15].

3.3.1 Local geology

Gneissic granitoids dominates the quarry where the grain size varies from fine to medium (Jern, 2004). The colour of the rock is towards the darker shade and is very homogeneous throughout the quarry[16]. The mineral composition consists of quartz, feldspar and mica. In the area a horizontal to sub-horizontal foliation can be observed (Jern, 2001). The rock is fairly fractured in the entire area. A bedrock map over the area can be seen in Appendix A.

3.3.2 Rock core mapping

The rock cores from Angered are very homogenous. The colour is mostly black or dark grey for the main part of the cores. The mineral composition of the gneiss is as stated above and it is mostly fine grained. The rock cores crosses through very narrow dykes, up to 10 cm, of pegmatite rich in k-feldspar and quartz with a greater grain size. The rock cores can be seen in Appendix B.

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[12] Gustavsson, Håkan; Production Manager, Skanska Asfalt och Betong AB. 2014. E-mail conversation April 23th.
[13] Gustafsson, Mikael; Geologist, Skanska Asfalt och Betong AB. 2014. Meeting May 8th.
[14] Ibid.
[15] Gustafsson, Mikael; Geologist, Skanska Asfalt och Betong AB. 2014. E-mail conversation May 13th.
[16] Gustafsson, Mikael; Geologist, Skanska Asfalt och Betong AB. 2014. Meeting May 8th.

3.4 Tanum

The last part of the European highway E6 between Oslo and Göteborg to be upgraded to a two-lane highway is the stage Pålen-Tanumshede (Trafikverket, 2014a). The contractor for this project is Skanska and the stage comprises of 7 km of two-lane highway with a width of 18,5 meter. The construction of the road started during the spring of 2013 and is planned to be finished during the summer of 2015. In Figure 3.4, an orientation map of the project is presented where the location for the drill and blast is marked. As the other parts of the E6 improvement, Tanum have also had problems with differences in expected LA-values from the pre-investigation and the one's found at site at construction[17]. Since Tanum has experienced differences in rock quality from expected and actual quality, regarding the LA-coefficient, it is an interesting location to test and evaluate.

Figure 3.4 Orientation map, Pålen-Tanumshede, modified (Trafikverket, 2014b).

Rock cores from the pre-investigation in Tanum have been tested regarding the LA-coefficient (Trafikverket, 2011c). The values ranged from LA 29 to LA 49 for the rock cores investigated along the stretch. Section 0/590 is located close to the area investigated in this thesis. The LA-value for the course-grained granite there were 47.

3.4.1 Local geology

The area where the road project is located lies within a boundary zone between the older gneiss belonging to the Stora Le-Marstrand formation and the younger Bohus granite (Trafikverket, 2011c). The bedrock in the area consists mainly of granitic rock with variations in grain size. The amount of k-feldspar varies which makes the colour of the rock ranging from pale red-greyish to light grey. Large parts of the granitic bedrocks contain banded gneiss. The gneiss is most commonly metamorphic with no

[17] Åkeson, Urban; Trafikverket. 2014. Start meeting January 27th.

foliation. However, dark coloured foliated gneiss can be found in the area as well. The different rock types occur regularly and alternately within the area and the grain size of the granite varies with diffuse transactions. A bedrock map over the area can be seen in Appendix A.

3.4.2 Rock core mapping

The rock cores from Tanum showed a great variety in rock type and heterogeneity. The main rock types were, in order after how frequently they appeared; gneiss, Bohus granite, granite and pegmatite. The gneiss was grey and fine-grained. It was clearly foliated and partly darker, where the concentration of biotite was high. The Bohus granite was light grey and medium grained. It was very homogenous and lacks the presence of darker minerals. The other granite that was present in the cores was light yellow in colour. The grains were medium to coarse and it was very brittle. This granite was not tested. The cores also had quite an amount of a grey-white pegmatite with very coarse grains. The rock cores can be seen in Appendix B.

3.5 Forserum

Forserum quarry is located outside the town of Forserum in the province of Småland. There has been quarry activity in Forserum since 1942 and about 12 million tonnes have been mined since then[18]. The aggregate production is around 300 000-400 000 tonnes distributed on 5-6 blasts per year. The LA-coefficient for base course in Forserum was 14 and 16 in 2013 and 15 and 13 in 2012. The quarry in Forserum can be seen in Figure 3.5 where the location for the drill and blast is highlighted.

Figure 3.5 Photo of Forserum quarry © Lantmäteriet [i2012/1099].

[18] Löfgren, Mikael; Project Engineer, Skanska Asfalt och Betong AB. 2014. E-mail conversation April 14th – 22th.

3.5.1 Local geology

The geology of the area around Forserum quarry consists of isotropic rocks younger than the svecokarelian orogeny, aging 1740-910 million years old, see Appendix A. The rocks that can be found in the local area are different types of ultramafic, mafic and intermediate intrusive rock, such as dolerite, gabbro and diorite. The most common rock in the quarry is dolerite[19]. However, significant amounts of quartzite are present within the quarry area as well.

3.5.2 Rock core mapping

The rock cores consist solely out of fine grained dolerite. The rock cores are very homogenous and only differ in different shades of black, grey and greenish. The grey parts are a light plagioclase mineral, and the green parts consist of transformed amphibole and pyroxene. Photos of the rock cores can be found in Appendix B.

[19] Gustafsson, Mikael; Geologist, Skanska Asfalt och Betong AB. 2014. Meeting May 8th.

4 METHODOLOGY

The methodology regarding collection of the samples and testing methods will be further developed in this chapter. Every step of the process will be explained in detail in the different subchapters. A flowchart describing the overall methodology can be seen in Figure 4.1.

Figure 4.1 *Flowchart describing the methodology.*

4.1 Method for rock core drilling

The core drilling was performed by GEO-gruppen AB. The drilling equipment consisted of a Longyear, BQTK with a core diameter of 40,7 mm. The cores were drilled from the top of the bench. To avoid potential damages due to previous blasts, the cores were drilled at a minimum distance of 10 meters from the face of the bench. To cover the variations in geology, the cores were drilled as evenly distributed over the bench as the equipment could reach. The core drilling machine was attached to an off-road vehicle, see Figure 4.2.

Figure 4.2 *The core drilling machine that performed the drilling at all locations.*

Three cores were drilled at each of the quarries. The lengths ranged from 10 to 20 meters. The cores were drilled with a vertical angle and the lengths of the cores are presented in Table 4.1.

Table 4.1 Length of drilled rock cores from quarries.

	Ale	Angered	Forserum
KBH1 [m]	14,1 m	14,35 m	16,32 m
KBH2 [m]	9,7 m	14,15 m	20,3 m
KBH3 [m]	2,3 m + 4,05 m 80,5 mm core	14,0 m	20,2 m

The bench height in Tanum was much less than in the quarries, why shorter cores had to be drilled. A total of six cores were drilled at three locations. From each location two rock cores were extracted, that only differed in direction. The two cores at each location where drilled with an angle of roughly 60 and 80 degrees and a length of 6-7 meters. The length and dip of the rock cores from Tanum are presented in Table 4.2.

Table 4.2 Length and dip of rock cores in Tanum.

	Core 1 (80°)	Core 2 (60°)	Total
KBH1	6,25 m	6,25 m	12,5 m
KBH2	6,2 m	6,25 m	12,45 m
KBH3	6,25 m	7,05 m	13,3 m

The rock cores from all locations can be seen in Appendix B and is further explained geologically in Chapter 3.

4.1.1 Deviation from method

Due to technical issues with the drilling equipment, KBH3 in Ale was partly drilled with a different core diameter. KBH3 consists of 2,3 m of 40,7 mm core and 4,05 m core with a diameter of 80,5 mm.

The drilling in Forserum was taking place on a previously blasted surface and therefore blast damages might be present in the upper layers. To avoid material with blast damages the first 10 meters from each core in Forserum was not a part of the study.

4.2 Blasting

The blasts in the quarries and in Tanum were carried out by different providers of blast services in February and March 2014. All blasts were a part of the normal quarry activity or project activity. A summary of the blast journals can be seen in Table 4.3. Complete blast journals and drill reports from all sites can be found in Appendix C. Explanation of some of the parameters in Table 4.3 can be found in Figure 2.7.

Table 4.3 Summary of blast journals from Ale, Angered, Tanum and Forserum.

	Ale	Angered	Tanum	Forserum
Date	2014-02-21	2014-03-24	2014-03-03	2014-03-06
Diameter [mm]	89	89	70	89
Dip [degree]	10	14	11,2	14
Bottom charge	Booster	Booster	N.D	Booster
Pipe charge	Bulk	Blendex 70	Poladyn 31 ECO	Blendex 70
Top charge	DX 55 mm	Exem	N.D	Exem 55
No. of holes	100	84	95	116
Subdrilling [m]	0	1,5[1]	1	1
Burden distance [m]	2,6	2,6	2	3
Spacing distance [m]	3,6	3,6	2,5	4
Depth of holes [m]	11-15	20,6-25[1]	3-5	13,1-24,4[1]
Total charge [kg]	8690	16176	657	10435,8
Weight [tonnes]	38000	48600	2244	65952
Density [kg/m^3]	N.D	2700[2]	2600	N.D
Volume [m^3]	14480	18000[3]	863	21984
Spec. charge [kg/m^3]	0,6[4]	0,90[4]	0,76	0,47

[1] Data from drill report.
[2] Density of gneiss (Waltham, 2009), not listed in blast journal.
[3] Not listed in blast journal. The volume is calculated using the density and the weight.
[4] Not listed in blast journal. The specific charge is calculated using the total charge and the volume.

4.3 Method for preparation of rock samples - Crushing

Preparation of rock samples include the method of crushing in laboratory, quarries and road project. Furthermore, the method for sieving and weighing of samples are described.

The homogeneity of the samples is very important. To validate the study, each and every one of the samples went through a petrography analysis. The petrography analysis focused on the samples to have the same colour and mineral grain size. No consideration was taken toward the samples to resemble each other in flakiness. This was conducted to make sure that the same rock type was tested for rock cores, cobbles and base course.

4.3.1 Rock core samples

The drilled rock cores were separated by rock type before crushing started in the laboratory. The crushing consisted of the following three steps:

1. Crushing in rough jaw crusher in laboratory (minimum gap 45 mm)
2. Crushing in fine jaw crusher in laboratory (minimum gap 10 mm)
3. Crushing in fine jaw crusher in laboratory (minimum gap 10 mm)

The rock types that were identified in the rock cores are presented in Table 4.4.

Table 4.4 Identified rock types at the four locations.

Location	Identified rock types
Ale	Red gneiss and black gneiss
Angered	Gneiss
Tanum	Bohus granite and gneiss
Forserum	Dolerite

4.3.2 Base course and cobble samples

The same rock types that were identified in the rock cores were selected from the collected base course and cobbles to create the base course and cobble samples. At all locations, the crushing procedures followed normal daily operation.

In Figure 4.3, the crushing steps to create samples of base course can be seen in a flowchart. Five different rock types of base course were tested; red and black gneiss from Ale, gneiss from Angered, mixed rock from Tanum and dolerite from Forserum. All samples were collected from flattened piles of aggregates in the fractions presented in Figure 4.3.

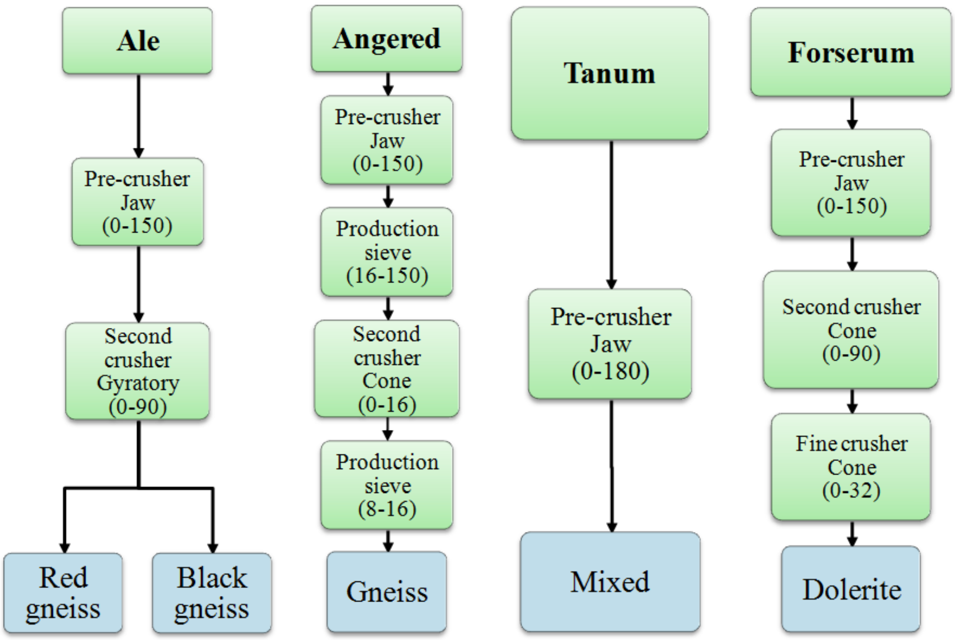

Figure 4.3 Flowchart for preparation of samples of base course.

Cobbles were abstracted from the 0-150 mm pile in Tanum after the pre-crusher. The cobbles from Ale were abstracted from the 0-90 mm pile after the second crushing step to create the cobble samples. In Figure 4.4, a flowchart showing the crushing steps to create the cobble samples can be seen. The cobble samples were additionally crushed in the laboratory. Four rock types of cobbles were tested, red and black gneiss from Ale and gneiss and Bohus granite from Tanum.

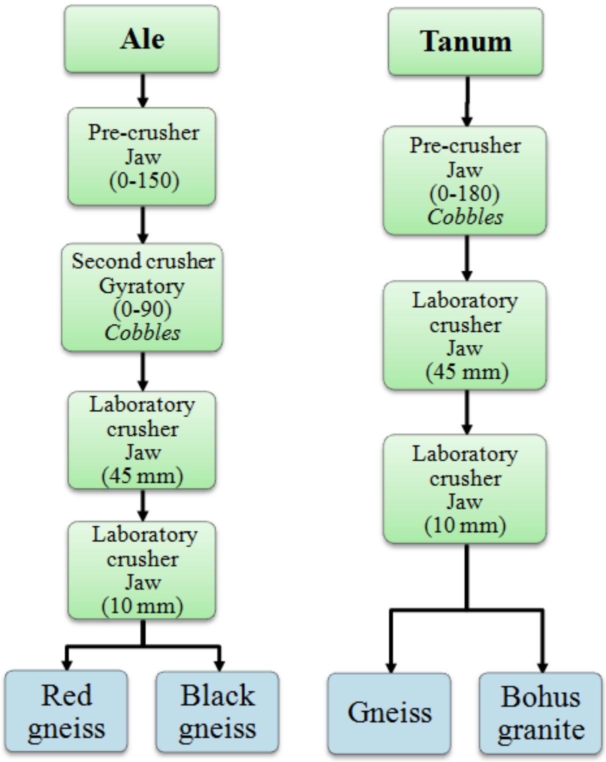

Figure 4.4 Flowchart for preparation of cobble samples.

4.3.3 Deviation from method

The amount of Bohus granite received from the rock cores was not enough to run a LA-test on. Three additional crushing steps of the grains larger than 14 mm were performed in the fine crusher in the laboratory. In Angered, the material of the poorest quality in fraction 0-16 mm was removed before production of the base course. This was not performed at the other locations. The base course from Forserum was collected from another bench than the one were the rock cores were drilled. This was because blasting did not occur within the time span for the thesis. Therefore, base course was taken from the bench blasted previously.

4.4 Method for preparation of rock samples - Sieving

The crushed rock cores, the crushed cobbles and the samples of base course were then sieved. The sieving was performed in a Gilson sieve, 10 minutes per bucket of material. The size of the sieves used from top to bottom was:

- 22,4 mm
- 16 mm
- 14 mm
- 11,2 mm
- 10 mm

The material remaining on sieve 11,2 and 10 mm were collected, prepared and used for testing. A flowchart describing the sieving process can be seen in Figure 4.5.

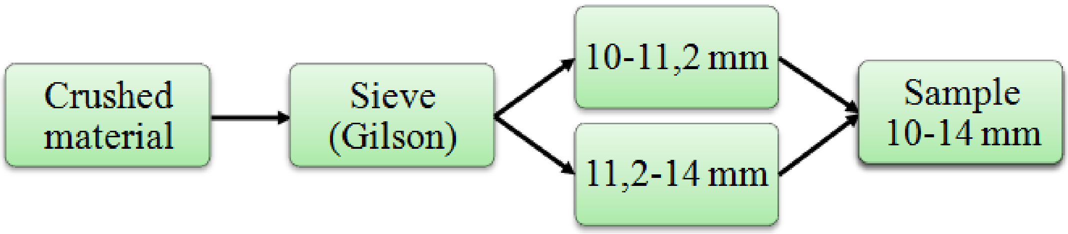

Figure 4.5 *Flowchart for sieving and creation of sample.*

The quantities of each fraction in the sample was 65 % of the fraction 11,2 – 14 mm and 35 % of the fraction 10 – 11,2 mm. The total sample mass of fraction 10-14 mm was 5000 grams for the LA-test and 500 grams for Micro-Deval test.

4.5 Testing methods

The Los Angeles and Micro-Deval tests were performed according to the European standards, SS-EN 1097-2 and SS-EN 1097-1. A description of the two methods can be found in Chapter 2.1. All rock types presented in the blue boxes in Figure 4.3 and Figure 4.4 were tested with the LA-method. The LA- and MD-tests that were conducted is presented in Table 4.5. Pictures of the samples before and after the LA-test can be seen in Appendix D. LA cobble and LA base course have not been tested for all samples because the material have not been available at site during the time frame of the thesis. MD tests were performed on selected samples in order to validate the LA-test results.

Table 4.5 *Conducted LA- and MD-tests.*

Samples	**LA Rock Core**	**LA Cobble**	**LA Base Course**	**MD Rock Core**	**MD Base Course**
Ale, Red Gneiss	X	X	X		
Ale, Black Gneiss	X	X	X	X	X
Angered, Gneiss	X		X	X	X
Tanum, Mixed	X		X		
Tanum, Gneiss	X	X			
Tanum, Bohus Granite	X	X			
Forserum, Dolerite	X		X	X	X

4.5.1 Flakiness index

Determination of a flakiness index was performed according to a modified version of the standard test. A sample of 5 kg was prepared for testing of the Los Angeles coefficient. 1,5 kg of this was used to obtain the modified flakiness index. The material was first sieved through an 8 mm grid sieve. The material that passed the grid was weighed and compared to the original weight of 1,5 kg. The material passing the 8 mm grid sieve was then sieved through the 6,3 mm grid sieve and weighed and compared to the original sample weight as well as the weight of the material passing through the 8 mm grid sieve.

5 RESULT

In the following chapter, results from the Los Angeles tests and Micro-Deval tests, as well as results from the flakiness index determination will be presented and visualized. The reports from the laboratory can be seen in Appendix E.

The result from the LA-tests for cobbles, rock core and base course is shown in Figure 5.1. It clearly shows that the LA-coefficient for a rock core is better than for base course and cobbles for all locations.

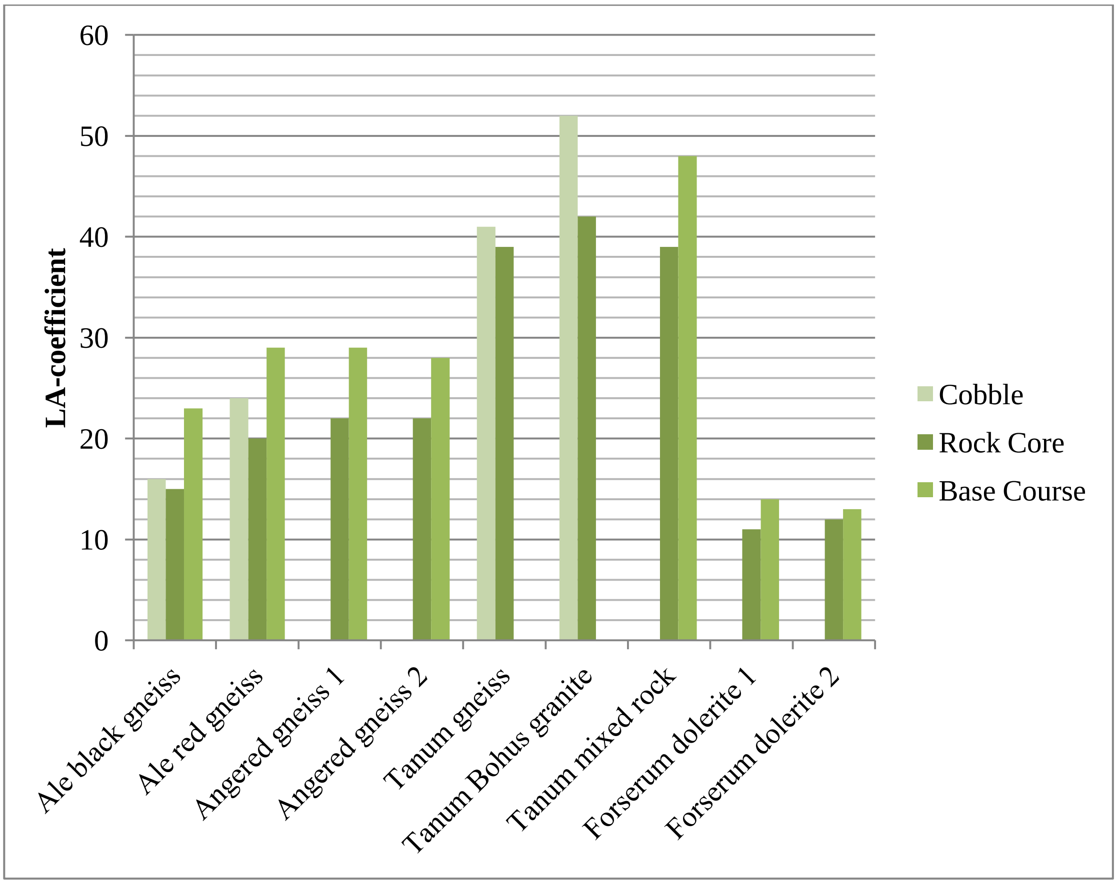

Figure 5.1 Comparison between LA-coefficient for cobbles, rock core and base course.

