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Geological investigations for the ROGFAST project in the area between Kvitsøy and Bokn

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REPORT

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Summary:

The Geological Survey of Norway (NGU) has previously been in involved in two reports describing the geological conditions along the trace of the ROGFAST tunnel. There it was concluded that the geological information for the area between Kvitsøy and Bokn was too scattered to give a reliable interpretation of the geology. New information in the form of 8 samples from the seafloor collected by ROV, and three additional sub-sea drill cores reaching down to the level of the tunnel has made it possible to revise the geological model : The area close to Kvitsøy is occupied by black shale and greenstone as could be expected according to the drill core from Sauholmen. The deepest part of the tunnel transect consists of a granite that most likely is a part of the Precambrian basement. The boundary to the shale and greenstone on Kvitsøy could either be a thrust, or it could be a fault. Three samples of phyllite or mica schist in the northern part of the tunnel transect probably belong to the Ryfylke schist and are interpreted as a thin cover on top of the Precambrian gneisses. This interpretation implies that most of the planned ROGFAST tunnel north of Kvitsøy will run in crystalline rocks of granitic composition. In the report other possible models are also briefly presented.

Keywords:	Bedrock geology	Drill core logging
		Scientific report

CONTENTS

FIGURES

1. INTRODUCTION

The Geological Survey of Norway has earlier been involved in regional studies characterizing the rock types and tectonic relations along the ROGFAST tunnel project from Randaberg (Stavanger) to Bokn. These studies were presented in the reports by Rønning et. al 2006, and Saintot & Solli 2011. Due to lack of data of the geology on the seafloor between Kvitsøy and Bokn, a white area has been left on the maps presented earlier, see Fig. 1. During 2014 new information has been obtained from the area, first by drilling 8 short cores or samples from the seafloor (maximum length c. 40 cm), and during the summer and autumn of 2014, by drilling three holes from the seafloor down to the tunnel level. These three drill holes were done from a ship with the equipment normally used for drilling oil wells. Most of the drill holes were only sampled as drill cuttings, but at the tunnel level full cores of good quality were sampled. The cores are about 4 cm in diameter. These samples has made it possible to present a far more reliably model of the geology between Kvitsøy and Bokn. The new model represents a considerable revision of earlier interpretations.

2. GENERAL GEOLOGY

The general geology of the Rogaland area has been presented in the previous reports and is also known from the bedrock map sheets Stavanger and Haugesund in scale 1:250 000 (Jorde et al. 1995, Ragnhildstveit et al. 1998). Only a short résumé is presented here. The bedrock consists of a Precambrian basement with a stack of Caledonian nappes above. See Fig. 1.

