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Geological and mechanical investigation of the Såt extraction prospect for hard rock aggregates in Espevik, Rogaland

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REPORT

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Title:
Geological and mechanical investigation of the Såt extraction prospect for hard rock aggregates in Espevik, Rogaland

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Summary:

A new potential extraction area for hard rock aggregates around Såt, near the existing quarry in Espevik has been mapped geologically. The main focus has been geological mapping and interpretation combined with sampling of the different rock types for mechanical testing and microscopical analyses.

The geology in the Såt prospect is complex. The dominating rock type is a porphyritic biotite gneiss-granite which occur in the north-eastern half of the prospect. The south-western half consists of fine-grained grey veined gneisses, which are intruded by tonalitic porphyritic to even-grained grey biotite gneiss-granitoids. The two rock types occur in roughly even proportions. The different types of biotite gneiss-granites and gneiss-granitoids are generally well-foliated to sheared-mylonitic, which give a textural variation in addition to a compositional variation.

The Los Angeles values for the porphyritic biotite gneiss-granite are in average similar to those for the Espevik gneiss-granite. The rock types within the south-western half of the prospect, mainly fine-grained grey gneisses and grey biotite gneiss-granitoids, shows much better results for the Los Angeles test. There are no significant differences in the polished stone value for the different rock types.

The mechanical properties for the rock types within the Såt prospect are evaluated as interesting for the export market in Europe. Because of the variation in rock types and mechanical strength, it is proposed to carry out a mining operation with selective extraction of rocks. In this way, materials from the different rock types with different mechanical properties could be mixed to achieve products that meet the various quality and requirement demands in the market.

Keywords: Geological mapping	Engineering geology	Hard Rock Aggregate
Mechanical properties	Mineralogy	Los Angeles Value
Polished Stone Value		

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ENCLOSURE

Geological map of the Såt area in scale 1: 5000.

APPENDIX

Appendix A : Description of laboratory methods
Appendix B : Sample description

CONCLUSION

The following conclusions can be made from the present investigation:

- The geology is much more complex in the new Såt prospect area than previous imagined.

- In addition to the known porphyritic biotite gneiss-granite from the north-eastern half of the prospect, the south-western half consists of veined fine-grained grey gneisses, which are intruded by porphyritic to even-grained grey tonalitic biotite gneiss-granitoids. The two rock types occur in roughly even proportions. The different types of biotite gneiss-granites and gneiss-granitoids are generally well-foliated to sheared-mylonitic, which give a textural variation in addition to a compositional variation.

- From the experience from areas with a complex geology like Såt, it is stresses how crucial it is to have good geological control before sampling for examination of mechanical properties is carried out. The first 7 samples taken in the Såt area in 2000 gives a completely misleading conclusion about the areas aggregate potential when compared with the results after the new sampling based on geological mapping.

- The dominant rock type in the area, the porphyritic biotite gneiss-granite shows an average LA-value of 24,1 $\pm$ 1,4, which is similar to the Espevik gneiss-granite. The other rock types, which are dominant in the south-western part of the investigated area, shows much better results for the Los Angeles test, in average 15,1 $\pm$ 2,8.

- There are no significant differences in the Polished Stone value for the different rock types which shows a variation between 50-56.

- The mechanical test results from the rocks in the Såt prospect are interesting for the European market and show values that should satisfy the requirements for aggregates for road construction purposes in several European countries.

- Because of the variation in rock types and mechanical strength throughout the Såt prospect, it is proposed to carry out a mining operation with selective extraction of rocks. In this way, materials from the different rock types with different mechanical properties could be mixed to achieve products that meet the various quality and requirement demands in the market.

1. INTRODUCTION

In co-operation with Amrock JV AS the Geological Survey of Norway (NGU) has mapped the geology of a new potential extraction area for hard rock aggregates around Såt, near the existing quarry in Espevik, Tysvær commune in Rogaland county. The main focus has been on geological mapping and interpretation combined with sampling of different rock types for mechanical testing and microscopical analyses. The aim of this report (part 1) is by combining geological information with testing results from mechanical properties to estimate the potential for extraction of future hard rock aggregates of the area.

During the implementation of the present work a drilling program has been set up in order to estimate the deep structure and volume of the different rock qualities in the Såt prospect. The results from this work will be presented in a following separate report (part 2).

Trondheim, 25. February 2002
Program for mineral resources

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2. FIELD INVESTIGATIONS

The geological mapping of the Såt prospect area (figure 1) was carried out September 9th-15th 2001 by Mogens Marker, NGU. During the mapping 23 hand specimens were collected from representative rocks for microscopy study of thin-sections at NGU. In addition, 5 locations were selected for blasting out large, fresh samples for subsequent mechanical investigation at NGU. The sampling in the field was supervised by Reidar Blesvik, Kon-Sul A/S. Two additional samples for mechanical testing were collected in January 2002, the results of which are included in this report (apart from the PSV test).

Figure 1. Location map for the investigated area at Såt (red) close to the existing extraction area in Espevik (grey).

3. ANALYSES

The Los Angeles test has been carried out at NGU, while the Polished Stone Value (PSV test) was carried out by Celtest Ltd. in Wales. The distribution of the minerals has been approximately estimated from thin-section analyses performed by August Nissen at NGU [1]. Appendix A describes these laboratory methods.

Material for mechanical testing consists of hand-size pieces amounting to a total of about 60 kg per sample. Prior to the mechanical testing, the samples were crushed using laboratory crushers under controlled conditions. The material was then sieved to the various grain fractions used for the different test methods. The demands placed on aggregates refer chiefly to material prepared in a full-scale crushing and screening plant. Investigations have, however, shown [2] that analytical results from samples taken from the production, "production samples", may deviate considerably from samples taken in the field, also called "geological specimen samples". The production samples will be influenced by how well the material has been prepared in the crushing and screening plant. Mechanical testing of geological specimen samples gives a more neutral evaluation of the "inherent properties" of the rock as compared with production samples. When preparation in an aggregate plant is optimal, it is assumed that the analytical results for production samples will be comparable with analytical results from geological specimen samples crushed under controlled laboratory conditions.

Various testing methods are used in Europe. The on-going CEN work (Comité Européen de Normalisation) has led to standardisation of the methods that are to be applied for all EU/EFTA countries. The Los Angeles and PSV tests are both approved as "CEN methods". Table 1 gives a simplified summary of the requirements for aggregates for road construction purposes in some European countries.

In general, the mechanical limit values for roads with a high traffic load should be fulfilled, whereas the limit values for roads with low traffic must be fulfilled, if a deposit will be of interest for extraction.

Table 1. Demands regarding the Los Angeles value (LA) and the Polished Stone Value (PSV) for some European countries.

Country	Area of use	Type of road	LA	PSV
England	Road surface	Motorways, special demands	< 16	> 65
	"	Roads with normal traffic	< 25	> 55
	"	Roads with low traffic	< 30	> 45
	Foundation and sub-foundation		< 35	-
Germany	Road surface	Motorways, special demands	< 15	> 55
	"	Roads with normal traffic	< 20	> 50
	"	Roads with low traffic	< 30	> 43
	Foundation and sub-foundation		< 40*	-
France	Road surface	Motorways, special demands	< 15	> 50
	"	Roads with normal traffic	< 20	> 50
	"	Roads with low traffic	< 25	> 40
	Foundation and sub-foundation		< 30	-
Netherlands	Road surface	Motorways, special demands	?	> 65
	"	Roads with normal traffic	?	> 53
	"	Roads with low traffic	?	> 48
	Foundation and sub-foundation		?	-
Belgium	Road surface	Motorways, special demands	?	?
	"	Roads with normal traffic	?	> 50
	"	Roads with low traffic	?	?
	Foundation and sub-foundation		?	-

* Demand depends on rock type

4. RESULTS

4.1 Geology

4.1.1 Introduction to the geological map

The geological mapping was based on the Økonomisk Kartverk map sheet SÅT (AK 032-5-4) in scale 1 : 5 000 (5 m contour distance). To aid location in forested parts and slopes without marked topographical features, GPS positioning assisted by an altimeter were used during the mapping. In addition, all sample locations were positioned using GPS. While the topographically highest, southern part of the prospect area generally is well exposed, the northern part is with some exceptions poorly exposed. This is particularly valid for the eastern part of the area which is densely populated by erratic blocks of one rock type: porphyritic biotite gneiss-granite. But since they from shape, lack of other rock types, and scattered exposures in between are estimated not to have travelled far, it is highly probable that the porphyritic biotite gneiss-granite dominate in the eastern area. In general, the impression was that the cover is rather thin throughout the area.

Because of scattered exposures in parts of the map area, many geological boundaries on the geological map are inferred, and outlines are drawn from the best qualified guess. Only boundaries in full line are observed. Exposures are shown by a stronger colour intensity on the map.

It should be noted that the rock names used in this report are designed to reflect colour, mineral content, texture/structure and composition in order to be able to describe the array of greyish rocks and their textural variants. A description of the individual samples collected during the fieldwork is found in Appendix B.