The result from the Micro-Deval tests is shown in Figure 5.2. The MD-coefficient for rock core is better than base course for all locations. In Appendix F, all values from the LA-tests and MD-tests are presented in a table.

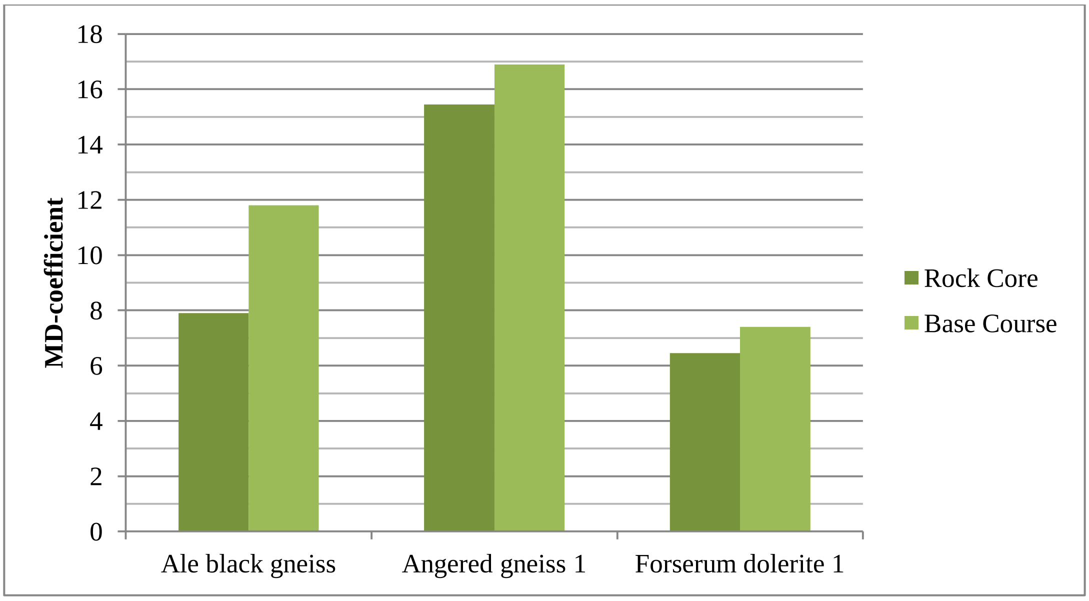

Figure 5.2 Comparison between MD-coefficient for rock core and base course.

The results from flakiness index tests are visualized in Figure 5.3. The base course has a higher flakiness index for all locations except for the gneiss in Angered. In Appendix F, the passing amount of material through the 6,3 mm grid sieve and the amount of material passing 8 mm that also passes 6,3 mm can be seen in tables and diagrams.

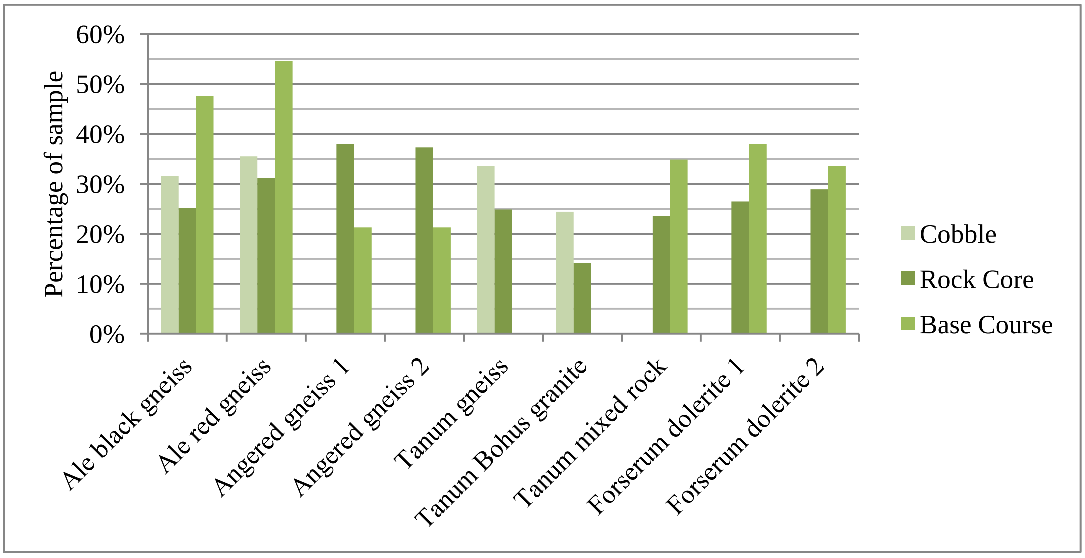

Figure 5.3 Comparison of flakiness index for 8 mm grid sieve between locations.

6 ANALYSIS

Chapter 6 analyses the results by comparing the result with different properties of the material, such as flakiness and location. Furthermore, different relations are plotted to see if any correlations can be found.

To determine if any correlation can be seen between the different locations, the relation of the LA-coefficient and flakiness index have been plotted for the different sampling methods, i.e. rock core, cobbles and base course, see Figures 6.1-6.3.

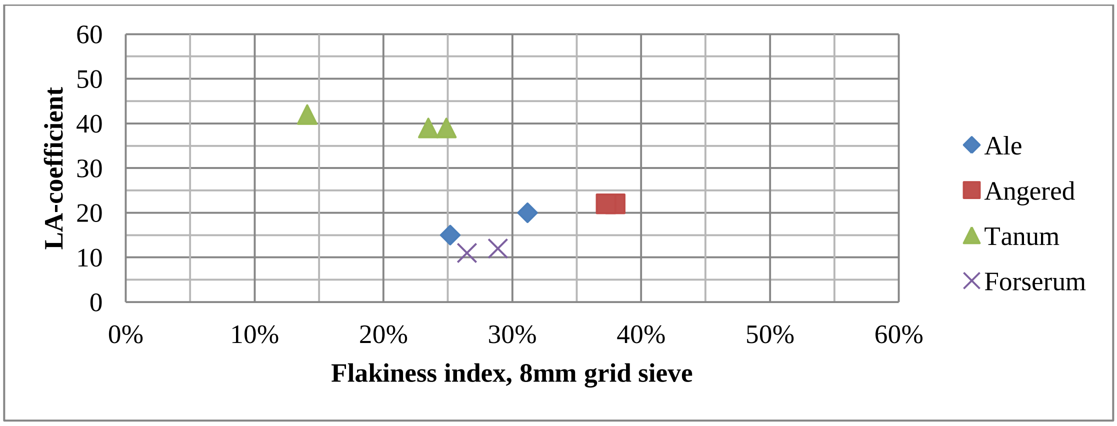

Figure 6.1 *Relation between LA-coefficient and flakiness index (8 mm grid sieve) for rock cores at all locations.*

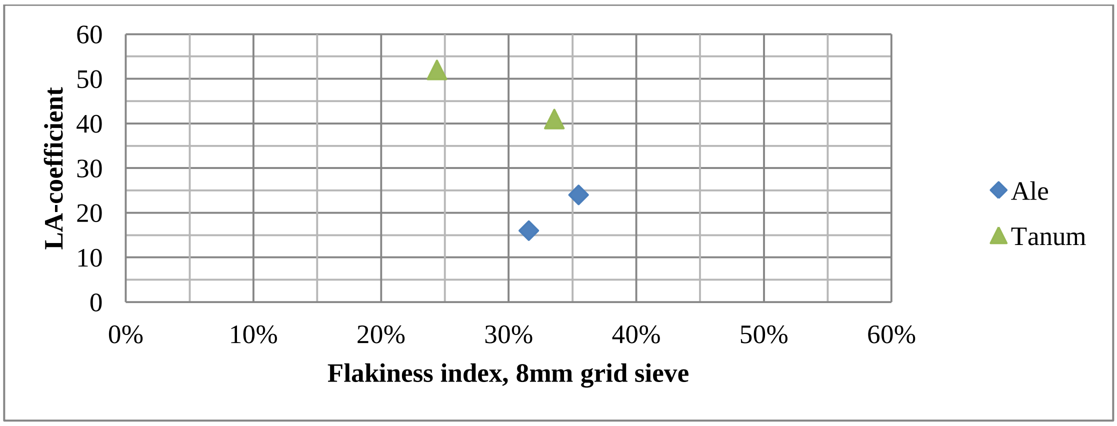

Figure 6.2 *Relation between LA-coefficient and flakiness index (8 mm grid sieve) for cobbles at all locations.*

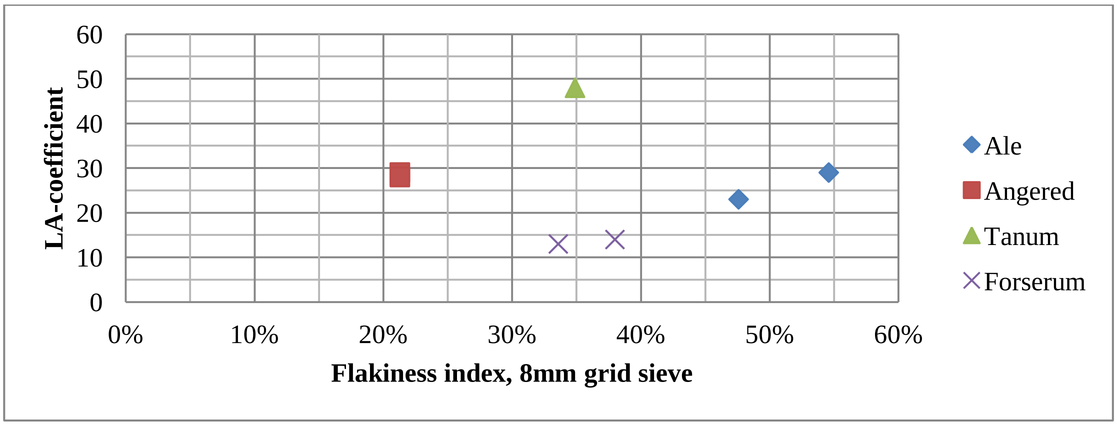

Figure 6.3 *Relation between LA-coefficient and flakiness index (8 mm grid sieve) for base course at all locations.*

The Figures 6.1-6.3 alone does not give any new information, but by combining and studying the three at the same time, some tendencies can be seen. The scale on both the x and y axis are the same for Figure 6.1-6.3, making the study of the three easier. The general trend that can be seen is that the points seem to be moving upward and to the right in the diagrams, except for Angered. This indicates that a higher flakiness index yields a higher LA-coefficient, i.e. lower resistance to fragmentation. Moreover, the Figures 6.1-6.3 deem it not likely that any correlation or relations between locations are present within this study. Similar diagrams, linking LA-coefficient with flakiness index, have been done for the other grid sieves and can be seen in Appendix G. The diagrams in Appendix G indicate the same tendencies and trends as Figure 6.1-6.3.

To determine if any patterns can be seen within the same location, the relation of the LA-coefficient and flakiness index for each location and rock type was plotted. The plot for Ale is shown in Figure 6.4. In the following figures, rock core will be referred to as RC and base course as BC.

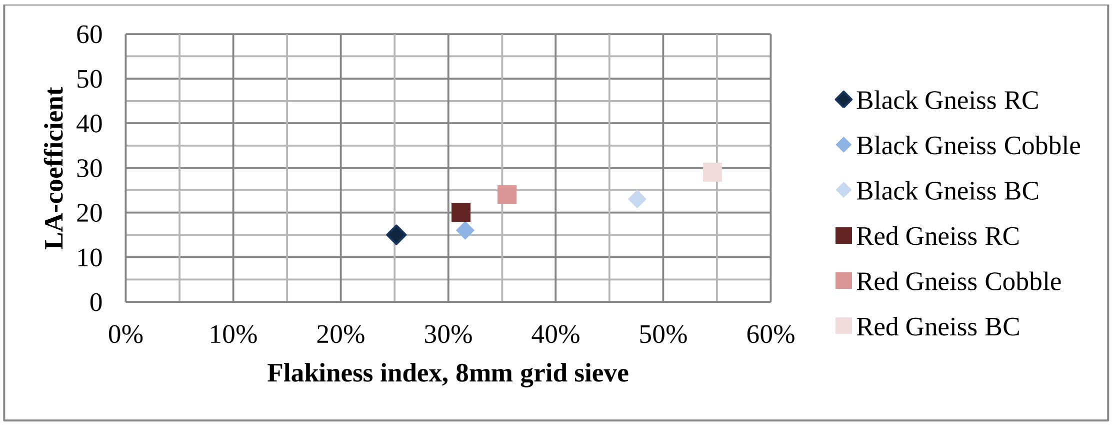

Figure 6.4 Relation between LA-coefficient and flakiness index (8 mm grid sieve) for Ale.

It is obvious from studying Figure 6.4 that the tendencies seen in Figure 6.1-6.3 apply for the different rock types and sample methods in Ale. A higher flakiness index will lead to a higher LA-coefficient. The same trend applies for both Tanum and Forserum and can be seen in Appendix H. In Appendix H the same plots for the other grid sieves can be seen as well. The other grid sieves indicates the same trends as for Figure 6.4. However, the trend is not applicable for Angered as shown in Figure 6.5.

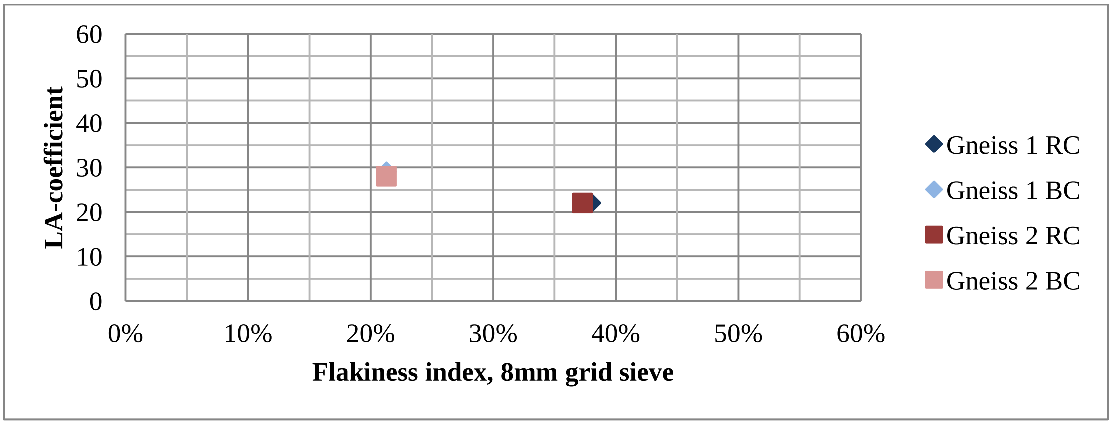

Figure 6.5 Relation between LA-coefficient and flakiness index (8 mm grid sieve) for Angered.

Angered is the only location where the base course material has a lower flakiness index than the rock cores. On the other hand, the LA-coefficient is still better for the rock cores than the base course, indicating that the flakiness index not solely determines the LA-coefficient. The difference between the rock core and base course is that the base course has gone through blasting and a different kind of crushing. It will be discussed what the reason for this likely depends on in chapter 7.1.

To determine the effect of the flakiness index on the change of LA-coefficient, the percentage increase of the LA-coefficients and flakiness index has been calculated according to Equation (8) and Equation (9).

$$\%\ increase\ of\ LA-coeff. = 100 * \left(1 - \frac{LA-coeff.\ Rock\ Core}{LA-coeff.\ Base\ Course/Cobble}\right) \quad (8)$$

$$\%\ increase\ of\ flakiness\ index\ = 100 * \left(1 - \frac{Flak.\ Index\ Rock\ Core}{Flak.\ Index\ Base\ Course/Cobble}\right) \quad (9)$$

The result of the calculations from Equation (8) and Equation (9) are presented in a table in Appendix I. The results are also plotted in Figure 6.6, except for the values for Angered that are neglected in this analysis since the flakiness index is higher for rock core than base course.

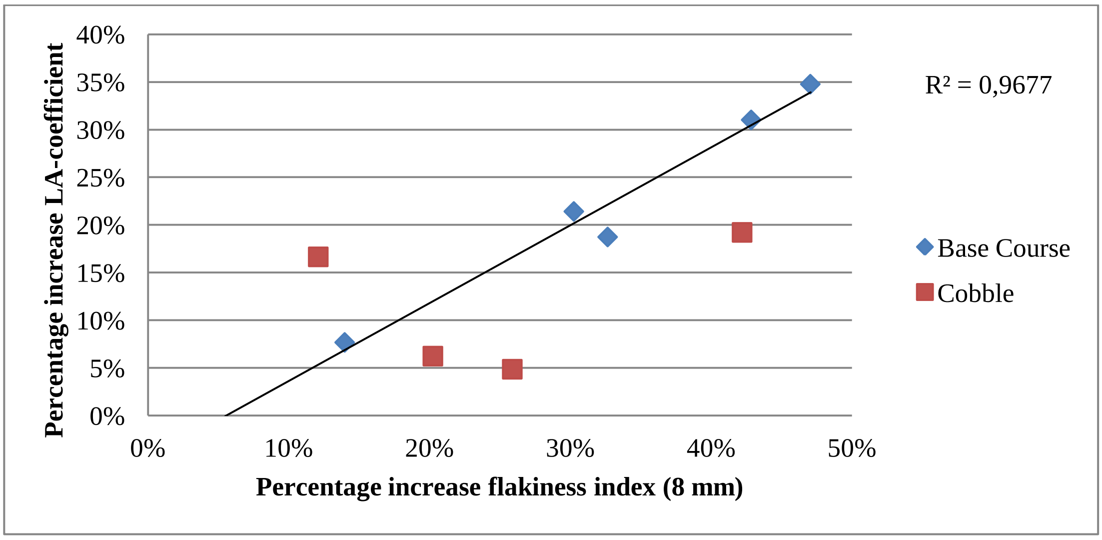

Figure 6.6 Relation between the percentage increase of the LA-coefficient and flakiness index (8 mm grid sieve) from rock core to base course and cobble, respectively.

Figure 6.6 shows a very strong correlation between the increase of LA-coefficient and flakiness index for base course. Cobbles do not show the same strong relationship as base course do, but the same trend can be observed if the furthermost left point is neglected. If the trend line where to intersect with the origin, it would have implied that the LA-coefficient and flakiness index are fully dependent on one another. Since the trend line does not go through origin, other factors affect the LA-coefficient as well. This will be discussed in chapter 7.1.

In Table I.1 in Appendix I it can be seen that the greatest percentage increase of the LA-coefficient occur for Ale black gneiss, which have an increase of 35 % from rock core to base course. By assuming 35 % is the greatest difference obtainable between rock core and base course, it can be applied on the limit of LA 40. A value of where the LA-coefficient might fall over 40 can thereby be obtained with Equation (10).

$$Indicator = \frac{40}{1,35} = LA\ 30 \quad (10)$$

Equation (10) indicates the threshold for the LA-coefficient of rock core where the base course lies at risk of not meeting the requirement of LA 40. Ale was the only location where all three different sample methods were collected. The LA-coefficient is plotted against the different rock types that were present in Ale in Figure 6.7.

