NGU Report 2003.012

Geological investigation of the Berakvam quarry and reserve area for hard rock aggregates, Jelsa, Rogaland

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

Geological Survey of Norway
N-7441 Trondheim, Norway
Tel.: 47 73 90 40 00
Telefax 47 73 92 16 20

REPORT

Report no.: 2003.012	ISSN 0800-3416	Grading: ~~Confidential until 10.03.2004~~ Åpen

Title: Geological investigation of the Berakvam quarry and reserve area for hard rock aggregates, Jelsa, Rogaland	
Authors: Mogens Marker	Client: Norsk Stein A/S and NGU
County: Rogaland	Commune: Suldal
Map-sheet name (M=1:250.000) Sauda	Map-sheet no. and -name (M=1:50.000) Vindafjord 1213 I
Deposit name and grid-reference: Berakvam	Number of pages: 30 Price (NOK): Kr. 385,- Map enclosures: 4

Fieldwork carried out: 04.07. - 11.07. 2002 29.07. - 02.08. 2002	Date of report: March 10th 2003	Project no.: 293401	Person responsible: Øystein Nordgulen

Summary:

Geological mapping and interpretation has shown that the rocks in the Berakvam operating quarry can be subdivided in four NW-trending zones, which continue at depth down to the northeast. The southwestern and northeastern zones consist almost exclusively of prophyritic granodiorite while the two central zones consist of prophyritic granodiorite with bodies of gneissic granite and fine-grained grey gneisses with subordinate sheets of pegmatite, respectively.

Since Norsk Stein A/S wish to extract rocks down to a level of –50 m in the present quarry, four boreholes supplemented geological mapping of the quarry. The interpretation concludes that the rock volume between the quarry's present level and the –50 m level in the southwestern 3/5 of the quarry predominantly consists of porphyritic granodiorite of known good mechanical quality. In the remaining northeastern 2/5 of the quarry, the rock volume down to the –50 m level consists of porphyritic granodiorite intercalated with c. 20% fine-grained grey gneisses. The latter will possibly raise the average mechanical properties, as argued from the petrological analysis. The fine-grained grey gneisses contain scattered <5 m wide sheet-like bodies of pegmatite a 100 m wide zone in the southwest, which locally could reduce the homogeneity and quality.

The geological investigation of the Berakvam reserve area shows that the rocks here must have similar or better mechanical properties than in the present quarry. The mapping showed that the northern and eastern parts of the reserve area predominantly consist of uniform porphyritic granodiorite of established good mechanical quality. The western part consists of porphyritic granodiorite with plenty of lenses of fine-grained grey gneisses, and some of small-porphyritic diorite. Particularly interesting is a large irregular body of fine-grained grey gneisses that dominates the southern half of this part of the reserve area. As for the quarry, the petrological analysis of rocks from the area indicate that the fine-grained grey gneisses may show better mechanical properties than those obtained for the porphyritic granodiorites.

At the moment, virtually no data exist to document the assumed better mechanical property of the fine-grained grey gneisses. Because they are so important in volume in the western part of the reserve area, close to the present quarry, mechanical testing of these gneisses is recommended.

Keywords: Geology	Hard rock aggregates	Geological mapping
Petrology	Texture	Structural geology
Mechanical properties	Core drilling	3-D model

CONTENT

NORSK SAMMENDRAG 4
1. INTRODUCTION 5
2. FIELD INVESTIGATIONS 6
2.1. Previous work 6
3. GEOLOGY 6
3.1. Introduction to the geological maps 6
3.2. Rocks 7
3.3. Geology of the Berakvam operating quarry 11
3.3.1. Present quarry 11
3.3.2. Geology down to level –50 m 13
3.4. Geology of the Berakvam reserve area 15
3.5. Joints 16
3.6. Petrology 18
3.6.1. Introduction 18
3.6.2. Petrology of the Berakvam rocks 19
4. ROCKS AND MECHANICAL PROPERTIES 20
5. CONCLUSIONS AND RECOMMENDATIONS 21
6. REFERENCES 22

ENCLOSURES

The Berakvam operating quarry – Geological map in scale 1:2000

The Berakvam operating quarry – Cross sections in scale 1:2000

The Berakvam reserve area – Geological map in scale 1:5000

The Berakvam reserve area – Cross sections in scale 1:5000

APPENDICES

Appendix 1: Drill-core logs of boreholes BH 1-4 by Reidar Blesvik

Appendix 2: Berakvam – Description of samples for thin section

NORSK SAMMENDRAG

Undersøkelsene ble utført i juli 2002 med kartlegging av geologien i det eksisterende bruddet til Norsk Stein A/S ved Berakvam og i et potensielt nytt uttaksområde nord for dette. Formålet var å vurdere potensialet for pukk med gode mekaniske egenskaper ned til en dybde av -50 meter i det eksisterende bruddet samt kartlegge fordelingen av bergartstyper og -kvaliteter i det potensielle nye uttaksområdet. I tilknytning til det førstnevnte formålet ble det utført fire kjerneboringer som ble plassert strategisk i det eksisterende bruddområdet slik at berggartsfordelingen og strukturene mot dypet kunne bestemmes mer presist. Bergartene i det eksisterende brudd og i det potensielle nye uttaksområdet er de samme. Kun fordelingen og dermed mengdeforholdet mellom dem varierer. Alle bergartene viser en sekundær omdannelse med grønnlig epidot, som forekommer i mm til cm tynne årer, uregelmessig fordelt i bergartene. Denne omdannelsen, især en sekundær omdannelse av plagioklas feltspat, synes ut fra erfaringen generelt å betinge en forbedring av de mekaniske egenskapene for bergarter hvor plagioklas dominerer over alkalifeltspat, som det oftest er tilfellet i Berakvam-området.

Geologisk kartlegging og tolkning viser at bergartene i det eksisterende bruddet kan deles i fire NV-gående soner, som fortsetter i dypet mot nordøst. De nordvestlige og nordøstlige sonene består nesten utelukkende av porfyrittisk granodioritt mens de to sentrale sonene, som stadig domineres av porfyrittisk granodioritt, inneholder legemer av henholdsvis granitt og finkornet grå gneis med spredte lag av pegmatitt.

Etter som Norsk Stein A/S ønsker å bryte stein for pukk ned til –50 m i det eksisterende bruddet, ble den geologiske kartleggingen her supplert med fire kjerneboringer ned til dette nivået. Det kan konkluderes med at bergartsvolumet mellom dagens uttaksnivå og –50 m nivået i de sørvestlige 3/5 av bruddet helt domineres av porfyrittisk granodioritt av kjent god mekanisk kvalitet. I de resterende 2/5 av bruddet består bergartsvolumet ned til – 50 m nivået av porfyrittisk granodioritt med lag av finkornet grå gneis (ca. 20%). Mens den porfyrittiske granodioritten også her må antas å ha gode mekaniske egenskaper, vil innholdet av finkornet grå gneis antagelig heve de gjennomsnittlige mekaniske egenskapene, som antydet av den petrologiske analysen (finkornet grå gneis var etter opplysninger fra driver også attraktiv da den ble uttatt på et høyere nivå i det eksisterende bruddet). I den sydvestlige delen er der imidlertid en ca. 100 m bred sone som inneholder enkelte, < 5 m brede lagformete legemer av pegmatitt, som lokalt kan redusere homogenitet og kvalitet.

Den geologiske undersøkelsen av det potensielle uttaksområdet nordøst for det eksisterende bruddet viser, at bergartene her må ha tilsvarende eller enda bedre mekaniske egenskaper enn i det nåværende bruddet. I tillegg inneholder det potensielle uttaksområdet få pegmatitter og granitter og vil derfor gi mer homogent produkt. Kartleggingen viste at de store nordlige og østlige delene av det potensielle uttaksområdet nesten utelukkende består av ensartet porfyrittisk granodioritt av påvist god mekanisk kvalitet. Den vestlige delen består av porfyrittisk granodioritt med tallrike linser av finkornet grå gneis, samt enkelte av små-porfyrisk dioritt. Et stort uregelmessig legeme av finkornet grå gneis dominerer den sørlige halvparten av denne delen av det potensielle området. Som i det eksisterende bruddet, sluttes det ut fra den petrologiske analysen utført for det potensielle uttaksområdet, at de finkornede grå gneisene også her kan ha bedre mekaniske egenskaper enn vist for porfyrittisk granodioritt.

I øyeblikket eksisterer det i realiteten ingen data som vil kunne bekrefte eller avkrefte de antatte bedre mekaniske egenskapene for finkornet grå gneis. Da de volummessig er så viktige i den vestlige delen av det potensielle nye uttaksområdet, foreslås det at det utføres et mekanisk testprogram for disse gneisene. Især det store volumet av finkornet grå gneis rett nord for det eksisterende bruddet kan vise seg å ha de beste mekaniske egenskapene i hele Berakvam-området.

1. INTRODUCTION

The Geological Survey of Norway (NGU) has carried out a geological investigation of the operating quarry for hard rock aggegates at Berakvam and its reserve area immediately north of the quarry near Jelsa, Suldal commune in Rogaland county. Norsk Stein A/S commissioned the task. The main focus has been on geological mapping and interpretation combined with microscopical analyses of main rock types. As part of the program, four boreholes were drilled in the operating quarry in order to, in combination with surface mapping, estimate the distribution of rocks down to a planned production base at –50 m. Engineer Reidar Blesvik, Kon-Sul as, has logged the drill cores and his results are incorporated in this report.
The final objective for the investigation was to establish, map and describe the constituting rocks and estimate their spatial distribution in both the operating quarry and the reserve area. By having an eye to previous mechanical test results, the volume and distribution of rock qualities for extraction of future hard rock aggregates is evaluated.

Trondheim, March 10th 2003
Program for mineral resources

Mogens Marker
Senior geologist, Ph.D.

Peer-Richard Neeb
Program leader

2. FIELD INVESTIGATIONS

The geological mapping of the Berakvam quarry and reserve area was carried out July 4th-11th and July 29th-August 2nd 2002. The quarry was mapped in the first period and on this basis the locations of four boreholes were selected in order to determine the structure and distribution of rocks at depth down to level –50 m. These were drilled in mid-July and later logged by Reidar Blesvik, Kon-Sul A/S. During the mapping twenty samples of representative rock types were collected for microscopical analyses.

The topographical basis for the mapping of the reserve area was 1: 5 000 maps (5 m contour distance) issued by Økonomisk Kartverk (AO032-5-1, AO033-5-3), while a special map with 1 m and 0.5 m contour distance provided by Norsk Stein A/S was used for the quarry area. Only an older version of the latter was available for the mapping in which location of quarry walls was outdated. Therefore, all main features in the quarry were positioned by using GPS. After the fieldwork, a new and more updated version of the map became available, which has been modified to reflect the situation at mid-July 2002 and used in the compilation of the geology in the quarry. This caused some troubles in the transference of geological data to the final quarry map, though almost all of these now are believed solved. Only the relative positioning of the granites between different quarry walls in the central eastern part of the quarry (around sample MM 02104) still remains imprecise. This minor problem can only be recovered by re-locating mapped geological boundaries in the quarry, but it does not influence the general interpretation.

2.1. Previous work

The Berakvam hard rock aggregate deposit has previously been investigated by Blesvik (1987), Blesvik and Kristensen (1987), Schellenberg (1996) and Erichsen (1999). These investigations deal with a combination of geological and mechanical issues with emphasis on the mechanical properties of the rocks, and no proper mapping or geological investigation have been carried out. This has caused introduction of confusing and inconsistent terminology for rocks and textures, which in many cases makes it difficult to identify even rocks for which mechanical properties are quoted. Also microscopical descriptions are generally insufficient.

3. GEOLOGY

3.1. Introduction to the geological maps

The geological mapping and interpretation of the Berakvam deposit is for the purpose of description divided into two parts: The operating quarry and the reserve area north of this.