The prospect area is built up of four main rock groups (see geological map).

1: The older group consists of fine-grained grey gneisses (migmatitic), which are limited to the south-eastern half of the prospect.
2: In the same area occur non-porphyritic to moderately porphyritic grey biotite gneiss-granitoids of tonalitic composition, which intrude the fine-grained grey migmatitic gneisses as major layer-shaped bodies or 1 to a few metres wide veins.
3: The north-eastern half is dominated by porphyritic biotite gneiss-granite and a non-porphyritic light grey biotite gneiss-granite, together forming the third group of granitic rocks.
4: The youngest group consist of a massive amphibolitic rock that form cross-cutting minor bodies, or dykes, with different orientation.

4.1.2 Rock descriptions

Fine-grained grey gneisses (migmatitic). This rock unit make up about half of the rock volume in the south-eastern half of the prospect. It is grey to dark grey in colour, rather homogeneous and fine-grained. It has a well-developed to moderately well-developed foliation due to finely disseminated biotite, assisted by hornblende in darker varieties. Locally, it contains scattered 1 mm big feldspar grains suggesting that the fine-grained grey gneisses represent deformed acid volcanic rocks. The grey gneisses ubiquitously have some

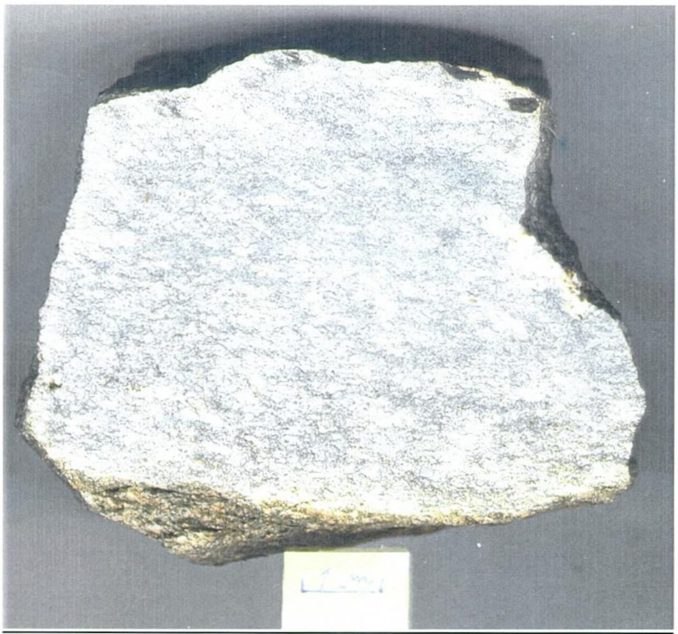

Figure 2. Fine-grained grey gneiss.

centimetres to 10-20 cm wide veins of likewise fine-grained whitish grey rock, which form a subordinate but important component of the fine-grained grey gneisses. In addition, the gneisses contain scattered, 1-2 cm wide quartzo-feldspatic veins related to partial melting. In large parts of their occurrence the fine-grained grey gneisses are intruded by more or less well-foliated porphyritic and non-porphyritic grey biotite gneiss-granitoids which form major layers or up to some metres thick sheets (see geological map). See also sample descriptions for MM01411, MM01416, MM01420, MM01421, sample C and sample G.

Grey biotite gneiss-granitoid (tonalitic). The grey biotite gneiss-granitoids are homogeneous, medium-grained or weakly to moderately porphyritic with scattered, smaller (c. ½-1 cm), partly recrystallised feldspar porphyroblasts, which are not so spectacular and thus give the rock a much more homogeneous appearance. Compared to the porphyritic light grey biotite gneiss-granite below, the medium-grained tonalitic granitoids are darker grey in colour, which seem to reflect a higher content of biotite and the low content of feldspar porphyroblasts. Homogeneous types of the grey biotite gneiss-granitoid tend to occur as elongate bodies inside the light grey porphyritic biotite gneiss-granite, while the weakly to moderately porphyritic grey biotite gneiss-granitoids prevails in bodies intruding the fine-grained grey gneisses (see geological map). Especially in the latter setting, foliation and lineation is well-developed, and more or less sheared textures are common. The reason for this is probably a marked difference in competence between the grey biotite gneiss-granitoid and the fine-grained grey gneisses, which have facilitated movement. The grey biotite gneiss-granitoids do not show veining from partial melting (anatexis). A few pegmatite veins may occur now and then, but are rare. See also sample descriptions for MM01412, MM01413, MM01414, MM01415, MM01417, MM01418 and MM01419, sample B, sample E and sample F.

Figure 3. Grey homogeneous biotite gneiss-granitoid.

The grey biotite gneiss-granitoid shows various degree of shearing in the folded structure in the south-eastern part of the prospect (see geological map) where it is interlayered with fine-grained grey gneisses on different scales. The commonly porphyritic gneiss-granitoids are here transformed into well-foliated to mylonitic rocks with flat lenticular to augen-shaped recrystallised feldspars. The sheared and mylonitic variants tend to have a darker grey colour due to finer grain size and possibly a higher content of biotite. Part of the folded structure contain plenty of white grey pegmatite veins. See also sample descriptions for MM01410.

Porphyritic light grey biotite gneiss-granite. The porphyritic biotite gneiss-granite is by volume the most important rock in the prospect area and dominates in its north-eastern half. A strong linear structure is generally more well-developed than the foliation. Because of its porphyritic texture, the rock give the impression of having an uneven (heteroblastic) grain size, but since the porphyroblasts mainly is recrystallised, the actual grainsize is medium-grained to finely medium-grained. The more or less completely recrystallised feldspar phenocrysts are ½-4 cm across with rather irregular outlines and diffuse boundaries to a dark grey, fine-grained matrix rich in biotite. Closely packed feldspar phenocrysts normally make up 50-75 % of the rock and contributes to its light colour. The porphyritic biotite gneiss-granite does not show partial melting (anatexis), but contains locally scattered whitish grey pegmatite and aplite veins which is related to the intrusion of the porphyritic biotite gneiss-granite itself. Up to 1-1½ m wide pegmatite veins are most common and were particularly observed in the northernmost part of the prospect and in the area 250 m E and ESE of Såt (see geological map). Up to some decimetres wide aplite veins were mainly observed in the northernmost prospect area. See also sample descriptions for MM01404, MM01406, MM01422 MM01423 and sample A.

Figure 4. Porphyritic light grey biotite gneiss-granite.

While the porphyritic light grey biotite gneiss-granite usually has a moderately well-developed foliation, shearing in a limited scale may occur locally as in the north-eastern part of the prospect. The sheared and mylonitic variants tend to have a darker grey colour due to finer grain size and possibly a higher content of biotite. The feldspar is usually completely recrystallised to a medium-grained aggregate. See also sample descriptions for MM01403.

Light grey biotite gneiss-granite. This homogeneous light grey gneiss-granite is considered as a non-porphyritic phase associated with the light grey porphyritic biotite gneiss-granite above. Its main occurrence is a N-S-oriented body in the central part of the prospect area (see geological map). The southern extension of the body is rather speculative since few exposures exist in this area, and drilling indicate that it is possible that the rocks in the fold-like structure in the south may extend farther north. The light grey biotite gneiss-granite is distinctly light coloured and medium-grained without feldspar porphyroblasts. It contains fine-grained biotite aggregates as dispersed short streaks and 1-3 mm long spots giving the rock a distinct linear structure. The foliation is usually weak. The light grey biotite gneiss-granite does not show partial melting (anatexis), and seems not to contain pegmatite veins. See also sample descriptions for MM01407 and sample D.

Figure 5. Light grey homogeneous biotite gneiss-granite.

Massive amphibolitic rock. This rock occurs as subordinate, elongate or sheet-like intrusive bodies that cross-cut all other rocks (see geological map). The massive amphibolitic rock is dark grey, homogeneous and fine- to medium-grained with a weakly, but distinctively developed foliation. It is without any veins. The amphibolitic rock is rather light coloured when compared to normal amphibolites. The rock represents a deformed intrusive mafic or intermediate rock. See also sample descriptions for MM01405, MM01408 and MM01409.

Amphibolite is very insignificant in the area and is only found as <1 m wide layers in two short, narrow zones in the north-central part of the prospect.

Quartz veins occur sporadically, but are completely insignificant by volume. The quartz veins are normally a few to 10-20 centimetres wide. The only part where they are more common is a small area 350 m SE of Såt at the margin of the prospect area (see geological map).