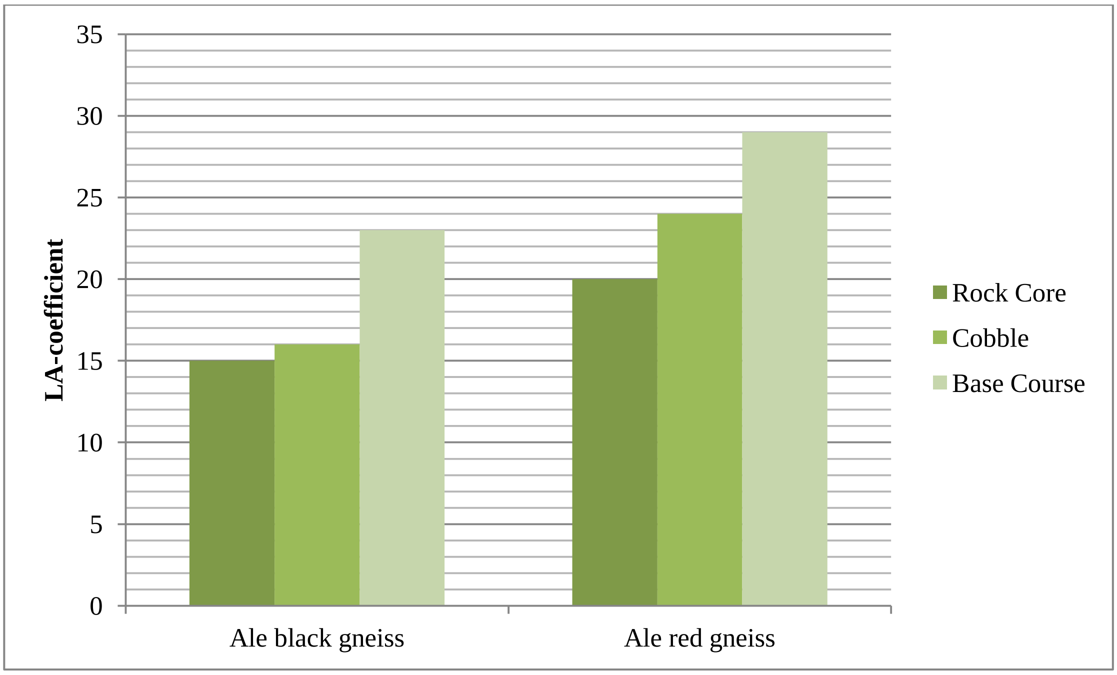

Figure 6.7 Comparison of LA-coefficient for rock core, cobbles and base course for Ale.

It is easy observable that the LA-coefficient is the lowest for rock core, highest for base course and in between for cobbles for both black and red gneiss. This is in line with the previous figures in chapter 5 and 6. The rock cores in Ale had different core diameters. Most of the sample of red gneiss came from the core with larger diameter and the sample of black gneiss came from the cores with smaller diameter. No conclusion or tendencies can be drawn to which extent the larger core differ regarding LA-testing compared with the smaller core. If more large cores had been drilled it would have been possible to investigate if any tendencies are present.

7 DISCUSSION

Chapter 7 will firstly deal with a discussion of the results and analysis. Secondly, uncertainties that can have affected the result will be brought up. Finally, recommendations will be given to further studies that would be relevant within the area of expertise.

7.1 Result and Analysis

The result corresponds well to the hypothesis of the thesis and previous experience from pre-studies. The values for the LA-coefficient for the different locations and rock types are within the same interval as previously tested base course. Therefore the results from the LA-testing are trustworthy. Rock cores consistently give a lower LA- and MD-coefficient than base course and cobble for the same material. The same trend can be seen for flakiness index, where the flakiness index is higher for base course than rock cores for all locations except for Angered. This lead to the conclusion that flakiness index is an important parameter for the outcome of the LA-test.

The fact that Angered had a lower flakiness index for base course than rock core, together with Figure 6.6, indicates that the flakiness index alone not is responsible for the lowered resistance to fragmentation of rock cores. To produce the base course sample, the rock has been blasted and crushed. Since the rock cores have been crushed as well, the difference ought to lie in the blasting procedure. Blasting is known to induce micro cracks in the material and it is likely that micro cracks can explain the difference between rock core, cobble and base course. The cobbles were assumed to lack damages from blasting, although no verification was performed. The fact that the LA-coefficient for cobbles in Ale was between rock core and base course, indicates that micro cracks affects the resistance to fragmentation.

Furthermore, the shape of the grain is very important. It is significant to understand that the same flakiness index does not confirm that the materials and grains look exactly the same. With this in mind, the difference between rock core and cobbles can be explained. The rock cores were drilled with a 40,7 mm diameter. The surface of the cores is rounded and it gives an unnatural surface shape when the cores are crushed compared to crushed cobbles and base course. The rounded edges of the rock core can explain why rock cores consistently show better LA-coefficients than cobbles.

The difference in LA-coefficient between cobbles and rock core differ widely in Tanum. It is likely that the difference in LA-coefficient between rock core and cobbles from Tanum Bohus granite should be smaller and more similar to the difference for Tanum gneiss. Due to the additional crushing on grains larger than 14 mm on the rock core sample of Bohus granite, the grain shape of the sample is improved. As presented in Chapter 2.4, the strength is improved for every crushing stage. It is thereby likely that the resistance to fragmentation also is improved for the rock core sample. If the crushing procedure had been similar, it is expected that the Bohus granite LA-coefficient for rock core would be higher, i.e. correspond to poorer rock quality.

The fact that the flakiness index in Angered is higher for base course than rock core is not consistent with the other locations. The crushing steps for receiving base course in Angered were set to smaller fractions in the production. This might have affected the flakiness of the material. The CSS (closed side setting), see Chapter 2.4, was in

Angered set to 16 mm, indicating that materials close to 16 mm will receive a better grain shape, i.e. lower flakiness index. Since the LA-test sample is in 10-14 mm fractions, by having the CCS set to 16 mm instead of 32 mm will give a much less flaky material. Furthermore, the material in fractions 0-16 was after the pre-crusher removed from the crush line to receive an end product with better quality. This procedure was only done in Angered. This is another likely reason why the flakiness index for base course is lower than for the other locations.

The indicator of LA 30 should not be seen as an absolute figure. Rock cores with a LA-coefficient above 30 do not necessarily give a LA-coefficient above 40 for base course. Conversely, LA-coefficient below 30 for rock cores does not guarantee a LA below 40 for base course. It is an indication of when attention should be drawn toward the LA-coefficient of the end product, i.e. the aggregates for the future road.

7.2 Locations

The locations for the case study were selected due to their different type of geology, they were owned by Skanska and were relatively close to Göteborg. Although that the study was controlled by the parameters mentioned above, it was not a limiting factor for the thesis. It is believed that a better result would not have been obtained if the locations where to be chosen differently. The sample location at each site was chosen where the next blast was to take place. Therefore, deciding exactly what type of rock to be tested could not be decided on beforehand. However, the material received corresponded well to what was expected.

7.3 Methodology – Sample collection uncertainties

The method of how the thesis was carried out was done to simulate how mechanical properties of a rock are obtained in a pre-study. In situ geological information is determined by tests on either rock cores or cobbles from a sledgehammer test. The cobbles were sampled as a material not having blasting damages and therefore corresponding to sledgehammer samples. However, no verification or testing was done to make sure it was no damages from blasting in the cobbles and can therefore not be fully related to sledgehammer samples.

The rock cores were drilled at a distance of at least 10 meters from the bench face to avoid blast damages. No verification of the cores actually being non-damaged was carried out. The length of the rock cores differed between the locations and also within the same location. However, the lengths should have no impact on the result because the essential is the rock type in the cores, and that they are representing the rock types in the bench. Additionally, it was important to keep the lengths of the cores approximately within the bench height, so that no new rock type was discovered in the cores and not in the blasted and crushed material. All rock cores were drilled with a vertical dip, except three cores from Tanum. Originally, the plan was to drill perpendicular to the foliation of the rock. However, this was not possible due to external factors at site such as bench width. The drilling in Forserum took place on a second bench. Fractured rock was observed several meters in the rock cores and was assumed to be blast damages and therefore not included in the study.

The fact that the base course did not go through the same amount and type of crushers is a limiting factor. Obviously, a more reliable comparison where the material actually was produced in exactly the same way would have been desirable. This was not possible during this thesis due to monetary terms, time frame and production controlled parameters. In further studies it should be of high priority to make sure the process is identical or at least equivalent to minimize sources of error.

The base course from Forserum was collected from another bench than the one were the rock cores were drilled. This was because blasting did not occur within the time span for the thesis. Therefore, base course had to be taken from the bench blasted previously. Since Forserum is a very homogenous quarry and the samples were inspected ocular before the LA-test, it is assumed to have no effect on the outcome.

Higher specific charge results in more micro cracks and higher proportion of fine fraction. The specific charge varied from 0,47 kg/m^3 to 0,90 kg/m^3 between the sites, with the highest specific charge in Angered and the lowest in Forserum. However, the effect of the specific charge on the amount of micro cracks is not investigated within the framework of this thesis.

Regarding which method that is the most reliable to use in a pre-investigation, sledgehammer sampling seem to be a better method. By not using rock cores the problem with unnatural surfaces and edges will be bypassed. Additionally, sledgehammer sampling is much more beneficial out of an economic point of view. The method is more accessible and faster than drilling rock cores. However, sledgehammer sampling is not suitable in all situations. For example where the soil layer above the rock is thick or where the rock is hard and without fractures.

7.4 Methodology – Laboratory uncertainties

Each and every sample was inspected ocular with high precision on rock type, colour, homogeneity and mineralogy. No uncertainties believe to be associated with testing of different rock types. The LA- and MD-testing followed the European standards and is therefore disregarded as a source of error. The flakiness index, on the other hand, was not tested according to any standard. The procedure was created for this thesis to be able to compare the samples with each other. Although the flakiness used in this thesis is not comparable to the standard flakiness it fulfilled its purpose more than well. One of the concerns and a possible source of error is that only 1,5kg out of 5 was tested with respect to flakiness. Subsequently, the degree of mixing of the 5kg sample, consisting of the fractions 10-11,2 and 11,2-14 mm, was crucial. If the mixing was not done correctly, the grain size rather than the grain shape would determine the outcome of the flakiness index.

The rock core was crushed three times in the laboratory, which is one extra step compared to the base course. It is standard procedure for crushing rock cores in laboratory three times to obtain the amount of material needed for a LA-test. This deviates with the amount of crush steps in production and is therefore deemed not appropriate. More reliable results could be obtained if simulation of the crushing procedure in laboratory is as similar as possible to the one performed in the quarries or at site. The largest difference between the crushers in laboratory and in quarries is the type and the size of the crushers. A possible solution to the crusher type is by imitating the type of crusher used in production. Regarding the difference in size, it needs to be researched if any differences actually exist.

7.5 Main source of error

The main source of error in the study was that the method for collecting base course and cobbles were not the same for the different locations, as presented in Chapter 4.3. It was due to external factors but is very important to control in future research that are to be done in the area. It is hard to predict in which extent this might have affected the result. The crushing procedure is important for the quality and shape of the grains, which have a large impact on the LA-coefficient.

7.6 Sustainability aspects

The report believes to have significant importance regarding sustainability aspects. Natural gravel and sand are finite resources and therefore crushed rock must be used to a greater extent from today and in the future. Additionally, by using the material at site, transport of aggregates to and from a road project can be minimized. Fewer transports lead to a better environment which is good out of a sustainable point of view.

7.7 Further studies

It is important to highlight that this study provide a direction on where future research is needed. Research is recommended to continue within the field of study, there is still much to find out about the factors affecting the LA-coefficient from in-situ condition to finished aggregate. First of all, the ingoing parameters must be isolated so that the uncertainties that were present in this study will be removed. To find a theory of how the LA-coefficient changes, all affecting parameters must be evaluated individually. Therefore, three main research directions are recommended.

Further research of how the flakiness index affects the LA-coefficient is needed. It would also be interesting to find out if the rounded edges of the rock core actually affect the LA-coefficient since it is only a hypothesis. Alternatively, the flakiness of the in-situ and finished aggregate can be modified to match each other to remove the impact of the flakiness on the end result.

The crush steps at laboratory should match the crushing in production. This is to make sure the difference is not associated with different techniques of crushing.

To evaluate if sledgehammer samples corresponds to the finished aggregate better than rock cores. Additionally, sledgehammer samples could be compared against cobbles to investigate if the cobbles are affected by blasting.

8 CONCLUSION

This thesis aimed to answer two research questions.

- Do differences occur between expected and received LA-coefficient?
- Does the grain shape affect the resistance to fragmentation?

Regarding if differences occur between expected and received LA-coefficient, the thesis clearly answers the question. Differences in LA-coefficient between rock core, cobble and base course can be seen consistently in the study. Rock cores tend to give lower LA-coefficients than cobbles and base course for the same material. The reason for this difference is believed to be because of grain shape, flakiness and micro cracks. The flakiness of a material affects the resistance to fragmentation to a large extent. Flakier material tends to give a higher LA-coefficient, which can be seen for seven out of nine rock type samples.

However, two materials with the same flakiness index do not automatically have the same grain shape. It has been observed that the LA-sample for rock cores tend to have rounded edges. It is because the surface of the core is rounded and it gives an unnatural surface shape when the cores are crushed. Rounded edges will most likely improve the LA-coefficient. Blasting induce micro cracks in the rock which weakens the resistance to fragmentation. The difference between cobbles (sledgehammer test) and base course ought to be that the base course has been blasted and therefore induced with micro cracks. To which extent the micro cracks affect the resistance to fragmentation depends on rock type, blasting properties such as specific charge, etc.

Finally, the purpose of the thesis was to find indicators when attention needs to be drawn to the rock quality versus the possible use of the material in a road construction. The quality limit for the LA-coefficient to be used in a road construction is LA 40. The thesis has drawn the conclusion that if pre-studies determine the LA-coefficient from rock cores to be LA 30, it might fail to stay below LA 40 when producing the material at site. The indicator of LA 30 should not be seen as an absolute figure. It is an indication of when attention should be drawn toward the LA-coefficient of the end product, i.e. the aggregate for the future road.

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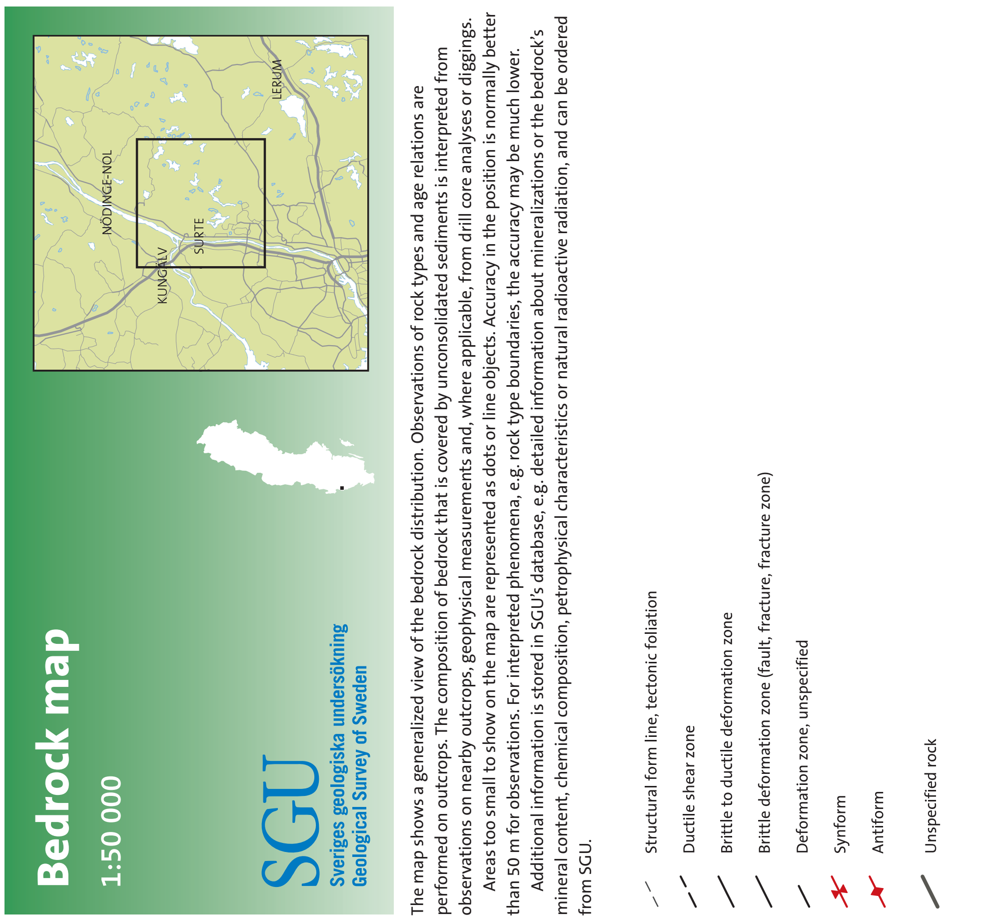
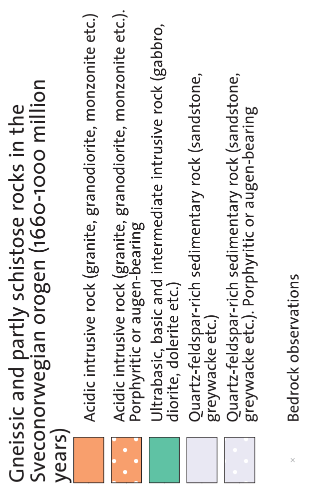
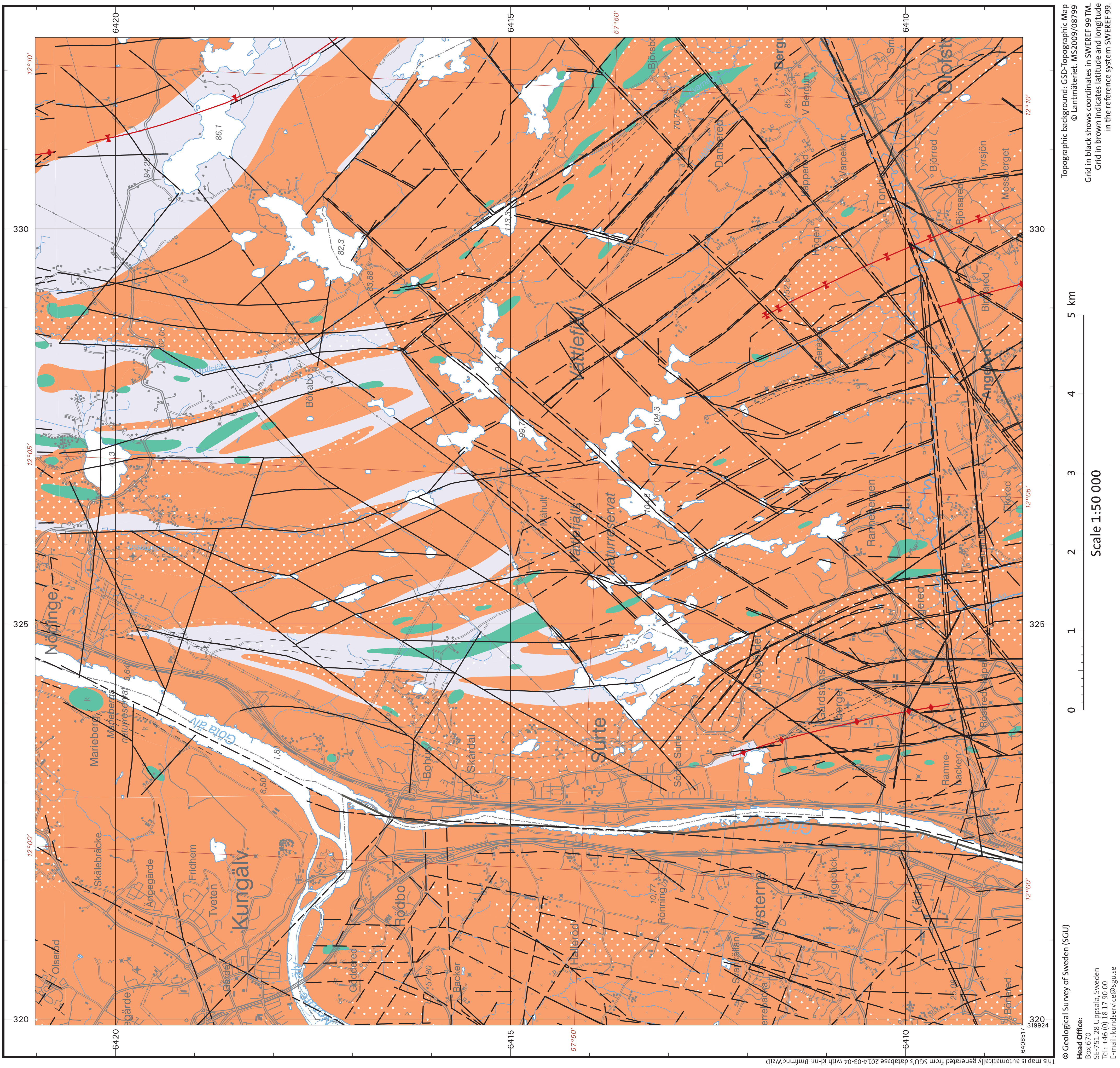
LIST OF APPENICES