In the operating quarry, the walls framing the different quarry levels were mapped in detail and depicted on the geological map as wall surfaces sloping out from the centre of the quarry. In this way the densely coloured concentric strips on the map depict geological sections shown in the quarry walls that surround the different levels. The quarry walls are usually 12 metres high with a subvertical to steep dip. The quarry levels, whose altitude is shown on the geological map, are covered with a thin layer of rock debris from the extraction and therefore rarely reveal any exposures. Within the present concession area, which is marked as limits for the geological map of the operating quarry, the northern and eastern parts are not yet quarried.

Surface mapping of these parts forms together with the mapping of quarry walls the basis for the interpretation.

Surface mapping alone was carried out in the reserve area north of the operating quarry. The area is generally well exposed except for minor parts in the south, which have a Quaternary cover. Therefore, it is likely that the mapping has disclosed all important rock units and that the drawn geological boundaries are confident. However, in moderately exposed areas as in the south some boundaries still have to be inferred. There is no evidence that the Quaternary cover, even in the south, attains any significant thickness.

The Berakvam operating quarry and the reserve area contain similar rock types though not always in the same proportion. Therefore the rocks for the two areas will be described together. On the geological maps mapped exposures are shown by stronger colour intensity. Not all exposures were visited in areas covered by surface mapping, which means that the total area of exposed rocks is larger than it appears from the maps.

3.2. Rocks

The rocks in the Berakvam operating quarry and reserve area are all of igneous origin. These have later been variably deformed, metamorphosed and recrystallised, but commonly original igneous features, mainly porphyritic textures, can easily be recognised. During deformation the rocks were metamorphosed in amphibolite facies. All rocks show secondary alteration with greenish epidote, which also occurs in mm to cm thick veins that are unevenly distributed in the rocks. But apart from alteration of plagioclase, the effects of retrogression of the amphibolite facies mineralogy outside these veins are surprisingly limited. The rocks in the Berakvam area can be divided into three main groups (see geological maps):

1: An older group consists of fine-grained grey gneisses of dacitic to rhyodacitic composition (Figs. 1 and 2), which form layers or lens-shaped bodies embedded in porphyritic granodiorite in the northeastern part of the operating quarry and the western part of the reserve area. A large irregular body of fine-grained grey gneiss occurs in the southwestern part of the reserve area, just north of the operating quarry. The fine-grained grey gneisses are because of their uniformity assumed to represent deformed volcanic rocks. In the central part of the reserve area occur a few lens-shaped bodies of likewise quite fine-grained, deformed small-porphyritic diorite, which seems to be related in origin to the fine-grained grey gneisses they are intermingled with.

2: The slightly younger group of porphyritic granodiorite (Fig. 3) dominates in both the operating quarry and in the reserve area, where it as a plutonic rock phase intrudes the former group of fine-grained grey gneisses. Both rock groups were probably formed in the same igneous complex and have subsequently been deformed together. The porphyritic granodiorite varies in colour from paler to darker shades of grey, and with increasing deformation from almost massive to foliated or locally mylonitic types (Fig. 4).

3: The third group comprises the youngest rocks of the area, namely crosscutting granite, pegmatite and amphibolite. Apart from larger granite bodies they have often been deformed into some degree of concordance with the prevailing NE-dipping foliation of the area. Granites (Fig. 5) are only significant in the central part of the operating quarry and close to the road in the southwesternmost part of the reserve area. Coarse-grained pegmatites (Fig. 6) occur most frequently in the same general area, but are only abundant as <5 m thick

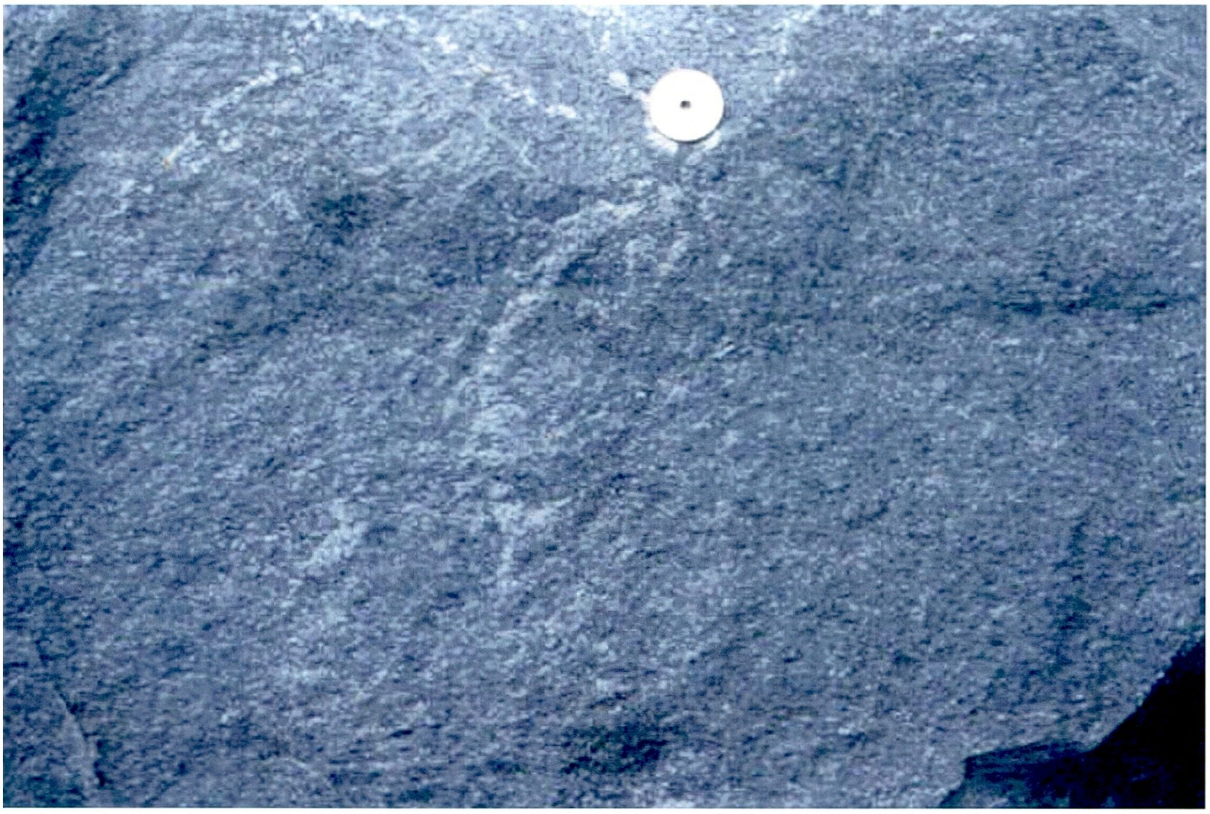


Fig. 1. Fine-grained grey gneiss; homogeneous and weakly foliated. Coin diameter 26 mm.

Fig. 2. Fine-grained grey gneiss; diffusely banded and foliated. Coin diameter 26 mm.

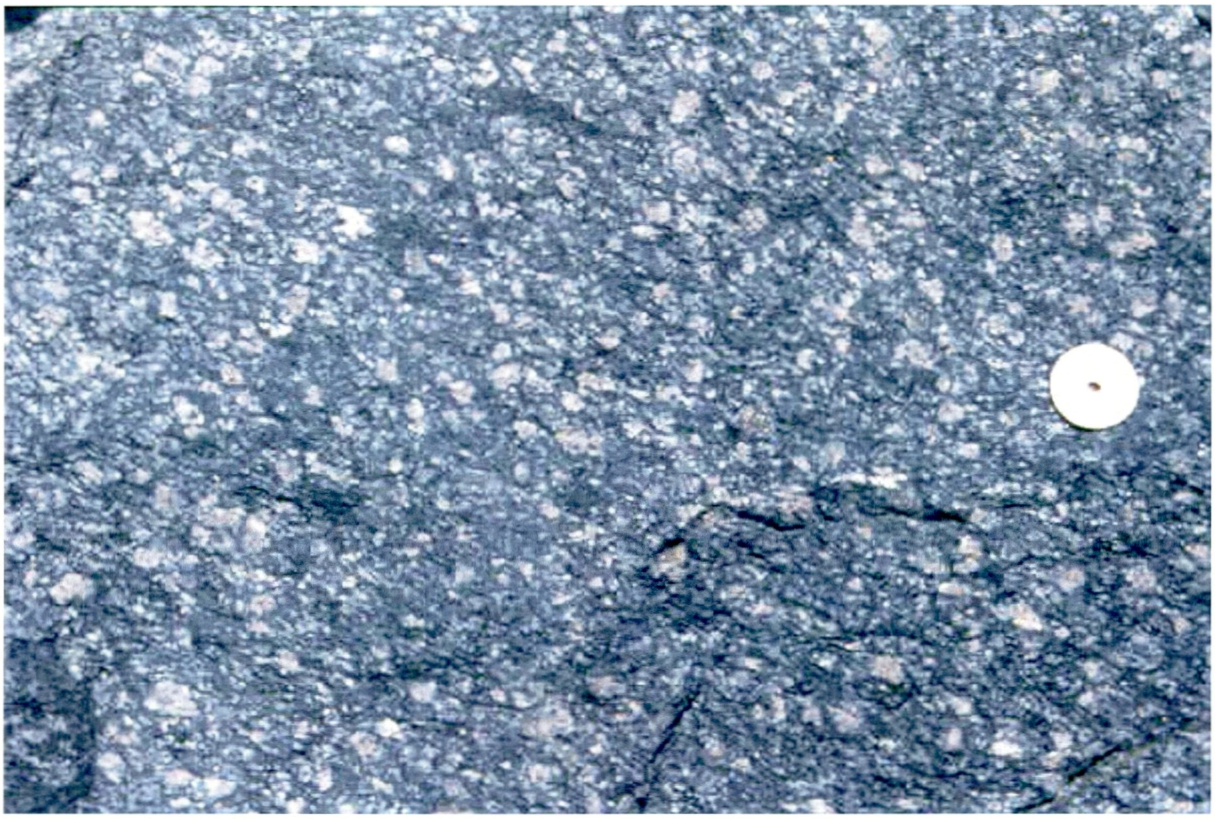


Fig. 3. Moderately foliated porphyritic granodiorite with pale feldspar phenocrysts. Coin diameter 26 mm.

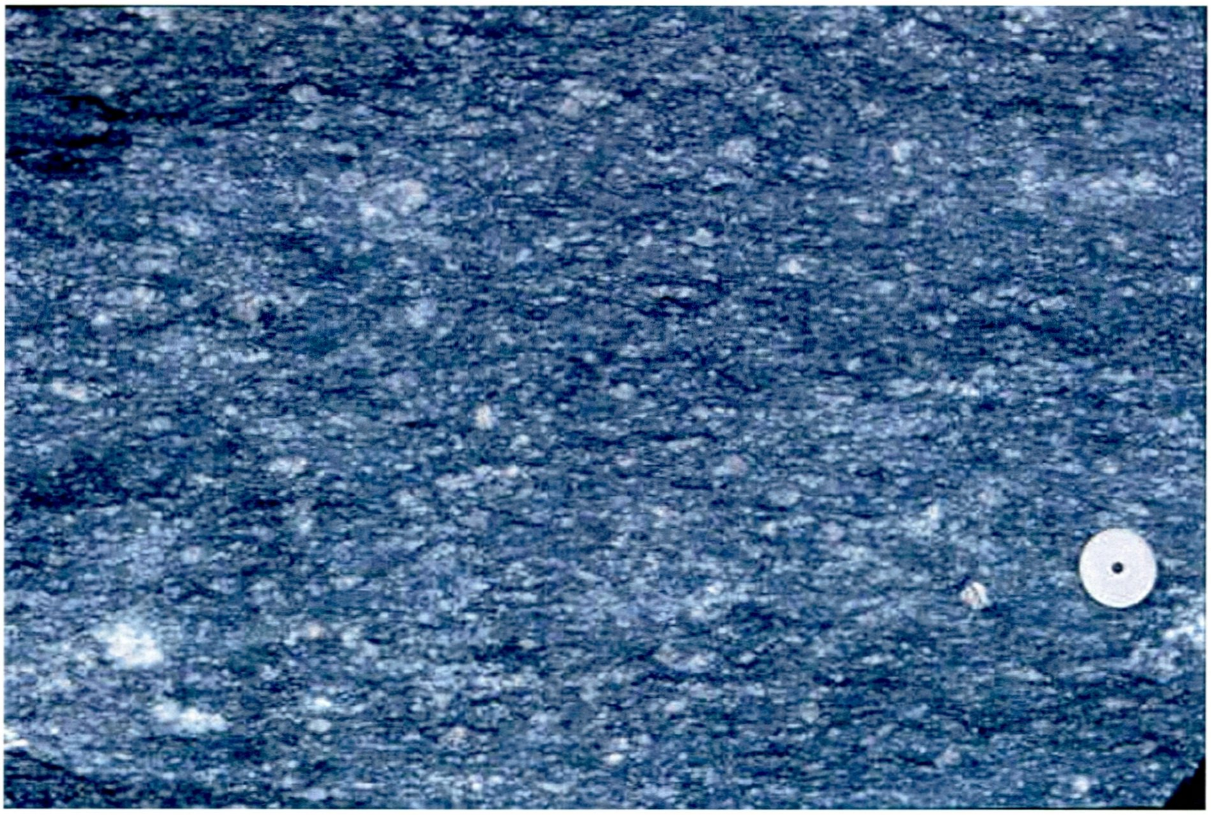


Fig. 4. Well-foliated, mylonitic porphyritic granodiorite with drawn-out feldspar phenocrysts. Coin diameter 26 mm.