4.1.3 Structural geology

The foliation in the prospect area varies in strike from N to NNW with steep dips (60-90°) both E and W (eastern dips prevail). Fluctuations in orientation are probably mainly related to shape-changes for the different rock bodies along strike. But fold structures occur, particularly in the south-eastern part of the prospect area where well-foliated to mylonitic porphyritic biotite gneiss-granitoids are folded in a tight north-closing, antiformal fold structure with a fold axis plunging 20° N. It is possible that folds also occur within the porphyritic biotite gneiss-granite in the northern part of the prospect area, where the foliation diverges, but no marker horizons exist to prove this. A stereo plot of all foliations from the prospect area indicate a fold axis plunging 10-40° N to NNW, which is parallel to the prominent lineation found throughout the area. This evidence together with the intrusive character for the different types of biotite gneiss-granites and granitoids makes the distribution of rocks at depths a little unpredictable. But since the geological boundaries mainly are steeply dipping, it is safe to assume that the rock distribution observed at the surface will continue at least to some depths. A fold axis and lineation plunging 10-40° N-NNW could indicate that the geology seen in the southern part of the prospect area will be projected northwards at depth along this line.

As mentioned above, the most well-developed foliation are found in the south-western part of the prospect area where also sheared and mylonitic rocks are found. The strongest tectonic movement, forming the well-developed foliation, thus seem to be located in the area where the fine-grained grey gneisses occur, probably facilitated by the difference in competence between these gneisses and the intruded biotite gneiss granites. Sheared textures may have a positive effect on the technical rock properties.

Major joint or fault zones have not been observed during the mapping. They were also to be expected unexposed. It is possible that N- and NNE-trending topographical lineaments could reflect such zones.

4.1.4 Geology of the area south-west of the prospect

One traverse was made on the hill north of the extraction pit in operation at Espevik, in the area south-west of the new prospect (see geological map). It showed that Espevik gneiss-granite similar to that in the operating pit occupy the south-western part of the area with an intrusive contact to banded metasediments in the north-east. The latter contains layers of homogeneous biotite gneiss. While foliations dip steeply WNW in the west, they dip steeply NE in the east defining an antiformal fold structure that plunges 35° N, in agreement with what was observed in the new prospect.

The Espevik gneiss-granite is distinctly foliated, though not well-developed, in the west with plenty of irregular whitish grey pegmatite veins. This foliation is parallel to plenty of narrow (1-10 cm) mylonite zones which contain thin, conformable quartz veins. In the east, the moderately porphyritic Espevik gneiss-granite is massive and weakly foliated with few pegmatite veins.

The banded metasediments is dominated by a dark grey schist which alternates with <15 cm wide, likewise dark grey, fine-grained quartzo-feldspatic bands or layers of mainly subordinate importance. The metasediments are intruded by the Espevik gneiss-granite and contains plenty of whitish grey pegmatitic veins near the boundary. The dark grey schist is fine- to medium-grained with a well-developed undulating schistosity due to fine-grained, wavy quartzo-feldspatic slender lentils that are smeared by rather fine-grained biotite+muscovite-rich material. The rock represent a metamorphosed clay-rich sediment with bands of more sandy material. See also sample descriptions for MM01402

A veined, homogeneous biotite gneiss form layers in the banded metasediments. It is grey, fine- to medium-grained and well-foliated with a homogeneous appearance. The foliation and texture is outlined by 2-3 mm thick flat lenses of quartz-feldspar material separated by dispersed stripes of mica (mainly biotite). The rock has scattered, 1-3 cm thick, more coarse-grained quartzo-feldspatic veins or bands derived from partial melting (anatexis). There is an indication of 1-2 mm long, deformed feldspar phenocrysts, and the protolith may have been an acid volcanic rock. The homogeneous biotite gneiss contains several 1-2 m wide whitish grey pegmatites, concordant to the foliation, in the easternmost exposures. See also sample descriptions for MM01401

Though the connection is not mapped, it is tempting to suggest that the banded metasediments and the fine-grained grey gneisses in the new prospect area are part of a one and the same volcano-sedimentary unit, which represents the oldest, migmatitic, rocks in the area.

4.1.5 Mineral composition and classification

The mineralogy and modal composition of all rock samples in the Såt prospect was examined from a thin sections by August Nissen [1]. The results are presentet in Table 2 and 3. Epidote and muscovite in both tables are almost exclusively the result of alteration (albitisation) of plagioclase, and occur as, respectively, very fine-grained saussurite and sericite within the outlines of plagiclase grains. This alteration process also partly transformed biotite into chlorite. The mineral composition largely confirmed the rock division established in the field, and only smaller adjustments had to be made. It also appeared that besides the amphibolites, both the fine-grained biotite gneisses and the grey biotite gneiss-granitoids may contain some hornblende in addition to biotite.

Table 2. Mineral composition of hand specimens collected during the mapping, which are not tested for mechanical properties. From modal analyses (in %) [1].

Sample	Rock type	Qz	Plag	K.f.	Hbl	Chl	Ep	Bi	Mu	Oth
MM01411	Fine-grained grey gneiss	35	34				10	10	10	1
MM01416	Fine-grained grey gneiss	20	25			5	10	20	20	
MM01420	Fine-grained grey gneiss, whitish grey vein	30	30	30		5	5			
MM01421	Fine-grained grey gneiss, whitish grey vein	20	20	25			5	10	20	
MM01413	Grey biotite gneiss-granitoid	30	40				10	10	10	
MM01417	Grey biotite gneiss-granitoid	30	35				10	5	20	
MM01419	Grey biotite gneiss-granitoid	30	25	5			10	10	20	
MM01415	Grey biotite gneiss-granitoid	20	40				10	10	20	
MM01418	Grey biotite gneiss-granitoid	20	44		10			20	5	1
MM01412	Grey biotite gneiss-granitoid	20	47		10		5	10	5	3
MM01410	Grey biotite gneiss-granitoid	30	10				20	10	30	
MM01414	Grey biotite gneiss-granitoid	30	15		10		30	10	5	
MM01423	Porphyritic biotite gneiss-granite	30	30	30		1	5	4		
MM01406	Porphyritic biotite gneiss-granite	30	20	30			5	5	10	
MM01422	Porphyritic biotite gneiss-granite	25	25	30		2	5	3	10	
MM01404	Porphyritic biotite gneiss-granite	25	30	25		2	3	5	10	
MM01403	Porphyritic biotite gneiss-granite	20	30	30		3	5	7	5	
MM01407	Light grey biotite gneiss-granite	20	30	30			5	5	10	
MM01401	Homogeneous biotite gneiss	10	30	30	10		1	9	20	
MM01408	Amphibolite	3	15		50		32			
MM01409	Amphibolite	1	10		40	10	39			
MM01405	Amphibolite		10		50		40			

Qz - quartz, Plag - plagioclase, K.f. – Alkali feldspar, Hbl - hornblende, Chl - chlorite, Ep – epidote (saussurite), Bi - biotite, Mu – muscovite (sericite), Oth - other minerals. Sample location – see geological map.

Table 3. Mineral composition of samples examined for mechanical properties. From modal analyses (in %) [1].

Sample	Rock type	Qz	Plag	K.f.	Hbl	Chl	Ep	Bi	Mu	Sph
1 ?	Deformed pegmatite	20	20	34		5			20	1
5 ?	Light grey biotite gneiss-granite	20	20	30			5	5	20	
2 ?	Light grey porphyritic gneiss-granite	20	30	36		4	3	6		1
3 ?	White grey quartzo-feldspatic gneiss	25	35	30					10	
C	Fine-grained grey gneiss	10	30		30		10	10	10	
G	Fine-grained grey gneiss, whitish grey vein	20	20	25			5	10	20	
B	Grey biotite gneiss-granitoid	15	40		15	5	5	15	5	
E	Grey biotite gneiss-granitoid	25	40	5				20	10	
F	Grey biotite gneiss-granitoid	30	10			5	40	15		
D	Light grey biotite gneiss-granite	25	40	25				10		
6	Light grey biotite gneiss-granite	25	40	19			1	5	10	
4	Porphyritic biotite gneiss-granite	20	27	35		2	5	8	3	
7	Porphyritic biotite gneiss-granite	25	35	30		3	3	4		
A	Porphyritic biotite gneiss-granite	25	30	30		3	3	7	2	

Qz - quartz, Plag - plagioclase, K.f. – Alkali feldspar, Hbl - hornblende, Chl - chlorite, Ep – epidote (saussurite), Bi - biotite, Mu – muscovite (sericite), Sph - sphene. Samples A-G – This study. Samples 1-7 – NOTEBY samples. Sample location – see geological map.

? – NOTEBY sample of uncertain location and rock type (see chapter 5; rock type estimated from small specimens kept at NGU). Samples 1-3 are located outside the present prospect area (see geological map).

In order to classify the rocks, epidote (saussurite) + muscovite (sericite) + plagioclase (albite) from the modal analyses were added to estimate the actual plagioclase content before alteration. From the content of this re-calculated plagioclase, alkali feldspar and quartz, all samples have been plotted in a common Streckeisen diagram for plutonic rocks (Figure 6) in order to classify the rocks. As it appears, the rocks in the Såt area plot in two well-separated groups of respectively tonalitic and granitic composition.