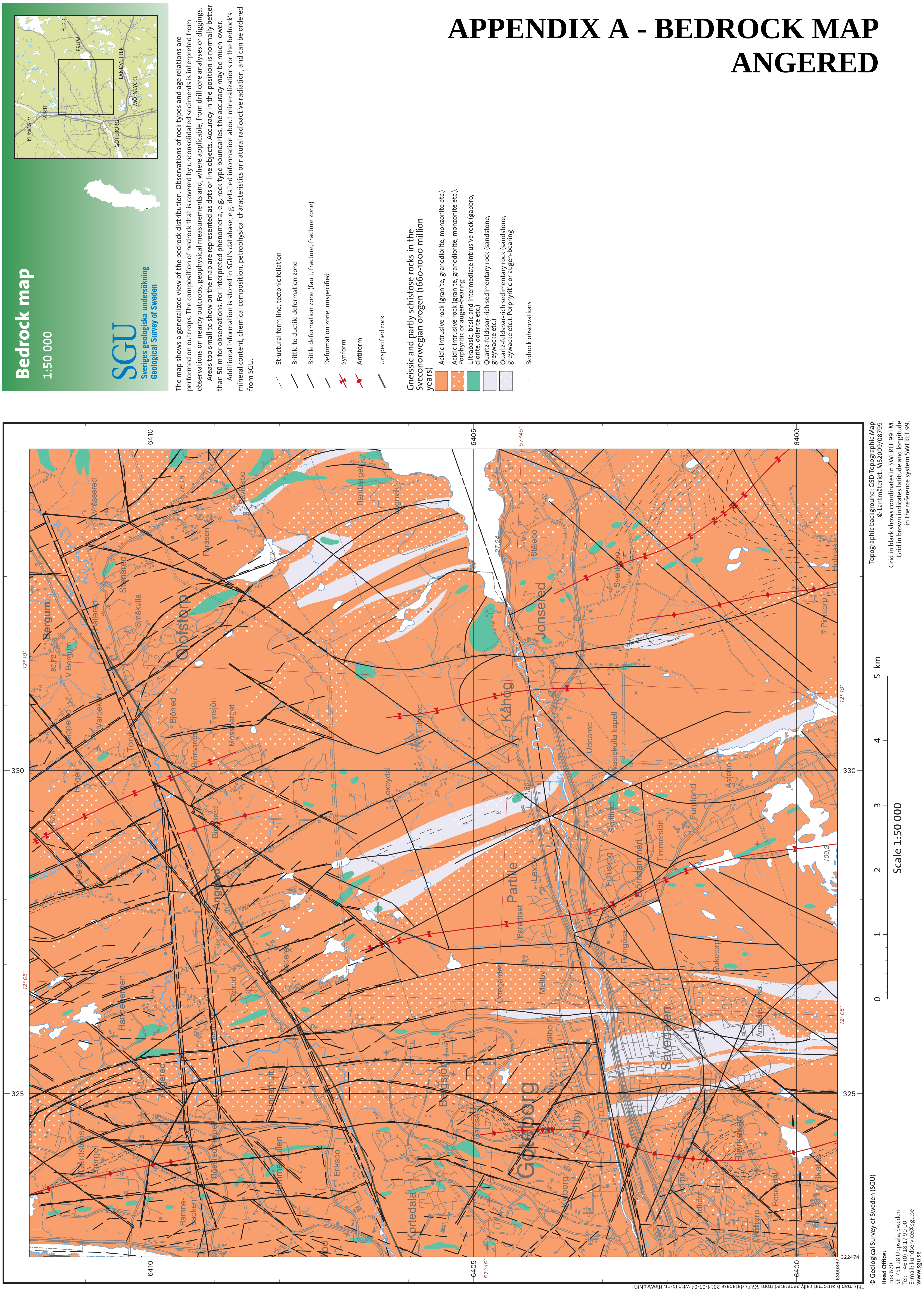
APPENDIX A - BEDROCK MAP ALE



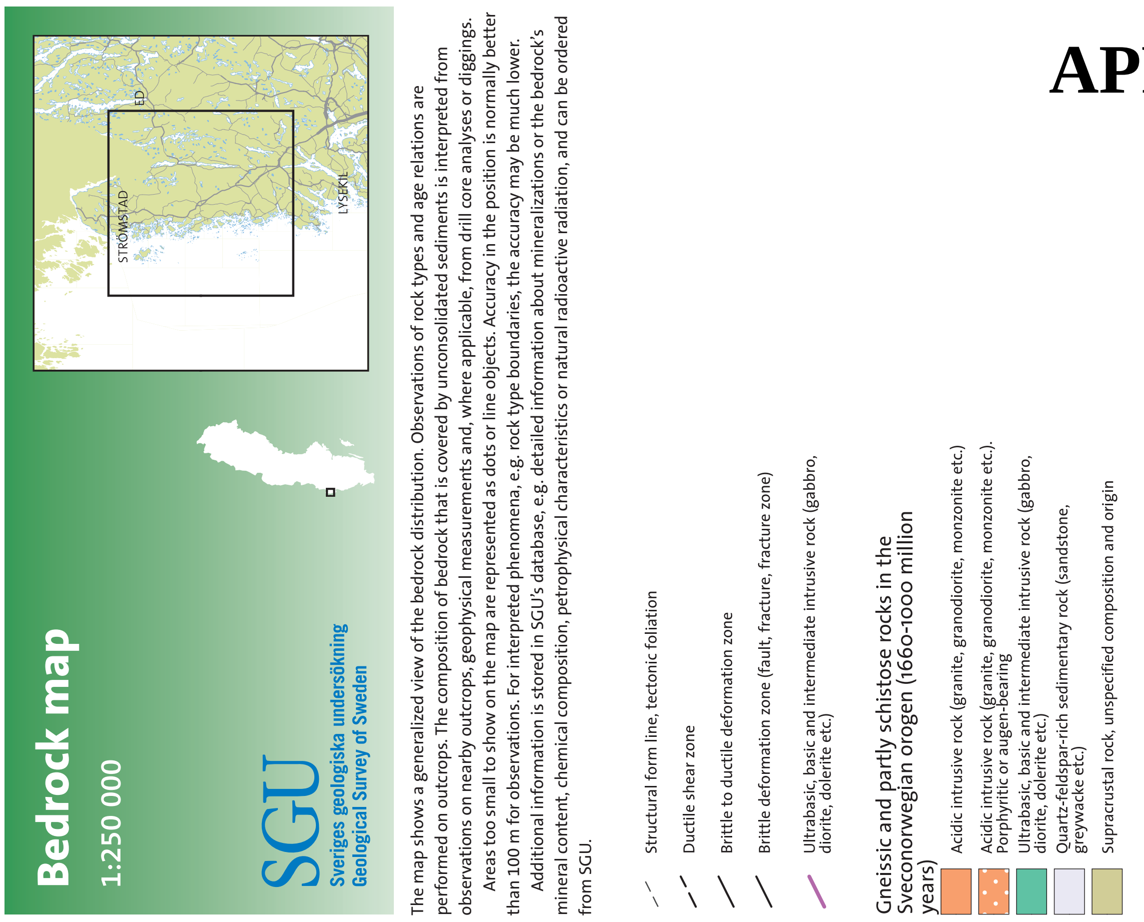


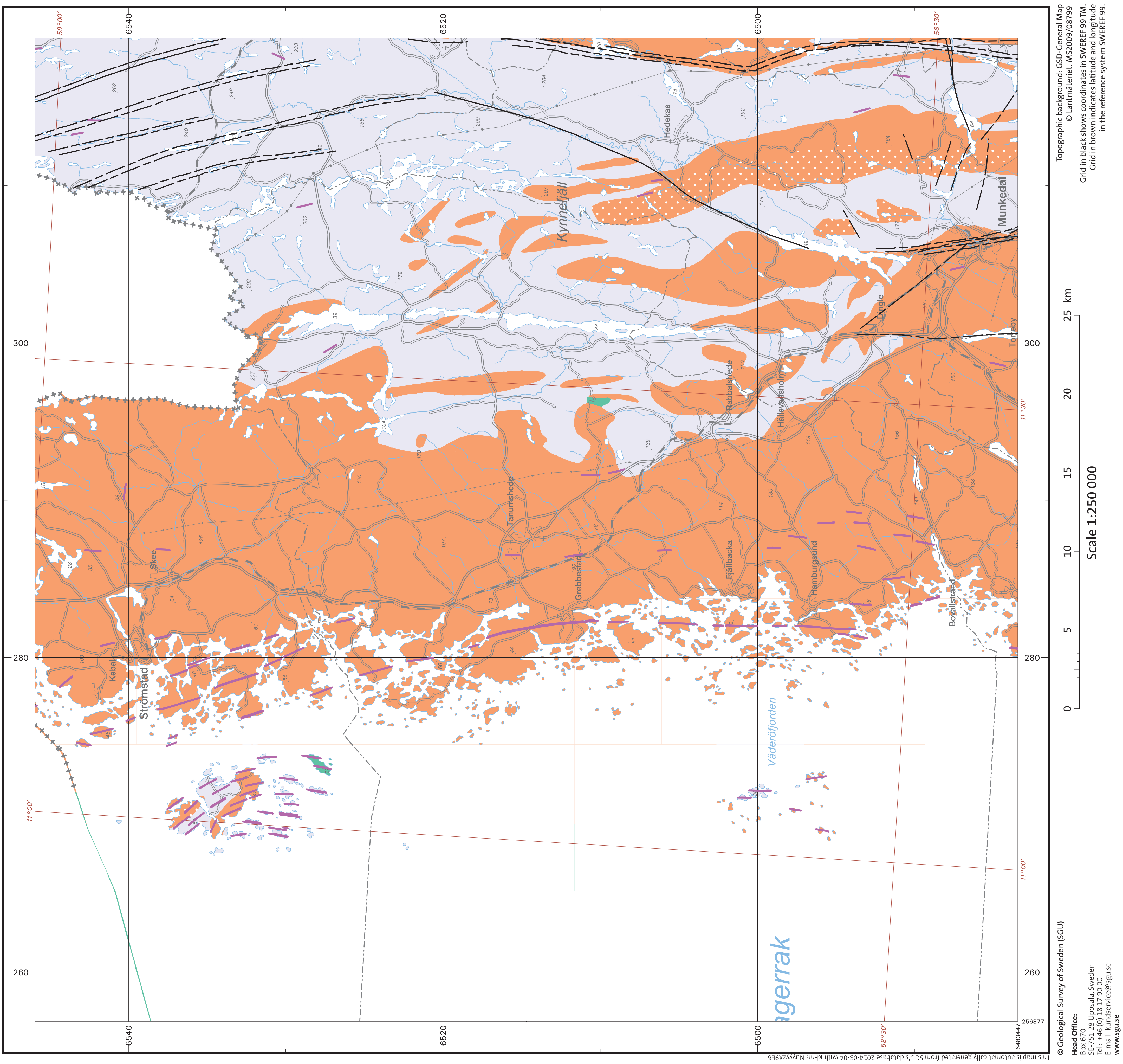


APPENDIX A - BEDROCK MAP ANGERED



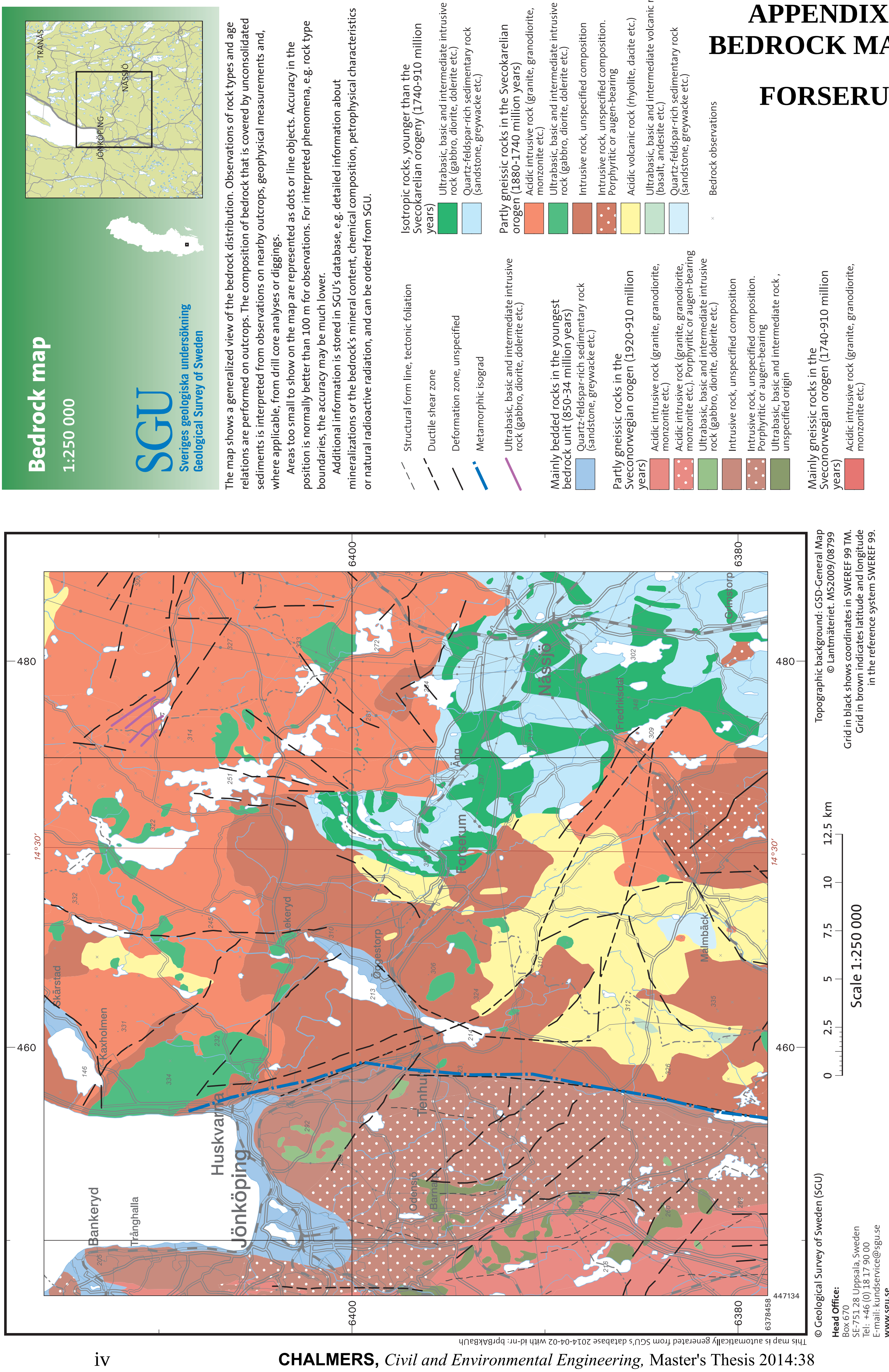
APPENDIX A - BEDROCK MAP TANUM





APPENDIX A
BEDROCK MAP

FORSERUM



APPENDIX B – Rock cores

Angered

Figure B.1 *Angered KBH1 Box 1 [0.0–5.84 m]*

Figure B.2 *Angered KBH1 Box 2 [5.84–11.54 m]*

Figure B.3 *Angered KBH1 Box 3 [11.54–14.35 m]*

Angered

Figure B.4 Angered KBH2 Box 1 [0.0–5.61 m]

Figure B.5 Angered KBH2 Box 2 [5.61–11.20 m]

Figure B.6 Angered KBH2 Box 3 [11.20–14.15 m]

Angered

Figure B.7 *Angered KBH3 Box 1 [0.0–5.73 m]*

Figure B.8 *Angered KBH3 Box 2 [5.73–11.29 m]*

Figure B.9 *Angered KBH3 Box 3 [11.29–14.00 m]*

Ale

Figure B.10 *Ale KBH1 Box 1 [0.0–5.70 m]*

Figure B.11 *Ale KBH1 Box 2 [5.70–11.55 m]*

Figure B.12 *Ale KBH1 Box 3 [11.55–14.10 m]*

Ale

Figure B.13 *Ale KBH2 Box 1 [0.0–5.60 m]*

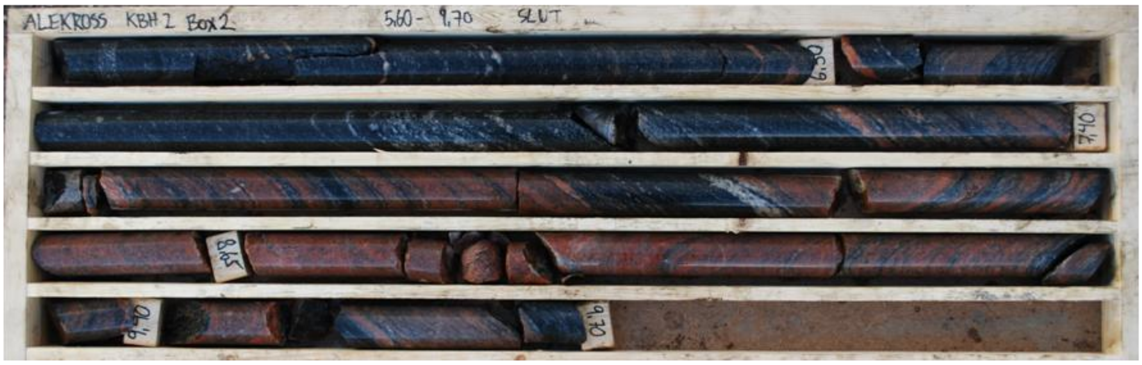


Figure B.14 *Ale KBH2 Box 2 [5.60–9.70 m]*

Ale

Figure B.15 Ale KBH3 Box 1 [0.0–2.30 m + 0.0–0.85 m]

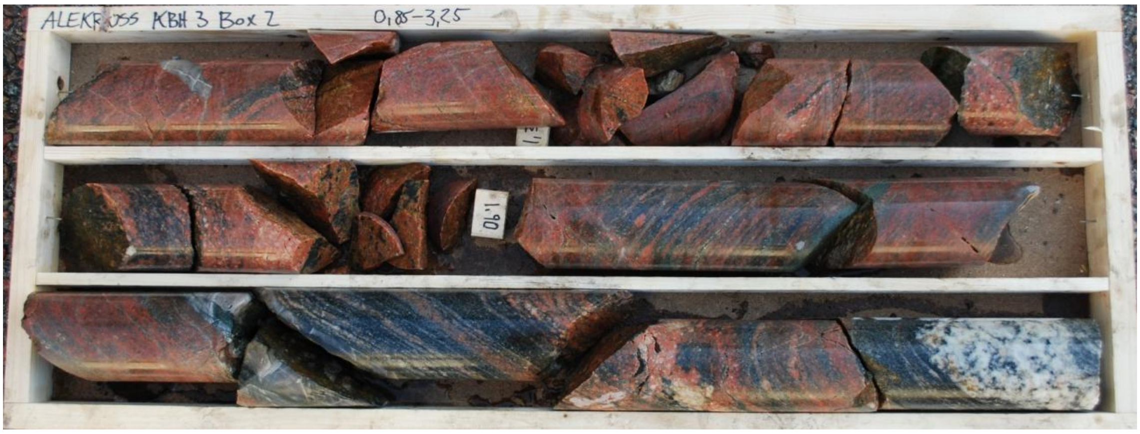


Figure B.16 Ale KBH3 Box 2 [0.85–3.25 m]

Figure B.17 Ale KBH3 Box 3 [3.25–4.02 m]

Tanum

Figure B.18 Tanum KBH1 Dip 60 Box1 [0.0–5.65 m]

Figure B.19 Tanum KBH1 Dip 60 Box 2 [5.65–6.25 m]

Figure B.20 Tanum KBH1 Dip 83 Box 1 [0.0–5.65 m]

Figure B.21 Tanum KBH1 Dip 83 Box 2 [5.65–6.25 m]

Tanum

Figure B.22 Tanum KBH2 Dip 60 Box 1 [0.0–5.65 m]

Figure B.23 Tanum KBH2 Dip60 Box 2 [5.65–6.25 m]

Figure B.24 Tanum KBH2 Dip 81 Box 1 [0.0–5.70 m]

Figure B.25 Tanum KBH2 Dip81 Box 2 [5.70–6.20 m]

Tanum

Figure B.26 *Tanum KBH3 Dip 60 Box 1 [0.0–5.75 m]*

Figure B.27 *Tanum KBH3 Dip 60 Box 2 [5.75–7.05 m]*

Figure B.28 *Tanum KBH3 Dip 85 Box 1 [0.0–5.75 m]*

Figure B.29 *Tanum KBH3 Dip 85 Box 2 [5.75–6.25 m]*

Forserum

Figure B.30 Forserum KBH1 Box 1 [0.0– ~7 m]

Figure B.31 Forserum KBH1 Box 2 [~7 – ~13 m]

Figure B.32 Forserum KBH1 Box 3 [~13–16.32 m]

Forserum

Figure B.33	Forserum KBH2 Box 1 [0.30–7.75 m]

Figure B.34	Forserum KBH2 Box 2 [7.75–14.04 m]

Figure B.35	Forserum KBH2 Box 3 [14.04–20.30 m]

Forserum

Figure B.36 *Forserum KBH3 Box 1 [0.0–6.50 m]*

Figure B.37 *Forserum KBH3 Box 2 [6.50–13.5 m]*

Figure B.38 *Forserum KBH3 Box 3 [13.5–20.2 m]*

APPENDIX C – Blast journals and drill reports

Ale

ALINGSÅS SPRÄNGTJÄNST

SPRÄNGJOURNAL

Datum: 21/2-14	Salva nr: 1
Täkt: Alekrossen	1:a/2:a pall:
Tid: 14⁰⁰	Borrare: Nisse