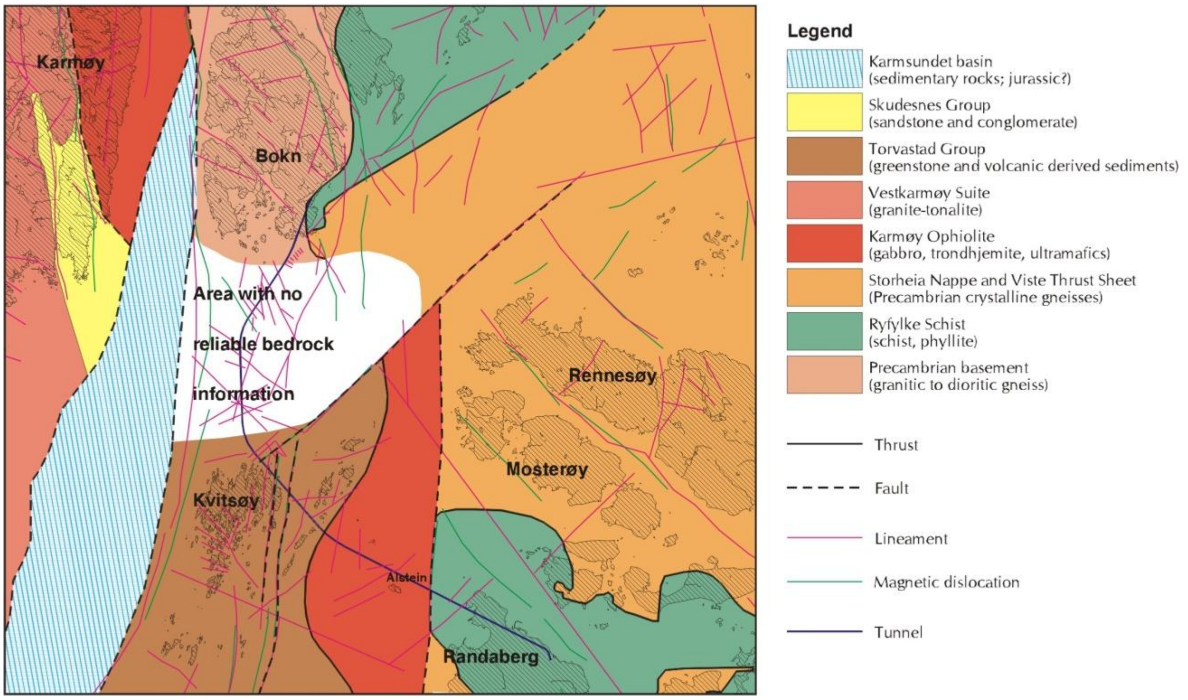

Fig. 1. *The geology between Randaberg and Bokn as it was presented by Rønning et al. (2006), Fig. 7.1 and Saintot & Solli (2011), Fig. 1.*

From bottom to top these units are:

1. *The Precambrian basement.* The main rock types are various type of granitic to granodioritic gneisses, but there are also felsic volcanic rocks, amphibolites and gabbros. Recent age determinations show a variation in ages from about 1500 Ma to 1030 Ma (Marker et al. 2013).

2. *Ryfylke schist*. During the late Precambrian time, the gneisses were eroded to a flat landscape followed by deposition of a sediment that in this area is known as the Ryfylke schist. In the Hardangervidda in the east the same type of schist is regarded as autochthonous on the Precambrian basement, but here in Rogaland most of it is thought to be allochthonous and the terms Viste Thrust sheet or Buadalen Nappe has also been used. The lower parts of the Ryfylke schist is graphitic and probably of Cambrian age.

3. *Storheia and Boknafjorden Nappes*. These two units occur above the Ryfylke Schist and are sometimes regarded as one unit, but from recent mapping it seems to be reasonable to regard them as two different nappes. The Storheia Nappe consists of strongly foliated Precambrian gneisses of granitic to quartz dioritic composition. The Boknafjorden Nappe is situated above the Storheia Nappe and is dominated by garnet mica schist and amphibolites with minor intrusions. Over the whole area where these Caledonian nappes are present, the thickness can vary from zero to several hundred meters (up to one kilometer) over distances of a few kilometers. Therefore, it is not possible to predict any average thickness, but the general picture is a thinning of the nappe sequence towards the west.

4. *Hardangerfjorden Nappe:* This unit consists of the Karmøy Ophiolite, the Vest-Karmøy suite, the Vistnes and Torvastad Groups and the Skudenes Group. a) The Karmøy Ophiolite dominated by gabbroic rocks is the oldest unit. The rocks of the island Alsten between Kvitsøy and Randaberg are thought to belong to this unit. b) The Vest-Karmøy Suite consists of trondhjemitic to granitic rocks of Early to Mid Ordovician ages and is not thought to occur in the ROGFAST area. c) The Vistnes and Torvastad Groups are a mixture of mafic to intermediate volcanic rocks and sediments which are commonly of volcanic origin. They are thought to be younger than the ophiolite and the Vest-Karmøy Suite, but on Karmøy where these rocks occur, there is always a tectonic contact to the surrounding units. Rocks from the Vistnes and Torvastad groups crop out on the island Kvitsøy. d) The Skudenes Group consists of sandstones deposited on top of the previously mentioned units and is not occurring in the ROGFAST area.