Fig. 5. Pale grey granite; weakly foliated although gneissic. Coin diameter 26 mm.

Fig. 6. Sheet of coarse-grained white pegmatite from Zone III in operating quarry. The c. 2 m wide pegmatite is intruded into fine-grained grey gneiss and porphyritic granodiorite. Length of compass is about 8 cm.

sheets in the north-central part of the quarry. Amphibolites are very rare and have only been observed as small insignificant bodies in the northern walls of the operating quarry, where they seem to be mafic dykes disrupted during deformation. The mapping showed that the rocks of this group mainly occur in a NW-trending zone through the central part of the operating quarry, and that they only occur insignificantly in the reserve area.

As mentioned above, the previous nomenclature for the Berakvam rocks is confusing, and the following additional terms (translated into English; list probably not complete) have earlier been used for the rock units established in this report:

Fine-grained grey gneisses: *Biotite gneiss* (Schellenberg 1996, Erichsen 1999).

Porphyritic granodiorite: *Dark mylonitic gneiss*, *mylonitic gneiss* or *mylonite* (Blesvik 1987, Blesvik & Kristensen 1987, Erichsen 1999 (one of his samples (= EE 99-6) is mylonitic)); *dark granodiorite* or *granodiorite* (Blesvik & Kristensen 1987, Schellenberg 1996); *gneiss granite* (Erichsen 1999, for a granitic variant of porphyritic granodiorite (= EE 99-2)); *dark gneisses (Dunkle Gneisse)* (Schellenberg 1996).

Granite and gneissic granite: *Quartz-feldspar fels* (Schellenberg 1996 (may also include pegmatite)); *Light coloured granitic gneiss (heller granitischen gneiss)* (Schellenberg 1996).

Pegmatite: *Coarse-grained granite* (Blesvik 1987).

Amphibolite (deformed mafic dyke?): *Diorite* (Erichsen 1999).

3.3. Geology of the Berakvam operating quarry

The geology of the operating quarry appears from the geological map. The foliation and most of the out-wedging layers of fine-grained grey gneiss generally strike NV-SE with 20-30^{0} NE dips.

3.3.1. Present quarry

For the purpose of description, the quarry has been subdivided into four NW-trending zones, without sharp mutual boundaries, which continues to the NE at depth. Note that in the cross sections the zone boundaries refer to the (original) surface, and that the zones dip to the northeast. From southwest to northeast these are (see geological map and cross section for the operating quarry):

Zone I is built up of uniform, weakly to moderately foliated porphyritic granodiorite and is almost devoid of other rock types.

Zone II consists of a similar porphyritic granodiorite as in Zone I, but contains in addition several larger and smaller bodies of weakly foliated pale grey granite. The biggest granite body occurs in the northwest where it continues under the road into the old quarry area. This body tapers out quickly southeastwards, and granite appears to be rare in the central part of the quarry. In the southeastern part of the zone granite occurs in several irregular bodies, at the same time as 20-40 m thick lenses of fine-grained grey gneiss appears, which disappear northwestwards. Both the latter and the enclosing prophyritic granodiorite are quite well foliated in this part of Zone II, a well-developed foliation that cannot be traced farther to the northwest. The irregular distribution and shapes of the intrusive granite bodies suggest that occurrence of granite at depth in Zone II is a bit difficult to predict from geological mapping only.

Zone III consists of moderately to well-foliated porphyritic granodiorite that contains several tapering layers or long flat lenses of fine-grained grey gneiss amounting to 20-25% by volume. More prominent layers are 5-20 m thick but several 1-2 dm-thick minor layers also occur. Similarly, thin layers or deformed veins of porphyritic granodiorite may occur in many of the fine-grained grey gneisses. The zone is further characterised by containing coarse-grained whitish pegmatites and, less commonly, weakly foliated pale grey granite. As shown by the map, the largest pegmatites form 75-150 m long and 3-5 m thick sheet-like bodies (Fig. 7), which appear to be roughly parallel to the general NE-dipping structure despite their crosscutting nature. In addition, several less than a few decimetres thick pegmatite and granite dykes/veins occur that may either be crosscutting or parallel to the foliation. More as a curiosity, the zone contains a few lenses of homogeneous fine-grained amphibolite (at levels +29 m and +53 m) suspected to represent deformed and disrupted dolerite dykes. Also a few thin, concordant bands of (biotite-rich?) ultramafic rock containing pyrite occur in this zone mainly, but are like the amphibolite very insignificant in volume (and not shown in sections).

Zone IV consists of uniform, weakly to moderately foliated porphyritic granodiorite with few other rock types intercalated. An exception is a few rather thin flat lenses of fine-grained grey gneiss, and two of granite, that occur in the southern part of the zone.

Fig. 7. Zone III in northern part of present quarry consisting of porphyritic granodiorite with lenses of fine-grained grey gneisses (both dark). 3-5 metres thick sheets of pegmatites (three different levels) show with pale colour in the left part of the picture. View to northeast from level +17 m.

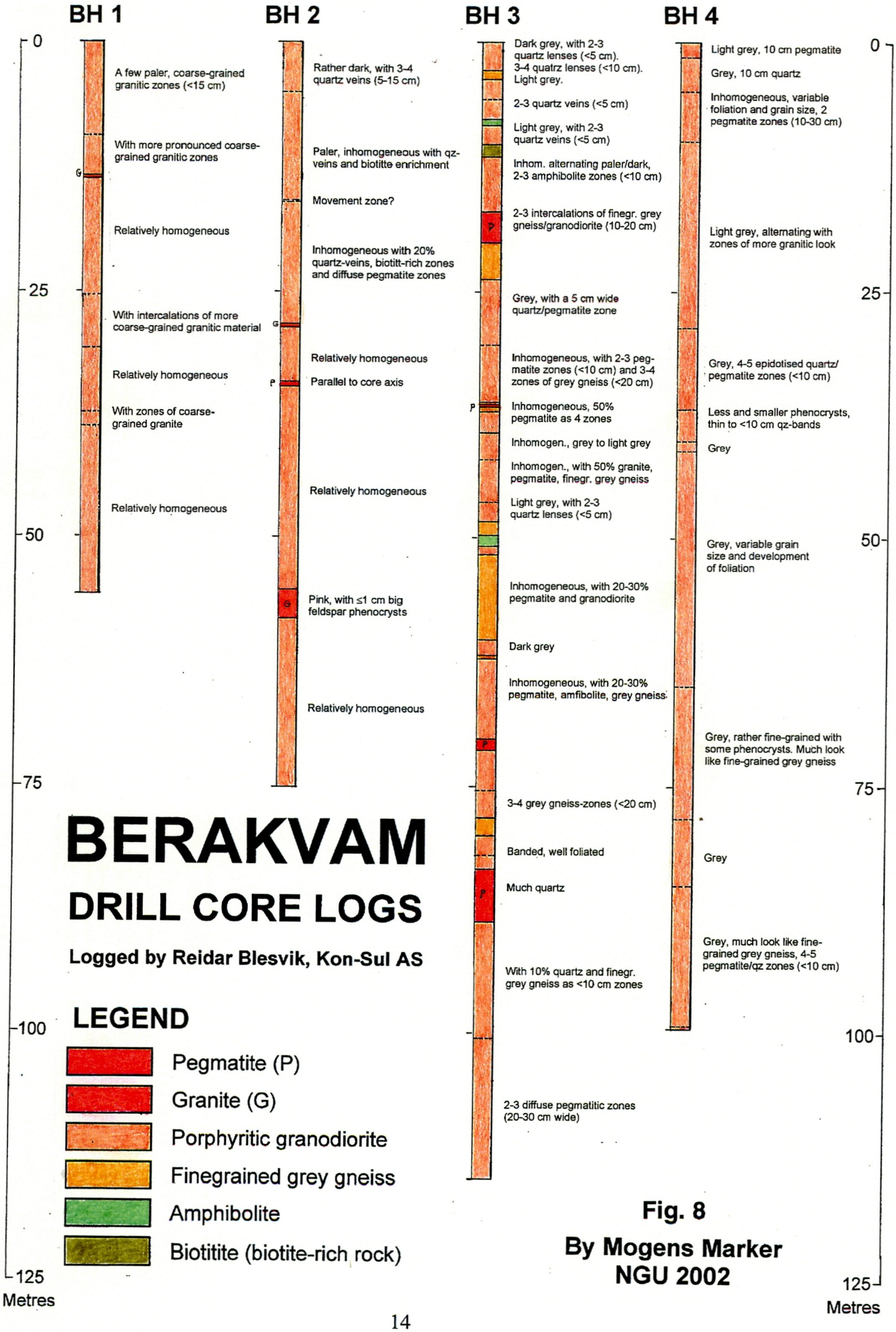
3.3.2. Geology down to level –50 m

Norsk Stein A/S wish to extract rocks for aggregates down to level –50 m in the present quarry, where the bottom levels today are +5 m and +17 m, respectively. As described above, the four zones in the operating quarry must be expected to continue at depth as tabular bodies that dip 20-30° NE. This implies e.g. that the 'pure' porphyritic granodiorite of Zone I will dominate at a still deeper level when moving northeastwards in the quarry.

In order to verify the deep structure and distribution of rocks down to –50 m, deduced from the mapping of the quarry, four boreholes (BH 1-4) were placed strategically in the present quarry area. The locations of the boreholes are shown on the geological map of the operating quarry. BH 1 and BH 4 were drilled vertically while BH 2 and BH 3 were drilled with a 65° plunge to the SW (direction 220°). Reidar Blesvik, Kon-Sul as, carried out the logging of the drill cores, which appears from Appendix 1. His results are presented graphically in the drill core logs, Fig. 8. The combined results from interpretation of the surface mapping and borehole data are illustrated in four cross sections through the operating quarry. In these sections full line boundaries have the highest degree of confidence while stippled and dotted boundaries are deduced and suggested, respectively.

As the logs for BH 1 and BH 2 show, porphyritic granodiorite must be expected to dominate between todays extraction level and the –50 m level in both Zone 1 and Zone 2. BH 2 in the middle part of Zone 2 has only minor granite and few pegmatites, and in accordance with the mapping results this suggests that Zone 2 is lacking the less attractive granite in the central part of the quarry. However, this does not exclude that unpredictable granite bodies still may occur in the distal nortwestern and southeastern parts of Zone 2. Cross section D-D' shows that granite indeed is expected to continue at depths in the westernmost part of the quarry, but since this area lies at the margin of the rock volume planned for extraction, this is not so important for future production. Accordingly, it is concluded that the rock volume between the quarry's present extraction level and the –50 m level in Zone 1and Zone 2 is expected to consist predominantly of porphyritic granodiorite of known quality.