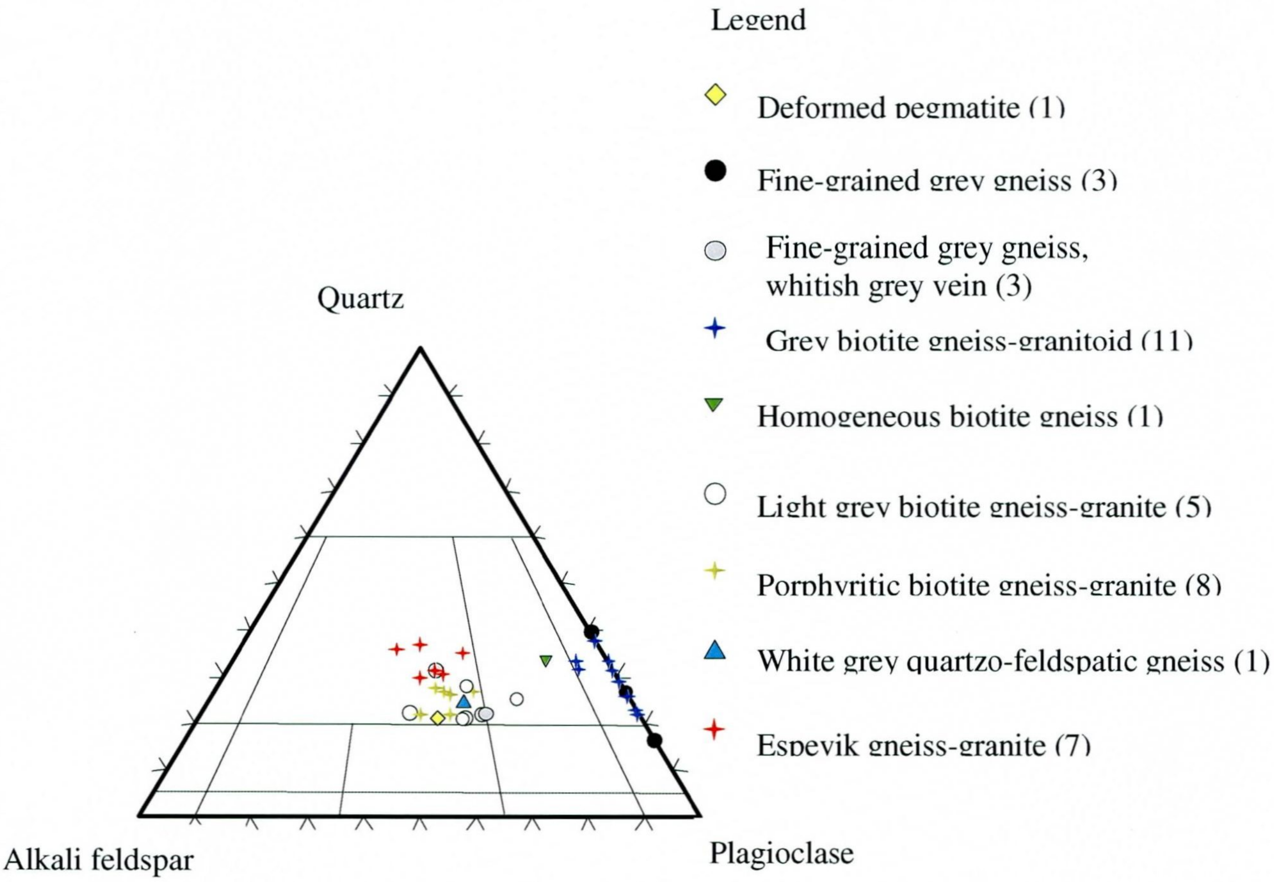

Figure 6. Classification of rocks from the Såt area in a Streckeisen diagram.

Rocks in the tonalitic group include the fine-grained grey gneisses (actually andesitic to dacitic compositions if originally volcanic rocks) and the grey biotite gneiss-granitoids from the south-western part of the prospect. On the other hand, rocks in the granitic group include the main porphyritic biotite gneiss-granite and the light grey biotite gneiss-granite from the north-eastern half of the prospect. In addition, the granitic group includes the whitish grey quartzo-feldspatic veins of minor importance in the fine-grained grey gneisses. All samples analysed by NOTEBY [3] also plot in the granitic group, with the exception of sample 6 which plots halfway to the tonalitic group. Seven samples of Espevik gneiss granite from the operating quarry [4] have been plotted in the diagram for comparison. They also plot in the granitic group, but in its upper part because of a slightly higher content of quartz.

As seen in the section below, there is an indication that the subdivision into tonalitic and granitic compositions is of importance for the mechanical quality of the rocks in the Espevik area. Good mechanical values tend to follow tonalitic lithologies found in the south-western half of the Såt prospect. The main exception among the granitic compositions is the light grey biotite gneiss-granite, which similarly shows good mechanical properties.

4.2 Mechanical and geometrical properties

The results of the mechanical and geometrical testing are presented in Table 4. Two additional samples (F and G) were collected during the follow-up drilling program in December 2001/January 2002. These are included in the table and their location shown on the geological map.

Table 4. Mechanical and geometrical properties.

Sample	Flakiness index	Los Angeles value	PSV
A	7,9	25,7	56
B	14,4	12,1	55
C	15,9	16,3	55
D	12,2	15,6	50
E	12,0	13,8	52
F	13,3	15,3	-
G	12,0	20,3	-

Results of the PSV test for F and G will appear later.

In an investigation done in 2000 by NOTEBY [3], 7 samples were collected within the Såt area (location - see geological map) and tested for mechanical properties. The results of the Los Angeles test, analysed at NGU, are shown in Table 5.

Tabell 5. Results of the Los Angeles test on rocks from the Såt area from the NOTEBY investigation in 2000 [3].

Sample	Los Angeles value
1	31,2
2	31,0
3	23,1
4	23,3
5	24,6
6	12,2
7	23,2

Table 6 shows the statistics for the mechanical properties of the different rock types within the Såt area compared with the results from the existing quarry operating in the Espevik gneiss-granite [4]. (NOTEBY's samples 1, 2, 3, 5 are not included in the statistics because of uncertain classification and location - see chapter 5)

Table 6. Statistic for the mechanical properties for the different rock types.

Rock types	Number of samples	Los Angeles value Average	Stand. div	Polished Stone value Average	Stand. div
Fine-grained grey gneiss	1	16,3	-	55	-
Fine-grained grey gneiss, whitish grey vein	1	20,3	-		-
Grey biotite gneiss-granitoid	3	13,7	1,6	54	2
Light grey biotite gneiss-granite	2	13,9	2,4	50	-
Porphyritic biotite gneiss-granite	3	24,1	1,4	56	-
All samples within Såt area	10	17,8	5,0	54	2,5
Espevik gneiss-granite	7	24,0	1,4	53	2

5. EVALUATION OF THE RESULTS

5.1 Mechanical and geometrical analyses

In order to compare the Los Angeles values for the different rock types in the Såt area the samples have been grouped together and plotted against the values from samples of the Espevik gneiss-granite [4] (figure 7). The NOTEBY samples 1, 2, 3 and 5 [3] are not shown in figure 7 either because they are located outside the present prospect area (1, 2, 3) and therefore not representative, or because the samples probably were taken very close to surface and therefore have been exposed to severe weathering. The latter could explain the relative high Los Angeles values obtained for samples 1 and 2. The location for NOTEBY sample 5 could not be re-found during NGU's field investigation in 2001 despite persistent search for the indicated location. It is therefore not possible to relate the mechanical properties of sample 5 to any specific rock unit within the Såt prospect, and it has for these reasons been omitted. From thin-section analysis of NOTEBY samples 1, 2, 3 and 5 we are, all together, uncertain about rock type, and therefore on how representative the mechanical test results for these samples are for the Såt prospect. Though not re-found near their shown positions, we have been able to locate NOTEBY samples 4, 6 and 7 during the fieldwork (true position shown on the map) and attach them to a specific rock unit. They are therefore included in the figure 7.

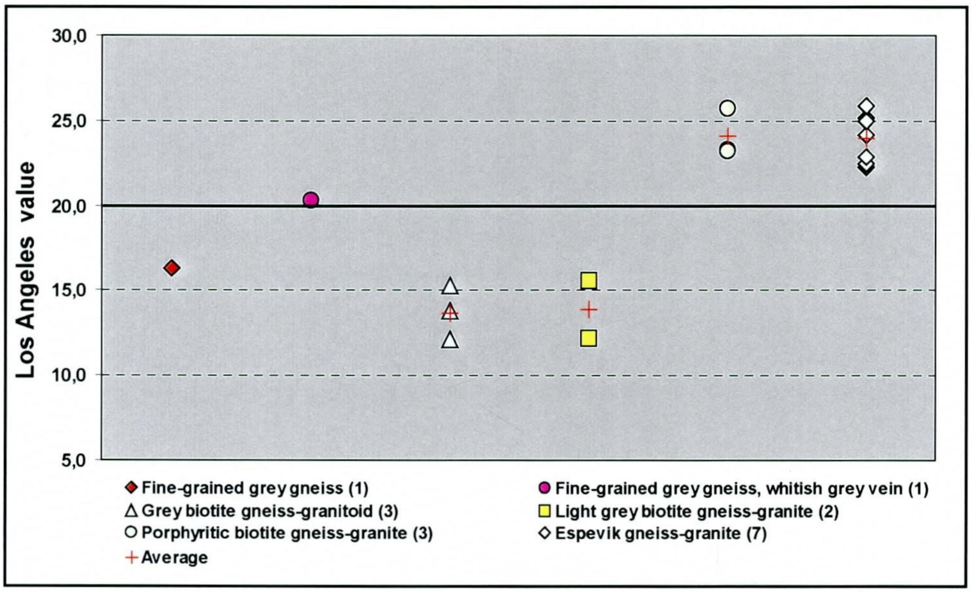

Figure 7. Los Angeles values for the different rock types.