5. Mesozoic sediments are deposited in a halfgraben on the seafloor just west of Kvitsøy, but are not thought to influence the ROGFAST tunnel (Bøe et al. 1992).

3. DESCRIPTION OF DRILL CORES AND SAMPLES

Fig. 2 shows the location of the samples collected from the seafloor and the location of the drilled cores. The logging was focused on describing the rock types and not much effort was made on describing tectonic zones. The coordinates for the samples and drill cores are all given in UTM zone 32, and WGS 84 datum.

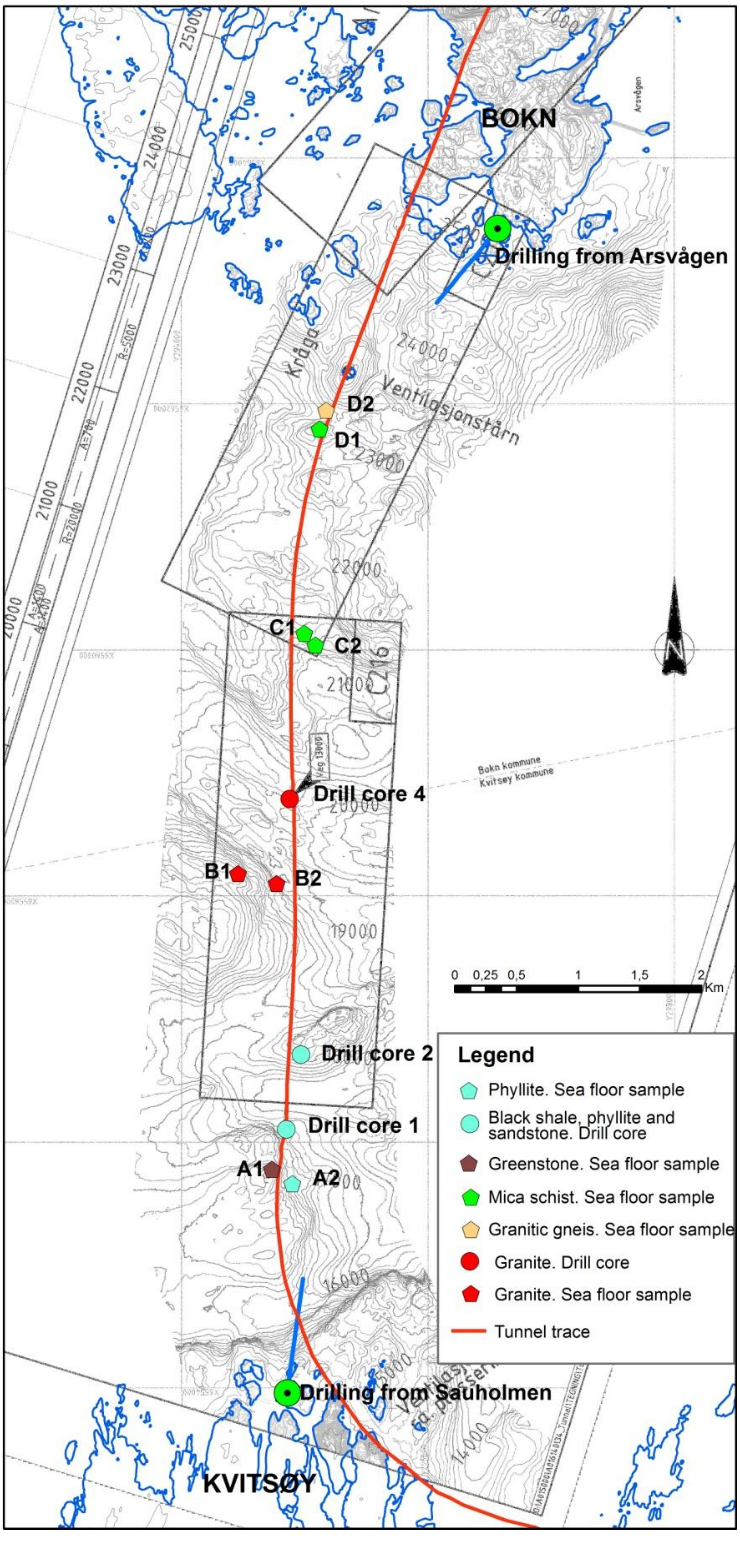

Fig. 2 *Location of drill cores (circles) and seafloor samples (pentagons) in relation to the tunnel trace and drilling from Sauholmen and Arsvågen. The seafloor topography is provided by Statens Vegvesen.*

3.1 DRILL CORES

Drill core 1:

The position for the start of this core was 294850E - 6556100N. The drilling started at seafloor bottom at 250,60 m water depth, for location see Fig. 2. Between this depth and 359 m only drill cuttings were retrieved, and were not included in this study. Between 359 m and 383.10 m, complete core was sampled, and this is the depth of planned tunnel.

359-361.5 m: Dark shale or phyllite with a lot of small calcite veins in mm scale, see Fig. 3 A.
361.5-366 m: Dominating green schist/phyllite and sandstone, but in places with interfingering black schist of the same type as above, see Fig. 3B

Fig. 3. A) Dark shale with carbonate veins from Drill core 1 at 360m. B) Sandstone with black shale interfingering, Drill core 1 at 364.5m

366-367.2 m: At this level there is darker shale with a quartz vein at 366.6m