In the northeastern part of the quarry, the boreholes BH 3 and BH 4 penetrate Zone III and Zone IV of porphyritic granodiorite with layers of fine-grained grey gneiss/pegmatite and quite uniform porphyritic granodiorite, respectively. As illustrated by the cross sections for the operating quarry, BH 3 confirms that Zone III continues down northeastwards at depths as predicted. The attractive fine-grained grey gneiss layers known from the surface are also important in BH 3, and they correlate well with those mapped in the quarry. As in the quarry, separate layers or thin veins of pegmatite also occur in BH 3 without being predominant. Below c. 90 m, BH 3 seems to penetrate into porphyritic granodiorite of Zone II. Borehole BH 4 penetrates Zone IV and consists of quite uniform porphyritic granodiorite without pegmatite and granite as deduced from the surface mapping (see cross sections). The lower part of BH 4 (below 65 m) contains according to the log description (Appendix 1) a large proportion of rocks looking like fine-grained grey gneiss. This is in agreement with the interpretation from surface mapping that BH 4 at depths should penetrate the upper part of Zone III with the fine-grained grey gneiss layers. With reservation for unpredictable but probably subordinate layers of pegmatite, it must be concluded that the northeastern part of the quarry also contain rocks with good technical properties down to the –50 m level. The quality may even be better than in the southwestern part of the quarry because of a larger content of fine-grained grey gneiss, which is considered more attractive during the present extraction of rocks.


BH 1
BH 2
BH 3
BH 4
0
25
50
75
100
125
Metres
A few paler, coarse-grained granitic zones (<15 cm)
With more pronounced coarse-grained granitic zones
G
Relatively homogeneous
With intercalations of more coarse-grained granitic material
Relatively homogeneous
With zones of coarse-grained granite
Relatively homogeneous
Rather dark, with 3-4 quartz veins (5-15 cm)
Paler, inhomogeneous with qz-veins and biotitte enrichment
Movement zone?
Inhomogeneous with 20% quartz-veins, biotitt-rich zones and diffuse pegmatite zones
G
Relatively homogeneous
P
Parallel to core axis
Relatively homogeneous
G
Pink, with ≤1 cm big feldspar phenocrysts
Relatively homogeneous
Dark grey, with 2-3 quartz lenses (<5 cm).
3-4 quatrz lenses (<10 cm).
Light grey.
2-3 quartz veins (<5 cm)
Light grey, with 2-3 quartz veins (<5 cm)
Inhom. alternating paler/dark, 2-3 amphibolite zones (<10 cm)
2-3 intercalations of finegr. grey gneiss/granodiorite (10-20 cm)
P
Grey, with a 5 cm wide quartz/pegmatite zone
Inhomogeneous, with 2-3 pegmatite zones (<10 cm) and 3-4 zones of grey gneiss (<20 cm)
P
Inhomogeneous, 50% pegmatite as 4 zones
Inhomogen., grey to light grey
Inhomogen., with 50% granite, pegmatite, finegr. grey gneiss
Light grey, with 2-3 quartz lenses (<5 cm)
Inhomogeneous, with 20-30% pegmatite and granodiorite
Dark grey
Inhomogeneous, with 20-30% pegmatite, amfibolite, grey gneiss
P
3-4 grey gneiss-zones (<20 cm)
Banded, well foliated
P
Much quartz
With 10% quartz and finegr. grey gneiss as <10 cm zones
2-3 diffuse pegmatitic zones (20-30 cm wide)
Light grey, 10 cm pegmatite
Grey, 10 cm quartz
Inhomogeneous, variable foliation and grain size, 2 pegmatite zones (10-30 cm)
Light grey, alternating with zones of more granitic look
Grey, 4-5 epidotised quartz/pegmatite zones (<10 cm)
Less and smaller phenocrysts, thin to <10 cm qz-bands
Grey
Grey, variable grain size and development of foliation
Grey, rather fine-grained with some phenocrysts. Much look like fine-grained grey gneiss
Grey
Grey, much look like fine-grained grey gneiss, 4-5 pegmatite/qz zones (<10 cm)
BERAKVAM
DRILL CORE LOGS
Logged by Reidar Blesvik, Kon-Sul AS
LEGEND
Pegmatite (P)
Granite (G)
Porphyritic granodiorite
Finegrained grey gneiss
Amphibolite
Biotitite (biotite-rich rock)
Fig. 8
By Mogens Marker
NGU 2002

3.4. Geology of the Berakvam reserve area

The reserve area for future extraction of hard rock aggregates for the Berakvam enterprise lies immediately northeast of the present quarry. It is limited by road R 517 in the west and north and overlying Caledonian rocks (Ryfylke schist) in the southeast that roughly follow a line from the farm Ytre Høyvik to the east corner of the present quarry.

The northern and eastern part of the Berakvam reserve area consists predominantly of porphyritic granodiorites showing varying degree of deformation (see geological map and cross sections). The foliation dips generally 25-40° to the northeast. The main rock is a weakly to moderately foliated porphyritic granodiorite similar to that in the operating quarry. The most massive and slightly paler grey variants (dotted on the map) occur particularly in the northeastern part of the area and in limited areas between Straumberget and the present quarry. The paler colour seems to be caused by a slightly higher proportion of feldspar phenocrysts than in the main type. Main type porphyritic granodiorite with an obvious foliation occurs in a NW-trending zone through the central part of the reserve area (see geological map). Well- foliated to mylonitic porphyritic granodiorite occurs in a west-facing cliff east of Straumberget and, not least, in the easternmost part of the reserve area southwest of Ytre Høyvik. In the latter, the foliation have sub-horizontal to gentle dips, and structural measurements indicate that the well-foliated rocks here lies in a shallow, gentle synform on top of weakly foliated porphyritic granodiorite. A thin, NE-dipping well-foliated zone with off-shots connects the eastern and western areas. They probably represent minor thrust zones (kinematic indicators show thrusting to the SE).

In the western part of the reserve area, north of the operating quarry, weakly to moderately foliated porphyritic granodiorite contains plenty of lenses and bodies of fine-grained grey gneisses, some of which are quite large (see geological map and cross sections). In addition, small-porphyritic diorite occurs in the north either as separate lenses or associated with fine-grained grey gneiss. Like in the quarry, the fine-grained grey gneisses may subordinately contain intruded veins of porphyritic granodiorite. Because of intrusive relations between the rocks, the continuation of the lenses with fine-grained grey gneiss and small-porphyritic diorite at depths is rather unpredictable, but is likely to resemble the pattern illustrated in the cross sections through the reserve area. Near road R 517 south of Straumberget a well-foliated fine-grained dark grey gneiss occurs with likewise well-foliated porphyritic granodiorite along its borders. This rock is not considered further, since it forms a southward-closing fold structure that does not enter the proper reserve area (see geological map).

Of particular interest is the large body of fine-grained grey gneisses that occurs immediately north of the operating quarry since this body forms the largest field of these rocks recorded in the area (see geological map). It is interesting because fine-grained grey gneiss is considered more attractive for hard rock aggregates during the present mining. The mapping showed that the body has a complicated shape as the result of irregularly intruded porphyritic granodiorite. This also means that its shape at depth cannot be predicted with great certainty from mapping results alone as illustrated in cross section C-C' (reserve area). It is however likely that the body continues at depth since both its NE- and SW-boundary dips 25-45° NE, which makes it probable that fine-grained grey gneisses also dominate at depth. Several larger bodies of gneissic granite similar to that in the operating quarry intrude the western part of the fine-grained grey gneiss body. All are recorded close to road R 517, and there is no evidence that they will be important at depth further to the east in the grey gneiss body.

The geological investigations of the reserve area show that this area is build up of the same rock types as in the operating quarry. Therefore it must be expected that the reserve area contain rocks with similar mechanical properties as those known from the quarry. The large volume of fine-grained grey gneisses in the western part of the reserve area may even indicate that the mechanical properties may be improved. At the same time, only few pegmatites and granites have been observed in the reserve area, which is different from the operating quarry.

3.5. Joints

All larger joints observed during the fieldwork were measured both in the operating quarry and the reserve area. The most prominent ones have been marked on the geological maps of the two areas, which also show the orientation of measured joints. Stereographic plots of the joint measurements (Fig. 10) show that a steeply dipping set of NE-SW and NW-SE joints dominate in both the operating quarry and the reserve area, and that the two areas as expected have a very similar pattern. No displacement has been observed for any of the joints. The two dominating joint directions, by the way, coincide with the two wall directions outlining the present quarry.