As it appears, the dominant rock type in the area, the porphyritic biotite gneiss-granite (samples A, 4, 7), shows an average LA-value (table 6), which is similar to the Espevik gneiss-granite. The other rock types, which are dominant in the south-western part of the investigated area, shows much better results for the Los Angeles test. The fine-grained grey gneisses and the grey biotite gneiss-granitoid shows together with the light grey biotite gneiss-granite show the best LA-values. Though whitish grey veins (sample G) in the fine-grained grey gneisses show a higher value, this is not considered to reduce the LA-value for the bulk fine grained grey gneisses significantly, since the veins are estimated only to make up 10-15% by volume.

There are no significant differences in the Polished Stone Value between the different rock types in the Såt prospect.

The Flakiness index for the porphyritic biotite gneiss-granite are lower (more cubic) compare to the other samples taken dominantly in the south–western part of the Såt area. This seem quit reasonable due to the more massive texture for this rock type. The other rocks are more foliated which can explain the difference.

Taken together, the mechanical test results from the rocks of the Såt prospect show values that should satisfy the requirements for aggregates for road construction purposes (shown simplified in table 1) in several European countries. It is not unusual, however, with variations in the requirements even within individual countries. *But in general aggregate material with LA values below 20 and PSV above 50, or better 53, are evaluated as interesting for the export market in Europe.*

5.2 Areal considerations of mechanical properties versus rock types

For these reasons, the south-western part of the Såt prospect looks promising with good mechanical properties, while the north-eastern part show more moderate qualities. The south-western part of the prospect consists of two dominating rock types in roughly equal amount: Fine-grained grey gneisses and grey biotite gneiss granitoid. All the 6 tested samples from this part show good mechanical qualities. While the grey biotite gneiss granitoid apart from occasional pegmatites seems quite uniform throughout the area, the fine-grained grey gneisses show distinctive lithological variations from grey biotite-bearing types to dark grey types richer in biotite and hornblende (see Table 2-3). All types are fine-grained with estimated 10-15% light coloured quartzo-feldspatic anatectic and pegmatitic veins. We cannot guarantee that this will not have a negative influence on the mechanical properties, but only state that the sample statistics so far are promising. Though not easily mappable, we know that the grey biotite gneiss-granitoid, particularly in the folded structure in the south-east (see geological map), contain intruded layers of granitic composition (sample 7 and D), but they are estimated to occur only in subordinate amounts. And as the test results from sample D shows, these layers do not necessarily imply poorer quality.

Another factor of unknown importance for the mechanical properties is the variably developed foliated structure seen in all rock types. The foliation is normally weakly to well-developed, but sheared and mylonitic structures occur locally. Since the 6 tested samples from the south-western area comprise differently developed foliated structures, there is again no direct evidence of any significant negative influence on the properties so far.

From the experience in areas with a complex geology like Såt, we like to stress how crucial it is to have good geological control before sampling for examination of mechanical properties is carried out. The first 7 samples taken in the Såt area in 2000 gives a completely misleading conclusion about the areas aggregate potential when compared with the results after the new sampling based on geological mapping.

5.3 Volume considerations and recommendations

A preliminary estimation is that the rocks with good technical qualities in the south-western part of the Såt prospect occupy minimum 40%, while the remaining part consist of prophyritic biotite gneiss with local bodies of light grey biotite gneiss granite. A drill program have been established and carried out during our work process in order to get a better control on the geological structure at depth in the prospect, and to make a more precise volume estimation of rock qualities. The results from this work will appear in a separate report.

Assumptions for the preliminary estimation are that the geological units at surface from the geological map continue at depths with sub-vertical orientations as observed in the field. An important complication might however be that the different rock types in the prospect show intrusive relations, which make continuation at depth somewhat unpredictable. Another unknown factor is the continuation to the north of the folded structure in rocks with good mechanical properties in the south-east of the prospect. From structural geometry this structure is estimated to plunge 20-35° to the north, meaning that the folded structure should project northwards along this line. Due to lack of exposures north of the folded structure the outcrop of good quality rocks shown on the geological map is considered as a minimum. Rocks in the folded structure could outcrop and extend even further north and thus increase the volume of good quality rocks.

Because of the variation in rock types and mechanical strength throughout the Såt prospect, it is proposed to carry out a mining operation with selective extraction of rocks. In this way, materials from the different rock types with different mechanical properties could be mixed to achieve products that meet the various quality and requirement demands in the market.

6. REFERENCES

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[2] Erichsen, E. 1993: Prøving av steinmaterialer - Laboratorieknusningens innvirkning på fallprøven, Konferanse «Stein i vei» i Bergen, feb. 1993.

[3] Holm, J.V. 2000: Nytt uttaksområde Såta - Geologiske undersøkelser, Felt- og laboratorieundersøkelser, NOTEBY. Oppdrag-/Rapportnr. 101046-2, 17. okt. 2000.

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LEGEND TO GEOLOGICAL MAP OF THE SÅT AREA, ESPEVIK. By Mogens Marker, NGU, 2001