367.2 - 373.2 m: A green sandstone, but rather foliated due to the chlorite content. The foliation was about a 30^o angle from the drill core, most likely indicating that the foliation is rather flat-lying. Between 370.80-371 m and 371.5 - 371.6 m there is black shale of the same type as described below.
373.2-383.1 m: A rather dark shale with some graphite, but also fairly rich in carbonate forming thin veins. Characteristic are black spots of biotite of 1-2mm size, see Fig. 4. There are also some sulphides (pyrite). In between the black schist there are more greenish chlorite-rich layers. A pronounced schistosity is present in these rocks.

Drill core 2:

The position for the start of this core was 294970E - 6565706E, for location see Fig 2. The drilling started at sea bottom at 200.90 m water depth. Cores were sampled between 361-369 m, 378-386.2 m, 406-410 m and 421-425.8 m. For the remaining part of the drill length only drill cuttings was sampled.
361-367 m: Black graphitic shale with only small sections of the core preserved, see Fig. 5A.
367-369 m: This is a more massive schist/phyllite with lots of small quartz veins along the foliation and, a bit greenish due to chlorite, but also with some graphite. Some carbonate also occurs.

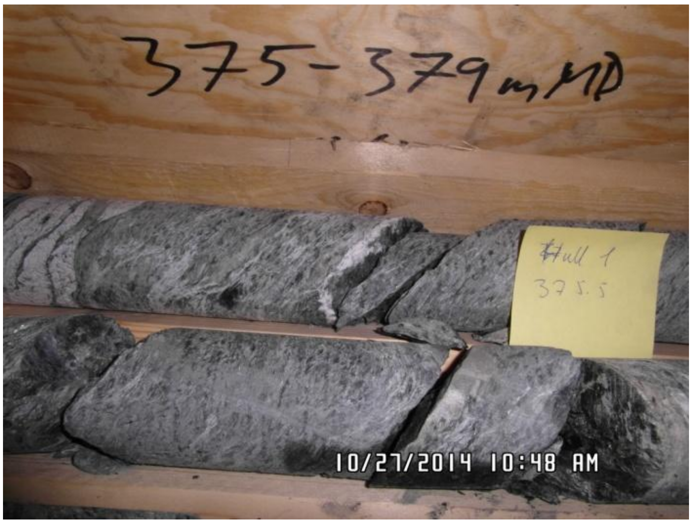

Fig 4. *Dark schist with characteristic black spots of biotite, Drill core 1, 375-376 m.*

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Fig. 5. A) Black graphitic shale with only small sections of the core preserved, Drill core 2, 361-367 m. Photo by Statens Vegvesen. B) Grey to green phyllite with lots of quartz veins, but also carbonate bearing. Drill core 2, 409-410 m.