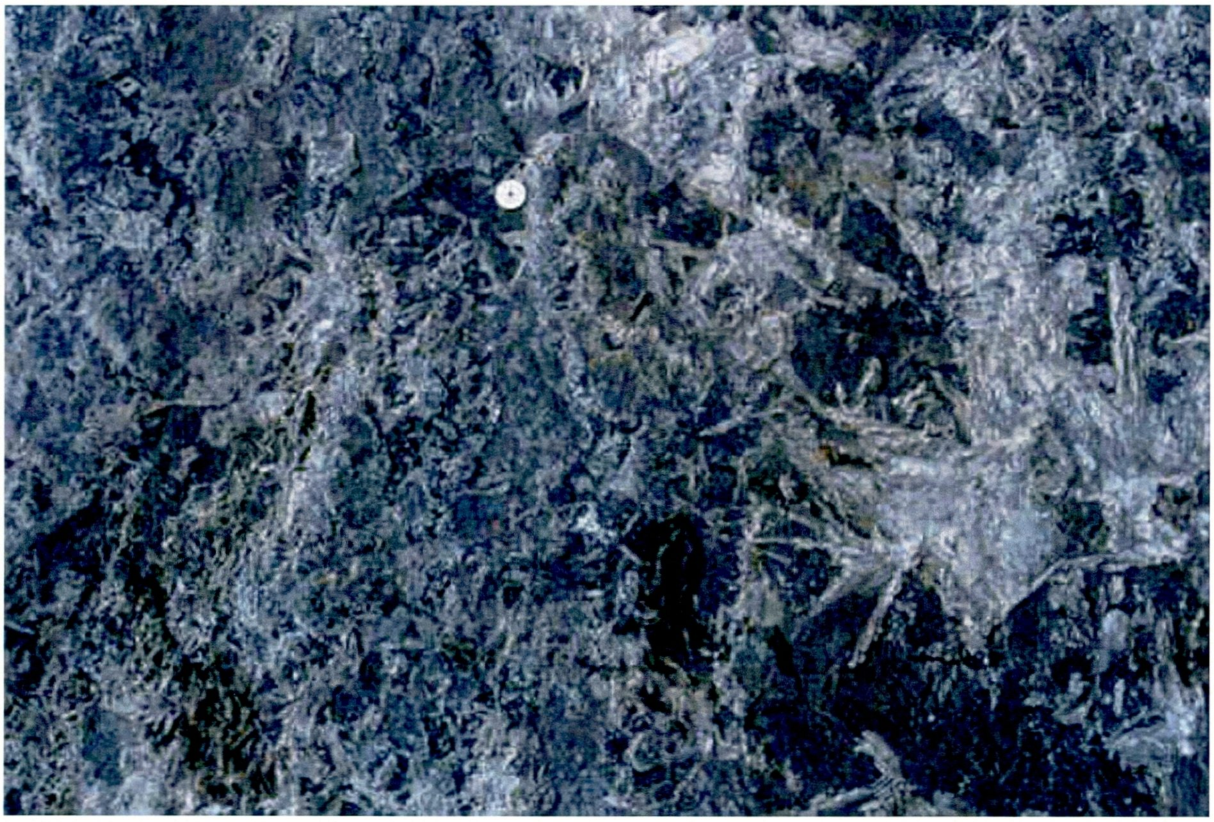
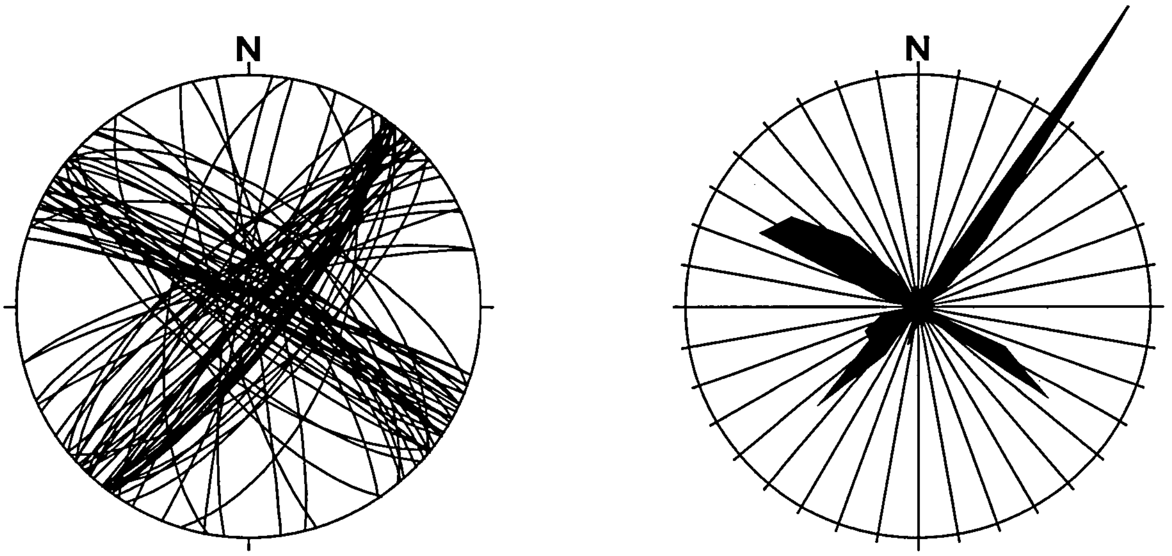
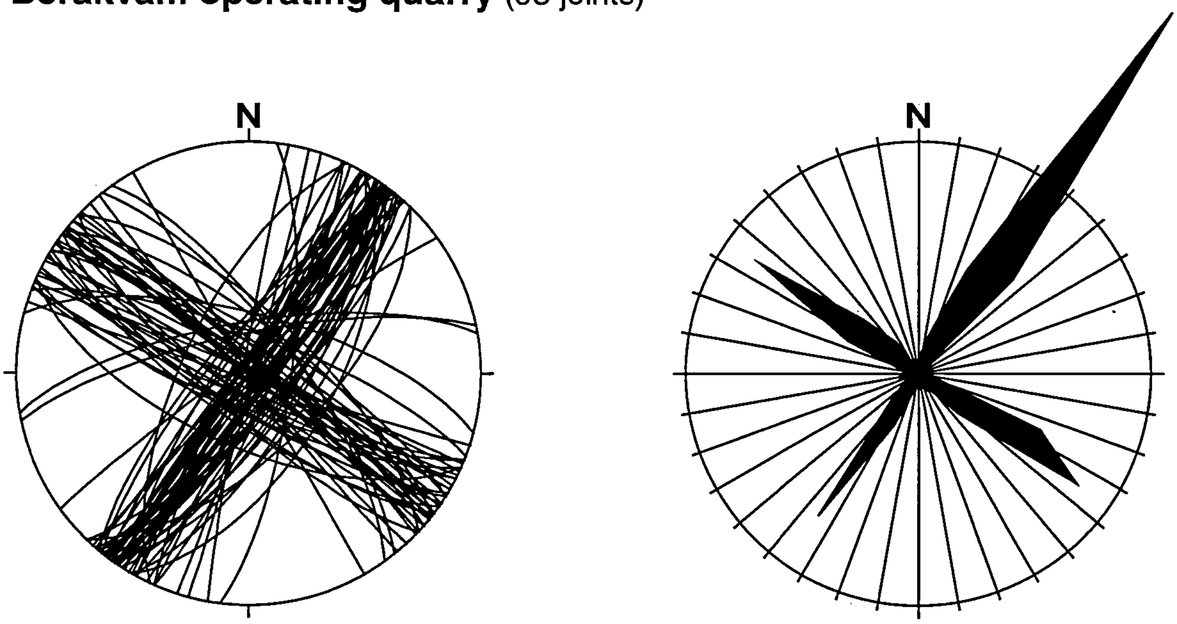


Fig. 9. Joint filled with coarse-grained carbonate in NW-SE trending joint from the southwestern limit of the operating quarry. Coin diameter 26 mm.

The majority of the joints show neither alteration nor coating. There is, however, a group of joints that are filled with carbonate and often are rusty on weathered surfaces. The carbonate fillings are from a few cm to 20 cm thick and consist of coarse-grained carbonate in up to 5-10 cm big grains (Fig. 9). It is possible that the carbonate filled joints have been (and still are?) conductors of water, which deposited the carbonate. Almost all the carbonate filled joints are oriented NW-SE and have only been observed in restricted areas. In the operating quarry (see geological map) they occur as continuous joints in a 75 m wide zone up to and along the southwestern margin of the concession. They have not been observed in the main body of the reserve area but only along its northeastern margin as continuous joints parallel to road R 517 northwestwards from Ytre Høyvik (see geological map).



Berakvam operating quarry (93 joints)



Berakvam reserve area (101 joints)

Fig. 2. Stereographic projections of joints from the Berakvam operating quarry and the Berakvam reserve area. The diagrams show a large concentration of joints in NW-SE and NE-SW directions in both the operating quarry and the reserve area. Left diagrams: Wulff net, lower hemisphere projection. Right diagrams: Rose diagram showing the frequency of joint directions.

3.6. Petrology

3.6.1. Introduction

During the geological mapping a number of samples were collected from both the operating quarry and the reserve area. Locations of the samples are shown on the geological maps. The samples have been selected so that they represent all main lithologies. For twenty of these samples thin sections have been prepared for microscope investigation of mineralogy, texture and metamorphism. In addition to these samples, thin sections from seven samples (EE 99-1 to EE 99-6 and EE 99-V) studied by Erichsen (1999) have been re-investigated. The six EE 99-1 to EE 99-6 samples, which all have been collected in the reserve area, are included since their mechanical properties were analysed by Erichsen (1999). They can thus be used as reference for prediction of mechanical properties for the new samples in the present investigation from their petrological evidence.

A short hand specimen description of all collected samples is given in Appendix 2, while the microscopical investigation of the 27 samples is summarised in Table 1. The following parameters were investigated in the microscope analysis (see Table 2):

Mineral composition. The mineral composition has been estimated visually (not by point counting). Plagioclase is variably altered during metamorphic retrogression with formation of secondary *sericite* (very fine-grained white mica), *saussurite* (very fine-grained epidote) and *Na-rich plagioclase* within the outlines of the original grains. All has been calculated together as plagioclase in the estimate. *Epidote* and *muscovite* have only been calculated separately when forming grains of a clearly larger size. *Carbonate* is accessory in some samples and most likely also a product of plagioclase alteration.

Texture. *Porphyroblastic* means that the rock has a bimodal distribution in grain size with distinctly larger grains (porphyroblasts; in this case of K-feldspar and plagioclase) in a finer grained matrix. The larger grains represent large remnants of partially recrystallised phenocrysts from the original magmatic rock. *Mylonitic* textures form in movement zones in the rock that give rise to a well-developed foliation in which drawn out quartz recrystallises to form ribbons and feldspars are drawn out to form lenses (see also Fig. 4). Mylonites usually show a grain size reduction due to recrystallisation during movement, and by increasing deformation large parts of the rock, except for the quartz ribbons, may recrystallise into tiny polygonal grains. The term *serial grained* denotes that the rock has a continuous distribution in grain size.

Grain size and grain boundaries. Here it is distinguished between old grains and recrystallised grains. *Old grains* are characterised by having been strained during deformation and is found both as porphyroblasts and as smaller grains in the matrix. With increasing deformation the grain boundaries become more complicated from *lobate* to *serrate*, which will increase the strength of the rock. With still stronger deformation, the minerals will start to recrystallise into a patchy mosaic of tiny, unstrained, polygonal grains, which efficiently will reduce the grain size of the rock.

Plagioclase alteration into very fine-grained *sericite* and *saussurite* seem to be another process that contributes to reduce the factual grain size of the rock, at the same time as fine-grained sericite and saussurite seem to lock the fragile crystal structure of the plagioclase. Based on the authors experience the last years, sericitisation and saussuritisation of plagioclase for these reasons will increase the mechanical properties of the rocks. Though other factors may be important, this also implicates that rocks with plagioclase as the major feldspar phase have better chance to show good mechanical properties. In the previous investigations at Berakvam Schellenberg (1996) also noted the sericitisation and saussuritisation of plagioclase.

3.6.2. Petrology of the Berakvam rocks

From the results of the microscopical analysis summarised in Table 1, the general petrology of the main rock types in the Berakvam operating quarry and reserve area will be presented.

The fine-grained grey gneisses of the older group (8 samples; see also Figs. 1 and 2) are generally composed of plagioclase and quartz with only subordinate K-feldspar (microcline). Biotite, partly altered to chlorite, usually make up c. 10% of the rocks. Two samples, MM 02115 (southwestern part of the reserve area) and EE 99-V (quarry) contain c. 20% K-feldspar, while K-feldspar dominate over plagioclase in one light grey sample, MM 02118 (lens in western part of the reserve area). This indicates, that the fine-grained grey gneisses (assumed originally volcanic rocks) have a dacitic composition but may grade into rhyodacite with increasing content of K-feldspar. The rocks have a grain size less than 1-1.5 mm and moderately complicated (lobate) grain boundaries. Recrystallisation to <0.1 mm polygonal grains are generally insignificant but amounts to 20-30% in 3 samples. The dominance of plagioclase over K-feldspar and an always-strong alteration of plagioclase, combined with the fine grain size, suggest that the fine-grained grey gneisses have a fine chance to show good mechanical properties.

Porphyritic granodiorite (13 samples; see also Fig. 3) is the dominating rock type in both the operating quarry and in the reserve area. Moderately to strongly sericitised and saussuritised plagioclase clearly dominate over K-feldspar (microcline), except for samples EE 99-2 (western part of reserve area) and EE 99-6 (eastern part of reserve area), which have a more granitic composition. There is a certain variation in e.g. the proportion of plagioclase to K-feldspar, but the overall composition is granodioritic. Some of the variation is certainly due to the fact that the rock is a porphyry, and because the mineral composition is calculated from a small, 2x4 cm big thin section the result will depend on the number of feldspar phenocrysts that happens to be included in the section. K-feldspar occurs first of all as 3-10 mm big porphyroblasts that together with a smaller amount of plagioclase porphyroblasts are remains of partially recrystallised feldspar phenocrysts, recrystallised during deformation. Porphyroblasts usually make up about 10-20% of the rock and are set in a fine-grained matrix with a grain size < 2-3 mm and lobate to serrate grain boundaries. The colour of the rock varies from grey to light grey and, as shown in Table 1, seems mainly to reflect the content of biotite (c. 15% in grey and 5-10% in light grey types). The light grey types are usually more massive with a slightly higher content of feldspar phenocrysts, while the grey types richer in biotite are better foliated. Titanite is a prominent accessory mineral in all porphyritic granodiorites, and often amounts to 3-5%.

With increasing deformation and better developed foliation new recrystallisation to tiny (<0.1 mm) polygonal grains occurs which in some samples amount to c. 20% (Table 1). This new recrystallisation becomes very pronounced in mylonitic porphyritic granodiorites (Fig. 4) where tiny (<0.1 mm) polygonal grains may constitute as much as 80-85% of the rock (samples MM 02108 and MM 02110). The mylonites also typically contain significant muscovite (c. 15%) and epidote (10-15%) and a reduced content of plagioclase, probably due to metamorphic mineral transformations during shearing. Quartz is drawn out to form ribbons of subgrains.