MASSIVE AMPHIBOLITIC ROCK
DARK GREY, HOMOGENEOUS

LIGHT GREY BIOTITE GNEISS-GRANITE
NON-PORPHYRITIC

PORPHYRITIC BIOTITE GNEISS-GRANITE
GENERALLY RICH IN FELDSPAR PORPHYROBLASTS

DITTO: WELL-FOLIATED TO MYLONITIC ~

DITTO: WITH INCLUSIONS OF FINE-GRAINED GREY GNEISS

GREY BIOTITE GNEISS-GRANITOID (TONALITIC)
LOCALLY WEAKLY TO MODERATELY PORPHYRITIC

DITTO: WELL-FOLIATED TO MYLONITIC ~

DITTO: WITH INCLUSIONS OF FINE-GRAINED GREY GNEISS

FINE-GRAINED GREY GNEISS
MIGMATITIC WITH SUBORDINATE WHITISH GREY VEINS

DITTO: WITH VEINS OF (+/-PORPHYRITIC) GREY BIOTITE GNEISS-GRANITOID

ESPEVIK GNEISS-GRANITE
MODERATELY PORPHYRITIC, WEAKLY TO MODERATELY FOLIATED

BANDED METASEDIMENT
DARK GREY SCHIST WITH SUBORDINATE QUARTZO-FELDSPATIC LAYERS

HOMOGENEOUS BIOTITE GNEISS
WELL-FOLIATED WITH SCATTERED MIGMATITIC VEINS

AMPHIBOLITE
AS THIN LAYERS

QUARTZ VEINS (Q)
SCATTERED, <15 CM THICK, ONLY MARKED WHERE OBSERVED

PEGMATITE VEINS (P)
ONLY MARKED WHERE OBSERVED

APLITE VEINS (A)
ONLY MARKED WHERE OBSERVED

STRUCTURAL SYMBOLS

s d, s — Foliation - strike and dip, vertical

P d — Lineation - direction and plunge, horizontal

SAMPLE LOCATIONS

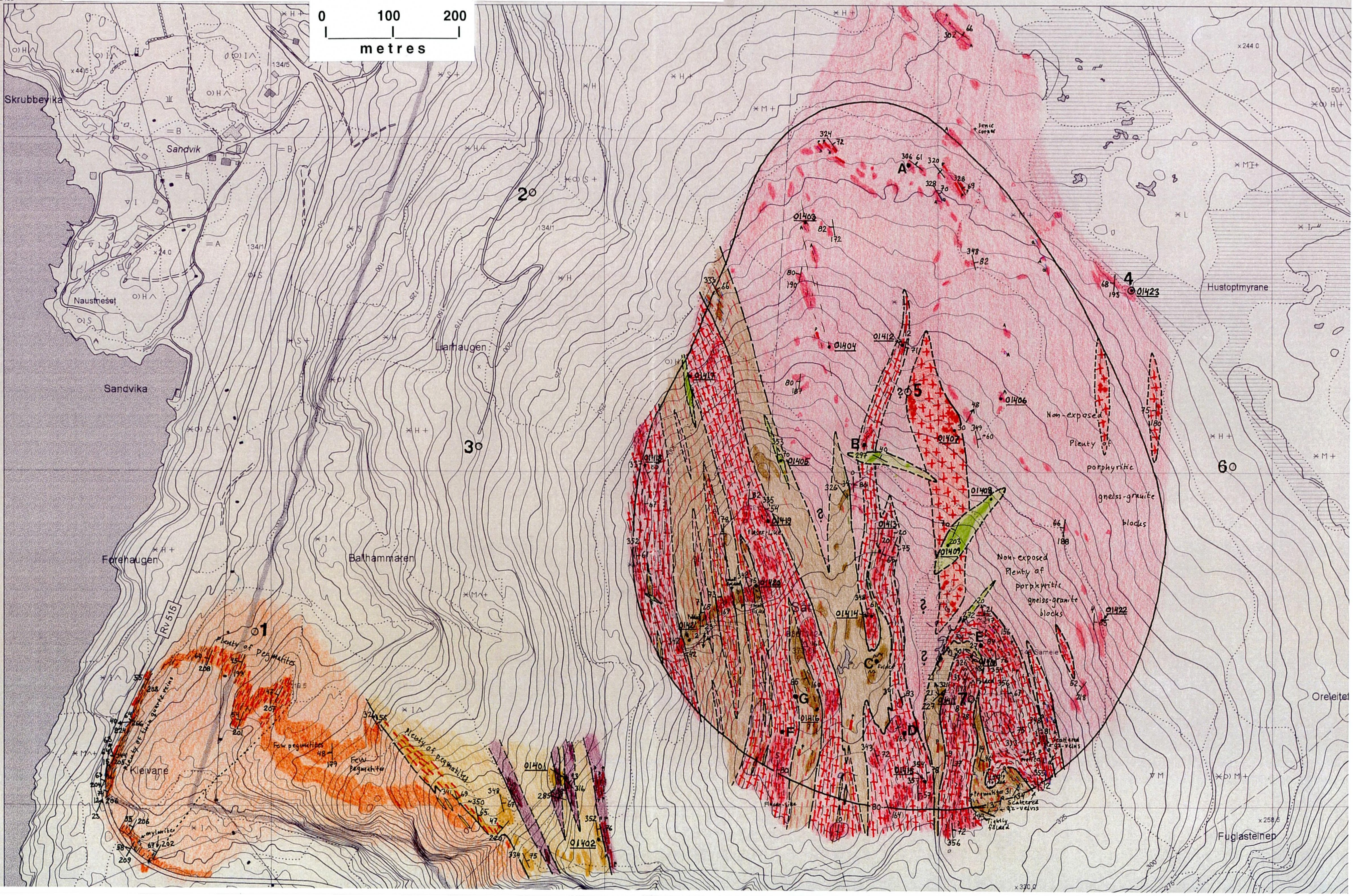
• 01401 — Samples for thin section

• A — Samples for technical analyses

○ 1 — Samples for technical analyses by NOTEBY A/S

GEOLOGICAL MAP OF THE SÅT AREA

BY MOGENS MARKER - SCALE 1: 5 000



*** Norwegian Impact Test (Impact- and flakiness value)**
*** Abrasion Test (Abrasion value)**
*** Resistance to wear (Sa-value)**
*** Nordic Test (Nordic abrasion value)**
*** Los Angeles Test (LA value)**
*** Polished Stone Value (PSV)**
*** Thin section**

Norwegian Impact Test

The ability of stone to resist mechanical impact stress can be determined by, for instance, the Norwegian Impact Test. This method is widely used in the Nordic countries (the way the test is carried out varies somewhat from country to country) and can to some extent be compared with the British 'aggregate impact test', the German 'Schlagversuch' and the American 'Los Angeles Test'.

The Norwegian Impact Test consists of the crushing of a specific fraction, 8.0-11.2 mm, of gravel or aggregate of known grain shape in a drop apparatus. The apparatus consists of a mortar in which the test material is exposed to the impact of a 14 kg weight falling 20 times from a height of 25 cm. The proportion of the test material whose grain size after crushing is less than the minimum grain size of the original fraction, in this case 8.0 mm, is called the uncorrected Impact value (S_0). This value is corrected for the degree of compaction in the mortar after the impact, permitting the **Impact value (S_8)** to be calculated.

The average grain shape of the material is expressed by the **flakiness value**, which is a physical property indicating the relationship between the mean width and thickness of the grains. The flakiness test is performed as part of the Norwegian Impact Test and is determined on the same sieved grain-size fraction as the Impact value. Flakiness verifications may, in addition, be made on any fractions desired. The width is determined on a sieve with a square mesh and the thickness on a sieve with a rectangular mesh. The method is used for both natural gravel and aggregate.

The results of the Norwegian Impact Test may vary from laboratory to laboratory, but the apparatus used has been reasonably well standardised since 1988. Unless otherwise stated, the Impact value is given as an average of three separate measurements.

The material is usually tested twice in the drop apparatus. The Impact value for the repeated impact, the Repeated Impact value, expresses the resistance of the material to repeated impact stress. The Repeated Impact value often reflects the improvement in quality which can be achieved by employing several stages of crushing in a crushing mill.

Stone is classified into stone categories based on the results of the Norwegian Impact Test. Five categories are recognised, depending on the Impact- and flakiness values.

Stone category	Impact value	Flakiness value
1	≤ 35	≤ 1.45
2	≤ 45	≤ 1.50
3	≤ 55	≤ 1.50
4	≤ 55	≤ 1.60
5	≤ 60	≤ 1.60

Classification of stone materials according to the Norwegian Impact Test. Stone category 1 is best and 5 is worst.

The results after the Norwegian Impact Test may vary, depending on how the material has been sampled and handled prior to the test itself. It is either collected as geological-specimen samples (hand-sized specimen of rock), or taken from a specific fraction prepared in a crushing mill (production sample).

Hand-specimen sampling is often employed when new areas that are of interest for extracting rock are being investigated. The sample is usually taken from a blasted road cut, or is blasted from a rock exposure. In both cases, the material will be exposed to crushing in connection with the blasting. Occasionally, hand-specimen samples are taken without them having been exposed to blasting. This occurs, for example, when a sample is taken from a scree, or struck directly off an exposure with a sledgehammer. In such cases, the rock must lack surface weathering. Hand specimens are always crushed in laboratory mills before undergoing the Norwegian Impact Test itself.

Hand-specimen sampling may also be carried out in an aggregate plant, but it is generally of greater interest to investigate the quality of the material after it has been through the crushing and screening plant (production samples). In the crushing plant, it is usual to crush the material in several stages. This improves its quality because it attains a more cubic grain shape (lower flakiness value), and also gives a better Impact value. This processing effect depends to some extent on the type of rock.

Production samples must be handled in accordance with the following guidelines:

a) For screened material with a stated upper grain size of less than 22 mm
the Norwegian Impact Test is performed on the 8.0-11.2 mm fraction screened from the product concerned, provided that that fraction comprises at least 15% of the product. If this requirement cannot be fulfilled, the Norwegian Impact Test is performed according to alternative b).

b) For screened material with a stated upper grain size in excess of 22 mm
the Norwegian Impact Test is performed on the 8.0-11.2 mm fraction of the product concerned sieved from material crushed in the laboratory.

In addition, in the case of production samples, verification of flakiness must be undertaken on the coarse fraction of plant-produced material in one of the following fractions: 11.2-16.0 mm, 16.0-22.4 mm, 22.4-32.0 mm, 32.0-45.2 mm or 45.2-64.0 mm. A fraction must be chosen which corresponds to at least 15% of the product and which is as close as possible to the stated upper grain-size limit of the product. Material that is produced must maintain a flakiness value > 11.2 mm.

Abrasion Test

Abrasion, or the **abrasion value**, expresses the abrasive resistance to wear or resistance to scratching, of the material. The abrasion method is a Nordic method (the way the test is carried out varies somewhat from country to country) evolved from the British aggregate abrasion test. It is chiefly used for quality appraisal of aggregate for asphalt wearing surfaces on roads with an annual daily traffic (ADT) load in excess of 1500 vehicles. Maximum abrasion values have also been introduced for aggregate to be used for roadbase and sub-base courses.

A representative selection of aggregate grains in the 11.2-12.5 mm fraction is cast on a square plate (10x10 cm) which is pressed with a given weight against a rotating disc carrying a standard grinding powder. The wear, or abrasion, is defined as the volume loss of the sample expressed in cubic centimetres.

The following classification is used:

< 0.35	**very good**
0.35-0.45	**good**
0.45-0.55	**moderate**
0.55-0.65	**poor**
> 0.65	**very poor**

Resistance to wear

The Impact value, flakiness value and abrasion values are measured to determine the suitability of stone as aggregate for asphalt road surfaces. The resistance of the material to wear from studded tyres, called the resistance to wear (Sa-value) is expressed as the product of the square root of the Impact value (S_8) and the abrasion value.