Borr och laddata

Borrning	Laddning
Antal borrmeter: 1300	DX 55 mm 100 kg
Antal borrhål: 100	DX ... mm ... kg
Försättning: 2,6	DX ... mm ... kg
Hålavstånd: 3,6	Booster: 100 kg
Borrhålsdiameter: 89mm	Bulk: 8490 kg
Hållutning: 10°	Anfo: ... kg
Max antal rader: 5	Delladdning toppen:
Håldjup: 11 - 15	Delladdning botten:
Underborrning: –	Hålinmätning: JA

Tändare

Bottentändare: U475	Topptändare: U500
Fördröjning rad: S167	Fördröjning sida: S125
Elektroniska rad:	Elektroniska sida:

Checklista före sprängning

Borrning OK: NH	Tändplan OK: NH
Laddning OK: NH	Avstängning OK: NH

Resultat

Sprängämne ton: 8690	Spec laddning kg/m3:
Uppsk vol ton: 38000	Uppsk vol m3: 14480

Vibrationsmätning

Mätplats:	mm/s:
Mätplats:	mm/s:

Övrigt

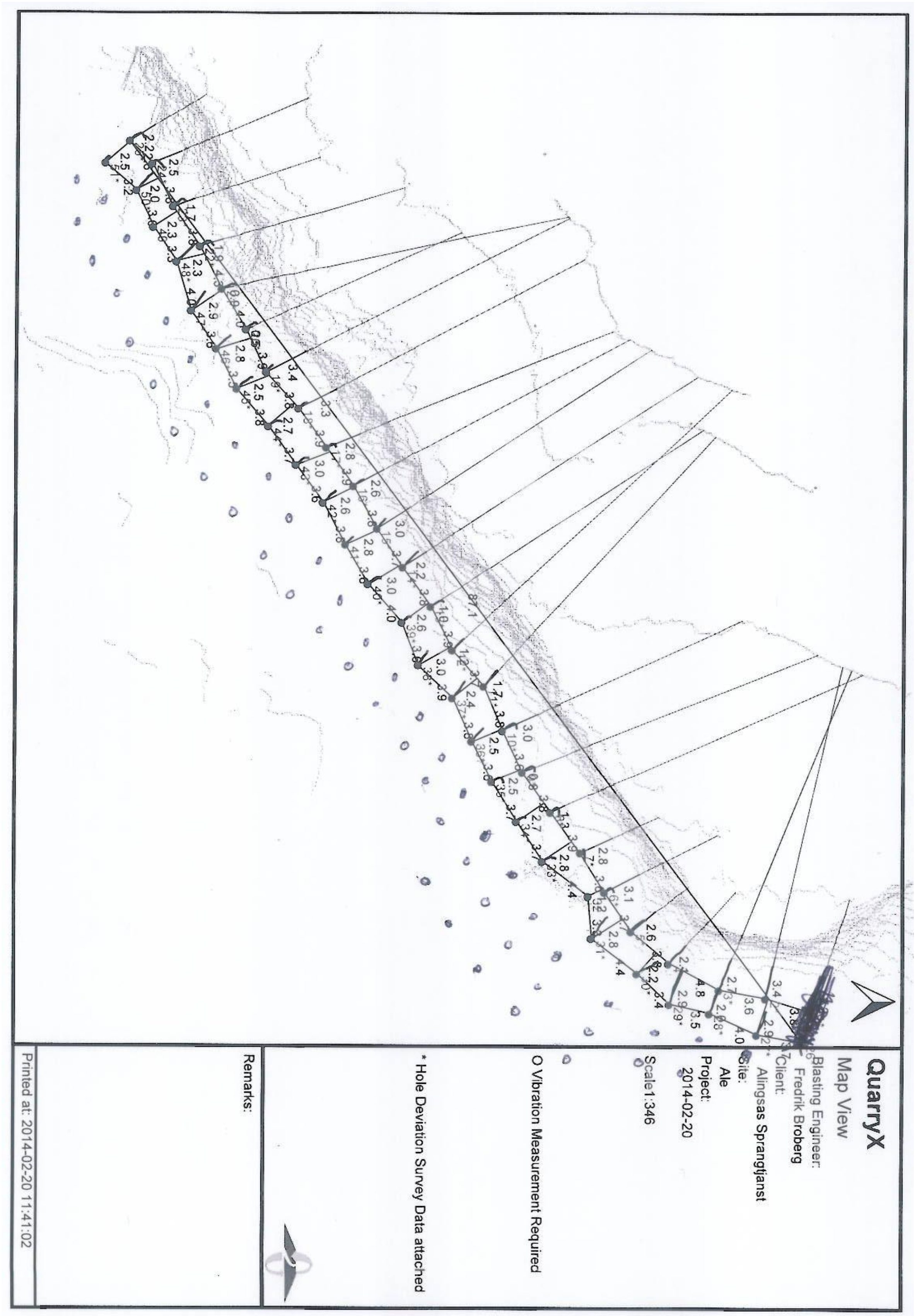
Laddservice: EPC	Avladdning: 1,6
Transport borr: LSA	Väg till salvan: DRA
Avtäckning: DRA	Berg framför: –

Övrigt:

Sprängarbas: Niklas Hermansson

Sign: [signature]

Ale


QuarryX
Map View
Blasting Engineer:
Fredrik Broberg
Client:
Alingsas Sprangtjanst
Site:
Ale
Project:
2014-02-20
Scale1:346
O Vibration Measurement Required
* Hole Deviation Survey Data attached
Remarks:
Printed at: 2014-02-20 11:41:02

Angered

SKANSKA

SPRÄNGJOURNAL

Datum	2014-03-24	Salva nr	**3 -14**
Tid	15:08	Övre pall	Ja, till höger om ramp, skj.rikt. 70,1°
Täkt	Angered	Nedre pall	
Borrvagn	122101	Borrare	Mikael Johansson

Borr & laddata

Borrning			**Laddning**	
Antal Borrmeter	1939,6 meter		Fordyn	
Antal hål	84 st		Exem	113 kg
Försättning	2,6 meter	Forcit	Kemmiitti 510	
Hålavstånd	3,6 meter	Orica	Centra Gold 80	
Borrhålsdiameter	89 mm	EPC	Blendex 70	15 980 kg
Hållutning	14 grader		Booster	83 kg

Checklista före Sprängning

Borrning	Ok	Bottentändare	24 -27 m 83 st
Borrhålsmätning	Ok		
Laddning	Ok		
Tändplan	Ok	Topptändare	7,8 m 79 st
Checklista	Ok	Kopplingsblock	
Riskområde	Ok	SL 0	1 st
Utrymmning	Ok	SL 9	18 st
		SL 17	6 st
Väder	Lätt molnigt.	SL 25	70 st
		SL 42	12 st
		SL 67	
Besiktning av salva, efter sprängning		SL 109	

Borrat till: + 81,5.

Dieselförbrukning: 1050 liter.

Resultat

Sprängämne totalt	16 176 kg	Spec laddn kg/m³	
Berg i Ton	48 600 ton	Max laddn/hål	192 kg

Vibrationsmätning

Mätplats 1		Mätvärde 1	
Mätplats 2		Mätvärde 2	
Mätplats 3		Mätvärde 3	
Mätplats 4		Mätvärde 4	

Övrigt

1:a Koordinat	East: 49509.4	North: 36043.7
2:a Koordinat	East: 49501.1	North: 36083.6
Transport borrvagn		

2014-04-11

Sprängarbas: Daniel Pettersson
Tlfnr: 0104483317

Angered

Täkt:	Angered	**Tändare**	**antal**	**HotShot**	**antal**
Borrperiod:	17/2-4/3	**4,8 m**	0 st	**6,0 m**	0 st
Borrare:	Micke	**7,8 m**	0 st	**10,0 m**	0 st
Borrvagn:	D7c	**10,2 m**	0 st	**15,0 m**	0 st
Rikt:	70.1°	**12,0 m**	0 st	**20,0 m**	0 st
Försättning första rad:	3,5 m	**15,0 m**	0 st	**25,0 m**	81 st
Försättning andra rad:	2,6 m	**18,0 m**	0 st	**30,0 m**	3 st
Hålavstånd:	3,6 m	**21,0 m**	2 st		
Underborrning:	1,5 m	**24,0 m**	49 st		
Övre/nedrepall:	övre	**27,0 m**	33 st		
Borrdiameter:	89 mm	**30,0 m**	0 st		
Hållutning:	14°	**36,0 m**	0 st		
Antal rader:	9 st	**42,0 m**	0 st		
Borrhål:	84 st				
Borrmeter:	1939,6 m				
Antal ton:	85853				
Antal ladd m:	1788,4				
Sprängämne/m:	7,4				
Sprängmedel:	13234 kg				
Borrat till:	81,5 m				
Gaddar i botten:	nej				
Proppgrus utlagt:	ja				
Medtag vattenpump:	nej				
Väg för laddbil OK:	ja				
Övrigt:					

ANGERED

1	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
2														25		24,9					
3					23		24,1		24,2		24,2		24,2		24,3		25		24,2		
4				22,6		23,9		24,3		24,2		23,9		24,2		24,3		24,2		23,9	
5			22		23,5		23,6		24		24		23,9		24,1		24,3		24,3		24,4
6				21,8		22,9		23,4		23,6		23,8		23,7		24		24,2		24,2	
7		20,6	20,6		21,2		22,6		22,5		22,3		23,1		23,7		23,4		23,9		23,8
8		22,2		20,9		20,7		21,5		22,4		22,7		23,3		22,8		23,4		23,7	
9	23		22,4		22,7		22,5		21,4		22,1		21,9		22,8		22,7		22,4		22,7
10		23,2		22,7		22,4		22,9		22,3		21,8		22,2		22		22,2		22,5	
11															22,6		22,3		22,4		21,9

Underborrning: 1,5 m

Tanum

BOHUS
BERGSPRÄNGNING AB

Prosjekt: Pålen-Tanum
Salve nr: 126
Utskriftsdato: 09.04.2014 03:40

Salvrapport

Plats:	0/300
Salve-ID:	630
Salve-nr:	126
Sprängarbas:	Andreas Haugerud (BOHUS BERGSPRÄNGNING AB)
GPS-position:	Inte angett
Planlagd sprängning:	3/3/2014 2:15:00 PM
Faktisk skjutet:	3/3/2014 2:15:00 PM
Salvplan registrerad:	4/8/2014 7:17:20 AM
Sprängjournal registrerad:	4/9/2014 3:37:35 PM
Revideringstidpunkt:	4/9/2014 3:37:35 PM
Revideringsnummer:	1 / 1

Kommentarer till revidering :
Original salverapport
Se revideringshistorik för ytterligare detaljer

Salvdata

		Salvhål		
		Plan	*Rapport*	*Avvikelse*
Borrdiameter	mm	70	70	0
Försättning	m	2.0	2.0	0.0
Hålavstånd	m	2.5	2.5	0.0
Underborrning	m	1.0	1.0	0.0
Förladdning	m	1.2	1.2	0.0
Hål per detonation	st	1	1	0
Hållutning	grader	11.2	11.2	0.0
Bottenladdning				
Patronlängd	mm	560	560	0
Patronvikt	gram	2080	2300	220
Patroner per hål	stk	2	1	1
Pipladdning				
Densitet	kg/l	0.00	0.00	0.00
Patronlängd	mm	560	560	0
Patronvikt	gram	1600	1600	0
Längd mellandäck	m	0.0	0.0	0.0

Håldata

	Salvhål	
Rad	Antal hål	Borrdjup
1	7	3
2	7	3
3	7	3
4	7	3
5	7	3
6	7	3
7	7	3
8	7	3
9	6	3
10	6	3
11	6	3
12	6	3
13	5	3
14	5	5
15	5	5

Tanum

Beräkningar

		Salvhål		
				
Teoretiska värden		*Plan*	*Rapport*	*Diff*
Antal hål	stk	95	95	0
Borrmeter	m	305.00	305.00	0.00
Volym	m³	863.24	863.24	0.00
Vekt (2.6 t/m³)	tonn	2244.43	2244.43	0.00
Sprängämnesförbrukning	kg	636.91	612.21	24.70
Bottenladdning	kg	395.20	218.50	176.70
Pipladdning	kg	241.71	393.71	152.00
Specifik laddning	kg/m³	0.74	0.71	0.03
Max laddning per int.	kg	11.82	11.56	0.26
Faktiska värden				
Borrmeter	m	-	305.00	-
Sprängämnesförbrukning (1)	kg	-	657.00	-
Specifik laddning (2)	kg/m³	-	0.76	-
Avvikelse teori / faktisk				
Borrmeter	m	-	0.00	-
Sprängämnesförbrukning	kg	-	44.79	-
Specifik laddning (2)	kg/m³	-	0.05	-

Fotnoter:
(1) - Faktisk sprängämnesförbrukning baserar sig på angiven produktförbrukning där sprängämnesmängden är hämtad från ett produktregister
(2) - Specifik laddning använder teoretisk volym som nämnare

Produktförbrukning

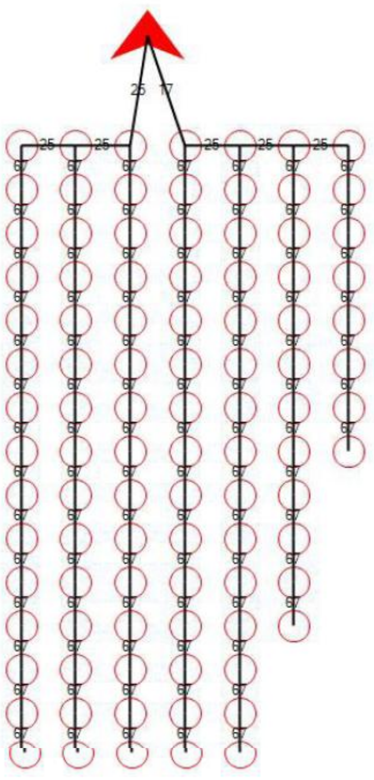
Produkter

Varunr	Produktnamn	Mängd	Enhet
60302005-6	HOT SHOT DETONATOR - 10 M / 5 M	98.0	stk
	Poladyn 31 eco plastpølser - 50 x 550	431.0	kg
	Poladyn 31 eco plastpølser - 60 x 550	226.0	kg

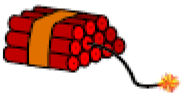
Borrmeter

Borrdimension (mm)	Beräknad/teoretisk bormeter (m)	Borrmeter från rigg (m)	Differens
70	305	305	0.0

Salve-ID: 630. Tilldelning: 0/300



Forserum



SPRÄNGJOURNAL

FORSERUM

SALVA: 14.01	DATUM: 2014-03-06	TID: 11,15	
ANTAL HÅL: 116	LÄGE: HÖGA & LÅGA SKJUTRIKTN. 229° ANDRA&TREDJEPALL		
VOLYM:	21 984 TFM3		
FÖRSÄTTNING :	3,00 METER		
HÅLAVSTÅND :	4,00 METER		
ANTAL BM:	1 948 METER		
VIKT:	65 952 TON		
PALLHÖJD :	15,79 METER		
HÅLDIAMETER :	89 mm		
UNDERBORRNING :	1,0 METER		
HÅLLUTNING :	14 GRADER		
MAX LADDNING / HÅL :	145 KG I DX		
SPRÄNGÄMNE I SALVAN:			
		ANTAL KG	ANTAL KG I DX
PENTEX	1KG		0,0
BP. BOOSTER	1KG	116,0	208,8
BLENDEX	70	13605,0	10067,7
CENTRA	GT		0,0
POLADYN	50x550		0,0
POLADYN	55x550		0,0
EXEM	50x475		0,0
EXEM	55x490	175,0	159,3
FORDYN	55x560		0,0
FORDYN	50x560		0,0
SUMMA		13896,0	10435,8
KG / M3 I DX	0,47		
BM / M3:	0,089		
LADDNING:	1 BOOSTER SOM BOTTENLADDNING. BLENDEX 70 SOM PIPLADDNING TILL 2,0M OLADDAT. 1 EXEM 55 SOM TOPPLADDNING. 1 HÅL OLADDAT PGA STOPP. 4 RADER DJUP.		
TÄNDNING :	MS475 SOM BOTTENTÄNDARE. MS500 SOM TOPPTÄNDARE. DY-17 I FRAMKANT. DY-42 RAKT BAKÅT		
LADDTID :	JIMMY ANDERSSON JENS ALVERUP DENNIS PERSSON		7 TIM 7 TIM 7 TIM
RESULTAT :	BRA! BORRAD AV BENNY		

Forserum

ÖVRIGT :	HÅLMÄTNING UTFÖRD AV LOUISE 25/2		
	SPRÄNGDES 7/3 KL.11,15 (ÄTTIKA SLUT 6/3)		
	VIBRATIONSMÄTNING :		
	Snuggarp 2:7		mm/s
	Måletorp 1:1		mm/s
	Krökesbo 1:4		mm/s
	Boarp 1:51	Pa	mm/s
UTFÖRT ENLIGT CHECKLISTA LOSSHÅLLNING:			X
UTLASTNINGSNIVÅ: SKALL VARA +284M. FÖR HÖGT FRAMFÖR HÖGPALL			
KOORDINATER:			
	HÅL 1: **X** 6397325.289 **Y** 470168.365 **Z** 303.610		
	HÅL 29: **X** 6397286.044 **Y** 470268.206 **Z** 295.550		

Forserum

BORRPLAN

SKANSKA ASFALT&BETONG

BERGTÄKT:	Forserum	FÖRSTARAD:	3,0	BORRKRONA:	89	SKJUTRIKTN.GRADER:	229	DATUM:	12/11-2013 v 46
BORRARE:	Benny Henriksson	FÖRSÄTTNING:	3,0	HÅLLUTNING:	14	STYRSTÅNG 51 MM:		ANTAL KRONOR:	4
BORRMETER:	1948,1	HÅLAVSTÅND:	4,0	RADER BRETT:	29	STYRRÖR 64 MM:		KASSERADE STÅL:	1
ANTAL HÅL:	116	BORRAR TILL +/- :	###	RADER BAKÅT:	4	STYRRÖR 72MM:			

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
14,0	14,3	14,4	13,8	13,8	13,2	13,1	13,5	14,0	13,8	13,8	13,9	13,8	13,7	13,2	13,9	14,0	14,4	14,7	14,2	14,5	23,2	23,3	24,2	23,8	24,1	23,9	23,9	24,2							
13,8	14,2	14,2	14,0	14,2	13,9	13,7	13,7	14,4	13,9	13,9	13,7	13,3	13,8	13,4	14,3	14,5	14,2	14,7	14,2	14,7	24,1	24,8	24,3	23,4	24,1	23,6	23,7	24,1							
14,3	14,1	13,9	14,1	14,5	14,1	14,3	14,5	14,3	14,0	13,4	13,8	14,2	13,5	14,0	14,2	14,3	14,1	14,5	14,2	14,6	24,6	24,7	24,4	23,5	23,7	23,5	24,2	24,3							
14,0	14,1	13,9	13,9	14,4	14,4	14,9	14,3	14,0	14,0	14,4	13,8	13,9	13,5	13,7	13,8	14,7	14,4	14,7	14,0	14,3	24,3	24,1	24,0	23,9	23,8	23,3	24,0	24,4							
																				(5)\															

APPENDIX D – Samples before and after LA-test

Pictures to the left: Samples before LA-test
Pictures to the right: Samples after LA-test