Small-porphyritic diorite (2(3) samples) is dark grey, rather fine-grained and deformed with scattered <5 mm big plagioclase phenocrysts. The rock occurs in lens-shaped bodies in the western part of the reserve area south of Straumberget, and has not been observed in the operating quarry. The small-porphyritic diorite consists of 60% plagioclase, 30% amphibole and only accessory quartz (Table 1). The plagioclase shows strong alteration to sericite and saussurite. One sample from borehole BH 4 in the quarry (MM 02124) has a somewhat similar mineral composition in spite of being reminiscent of, and sampled as, porphyritic granodiorite (Table 1). Quartz makes up 15%, plagioclase 55%, and biotite and amphibole 15% each giving a quartz-dioritic composition for sample MM 02124. It is unknown which distribution this porphyritic quartz-diorite type has but most likely, it is an uncommon variant of porphyritic granodiorite.

Granite (3 samples; see also Fig. 5) is common in the central part of the quarry (Zone II) and in the southwestern margin of the reserve area. These pale grey weakly foliated gneissic rocks have a granite composition with about 50% K-feldspar and 20% plagioclase (Table 1). Biotite, partly altered to chlorite, is only a minor constituent making up 4% in a striped medium-grained type and 1-2% in an aplitic type. Plagioclase show only limited to moderate alteration. There is a serial distribution of 0.2-1.5, some times up to 4 mm big grains with rather simple lobate boundaries.

4. ROCKS AND MECHANICAL PROPERTIES

Tests of mechanical properties for rocks in the Berakvam quarry have been carried out both in previous investigations and during the present extraction operation. Since mechanical testing is not a purpose for the present investigation, these results will not be discussed further here. Erichsen (1999, Table 11) has carried out mechanical testing of rocks from six localities in the new reserve area using conventional methods. The petrology of samples from these localities have been re-investigated in the present study, and on this background, his results will form the basis for a discussion of expected mechanical properties for rocks in the future extraction fields.

Erichsen's (1999) samples from the reserve area (EE 99-1 to EE 99-6) are all representative for the variation of typical porphyritic granodiorites. As Table 1 shows, EE 99-1, EE 99-3, EE 99-4 and EE 99-5 have granodioritic composition as the main type, while EE 99-2 and EE 99-6 have more granitic compositions. There is a variation in the strength of the foliation from weak to distinct with one sample showing well-foliated mylonitic texture (EE 99-6). Grain-size for all six fall in the fine- to medium-grained range. The mylonitic sample (EE 99-6) shows in addition a large amount of <0.1 mm big recrystallised polygonal grains reducing the average grain-size. All show a strong sericitisation and saussuritisation of plagioclase except for the most massive samples (EE 99-2 and EE 99-4), which show more moderate alteration. The selected mechanical tests in Table 1 (from Erichsen 1999, Table 11) show little variation for all six porphyritic granodiorite samples. If there is a trend, the mylonitic sample (EE 99-6) shows slightly lower Los Angeles value, while those samples with the highest content of tiny recrystallised grains (EE 99-3, EE 99-5 and EE 99-6), and thus the smallest average grain-size, have the highest Studded tyre test value (opposite to what would be expected). But such deductions are probably to violate the statistics, and in stead it should be concluded that all porphyritic granodiorites must have rather similar, good mechanical properties.

The fine-grained grey gneisses have been considered to be the most attractive rock for hard rock aggregates in the present quarry. Erichsen (1999) did not sample these gneisses for mechanical testing, and the author has no knowledge to comprehensive testing. However, there are good petrological arguments that the fine-grained grey gneisses have at least similar or probably better mechanical properties than the porphyritic granodiorites. The arguments (see petrological section) are that the fine-grained grey gneisses are more finegrained, richer in strongly sericitised and saussuritised plagioclase and poor in K-feldspar.

No mechanical tests exist for the small-porphyritic diorite that occurs subordinately in the southwestern part of the new reserve area. From the parametres listed in Table 1, it must be expected that the mechanical properties will good. However, the density must be higher than for both the fine-grained grey gneisses and the porphyritic granodiorite.

Gneissic granite was not tested mechanically either by Erichsen (1999), and the author knows no results. Granite is only important in the central part of the operating quarry, but has during the mining been considered less attractive than the porphyritic granodiorite. If the granites will have poorer mehanical properties the petrological reason (see table 1 and the petrological section) could be a high content of K-feldspar and a rather low content of plagioclase, which at the same time shows limited to modereate alteration to sericite and saussurite.

5. CONCLUSIONS AND RECOMMENDATIONS

Geological mapping and interpretation has shown that the rocks in the Berakvam operating quarry can be subdivided in four NW-trending zones, which continue at depth down to the northeast. The southwestern and northeastern zones consist almost exclusively of prophyritic granodiorite while the two central zones, though still dominated by prophyritic granodiorite, contain bodies of gneissic granite and fine-grained grey gneisses containing sheets of pegmatite, respectively.

Since Norsk Stein A/S wishes to extract rocks down to a level of –50 m in the present quarry, four boreholes supplemented geological mapping of the quarry in order to establish the geology down to this level. It is concluded that the rock volume between the quarry's present extraction level and the –50 m level in the southwestern 60% of the quarry predominantly consists of porphyritic granodiorite of known good mechanical quality, with only negligible pegmatite and granite material. In the remaining northeastern 40% of the quarry, the rock volume down to the –50 m level consists of porphyritic granodiorite intercalated with c. 20% fine-grained grey gneisses. While the porphyritic granodiorite also here must be assumed to possess a good quality, the content of fine-grained grey gneisses might even raise the average mechanical properties, as argued from the petrological analysis. There is, however, a 100 m wide zone in the southwestern part of this volume that contain scattered <5 m wide sheet-like bodies of pegmatite, which locally could reduce the homogeneity and quality.

The geological investigation of the Berakvam reserve area to the northeast of the present quarry shows that the rocks here must have similar or even better mechanical properties than in the present quarry. In addition, the reserve area contains few pegmatites and granites and therefore will provide homogeneous products. The mapping showed that the northern and eastern parts of the reserve area predominantly consist of uniform porphyritic granodiorite of established good mechanical quality. The western part consists of porphyritic granodiorite with plenty of lenses of fine-grained grey gneisses, and a few of small-porphyritic diorite. A large irregular body of fine-grained grey gneisses that must be expected to continue at depth dominates the southern half of this part of the reserve area. As for the quarry, it is argued from the petrological analysis of rocks carried out for the area that the fine-grained grey gneisses may show better mechanical properties than those obtained for the porphyritic granodiorites. This agrees with information from the present operation staff that fine-grained grey gneisses are more attractive than porphyritic granodiorite in the production of hard rock aggregates.

At the moment, virtually no data exist to document the assumed better mechanical property of the fine-grained grey gneisses. Because they are so important in volume in the western part of the reserve area, it is recommended that a mechanical test program is carried out for these gneisses. Particularly the large volume of fine-grained grey gneisses just north of the present quarry might exhibit the best mechanical quality in the whole Berakvam area.

6. REFERENCES

Blesvik, R., 1987: Berakvam. Ingeniørgeologiske forundersøkelser. NOTEBY rapport 35121-1.

Blesvik, R. & Kristiansen, K., 1987: Berakvam. Ingeniørgeologiske forundersøkelser. NOTEBY rapport 35121-2.

Erichsen, E., 1999: Pukkundersøkelser av forekomsten Berakvam i Suldal kommune. NGU Rapport 99.087.

Schellenberg, F., 1996: Gutachten und Eignungsnachweis. Gleisschotter Jelsa/Norwegen. Abbaufeld V. Kreis Rogaland. GEO montan Rapport.

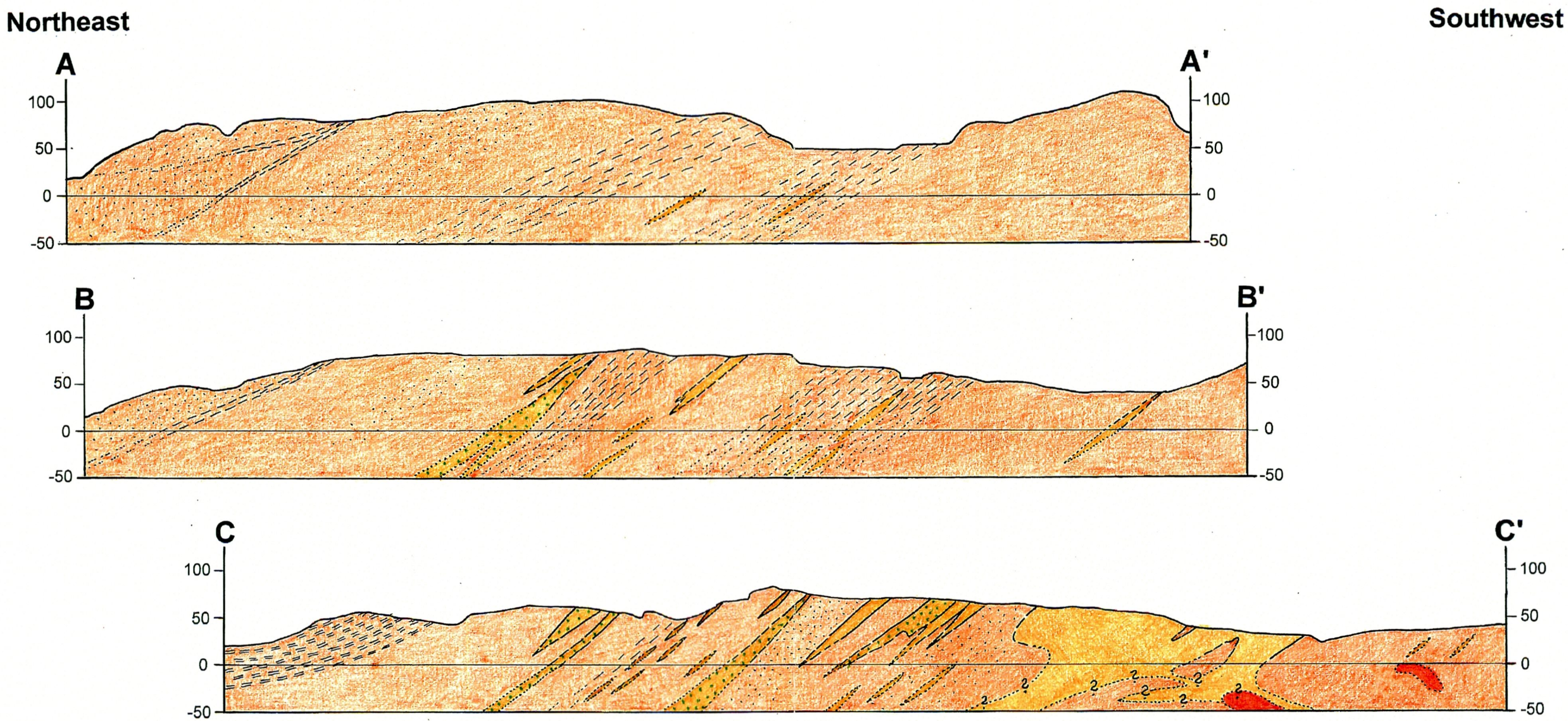
Sample	Rock	Colour	Foliation	Mineral composition													Texture	Grain size			Grain boundaries		Plagioclase alteration	Mechanical analyses			
				Qz	Kf	Plag*	Bi	Chl	Mu	Amp	Ep	Tit	Ap	Ore	Carb	Tur?		Main/matrix in mm	Porphyroblast in mm	Recrystallized <0.1 mm in %	Old grains	recrystallized	Sericite-saussurite	LA-value	PSV-value	Studded tyre test value	Density
	FINE-GRAINED GREY GNEISSES																										
MM 02109	Grey gneiss, finegrained	grey	weak	30		55	5	8		1	1	x		x	x		even-grained	<0.5-1		0	lobate	polygonal	strong				
MM 02103	Grey gneiss, uniform	grey	weak	30		60	7	2				x	1				even-grained	0.2-1.2		2	lobate	polygonal	strong				
MM 02119	Grey gneiss, finegrained	grey	weak	35	5	50	2				1	1	x	x			serial-grained	0.2-0.8		30	lobate	polygonal	strong				
MM 02121	Grey gneiss, finegrained	grey	weak	40	6	45	4	3			2	x	x	x		x	(porphyroblastic)	0.2-1	1-1.5	5	lobate	polygonal	strong				
MM 02122	Grey gneiss, finegrained	grey	moderate	30	8	55	5	2			x	x	x	x			uneven-grained	0.2-1.1(1.8)		25	lobate	polygonal	strong				
MM 02115	Grey gneiss, finegrained	grey	moderate	30	20	40	8				1	1	x	x			serial-grained	0.2-1.4	x?	20	lobate	polygonal	strong				
EE 99-V	Grey gneiss, uniform	grey	weak	25	20	40	15					x	x				even-grained	0.2-1.1		0	lobate	polygonal	strong				
MM 02118	Light grey gneiss, finegrained	light grey	moderate	35	40	20	2		2		1						serial-grained	0.3-1.6		5	lobate	polygonal	strong				
	PORPHYRITIC GRANODIORITE																										
MM 02102	Porphyritic granodiorite	grey	moderate	30	15	40	10				1	4	x	x	x		porphyroblastic	<1-2.5	4-8	7	lobate	polygonal	advanced				
MM 02112	Porphyritic granodiorite	light grey	weak	25	15	45	10				1	2	1	1			porphyroblastic	0.8-3	3-9	5	lobate	polygonal	advanced				
MM 02107	Porphyritic granodiorite	grey	foliated	30	20	25	15				5	4	1	x	x		porphyroblastic	0.2-3	2-9	15	serrate	polygonal	strong				
EE 99-3	Porphyritic granodiorite	grey	foliated	30	20	30	15				x	4	1	x	x		porphyroblastic	0.3-2	2-6	25	lobate-serrate	polygonal	strong	19.5	55	11	2.78
EE 99-5	Porphyritic granodiorite	grey	moderate	30	20	30	14				veins	5	1	x			porphyroblastic	0.3-2	2-6	20	lobate-serrate	polygonal	strong	18.2	54	9.7	2.76
MM 02105	Porphyritic granodiorite	grey	foliated	25	20	35	14	x			1	4	1	x			porphyroblastic	0.2-2	2-6.5	20	serrate	polygonal	strong				
EE 99-1	Porphyritic granodiorite	grey	foliated	25	20	35	13				1	5	1	x		x	porphyroblastic	0.3-2.5	2.5-6	10	lobate-serrate	polygonal	strong	20	53	12	2.78
MM 02113	Porphyritic granodiorite	light grey	weak	30	20	35	9				x	4	1	1			porphyroblastic	0.5-3.5	3-7	2	lobate-serrate	polygonal	advanced				
EE 99-4	Porphyritic granodiorite	light grey	weak	27	25	40	5				x	3	x	x			porphyroblastic	0.5-3	3-9	1	lobate	polygonal	moderate	18.2	53	8.9	2.77
EE 99-2	Porphyritic granodiorite/granite	light grey	weak	30	45	20	4				x	1	x	x			porphyroblastic	0.3-3	3-10	3	lobate-serrate	polygonal	moderate	19.2	52	7.4	2.68
MM 02108	Porphyritic granodiorite, sheared	dark grey	well-developed	25	15	20	10		14		15	1	x				mylonitic	<0.1-1	<1-2	85	straight	polygonal	strong				
MM 02110	Porphyritic granodiorite, mylonitic	dark grey	well-developed	25	15	20	10		15		10	4	1	x	x		mylonitic	<0.1-0.6	<1	80	straight	polygonal	strong				
EE 99-6	Porphyritic granodiorite, mylonitic	grey	well-developed	25	35	20	10				3	4	1	x		2	mylonitic	0.2-2	2-12	40	serrate-lobate	polygonal	strong	17.2	55	10.7	2.76
MM 02124	Porphyritic quartz-diorite (drill core)	grey	weak	15		55	15			15	x		x	x			porphyroblastic	0.2-3	3-5	0	lobate	polygonal	strong				
	SMALL-PORPHYRITIC DIORITE																										
MM 02116	Small-porphyritic diorite	dark grey	weak	5		60	3	x		30	x	1	x	1			porphyroblastic	0.2-1(2)	2-4	2	lobate	polygonal	strong				
MM 02117	Small-porphyritic diorite	dark grey	weak	2		63	x	4		30	x	1	x	x			porphyroblastic	0.2-2	2-4	0	lobate	polygonal	strong				
	GRANITE																										
MM 02101	Granite, gneissic, medium-grained	pale grey	moderate	35	40	20	4				1	x	x	x	x		(porphyroblastic)	0.2-1.2	2-5	1	lobate	polygonal	moderate				
MM 02104	Granite, gneissic, aplitic	pale grey	weak	25	48	20	x	2			x	x					serial grained	0.2-1.1(1.5)		0		polygonal	moderate				
MM 02123	Granite, gneissic, aplitic	light grey	weak	30	50	18	x	1			1	x					serial grained	0.3-4		7	lobate	polygonal	limited				