The following classification is used:

< 2.0	**very good**
2.0-2.5	**good**
2.5-3.5	**moderate**
3.5-4.5	**poor**
> 4.5	**very poor**

Nordic Test

The Nordic Test, like the Abrasion Test, expresses the resistance to wear of the stone. It has been introduced as a Nordic method in connection with the European standardisation programme for aggregates (CEN/TC 154). It is designed to determine the resistance of aggregate to wear deriving from studded tyres. The method should in due course replace the abrasion method.

Briefly, the method is as follows. 1 kg of stone in the 11.2-16.0 mm fraction is rotated in a drum for 1 hour at 5400 revolutions per hour together with 7 kg of steel balls and 2 litres of water. The drum has a specific shape and is equipped with three devices which raise and mix its contents as it rotates. The stone is exposed to both impact and wear, but mainly wear. After the rotation period, the material is wet sieved and dried. After weighing, the proportion that passes through a 2 mm square-mesh sieve is calculated. This expresses the wear, and is termed the **Nordic abrasion value (A_N)**.

The following classification is used:

≤ 7.0	**category A**
≤ 10.0	**category B**
≤ 14.0	**category C**
≤ 19.0	**category D**
≤ 30.0	**category E**
No demand	**category F**

Category A is best and category F worst.

Los Angeles Test

The Los Angeles Test expresses the ability of material to resist both impact and wear. The method is originally American, but has been in use for many years in several European countries, for instance by the Norwegian State Railways (NSB) in Norway. It can be performed using the standard American procedure, ASTM C131 (fine aggregate) and ASTM C535 (coarse aggregate), or the new European CEN procedure prEN 1097-2, §4.

When the CEN procedure is used, 5 kg of stone in the 10.0-14.0 mm fraction are rotated in a drum together with 11 steel balls. The inside of the drum is equipped with a steel plate which, as the drum revolves, lifts the material and the steel balls up before dropping them again. After about 15 minutes and 500 revolutions, the material is removed, wet sieved and dried. After weighing, the proportion that passes through a 1.6 mm square-mesh sieve is calculated. This expresses the mechanical load and is called the **Los Angeles value** (the **LA value).**

The following classification is used:

≤ 15.0	**category A**
≤ 20.0	**category B**
≤ 25.0	**category C**
≤ 30.0	**category D**
≤ 40.0	**category E**
≤ 50.0	**category F**
No demand	**category G**

Category A is best and category G worst.

Polished Stone Value (PSV)

PSV is a British method used for recording the resistance to polishing of aggregates that are to be used in road surfaces. In central Europe, it is desirable to have road surfaces with a high resistance to friction to avoid them becoming slippery. This is not a problem in Nordic countries because the studded tyres used in winter roughen the surface of the aggregate in the surface layer.

The test procedure requires that 35 to 50 particles of a specific grain fraction, < 10 mm in a square-mesh sieve and > 7.2 mm in a rectangular-mesh sieve are cast on a convex, rectangular sheet (90.6 x 44.5 mm). 12 test sheets (4 for each sample) and 2 control sheets are mounted on a road wheel that is itself mounted vertically on a polishing machine. The wheel rotates for 3 hours at 315-325 revolutions per minute. It is loaded by a wheel consisting of compact rubber that is rotated in the opposite direction from the road wheel.

Water and grinding powder are applied to the rubber wheel. After the test sheets have been in the polishing machine for the allotted time, the polishing resistance is measured with a pendulum apparatus. A pendulum arm is brushed across the test sheet giving a reaction on a calibrated scale. This reaction is the friction coefficient, stated as a percentage and also called the PSV value.

The following classification is used:

≥ 68.0	**category A**
≥ 62.0	**category B**
≥ 56.0	**category C**
≥ 50.0	**category D**
≥ 44.0	**category E**
No demand	**category F**

Category A is best and category F worst.

Thin section

The term thin section is used for a thin slice of a rock that is glued to a glass slide. This forms the basis for the microscopic determination of minerals and their relative occurrence. When polarised light passes through the transparent slice, which is usually approximately 0.020 mm thick, the various minerals will be identifiable in the microscope owing to their characteristic optical properties.

The distribution of the minerals, along with the visual appraisal of structures in the terrain, form the basis for deciding the rock type. The microscopic examination also permits the study of internal textures, the shape and size of mineral grains, alteration phenomena and the mode of formation of the rock, etc.

Special textures can be observed, such as microfractures between the minerals, or rod-shaped feldspar grains which function as a kind of armour in an otherwise granular groundmass (ophitic texture). Foliation is another term which is often used in rock descriptions. That a rock is foliated means that the constituent minerals have a preferred planar axial orientation, or are concentrated in narrow, parallel layers or laminae. The grain size of the minerals is divided on the following scale:

< 1 mm - fine grained
1-5 mm - medium grained
> 5 mm - coarse grained

A thin section usually covers about 5 square centimetres. The result of one thin-section analysis is therefore rarely fully representative of the rock.

APPENDIX B - Sample description

MM01401 – Foliated, veined, homogeneous biotite gneiss.
The rock is grey, fine- to medium-grained and well-foliated with a homogeneous appearance. The foliation and texture is outlined by 2-3 mm thick flat lenses or disks of quarts-feldspar material separated by evenly dispersed, discontinuous, thin 'films' of mica (mainly biotite). The rock is migmatitic with scattered, 1-3 cm thick, more coarse-grained quartzo-feldspatic veins or bands (of anatectic origin). There is an indication of 1-2 mm long deformed feldspar phenocrysts, and the protolith may have been an acid volcanic rock.

MM01402 – Dark grey schist.
The rock alternates in the field with <15 cm wide, likewise dark grey quartzo-feldspatic bands or layers of mainly subordinate importance. The schist is dark grey, fine- to medium-grained, with a well-developed undulating schistosity due to fine-grained, wavy quartzo-feldspatic lentils smeared by rather fine-grained biotite+muscovite-rich material. The rock represent a metamorphosed clay-rich sediment with bands of more sandy material.

MM01403 – Sheared, grey, porphyritic biotite gneiss-granite.
The porphyritic gneiss-granite appears heteroblastic (uneven grainsize) and has a rather mylonitic texture. Stretched feldspar porphyroblasts, some millimetres to 4x2 cm across are embedded in a darker grey, fine-grained biotite-bearing matrix. The light grey feldspar porphyroblasts, which make up about half of the rock, are highly recrystallised to medium grain size. The rock represents a deformed porphyritic granite.

MM01404 – Lineated, light grey, porphyritic biotite gneiss-granite.
The rock appears heteroblastic and is light grey due to dominance of stretched feldspar porphyroblasts, which give the rock a well-developed linear structure. The porphyroblasts are ½-3 cm across and recrystallised into a medium-grained mosaic. The close-lying feldspar porphyroblasts are embedded in a dark grey, fine-grained matrix rich in biotite. The rock represents a deformed porphyritic granite which was rich in feldspar phenocrysts.

MM01405 – Dark grey, massive amphibolitic rock.
Homogeneous, medium-grained (finer part), dark grey amphibolitic rock with a distinct but weakly developed foliation. It is without veins and rather light coloured when compared to normal amphibolites. The rock cuts all other rock types and represents a deformed intrusive basic or intermediate rock.

MM01406 – Lineated, light grey, porphyritic biotite gneiss-granite.
The rock appears heteroblastic and is light grey due to dominance of stretched feldspar porphyroblasts, which give the rock a well-developed linear structure. The porphyroblasts are ½-2 cm across and recrystallised into a medium-grained mosaic. The close-lying feldspar porphyroblasts are embedded in a dark grey, fine-grained matrix rich in biotite. The rock represents a deformed porphyritic granite which was rich in feldspar phenocrysts.

MM01407 – Light grey, homogeneous biotite gneiss-granite.
The granite is medium-grained and quite light coloured without feldspar porphyroblasts. It contains fine-grained biotite aggregates as dispersed short streaks and 1-3 mm long spots giving the rock a distinct linear structure. The rock is considered as an non-porphyritic variant genetically associated with the biotite augen-granite.

MM01408 – Dark grey, massive amphibolitic rock.
Homogeneous, fine-grained, dark grey amphibolitic rock with a weakly developed foliation. It is without veins and rather light coloured when compared to normal amphibolites. The rock represents a deformed intrusive basic or intermediate rock.

MM01409 – Dark grey, massive amphibolitic rock.
Homogeneous, medium-grained, dark grey amphibolitic rock with a distinct but weakly developed foliation and lineation. It is a medium-grained variant from the centre of the same body as sample MM01408. The rock represents a deformed intrusive basic or intermediate rock.

MM01410 – Fine-grained, grey, mylonitic (porphyritic) biotite gneiss-granitoid.
The rock is a well-foliated, fine- to medium-grained, grey; with fine-grained biotite, a good lineation and a mylonitic texture. It contains scattered, flat eye-shaped, sheared feldspar porphyroclasts which are 1-3 mm thick, up to 1-2 cm long and recrystallised. The mylonite represents a sheared porphyritic biotite gneiss-granitoid, which in the field show a gradual transition into more massive porphyritic gneiss-granitoid with decreasing shear strain.