Angered

Figure D.1 145282 Rock core gneiss 1 Angered

Figure D.2 145308 Crushed rock base course gneiss 1 Angered

Figure D.3 145283 Rock core gneiss 2 Angered

Figure D.4 145309 Crushed rock base course gneiss 2 Angered

Ale

Figure D.5 145261 Rock core black gneiss Ale

Figure D.6 145298 Crushed rock base course black gneiss Ale

Figure D.7 145395 Crushed rock cobbles black gneiss Ale

*Figure D.8		145262 Rock core red gneiss Ale*

*Figure D.9		145299 Crushed rock base course red gneiss Ale*

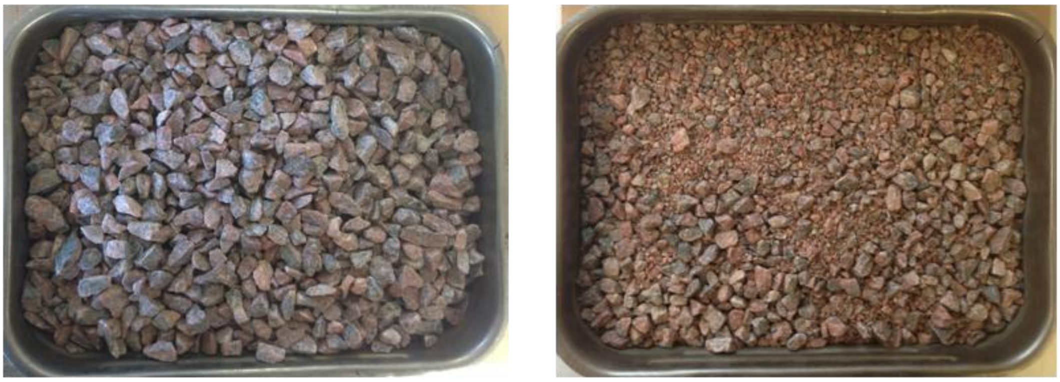


*Figure D.10		145396 Crushed rock cobbles red gneiss Ale*

Tanum

*Figure D.11		145263 Rock core gneiss Tanum*

Figure D.12 145279 Crushed rock cobbles gneiss Tanum

Figure D.13 145266 Rock core Bohus granite Tanum

Figure D.14 145280 Crushed rock cobbles Bohus Granite Tanum

Figure D.15 145285 Rock core mixed Tanum

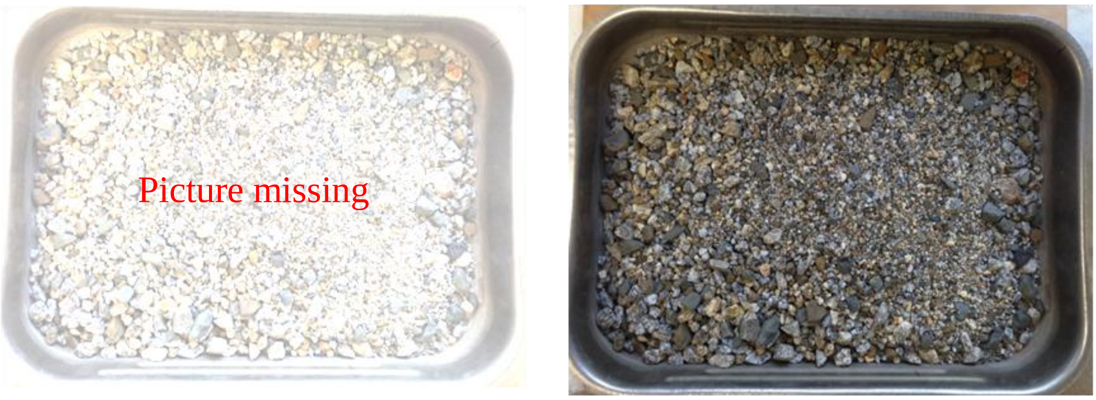


Figure D.16 *145254 Crushed rock mixed base course Tanum*

Forserum

Figure D.17 *145287 Rock core dolerite 1 Forserum*

Figure D.18 *145264 Crushed rock base course dolerite 1 Forserum*

Figure D.19 145288 Rock core dolerite 2 Forserum

Figure D.20 145265 Crushed rock base course dolerite 2 Forserum

APPENDIX E – Laboratory reports

Ale

SKANSKA

Analys Stenmaterial Provnummer **11S140314** **Sidan 1 av 1**

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-02-20**	
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-13**	**145261**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA / SÖ**	**Ale Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Rock core - black gneiss	Entreprenör	
Leverantör		
Skanska Asfalt och Betong AB, Täkt Alekrossen	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-1:2011, Bestämning av nötningsmotstånd (Vikt-%)	8	10 - 14 mm
Analysprov A(%):	7,9	
Analysprov B (%)	7,9	
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	15	10 - 14 mm

Notering

Andel av provet som passerar 8mm 25,2%
Andel av provet som passerar 6,3mm 8,0%
Andel av det som pass. 8mm som pass. 6,3mm 32,0%

Ort och datum
Gunnilse, 2014-03-27

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavsteglista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484257	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

SKANSKA

Analys Stenmaterial	Provnummer **11S140316**	**Sidan 1 av 1**

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-03-25**	
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-25**	**145298**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA / SÖ**	**Ale Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Crushed rock - black gneiss	Entreprenör	
Leverantör		
Skanska Asfalt och Betong AB, Täkt Alekrossen	Märkning	

Provresultat	**Värde**	**Fraktion**
SS-EN 1097-1:2011, Bestämning av nötningsmotstånd (Vikt-%)	12	10 - 14 mm
Analysprov A(%):	11,5	
Analysprov B (%)	12,1	
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	23	10 - 14 mm

Notering

Analys av provet som passerar 8mm 47,6%
Analys av provet som passerar 6,3mm 23,3%
Analys av det som pass. 8mm som pass. 6,3mm 49,0%

Ort och datum

Gunnilse, 2014-03-28

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

SKANSKA

Analys Stenmaterial

Provnummer **11S140430** **Sidan 1 av 1**

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-04-22**	**2014-04-24**
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-04-22**	**145395**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA/SÖ**	**Ale Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Crushed rock - black gneiss, cobble	Entreprenör	
Leverantör		
Skanska Asfalt och Betong AB, Täkt Alekrossen	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	16	10 - 14 mm

Notering

Analys av provet som passerar 8mm 35,5%
Analys av provet som passerar 6,3mm 9,8%
Analys av det som pass.8mm som pass.6,3mm 27,7%

Ort och datum

Gunnilse, 2014-04-24

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

SKANSKA

Analys Stenmaterial

Provnummer **11S140315** Sidan 1 av 1

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-02-20**	
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-13**	**145262**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA / SÖ**	**Ale Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Rock core - red gneiss	Entreprenör	
Leverantör		
Skanska Asfalt och Betong AB, Täkt Alekrossen	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	20	10 - 14 mm

Notering

Andel av provet som passerar 8mm 31,2%
Andel av provet som passerar 6,3mm 10,5%
Andel av det som pass. 8mm som pass. 6,3mm 33,7%

Ort och datum

Gunnilse, 2014-03-27

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

SKANSKA

Analys Stenmaterial

Provnummer **11S140318** **Sidan 1 av 1**

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-03-25**	
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-25**	**145299**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA / SÖ**	**Ale Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Crushed rock - red gneiss	Entreprenör	
Leverantör		
Skanska Asfalt och Betong AB, Täkt Alekrossen	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	29	10 - 14 mm

Notering

Analys av provet som passerar 8mm 54,6%
Analys av provet som passerar 6,3mm 22,6%
Analys av det som pass. 8mm som pass. 6,3mm 41,4%

Ort och datum

Gunnilse, 2014-03-28

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484257	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

SKANSKA

Analys Stenmaterial	Provnummer **11S140429**	**Sidan 1 av 1**

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-04-22**	**2014-04-24**
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-04-22**	**145396**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA/SÖ**	**Ale Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Crushed rock - red gneiss, cobble	Entreprenör	
Leverantör		
Skanska Asfalt och Betong AB, Täkt Alekrossen	Märkning	

Provresultat	**Värde**	**Fraktion**
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	24	10 - 14 mm

Notering

Analys av provet som passerar 8mm 31,6%
Analys av provet som passerar 6,3mm 9,7%
Analys av det som pass.8mm som pss6,3mm 30,6%

Ort och datum

Gunnilse, 2014-04-24

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943835	SE 663000022901	www.skanska.se

Angered

SKANSKA

Analys Stenmaterial	Provnummer 11S140312	Sidan 1 av 1

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-03-11**	
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-18**	**145282**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA / SÖ**	**Angered Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Rock core - gneiss 1	Entreprenör	
Leverantör		
Skanska Asfalt och Betong AB, Täkt Angeredskrossen	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-1:2011, Bestämning av nötningsmotstånd (Vikt-%)	15	10 - 14 mm
Analysprov A(%):	15,6	
Analysprov B (%)	15,3	
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	22	10 - 14 mm

Notering

Andel av provet som passerar 8mm 38,0%

Andel av provet som passerar 6,3mm 10,0%

Andel av det som pass. 8mm som pass. 6,3mm 26,4%

Ort och datum

Gunnilse, 2014-03-27

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

SKANSKA

Analys Stenmaterial		Provnummer **11S140321**	**Sidan 1 av 1**

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-03-26**	
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-26**	**145308**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA / SÖ**	**Angered Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Crushed rock - gneiss 1	Entreprenör	
Leverantör		
Skanska Asfalt och Betong AB, Täkt Angeredskrossen	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-1:2011, Bestämning av nötningsmotstånd (Vikt-%)	17	10 - 14 mm
Analysprov A(%):	17,2	
Analysprov B (%)	16,6	
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	29	10 - 14 mm

Notering

Analys av provet som passerar 8mm 21,3%
Analys av provet som passerar 6,3mm 4,8%
Analys av det som pass. 8mm som pass. 6,3mm 22,5%

Ort och datum

Gunnilse, 2014-03-28

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484257	556033-9086	madelaine.matsson@skanska.se
PI 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

SKANSKA

Analys Stenmaterial	Provnummer **11S140313**	**Sidan 1 av 1**

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-03-11**	
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-18**	**145283**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA / SÖ**	**Angered Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Rock core - gneiss 2	Entreprenör	
Leverantör		
Skanska Asfalt och Betong AB, Täkt Angeredskrossen	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	22	10 - 14 mm

Notering

Andel av provet som passerar 8mm 37,3%
Andel av provet som passerar 6,3mm 11,8%
Andel av det som pass. 8mm som pass. 6,3mm 31,6%%

Ort och datum

Gunnilse, 2014-03-27

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

SKANSKA

Analys Stenmaterial

Provnummer **11S140322** **Sidan 1 av 1**

Beställare **Chalmers tekniska högskola**	Provtagningsdatum **2014-03-26**	Analys datum
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-26**	**145309**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA / SÖ**	**Angered Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Crushed rock - gneiss 2	Entreprenör	
Leverantör **Skanska Asfalt och Betong AB, Täkt Angeredskrossen**	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	28	10 - 14 mm

Notering

Analys av provet som passerar 8mm 21,3%
Analys av provet som passerar 6,3mm 4,8%
Analys av det som pass. 8mm som pass. 6,3mm 22,5%

Ort och datum
Gunnilse, 2014-03-28

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

Tanum

SKANSKA

Analys Stenmaterial	Provnummer 11S140307	Sidan 1 av 1
Beställare **Chalmers tekniska högskola** **Maskingränd 2** **412 58 Göteborg** Kontaktperson **Sofia Öjerborn** Produkt **Rock core - gneiss** Leverantör **Skanska Sverige AB**	Provtagningsdatum **2014-02-27** Ankomstdatum **2014-03-13** Provtagare **Geo-gruppen** Objekt **SBUF 12940** Entreprenör Märkning	Analys datum ID-nummer **145263** Provtagningsplats **Tanum E6**

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	39	10 - 14 mm

Notering
Andel av provet som passerar 8mm 24,9%
Andel av provet som passerar 6,3mm 4,9%
Andel av det som pass. 8mm som pass. 6,3mm 19,6%

Ort och datum
Gunnilse, 2014-03-26

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484257	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

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Analys Stenmaterial		Provnummer **11S140304**	Sidan 1 av 1

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-03-05**	
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-17**	**145279**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA / SÖ**	**Tanum E6**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Crushed rock - gneiss	Entreprenör	
Leverantör		
Skanska Sverige AB	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	41	10 - 14 mm

Notering

Andel av provet som passerar 8mm 33,6%
Andel av provet som passerar 6,3mm 10,7%
Andel av det som pass. 8mm som pass. 6,3mm 31,9%

Ort och datum

Gunnilse, 2014-03-26

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

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Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
PI 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

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Analys Stenmaterial	Provnummer **11S140305**	**Sidan 1 av 1**

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-02-27**	
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-13**	**145266**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**Geo-gruppen**	**Tanum E6**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Rock core - Bohus granite	Entreprenör	
Leverantör		
Skanska Sverige AB	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	42	10 - 14 mm

Notering

Andel av provet som passerar 8mm 14,1%
Andel av provet som passerar 6,3mm 2,6%
Andel av det som pass. 8mm som pass. 6,3mm 18,5%

Ort och datum

Gunnilse, 2014-03-26

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Skanska Sverige AB
Teknik - VTC
Pl 6185
424 57 Gunnilse

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SE 663000022901

E-post
madelaine.matsson@skanska.se
Internet adress
www.skanska.se

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Analys Stenmaterial		Provnummer **11S140303**	Sidan 1 av 1

Beställare **Chalmers tekniska högskola**	Provtagningsdatum **2014-03-05**	Analys datum
Maskingränd 2 **412 58 Göteborg**	Ankomstdatum **2014-03-17**	ID-nummer **145280**
Kontaktperson **Sofia Öjerborn**	Provtagare **EA / SÖ**	Provtagningsplats **Tanum E6**
Produkt **Crushed rock - Bohus granite**	Objekt **SBUF 12940**	
Leverantör **Skanska Sverige AB**	Entreprenör	
	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	52	10 - 14 mm

Notering

Andel av provet som passerar 8mm 24,4%
Andel av provet som passerar 6,3mm 6,9%
Andel av det som pass. 8mm som pass. 6,3mm 28,1%

Ort och datum

Gunnilse, 2014-03-26

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

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Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484257	556033-9086	madelaine.matsson@skanska.se
PI 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

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Analys Stenmaterial

Provnummer **11S140306** **Sidan 1 av 1**

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola	**2014-02-27**	
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-19**	**145285**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**Geo-gruppen**	**Tanum E6**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Rock core - Mixed	Entreprenör	
Leverantör		
Skanska Sverige AB	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	39	10 - 14 mm

Notering

Andel av provet som passerar 8mm 23,5%
Andel av provet som passerar 6,3mm 6,2%
Andel av det som pass. 8mm som pass. 6,3mm 26,4%

Ort och datum

Gunnilse, 2014-03-26

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

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Analys Stenmaterial	Provnummer **11S140308**	**Sidan 1 av 1**

Beställare **Chalmers tekniska högskola** **Maskingränd 2** **412 58 Göteborg**	Provtagningsdatum **2014-03-05** Ankomstdatum **2014-03-10**	Analys datum ID-nummer **145254**
Kontaktperson **Sofia Öjerborn**	Provtagare **EA / SÖ**	Provtagningsplats **Tanum E6**
Produkt **Crushed rock - Mixed**	Objekt **SBUF 12940**	
Leverantör **Skanska Sverige AB**	Entreprenör Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	48	10 - 14 mm

Notering

Andel av provet som passerar 8mm 34,9%
Andel av provet som passerar 6,3mm 12,6%
Andel av det som pass. 8mm som pass. 6,3mm 36,0%

Ort och datum
Gunnilse, 2014-03-26

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
PI 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

Forserum

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Analys Stenmaterial Provnummer **11S140310** **Sidan 1 av 1**

Beställare **Chalmers tekniska högskola**	Provtagningsdatum **2014-03-19**	Analys datum
Maskingränd 2 **412 58 Göteborg**	Ankomstdatum **2014-03-20**	ID-nummer **145287**
Kontaktperson **Sofia Öjerborn**	Provtagare **Geo-gruppen**	Provtagningsplats **Forserum Quarry**
Produkt **Rock core - dolorite 2**	Objekt **SBUF 12940**	
Leverantör **Skanska Asfalt och Betong AB** **Krossen Forserum**	Entreprenör Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	12	10 - 14 mm

Notering

Andel av provet som passerar 8mm 28,9%
Andel av provet som passerar 6,3mm 6,3%
Andel av det som pass. 8mm som pass. 6,3mm 22,0%

Ort och datum
Gunnilse, 2014-03-26

Madelaine Matsson, lab.föreståndare

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Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

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Analys Stenmaterial

Provnummer **11S140309** **Sidan 1 av 1**

Beställare **Chalmers tekniska högskola**	Provtagningsdatum	Analys datum
Maskingränd 2 **412 58 Göteborg**	Ankomstdatum **2014-03-13**	ID-nummer **145264**
Kontaktperson **Sofia Öjerborn**	Provtagare **EA / SÖ**	Provtagningsplats **Forserum Quarry**
Produkt **Crushed rock - dolorite 1**	Objekt **SBUF 12940**	
Leverantör **Skanska Asfalt och Betong AB** **Krossen Forserum**	Entreprenör Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-1:2011, Bestämning av nötningsmotstånd (Vikt-%)	7	10 - 14 mm
Analysprov A(%):	7,2	
Analysprov B (%)	7,6	
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	14	10 - 14 mm

Notering

Andel av provet som passerar 8mm 38,0%
Andel av provet som passerar 6,3mm 13,7%
Andel av det som pass. 8mm som pass. 6,3mm 36,2%

Ort och datum
Gunnilse, 2014-03-26

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
Teknik - VTC	Rågårdsvägen, Laboratoriet	010-4484267	556033-9086	madelaine.matsson@skanska.se
Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

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Analys Stenmaterial	Provnummer **11S140311**	**Sidan 1 av 1**

Beställare **Chalmers tekniska högskola** **Maskingränd 2** **412 58 Göteborg**	Provtagningsdatum **2014-03-19** Ankomstdatum **2014-03-20**	Analys datum ID-nummer **145288**
Kontaktperson **Sofia Öjerborn**	Provtagare **Geo-gruppen** Objekt	Provtagningsplats **Forserum Quarry**
Produkt **Rock core - dolorite 1**	**SBUF 12940** Entreprenör	
Leverantör **Skanska Asfalt och Betong AB** **Krossen Forserum**	Märkning	

Provresultat	Värde	Fraktion
SS-EN 1097-1:2011, Bestämning av nötningsmotstånd (Vikt-%)	6	10 - 14 mm
Analysprov A(%):	6,5	
Analysprov B (%)	6,4	
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	11	10 - 14 mm

Notering

Andel av provet som passerar 8mm 26,5%
Andel av provet som passerar 6,3mm 7,8%
Andel av det som pass. 8mm som pass. 6,3mm 29,3%

Ort och datum

Gunnilse, 2014-03-26

Madelaine Matsson

Madelaine Matsson, lab.föreståndare

Skanska Sverige AB	Besöksadress	Telefon nr	Org.nr	E-post
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PI 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
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Analys Stenmaterial

Provnummer **11S140300** **Sidan 1 av 1**

Beställare	Provtagningsdatum	Analys datum
Chalmers tekniska högskola		
	Ankomstdatum	ID-nummer
Maskingränd 2	**2014-03-13**	**145265**
412 58 Göteborg	Provtagare	Provtagningsplats
Kontaktperson	**EA/SÖ**	**Forserum Quarry**
Sofia Öjerborn	Objekt	
Produkt	**SBUF 12940**	
Crushed rock - dolorite 2	Entreprenör	
Leverantör		
Skanska Asfalt och Betong AB	Märkning	
Krossen Forserum		

Provresultat	**Värde**	**Fraktion**
SS-EN 1097-2:2010, Motstånd mot fragmentering (Vikt-%)	13	10 - 14 mm

Notering

Andel av provet som passerar 8mm 33,6%
Andel av provet som passerar 6,3mm 11,3%
Andel av det som pass. 8mm som pass. 6,3mm 33,6%

Ort och datum

Gunnilse, 2014-03-26

Madelaine Matsson, lab.föreståndare

Denna rapport måste återges i sin helhet. Provresultatet avser levererat prov. Mätosäkerhetslista, metodavstegslista och metodlista har överlämnats vid kontraktsgenomgång.

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Pl 6185	Styrelsens säte	Telefax nr	VAT nr	Internet adress
424 57 Gunnilse	Solna	031-943335	SE 663000022901	www.skanska.se

APPENDIX F – Tables and diagrams result

Table F.1 LA- and MD-test results for all locations.

LOCATION					
ALE	**LA Rock Core**	**LA Cobble**	**LA Base Course**	**MD Rock Core**	**MD Base Course**
Black Gneiss	15	16	23	7,9	11,8
Red Gneiss	20	24	29	-	-
ANGERED	**LA Rock Core**	**LA Cobble**	**LA Base Course**	**MD Rock Core**	**MD Base Course**
Gneiss 1	22	-	29	15,45	16,9
Gneiss 2	22	-	28	-	-
TANUM	**LA Rock Core**	**LA Cobble**	**LA Base Course**	**MD Rock Core**	**MD Base Course**
Gneiss	39	41	-	-	-
Bohus granite	42	52	-	-	-
Tanum Mixed	39	-	48	-	-
FORSERUM	**LA Rock Core**	**LA Cobble**	**LA Base Course**	**MD Rock Core**	**MD Base Course**
Dolerite 1	11	-	14	6,45	7,4
Dolerite 2	12	-	13	-	-

Table F.2 Result of flakiness index for 8 mm and 6,3 mm grid sieve.