Abbreviations: Qz - quartz, Kf - alkali feldspar, Plag - plagioclase, Bi - biotite, Chl - chlorite, Mu - muscovite, Amp - amphibole, Ep - epidote, Tit - titanite, Ap - apatite, Ore - ore minerals, Carb - carbonate, Tur? - Turmaline?, * sericite and saussurite in plagioclase is calculated as plagioclase

Table 1. Microscopical analyses of rocks from the Berakvam operating quarry and reserve area.
See explanation in text. For location of samples - see geological maps.

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

BERAKVAM – RESERVE AREA
CROSS SECTIONS



Scale 1:5.000

0 100 250
metres

Location of sections – see geological map

Scale in metres

LEGEND

- Granite
- Porphyritic granodiorite
- Small-porphyritic diorite
- Finegrained grey gneiss
- Weakly foliated, massive
- Developed foliation
- Well-developed foliation

By Mogens Marker - NGU 2002

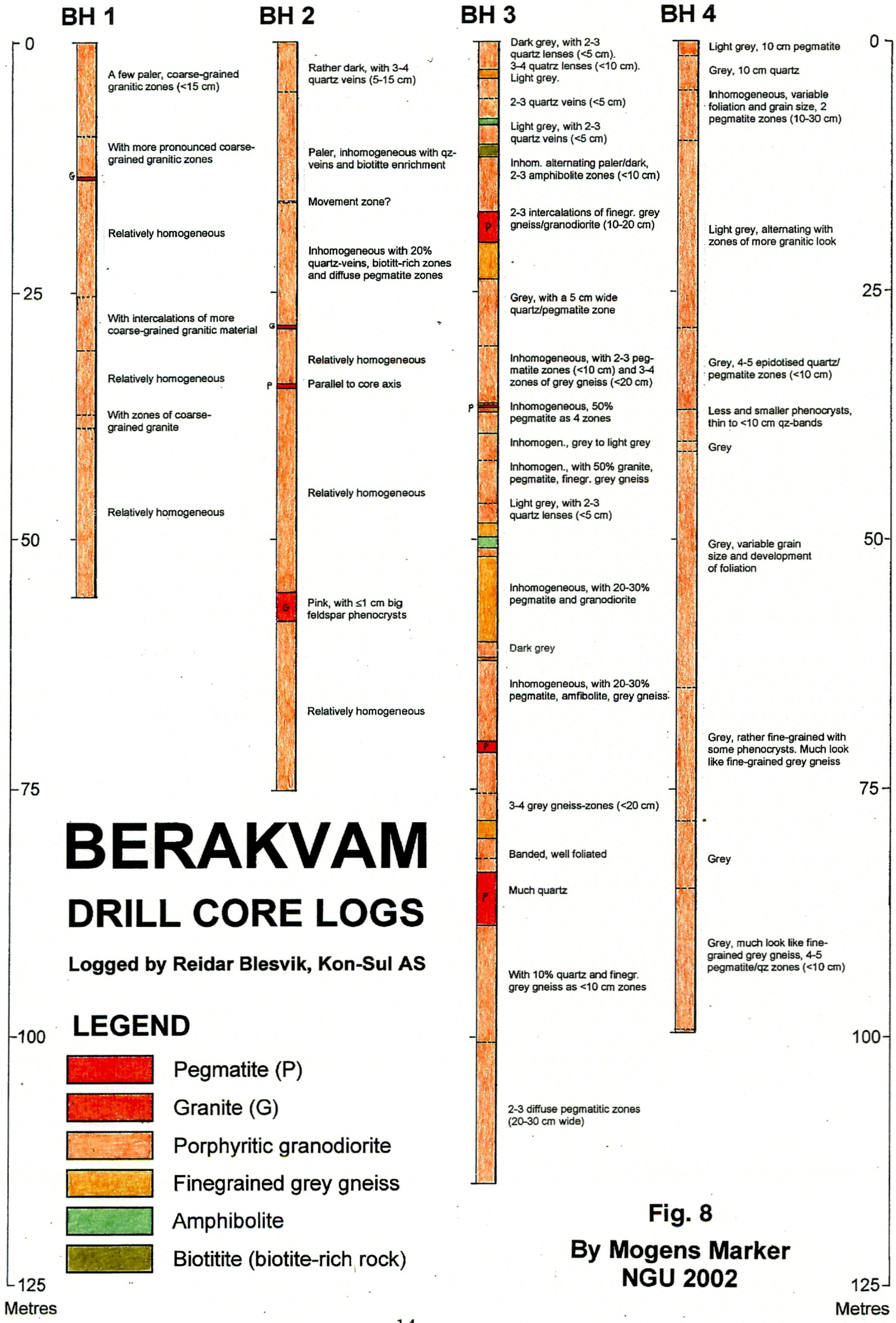


Fig. 8
By Mogens Marker
NGU 2002

Appendix 1.

NORSK STEIN A/S
LOGGING AV BORKJERNER
UTFØRT AV REIDAR BLESVIK

BOREHULL NR.	1
LOKALITET	
DYBDE	55,60 m
RETNING	vertikal

Fra (m)	Til (m)	Bergart	Foliasjon	Fol. vinkel	Kornstørr.	Merknad
0	9.4	gr.dioritt	0-2	40-50	1-2/+feno	rosa fenokr., 3-4 soner < 15 cm med lysere grovk. granittisk
9.4	13.45	gr.dioritt	0-1	40-50	1-2/+feno	mer utpregede soner med grov. granittisk, totalt 20-30%
13.45	13.85	granitt	1-2	40-50	2-3	
13.85	25.4	gr.dioritt	1-2	40-50	1-2/+feno	relativt homogen
25.4	30.8	gr.dioritt	0-2	40-50	1-2/+feno	innslag av mer grovk. granittisk ca 30%
30.8	37.3	gr.dioritt	1-2	40-50	1-2/+feno	relativt homogen
37.3	38.7	gr.dioritt	1-2	40-50	1-2/+feno	soner med grovk. granitt ca 20%
38.7	55.6	gr.dioritt	1-2	40-50	1-2/+feno	relativt homogen

Svakhetssoner: Bergarten er relativt massiv, 5-6 mindre soner/slepper

Det er tatt ut representative prøvestykker på følgende dybder: 2,4 m, 11,5 m og 47,3 m

Foliasjon:
1: svak
2: moderat
3: normal
4: velfoliert

Fol. vinkel: I forhold til kjerneaksen

Kornstørrelse:
1: finkornet, < 1 mm
2: fin/middels, 1-2 mm
3: middels, 2-5 mm
4: grovkornet, > 5 mm

NORSK STEIN A/S
LOGGING AV BORKJERNER
UTFØRT AV REIDAR BLESVIK

BOREHULL NR.	2
LOKALITET	
DYBDE	75,05 m
RETNING	65/220

Fra (m)	Til (m)	Bergart	Foliasjon	Fol. vinkel	Kornstørr.	Merknad
0.00	5.00	gr.dioritt	1-2	70-90	2-3/+feno	relativt mørk, 3-4 kvartsårer 5-15 cm
5.00	15.95	gr.dioritt	1-2	70-90	1-2/+feno	litt lysere, inhomogen, kvartsårer, biotittanr.
15.95	16.05	gr.dioritt	4	40	1-2	bevegelsessone?
16.05	28.40	gr.dioritt	1-2	70-90	1-2/+feno	inhomogen, kvartsårer, biottitsoner, diffuse pegmatittsoner, totalt ca 20%
28.40	28.75	rød granitt	1			skjærer med ca 35 grader
28.75	34.30	gr.dioritt	1	70-90	1-2/+feno	relativt homogen
34.30	34.80	pegm.sone				nær parallell kjerneakse
34.80	55.20	gr.dioritt	0-1	70-90	1-2/+feno	relativt homogen
55.20	58.05	grovk.granitt			1-2/+feno	lys rosa, opptil 1 cm feltspatkryst.
58.05	75.05	gr.dioritt	1-2	70	1-2/+feno	relativt homogen