MM01411 – Foliated, fine-grained grey gneiss.
The rock is a well-foliated (sheared?), fine-grained, uniform rather dark grey gneiss with finely disseminated biotite and a somewhat laminated texture. In the field, it contains scattered light-coloured veins and veins formed during partial melting (anatexis) of the rock. The fine-grained grey gneiss may represent a deformed acid volcanic rock.

MM01412 – Grey biotite gneiss-granitoid.
The gneiss is a homogeneous, rather dark grey, medium-grained biotite gneiss with a foliation of dispersed, fine- to medium-grained biotite. A lineation is also distinct. The biotite gneiss is assumed to represent a deformed non-porphyritic type of granitoid

MM01413 – Lineated, grey, porphyritic biotite gneiss-granitoid.
The rock appears heteroblastic and is grey with a quite good foliation. It consists of stretched feldspar porphyroblasts (half of the rock) embedded in a dark grey, fine-grained, biotite-rich matrix with rather diffuse boundaries to each other. The feldspar porphyroblasts are deformed into 2-5 mm thick, partly recrystallised, flat lenses. The rock represents a deformed porphyritic type of granitoid.

MM01414 – Grey biotite gneiss-granitoid.
The rock is a homogeneous, rather dark grey, medium-grained gneiss-granitoid with a foliation of dispersed stripes of fine- to medium-grained biotite. It is rather well-foliated with a distinct lineation. The biotite gneiss-granitoid appears to represent a deformed non-porphyritic type of granitoid.

MM01415 – Lineated, weakly porphyritic grey biotite gneiss-granitoid.
The rock is grey and somewhat heteroblastic medium-grained with a rather weakly developed foliation and a strong lineation. Normal to the lineation, the rock has a diffusely spotted appearance with scattered larger (≤5 mm) feldspar grains or aggregates (representing deformed and recrystallised phenocrysts?) in an otherwise "granitic" texture with fine-grained biotite. The rock represents a deformed, weakly porphyritic type of granitoid.

MM01416 – Veined, fine-grained grey gneiss.
The rock is a moderately well-foliated, fine-grained, uniform rather dark grey gneiss with finely disseminated biotite and some scattered 1 mm big feldspar grains. It contains scattered, 1-2 cm wide, quartzo-feldspatic veins that formed during partial melting (anatexis) of the rock. In the field, it contains also fine-grained, light-coloured intrusive veins. The fine-grained grey gneiss may represent a deformed acid volcanic rock, that had small feldspar phenocrysts.

MM01417 – Lineated, weakly porphyritic grey biotite gneiss-granitoid.
The rock is grey, medium-grained and somewhat heteroblastic with a rather weakly developed foliation and a good lineation. Normal to the lineation, the rock has a diffusely spotted appearance with scattered larger (≤5 mm) feldspar grains or aggregates (representing deformed and recrystallised phenocrysts?) in an otherwise "granitic" texture with fine-grained biotite (and muscovite?). The rock represents a deformed, weakly porphyritic type of granitoid.

MM01418 – Sheared, grey, porphyritic biotite gneiss-granitoid.
The rock appears heteroblastic and is grey with a well-developed, somewhat wavy foliation and a good lineation. It is uniform consisting of closely packed, flat-lenticular feldspar porphyroblasts embedded in a dark grey, fine-grained, biotite-rich matrix. Normal to the lineation, the deformed feldspar porphyroblasts are 2-6 mm thick, 1-3(-5) cm long and recrystallised into a finely medium-grained aggregate. The rock represents a moderately sheared porphyritic type of granitoid.

MM01419 – Sheared, moderately porphyritic, grey biotite gneiss-granitoid.
The rock is grey and clearly appears heteroblastic with a good foliation and lineation. It contains scattered, deformed, lens-shaped feldspar porphyroblasts with diffuse boundaries to a dominant matrix with fine-grained biotite. The deformed porphyroblasts are 2-5 mm thick, 5-12 mm long and recrystallised into a medium-grained aggregate. The rock represents a deformed, moderately porphyritic type of granitoid.

MM01420 – Light grey rock, from veins in fine-grained grey gneiss.
The rock is a homogeneous, whitish grey, fine-grained quartzo-feldspatic rock with subordinate, finely disseminated biotite. Its foliation and lineation are weakly developed.
The light grey veins form an ubiquitous and important component in the fine-grained grey gneisses and may have formed during partial melting (anatexis) of this rock or have been intruded at an early stage before its deformation.

MM01421 – Light grey rock, from veins in fine-grained grey gneiss.
The rock is a homogeneous, light grey, fine-grained quartzofeldspatic rock with subordinate, finely disseminated biotite. Both foliation and lineation are weakly developed. The light grey veins form an ubiquitous and important component in the fine-grained grey gneisses and may have formed during partial melting (anatexis) of this rock or have been intruded at an early stage before its deformation. The veins are usually some centimetres to 10-20 cm wide.

MM01422 – Lineated, light grey, porphyritic biotite gneiss-granite.
The rock appears heteroblastic and is light grey due to dominance of stretched feldspar porphyroblasts, which give the rock a quite well-developed linear stucture. The deformed porphyroblasts are 0.5-3 cm across and recrystallised into a medium-grained aggregate. The close-lying feldspar porphyroblasts are embedded in a subordinate, dark grey, fine-grained matrix rich in biotite. The rock represents a deformed porphyritic granite which was rich in feldspar phenocrysts.

MM01423 – Lineated, light grey, porphyritic biotite gneiss-granite.
The rock is light grey and appears heteroblastic with a weakly developed foliation and a strong lineation. It consists of stretched feldspar porphyroblasts (2/3 of the rock) embedded in a dark grey, fine-grained, biotite-rich matrix. The stretched feldspar porphyroblasts are ½-2 cm across and recrystallised into a medium-grained aggregate. The rock represents a deformed porphyritic granite which was rather rich in feldspar phenocrysts.

Sample A – Lineated, light grey, porphyritic biotite gneiss-granite.
The rock is light grey and appears heteroblastic with a moderately developed foliation and a strong lineation. It consists of stretched feldspar porphyroblasts (2/3 of the rock) diffusely separated from a dark grey, fine-grained, biotite-rich matrix. The stretched feldspar porphyroblasts are ½-2 cm across and recrystallised into a medium-grained aggregate. The rock represents a deformed porphyritic granite which was rather rich in feldspar phenocrysts.

Sample B – Grey biotite gneiss-granitoid.
The gneiss is a homogeneous, rather dark grey, medium-grained biotite gneiss with a foliation of dispersed, fine- to medium-grained biotite. A lineation is also distinct. The biotite gneiss-granitoid is assumed to represent a deformed non-porphyritic type of granitoid.

Sample C – Veined, fine-grained grey gneiss.
The rock is a foliated, fine-grained, rather dark grey and uniform gneiss with finely disseminated, dispersed biotite. In the field, scattered, fine-grained, light-coloured veins occur in addition, but they are (almost?) absent in the sample. There is a faint grey-scale colour variation/banding in the sample, which seem to reflect a slight variation in the biotite content. The fine-grained grey gneiss may represent a deformed acid volcanic rock.

Sample D – Lineated, light grey biotite gneiss-granite.
The rock is quite even grained, light grey and medium-grained with a weakly developed foliation and a strong lineation. It has a "granitic" texture with medium-grained feldspar and fine-grained biotite. The rock represents a deformed, non-porphyrtic granite, which may be related in origin to the main porphyritic granite.

Sample E – Weakly porphyritic grey biotite gneiss-granitoid.
The rock is grey and heteroblastic medium-grained with a distinct foliation and lineation. It has a diffusely spotted appearance with scattered, up to 1-1½ cm long (normal to the lineation), partly recrystallised feldspar phenocrysts in an otherwise "granitic" texture with fine-grained biotite. The rock represents a deformed, weakly porphyritic type of granitoid.

Sample F – Foliated, moderately porphyritic, grey biotite gneiss-granitoid.
The rock is grey and heteroblastic with a good foliation and lineation. It contains deformed, lens-shaped feldspar porphyroblasts with diffuse boundaries to a dominant matrix with fine-grained biotite. The stretched porphyroblasts are lens-shaped 2-5 mm thick, 5-10 mm long and recrystallised into a medium-grained aggregate. The rock represents a somewhat sheared, moderately porphyritic type of granitoid.

Sample G – Light grey vein rock with thin bands of fine-grained grey gneiss.
The rock is a foliated, heterogeneous, light grey, fine- to medium-grained quartzo-feldspatic rock with subordinate, 2-4 mm thick, diffuse bands of fine-grained grey biotite gneiss. The light grey veins form an ubiquitous and important component in the fine-grained grey gneisses and may have formed during partial melting (anatexis) of this rock or have been intruded at an early stage before its deformation.