LOCATION	Passing 8mm grid sieve [%]			Passing 6,3mm grid sieve [%]		
ALE	**Rock C**	**Cobble**	**Base C**	**Rock C**	**Cobble**	**Base C**
Black Gneiss	25 %	32 %	48 %	8 %	10 %	23 %
Red Gneiss	31 %	36 %	55 %	11 %	10 %	23 %
ANGERED	**Rock C**	**Cobble**	**Base C**	**Rock C**	**Cobble**	**Base C**
Gneiss 1	38 %	-	21 %	10 %	-	5 %
Gneiss 2	37 %	-	21 %	12 %	-	5 %
TANUM	**Rock C**	**Cobble**	**Base C**	**Rock C**	**Cobble**	**Base C**
Gneiss	25 %	34 %	-	5 %	11 %	-
Bohus granite	14 %	24 %	-	3 %	7 %	-
Tanum Mixed	24 %	-	35 %	6 %	-	13 %
FORSERUM	**Rock C**	**Cobble**	**Base C**	**Rock C**	**Cobble**	**Base C**
Dolerite 1	27 %	-	38 %	8 %	-	14 %
Dolerite 2	29 %	-	34 %	6 %	-	12 %

Table F.3 *Result of flakiness index for part of material passing 8 mm that also passes 6,3 mm grid sieve.*

LOCATION	**Part of material passing 8 mm grid that also pass 6,3 mm grid [%]**		
ALE	**Rock Core**	**Cobble**	**Base Course**
Black Gneiss	32 %	28 %	49 %
Red Gneiss	34 %	31 %	41 %
ANGERED	**Rock Core**	**Cobble**	**Base Course**
Gneiss 1	26 %	-	23 %
Gneiss 2	32 %	-	23 %
TANUM	**Rock Core**	**Cobble**	**Base Course**
Gneiss	20 %	32 %	-
Bohus granite	19 %	28 %	-
Tanum Mixed	26 %	-	36 %
FORSERUM	**Rock Core**	**Cobble**	**Base Course**
Dolerite 1	29 %	-	36 %
Dolerite 2	22 %	-	34 %

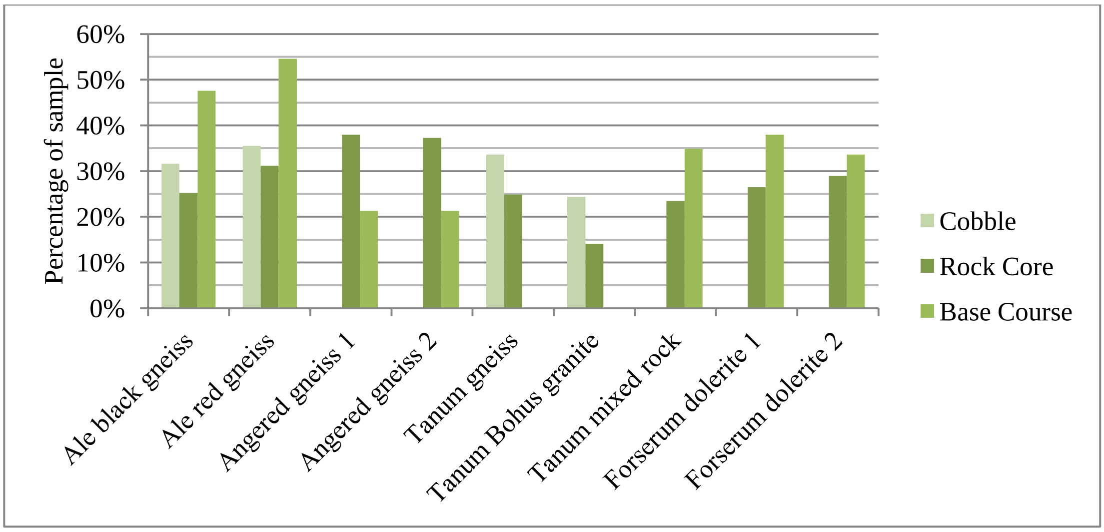

Figure F.1 *Comparison of flakiness index for 8 mm grid sieve between locations.*

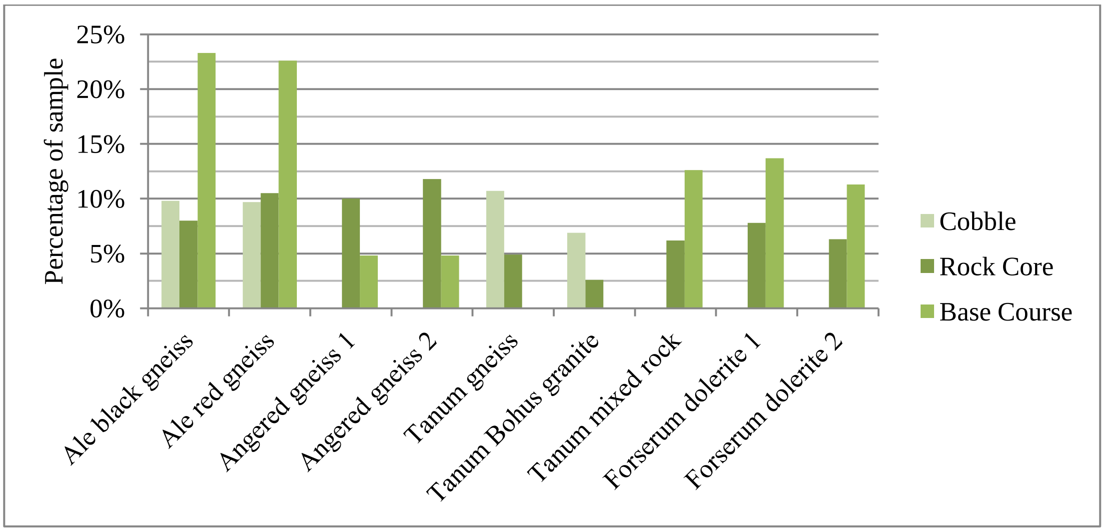

Figure F.2 *Comparison of flakiness index for 6,3 mm grid sieve between locations.*

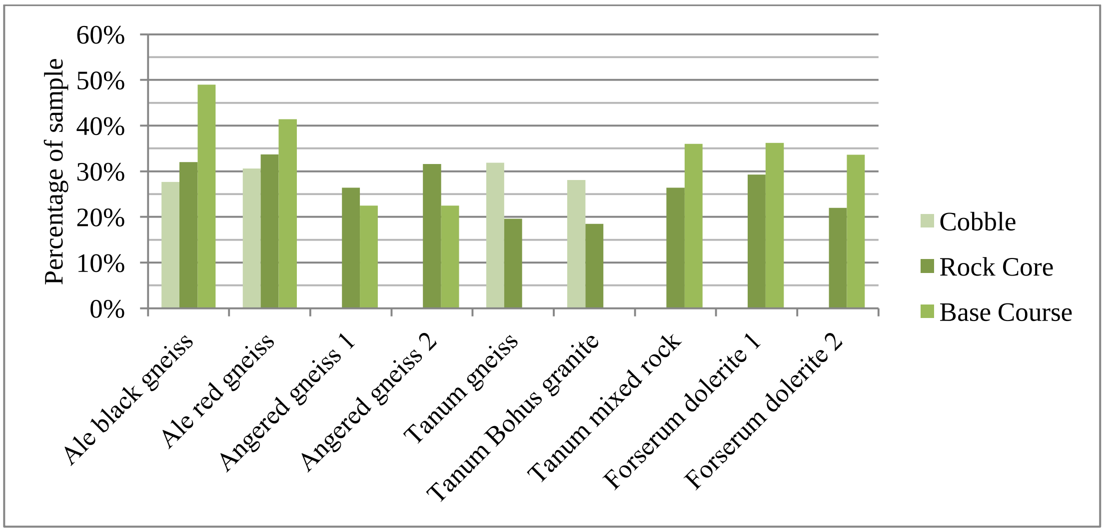

Figure F.3 *Comparison of flakiness index for part of 8 mm passing through 6,3 mm grid sieve between locations.*

APPENDIX G – Diagram for sampling method

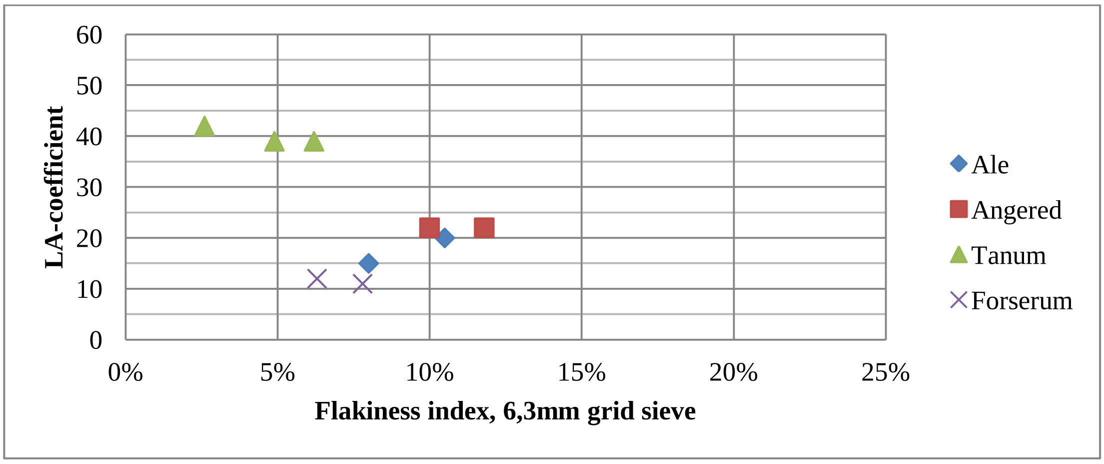

Figure G.1 *Relation between LA-coefficient and flakiness index (6,3 mm grid sieve) for rock cores at all locations.*

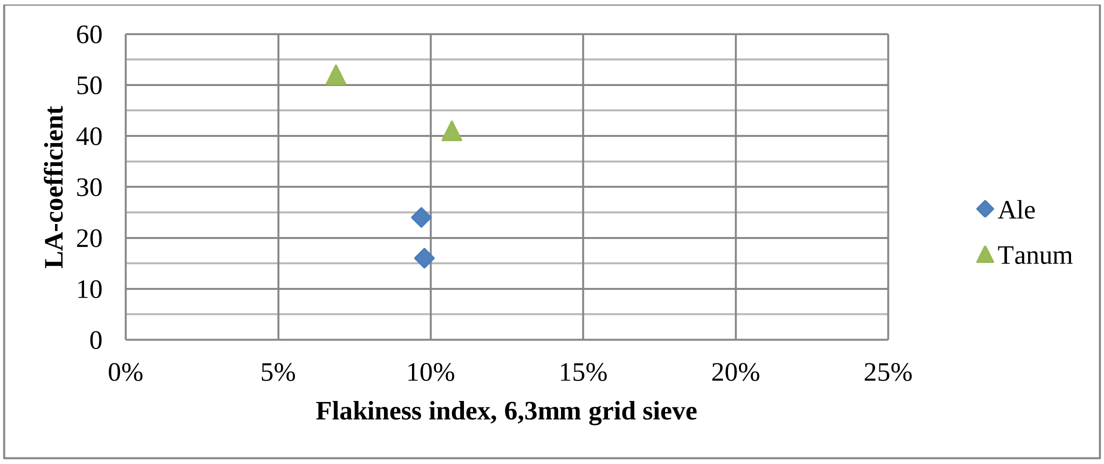

Figure G.2 *Relation between LA-coefficient and flakiness index (6,3 mm grid sieve) for cobbles at all locations.*

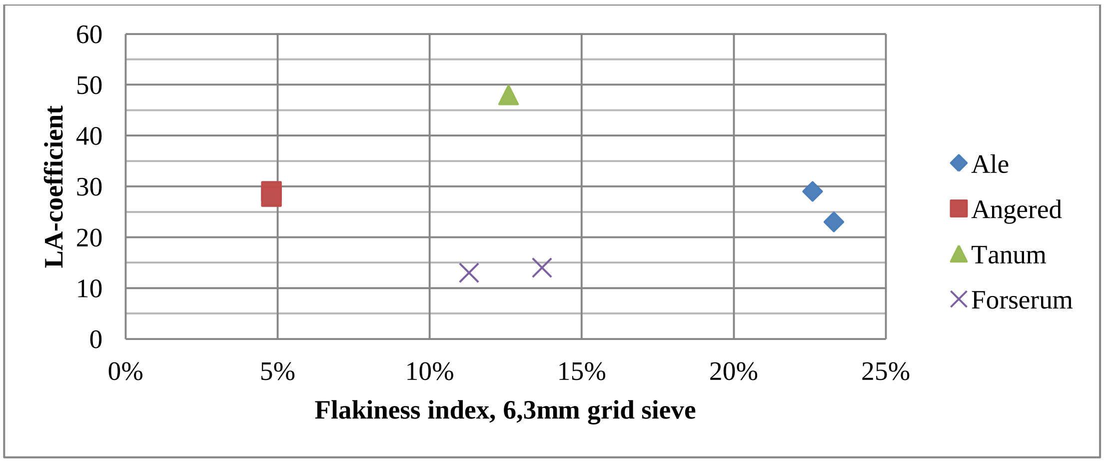

Figure G.3 *Relation between LA-coefficient and flakiness index (6,3 mm grid sieve) for base course at all locations.*

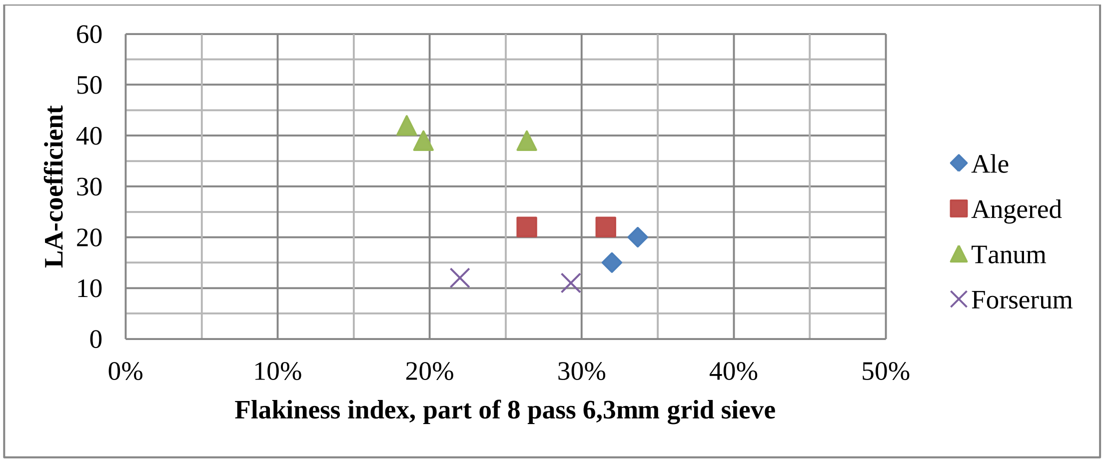

Figure G.4 *Relation between LA-coefficient and flakiness index (part of 8 mm passing through 6,3 mm grid sieve) for rock cores at all locations.*

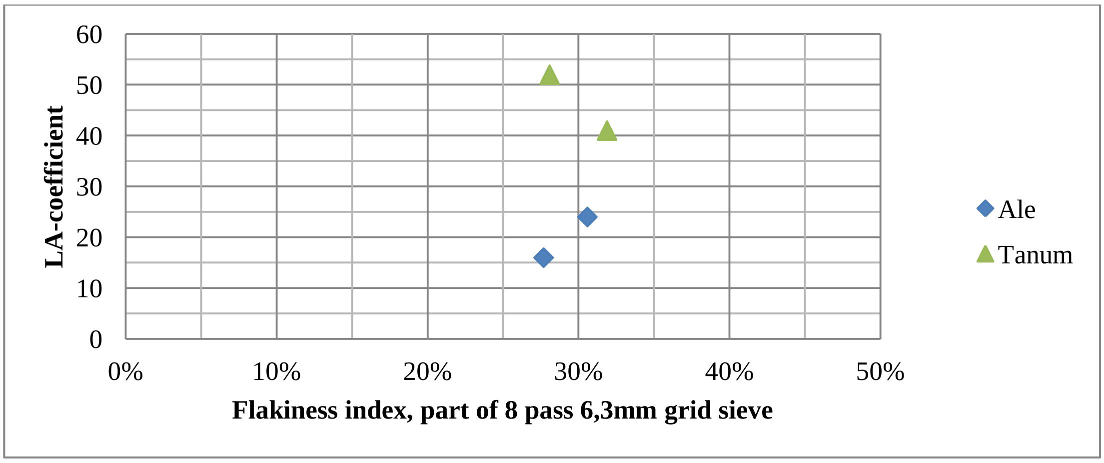

Figure G.5 *Relation between LA-coefficient and flakiness index (part of 8 mm passing through 6,3 mm grid sieve) for cobbles at all locations.*

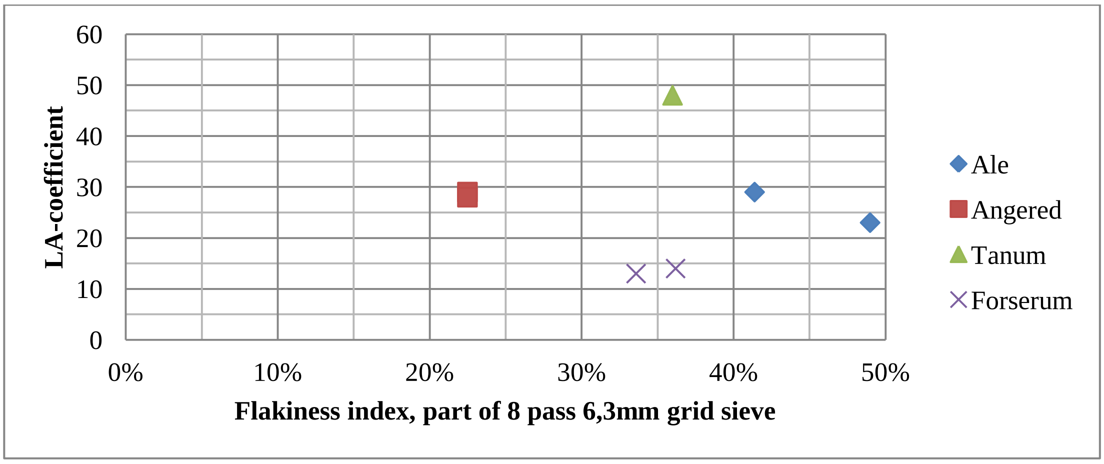

Figure G.6 *Relation between LA-coefficient and flakiness index (part of 8 mm passing through 6,3 mm grid sieve) for base course at all locations.*

APPENDIX H – Diagram for location

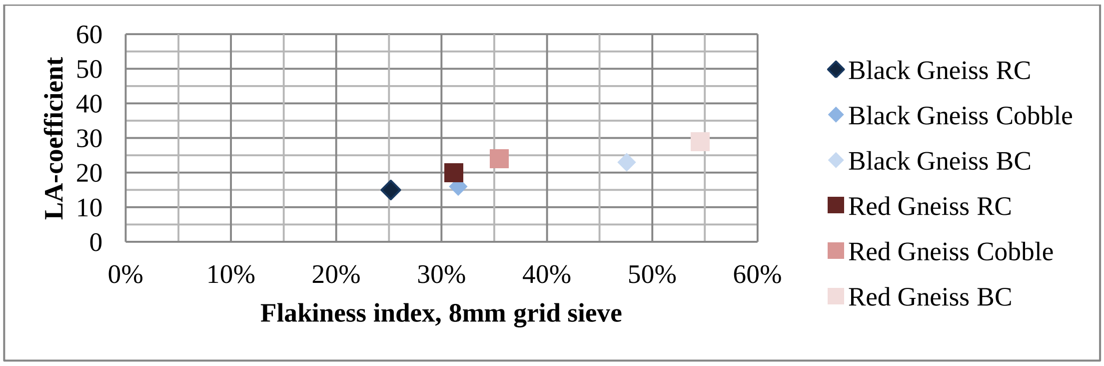

Figure H.1 Relation between LA-coefficient and flakiness index (8 mm grid sieve) for Ale.

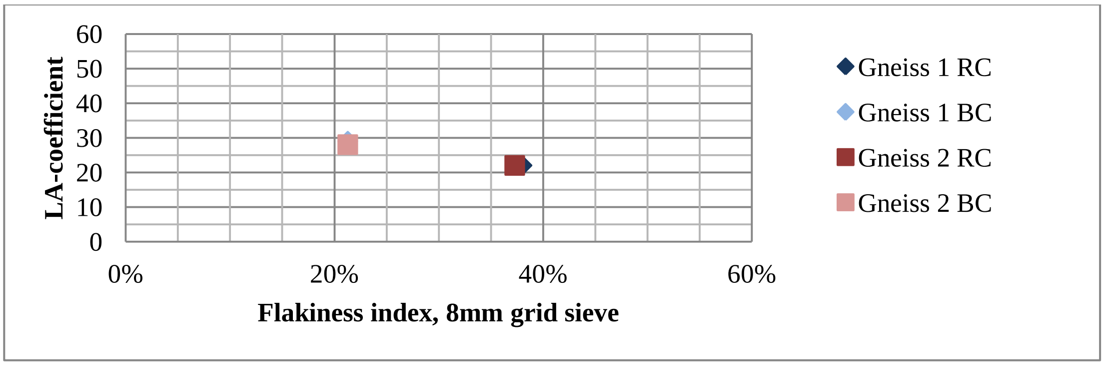

Figure H.2 Relation between LA-coefficient and flakiness index (8 mm grid sieve) for Angered.