Svakhetssoner: Bergarten er relativt massiv med lite svakhetssoner og slepper

Det er tatt ut representative prøvestykker på følgende dybder: 12,1 m, 41,2 m og 56,0 m

Foliasjon:
1: svak
2: moderat
3: normal
4: velfoliert

Fol.vinkel: I forhold til kjerneaksen

Kornstørrelse:
1: finkornet, < 1 mm
2: fin/middels, 1-2 mm
3: middels, 2-5 mm
4: grovkornet, > 5 mm

NORSK STEIN A/S
LOGGING AV BORKJERNER
UTFØRT AV REIDAR BLESVIK

BOREHULL NR.	3
LOKALITET	
DYBDE	114,6 m
RETNING	65/220

Fra (m)	Til (m)	Bergart	Foliasjon	Fol. vinkel	Kornstørr.	Merknad
0.00	2.80	gr.dioritt	1	70	1-2/+feno	mørk grå, 2-3 kvartslinser < 5 cm
2.80	3.75	grå gneis	1	70-90	1	3-4 kvartslinser < 10 cm
3.75	5.70	gr.dioritt	1	70-90	1-2/+feno	lys grå
5.70	7.80	gr.dioritt	2-3	60-70	1-2/+feno	2-3 kvartsårer < 5 cm
7.80	8.40	amfibolitt	1	70-90	1	
8.40	10.30	gr.dioritt	1	70-90	1-2/+feno	lys grå, 2-3 kvartslinser < 5 cm
10.30	11.50	biotititt	1	20-30?	1	
11.50	17.00	gr.dioritt	1-2	70-90	1-2/+feno	inhomogen, vekslende lys/mørk, 2-3 amfibolittsoner < 10 cm
17.00	20.00	pegmatitt				2-3 innslag av fink. grå gneis og granodioritt, 10-20 cm
20.00	23.70	grå gneis	2-3	70-90	1-2	
23.70	30.50	gr.dioritt	1-2	70-90	1-2/+feno	grå, en kvarts/pegmatittsone ca 5 cm
30.50	36.20	gr.dioritt	1-2	70-90	1-4	inhomogen, vekslende med 2-3 pegm.soner < 10 cm og fink. grå gneis 3-4 stk < 20 cm
36.20	36.40	grå gneis	1-2	70-90	1	
36.40	36.70	pegmatitt				
36.70	37.05	grå gneis	1-2	70	1	2 cm biotittsone
37.05	39.40	gr.dioritt	1-2	70-90	1-2/+feno	inhomogen, 4 pegmatittsoner totalt ca 50%
39.40	42.00	gr.dioritt	1-2	70-90	1-2/+feno	inhomogen, grå/lys grå
42.00	46.40	gr.dioritt	1-4	70-90	1-4	inhomogen, vekslende granitt/pegmatitt/grå gneis totalt ca 50%
46.40	48.40	gr.dioritt	1	60-90	1-2/+feno	lys grå, 2-3 kvartslinser < 5 cm
48.40	49.70	grå gneis	2	70-90	1-2	
49.70	50.90	amfibolitt	1	70-90	1	
50.90	51.60	grå gneis	1-2	70-90	1	
51.60	60.20	grå gneis	1-2	70-90	1-4	inhomogen, totalt 20-30% pegmatitt og gr.dioritt
60.20	61.90	gr.dioritt	1-2	70-90	1-2/+feno	mørk grå
61.90	62.20	grå gneis	1-2	70-90	1	diffuse overganger
62.20	70.20	gr.dioritt	1-2	70-90	1-2/+feno	inhomogen, pegmatitt, amfibolitt og finkornet grå gneis totalt 20-30%
70.20	71.40	pegmatitt				

71.40	75.50	gr.dioritt	3-4	70-90	1/+feno	
75.50	78.10	gr.dioritt	1-2	70-90	1-2/+feno	3-4 soner < 20 cm med grå fink. gneis
78.10	80.00	grå gneis	2	70-90	1-2	
80.00	82.00	gr.dioritt	2-3	70-90	1-2/+feno	
82.00	83.40	gr.dioritt	4	70-90	2	båndet, velfoliert
83.40	88.70	pegmatitt	1-4	70-90		mye kvarts
88.70	100.50	gr.dioritt	1-2	40-90	1-2/+feno	soner < 10 cm med kvarts og fink. grå gneis, tilsammen ca 10%
100.50	114.60	gr.dioritt	1-2	70-90	1-2/+feno	3-4 soner 20-30 cm diffust pegmatittisk

Svakhetssoner: Generelt er bergarten massiv med lite slepper. En svakhetssone i pegm.sone ca 87,5-88,0

Det er tatt ut representative prøvestykker på følgende dybder: 5,1m, 20,5m, 51,3m, 73,6m, 90,5m

Foliasjon:
1: svak
2: moderat
3: normal
4: velfoliert

Fol.vinkel: I forhold til kjerneaksen

Kornstørrelse:
1: finkornet, < 1 mm
2: fin/middels, 1-2 mm
3: middels, 2-5 mm
4: grovkornet, > 5 mm

NORSK STEIN A/S
LOGGING AV BORKJERNER
UTFØRT AV REIDAR BLESVIK

BOREHULL NR.	4
LOKALITET	
DYBDE	99,5 m
RETNING	vertikal

Fra (m)	Til (m)	Bergart	Foliasjon	Fol. vinkel	Kornstørr.	Merknad
0.00	1.50	gr.dioritt	1	50-70	1-2/+feno	lys grå, 10 cm pegmatitt
1.50	5.00	gr.dioritt	1-2	50	1-2/+feno	grå, 10 cm kvarts
5.00	10.00	gr.dioritt	1-3	50-70	1-2/+feno	inhomogen, varierende fol. og kornstørrelse, 2 soner 10-30 cm pegmatitt
10.00	28.70	gr.dioritt	1-3	50-70	1-3	lys grå, vekslende med mer granittisk preg
28.70	37.00	gr.dioritt	1-3	50-70	1-3	grå, 4-5 kvarts/pegm. soner < 10 cm, epidotisering
37.00	40.10	gr.dioritt	2-3		1-2/+feno	mindre/færre fenokr., kvarts < 10 cm og tynne bånd
40.10	41.20	gr.dioritt	1	50-70	1-2	grå
41.20	65.00	gr.dioritt	2-3	50-90	1-2/+feno	grå, varierende kornst. og foliasjonsgrad
65.00	78.40	gr.dioritt	3	50-90	1-2	grå, stort sett finkornet, men noe fenokr., mye ligner fink. grå gneis
78.40	85.10	gr.dioritt	1-2	50-90	1-2/+feno	grå
85.10	99.20	gr.dioritt	1-3	50-90	1-2	grå, 4-5 soner med pegmatitt/kvarts < 10 cm, mye ligner fink. grå gneis
99.20	99.50	gr.dioritt	1	50-90	1-2/+feno	

Svakhetssoner: noen tynne slepper første 40 m, svakhetssone ca 68-69

Det er tatt ut representative prøvestykker på følgende dybder: 3,3m, 14,9m, 53,1m, 61,1m 72,5m 82.4m, 87,1m

Foliasjon:
1: svak
2: moderat
3: normal
4: velfoliert

Fol.vinkel: I forhold til kjerneaksen

Kornstørrelse:
1: finkornet, < 1 mm
2: fin/middels, 1-2 mm
3: middels, 2-5 mm
4: grovkornet, > 5 mm

Appendix 2.

BERAKVAM –Description of samples for thin section

MM 02101 - **Striped meta-granite.** Medium-grained (rather fine-grained), faintly pinkish grey with ½-<1 mm wide, 5-10 mm long dark stripes with biotite. Contains a few 6-8 mm long porphyroblastic feldspar grains.

MM 02102 - **Porphyritic granodiorite.** Grey moderately foliated with 1-1.5 cm long feldspar porphyroblasts.

MM 02103 - **Fine-grained grey gneiss.** Weakly foliated, uniform.

MM 02104 - **Granitic gneiss.** Light grey, dispersedly spotted-striped, and weakly foliated.

MM 02105 - **Porphyritic granodiorite.** Grey, foliated, with densely packed feldspar porphyroblasts in a darker biotite-rich matrix.

MM 02107 - **Porphyritic granodiorite.** Grey, foliated, with oriented 5-12 mm long feldspar porphyroblasts (deformed) in a darker biotite-rich matrix.

MM 02108 - **Mylonitic porphyritic granodiorite.** Dark grey, fine-grained, well-foliated, with 2-12 mm long flat lens-shaped (drawn out) recrystallised feldspar porphyroblasts.

MM 02109 - **Fine-grained grey gneiss.** Weakly foliated, uniform.

MM 02110 - **Mylonitic porphyritic granodiorite.** Dark grey, fine-grained, well-foliated with well-developed C/S fabric, with 2-12 mm long flat lens-shaped (drawn out) recrystallised feldspar porphyroblasts.

MM 02112 - **Porphyritic granodiorite.** Somewhat pinkish light grey, medium-grained, weakly foliated; with close-lying, 1-2 cm long, lens-shaped feldspar porphyroblasts.

MM 02113 - **Porphyritic granodiorite.** Rather uniform, light grey, medium-grained, weakly foliated; with close-lying, 0.5-1.5 cm long feldspar porphyroblasts in a less prominent biotite-rich matrix.

MM 02115 - **Fine-grained grey gneiss.** Rather light-coloured, moderately foliated.

MM 02116 - **Small-porphyritic dioritic gneiss.** Grey, homogeneous, fine medium-grained, weakly foliated, with 2-4 mm long feldspar porphyroblasts.

MM 02117 - **Small-porphyritic dioritic gneiss.** Grey, homogeneous, fine medium-grained, weakly foliated, with 2-4 mm long feldspar porphyroblasts.

MM 02118 - **Fine-grained grey gneiss.** Rather light grey, moderately foliated.

MM 02119 - Fine-grained grey gneiss. Uniform, moderately foliated.

MM 02121 - Fine-grained grey gneiss. Homogeneous, moderately foliated, with a few 3-6 mm "porphyroblastic" spots (quartz?).

MM 02122 - Fine-grained grey gneiss. Somewhat inhomogeneous, moderately foliated.

MM 02123 - Granitic gneiss. Light grey, fine medium-grained, weakly foliated, with very thin dark joints.

MM 02124 (BH 4, 22.90-23.00 m) - Porphyritic meta-diorite. Grey, medium-grained, weakly foliated, with 2-6 mm big feldspar porphyroblasts in a darker fine medium-grained matrix.

EE 99-1 - Porphyritic granodiorite. Grey, medium-grained, foliated; with 4-9 mm big feldspar porphyroblasts in a darker matrix.

EE 99-2 - Porphyritic granodiorite. Light grey, medium-grained, and weakly foliated, with 3-7 mm big feldspar porphyroblasts.

EE 99-3 - Porphyritic granodiorite. Grey, medium-grained, foliated, with feldspar porphyroblasts.

EE 99-4 - Porphyritic granodiorite. Rather uniform, light grey, medium-grained, weakly foliated, rich in 8-14 mm big feldspar porphyroblasts in a darker matrix.

EE 99-5 - Porphyritic granodiorite. Grey, medium-grained, moderately to weakly foliated; with rather pinkish, 5-10 mm big feldspar porphyroblasts in a darker matrix.

EE 99-6 - Porphyritic granodiorite. Well-foliated (quite mylonitic), rather dark grey, fine medium-grained; with 0.5-1 cm long eye-shaped feldspar porphyroblasts.

EE 99-V - Fine-grained grey gneiss. Homogeneous, weakly foliated.