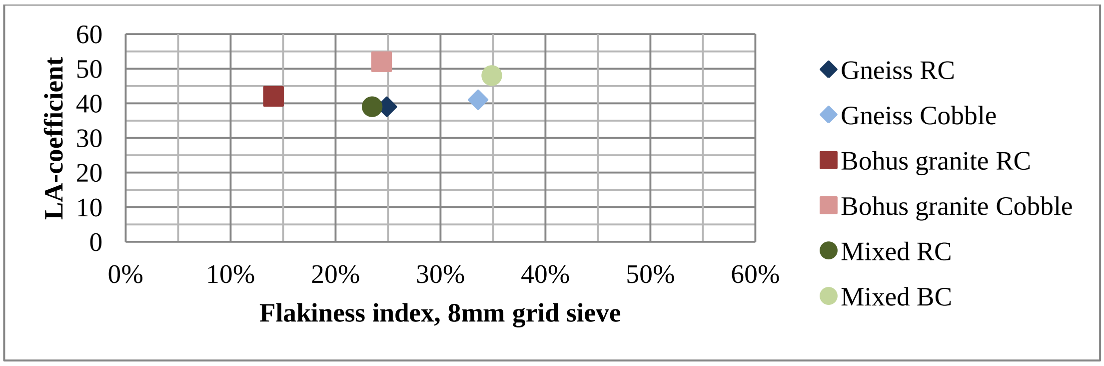

Figure H.3 Relation between LA-coefficient and flakiness index (8 mm grid sieve) for Tanum.

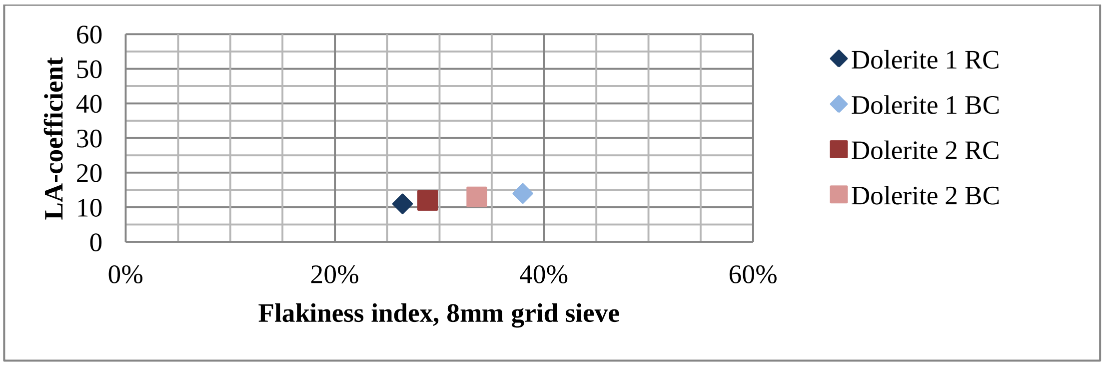

Figure H.4 Relation between LA-coefficient and flakiness index (8 mm grid sieve) for Forserum.

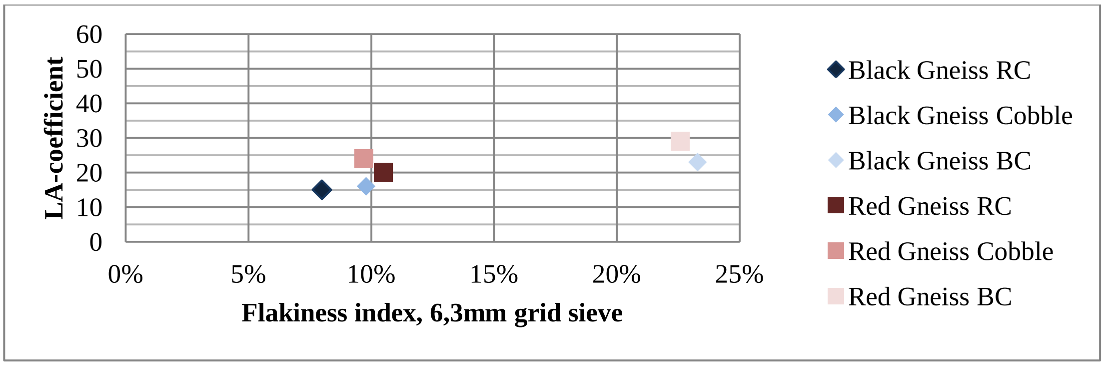

Figure H.5 Relation between LA-coefficient and flakiness index (6,3 mm grid sieve) for Ale.

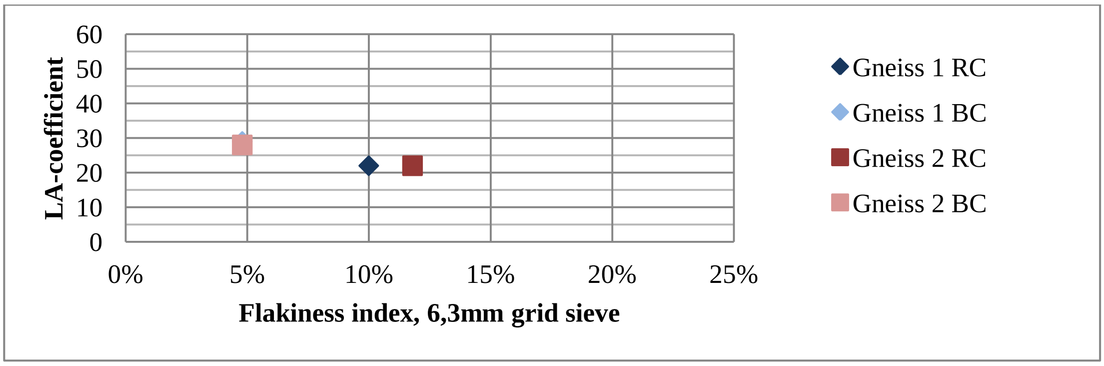

Figure H.6 Relation between LA-coefficient and flakiness index (6,3 mm grid sieve) for Angered.

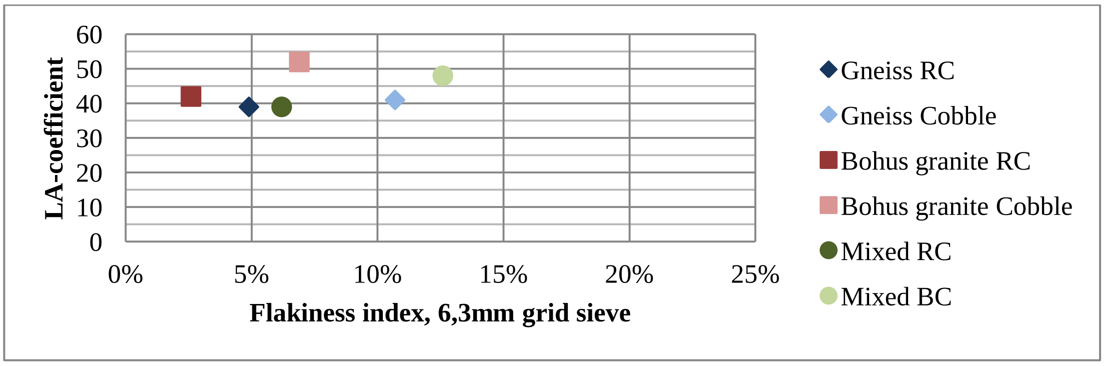

Figure H.7 Relation between LA-coefficient and flakiness index (6,3 mm grid sieve) for Tanum.

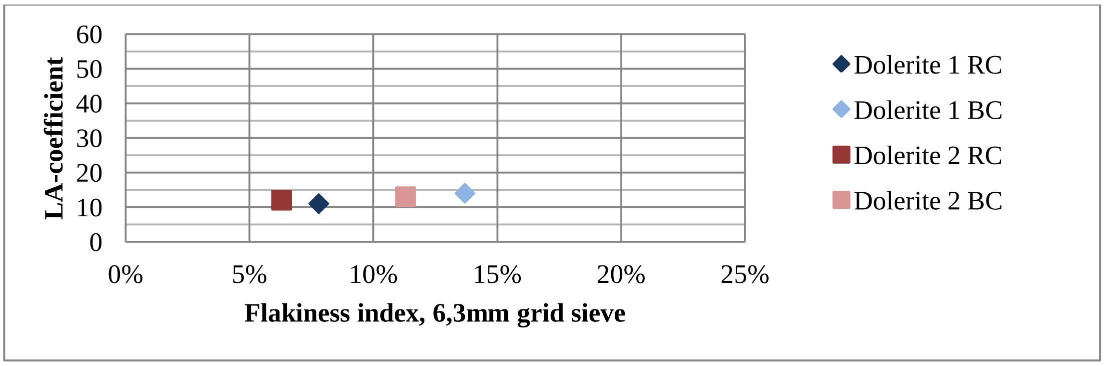

Figure H.8 Relation between LA-coefficient and flakiness index (6,3 mm grid sieve) for Forserum.

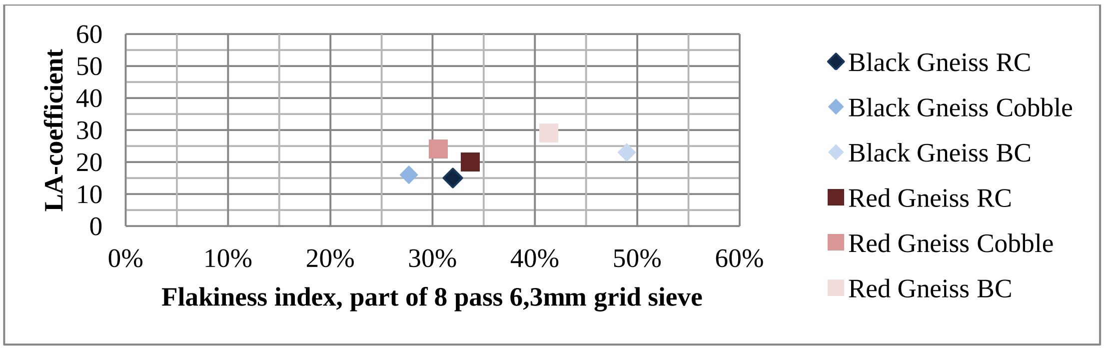

Figure H.9 Relation between LA-coefficient and flakiness index (part of 8 mm passing through 6,3 mm grid sieve) for Ale.

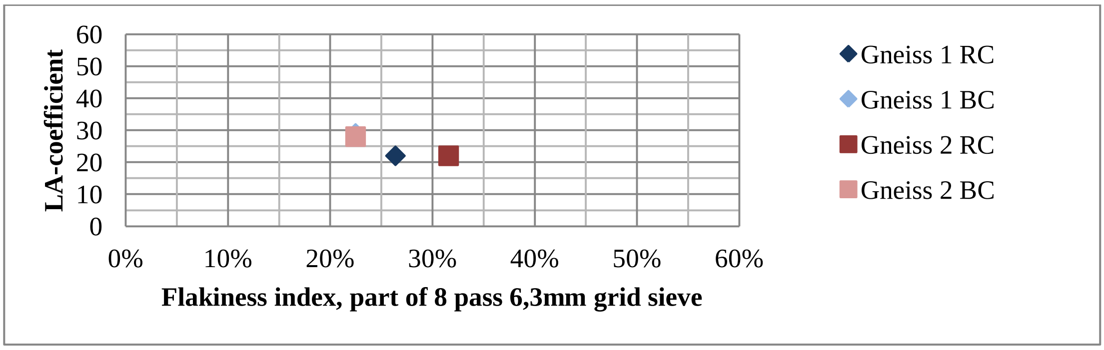

Figure H.10 Relation between LA-coefficient and flakiness index (part of 8 mm passing through 6,3 mm grid sieve) for Angered.

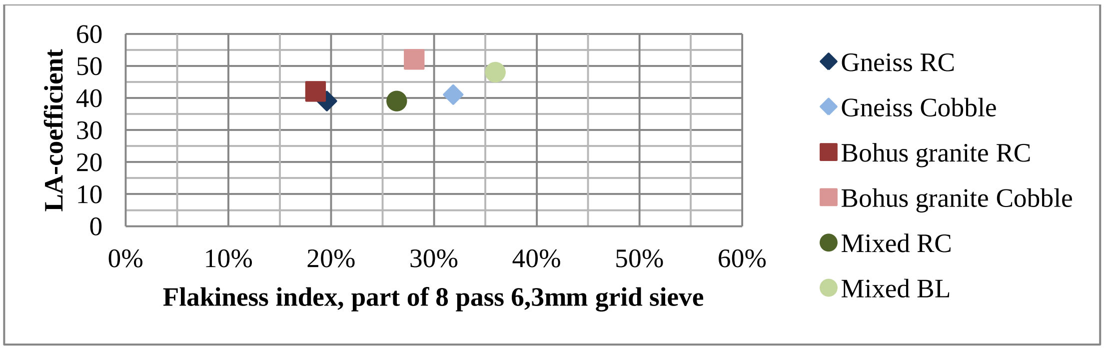

Figure H.11 Relation between LA-coefficient and flakiness index (part of 8 mm passing through 6,3 mm grid sieve) for Tanum.

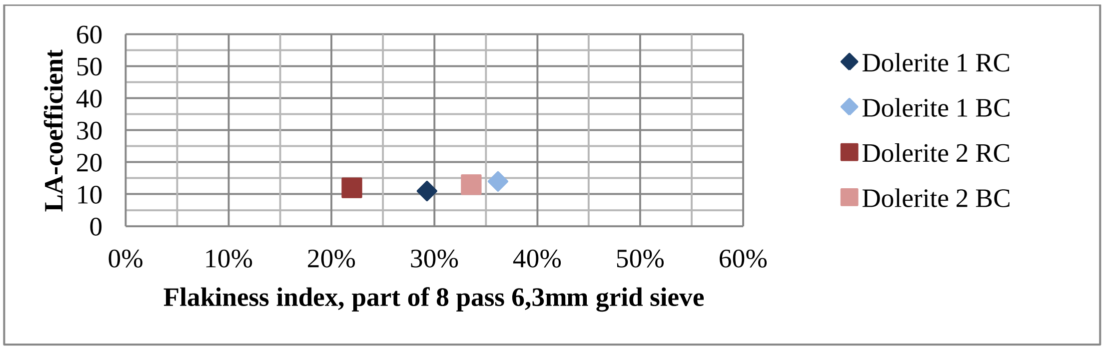

Figure H.12 Relation between LA-coefficient and flakiness index (part of 8 mm passing through 6,3 mm grid sieve) for Forserum.

APPENDIX I – Diagram and tables for percentage differences

Table I.1 Percentage increase of the LA-coefficient and flakiness index from rock core to base course.

	LA INCREASE [%]	FLAKE INCREASE 8 MM GRID [%]	FLAKE INCREASE 6,3 MM GRID [%]	FLAKE INCREASE PART 8 PASS 6,3 MM GRID [%]
Ale Black Gneiss	35 %	47 %	66 %	35 %
Ale Red Gneiss	31 %	43 %	54 %	19 %
Angered Gneiss 1	24 %	-78 %	-108 %	-17 %
Angered Gneiss 2	21 %	-75 %	-146 %	-40 %
Tanum Mixed Rock	19 %	33 %	51 %	27 %
Forserum Dolerite 1	21 %	30 %	43 %	19 %
Forserum Dolerite 2	8 %	14 %	44 %	35 %

Table I.2 Percentage increase of the LA-coefficient and flakiness index from rock core to cobbles.

	LA INCREASE [%]	FLAKE INCREASE 8 MM GRID [%]	FLAKE INCREASE 6,3 MM GRID [%]	FLAKE INCREASE PART 8 PASS 6,3 MM GRID [%]
Ale Black Gneiss	6 %	20 %	18 %	-16 %
Ale Red Gneiss	17 %	12 %	-8 %	-10 %
Tanum Gneiss	5 %	26 %	54 %	39 %
Tanum Bohus Granite	19 %	42 %	62 %	34 %

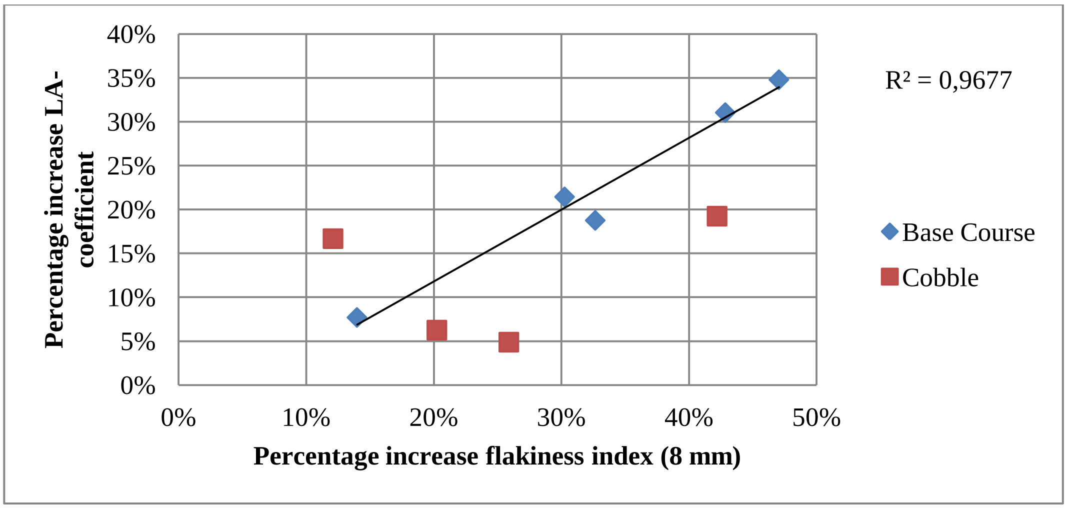

Figure I.1 *Relation between the percentage increase of the LA-coefficient and flakiness index (8 mm grid sieve) from rock core to base course and cobble, respectively.*

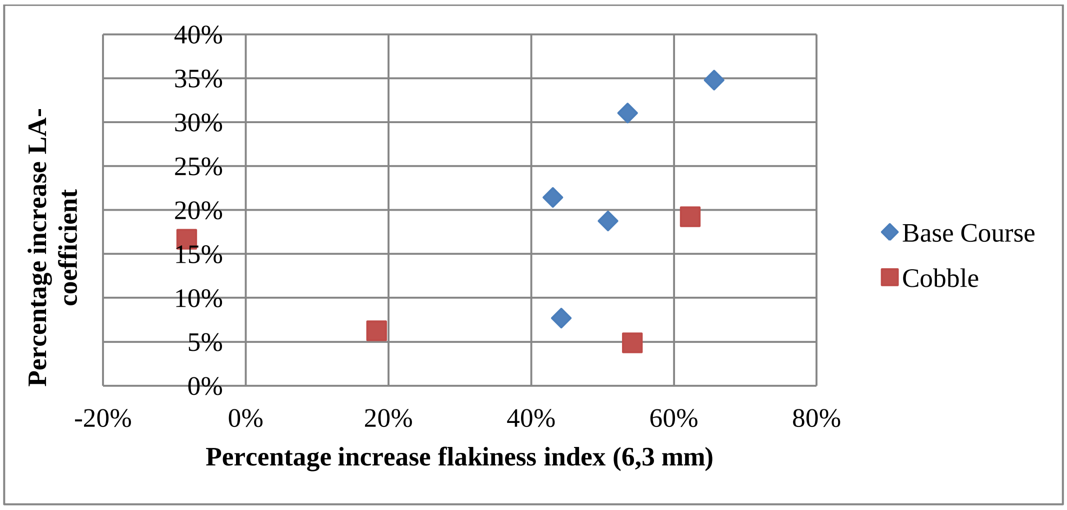

Figure I.2 *Relation between the percentage increase of the LA-coefficient and flakiness index (6,3 mm grid sieve) from rock core to base course and cobble, respectively.*

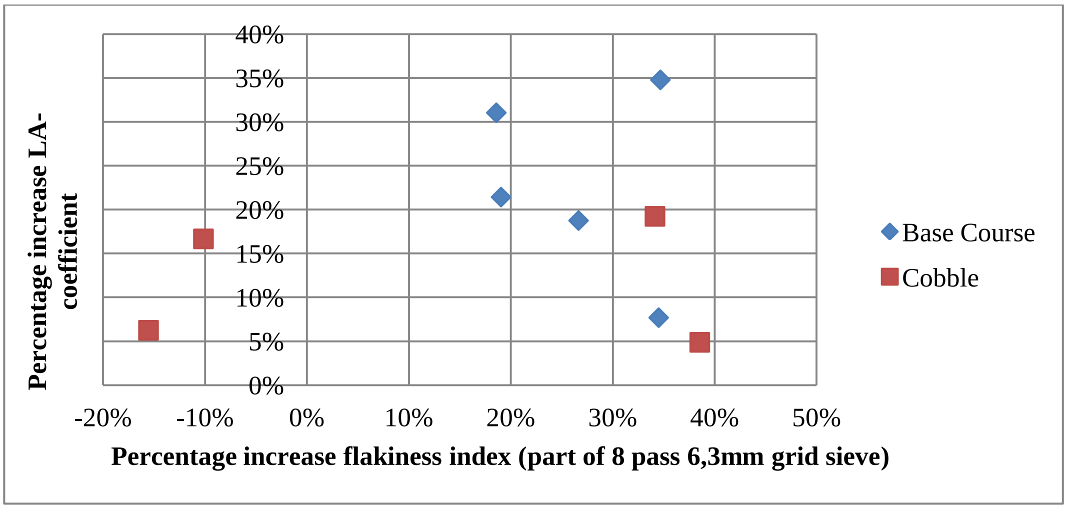

Figure I.3 *Relation between the percentage increase of the LA-coefficient and flakiness index (part of 8 mm passing through 6,3 mm grid sieve) from rock core to base course and cobble, respectively.*