378-386.2 m: Green chloritic schist or phyllite, but there is also some graphitic schist. The schist contains carbonate, and there is also some pyrite. It is strongly foliated and has some small quartz veins. Between 383-383.5 m there is loss of core.
406-412.5 m: Grey to green phyllite with lots of small quartz veins, strongly folded. The cores seems to be continuous and unbroken, see Fig. 5B.
421-425.8 m: Same grey phyllite as in the interval above. Except the last meter the core is continuous and without significant fractures.

Drill core 4:
The position for the start of this core was 294878E - 6558785N, for location see Fig 2. The drilling started at seafloor bottom at 286 m water depth. Full core was collected between 370.6-413.9 m and between 433.9-442.2 m, the latter below the actual tunnel level. Drill cuttings are available from the rest of the drill hole.

370.6-376.6 m: Well foliated granitic to granodioritic grey gneiss. It is medium-grained but weakly porphyritic with K-feldspar grains up to 1 cm. The foliation is about at 45^o angle to the drill hole. Between 373.6-373.7 m there is a thin schistose layer.
376.6-377.4 m: No core
377.7-381.4 m: Granitic gneiss, porphyritic and well foliated. Between 380-381.4 m the foliation in the gneiss is parallel to the drill hole.
381.4-384.15 m: No core
384.15-399.2 m: Same type of granitic gneiss as described above, rather coarse-grained, well foliated and porphyritic. Between 384-386 m the foliation is sub-parallel to the drill core. At 386.5 m a small fracture with some zeolite minerals occurs. Between 391.2-393.9 m and 397.5-398.5 m the core is rather disintegrated.
399.7-413.9 m: Very homogeneous porphyritic granitic gneiss with hardly any fractures and intact cores, see Fig. 6.
433.9-442.2 m: Same type of rather coarse grained granitic gneiss with a few thin aplitic veins. This interval is below the planned tunnel trace.

Fig. 6. Porphyritic granite with continuous core, Drill core 4, 400-403 m. The main part of the drill core looks like this.

An additional ***Drill core 3*** was originally planned, but was dropped for various reasons.

3.2 SAMPLES COLLECTED AT THE SEAFLOOR

These are drilled cores with a diameter of about 15 cm and length up to c. 40 cm collected on the seafloor by ROV more or less directely above the planned tunnel. The locality for all samples is shown in Fig. 2. All coordinates are given in UTM zone 32, and datum WGS84.

<u>Sample A1:</u> The sample is collected at locality 294734E - 6555775N, at water depth 132 m, and above the tunnel level. This is a rather massive greenstone with some biotite and some pyrite, Fig. 7A.

<u>Sample A2</u>: Collected at locality 294900E - 6555660N, at water depth 180 m, and above the tunnel trace, see Fig. 2. This is a green to grey phyllite with a lot of quartz veins. It is also carbonate bearing. Some of the quartz veins are isoclinally folded, Fig 7B.

Fig. 7. A) Sample A1, greenstone. B) Sample A2, green phyllite with a quartz lens and small veins of quartz. Carbonate bearing.

<u>Sample B1</u>: Collected at locality 294460E – 6558180N at 148 m water depth. This is a granitic gneiss with some biotite and amphibole as dark minerals. Hardly any foliation is seen, Fig 8A.

<u>Sample B2:</u> Sample collected at locality 294773E 65658100N, at water depth 253 m, and above the tunnel level, see Fig. 2. Red granitic gneiss with hardly any foliation and a joint filled with chlorite, Fig. 8B.

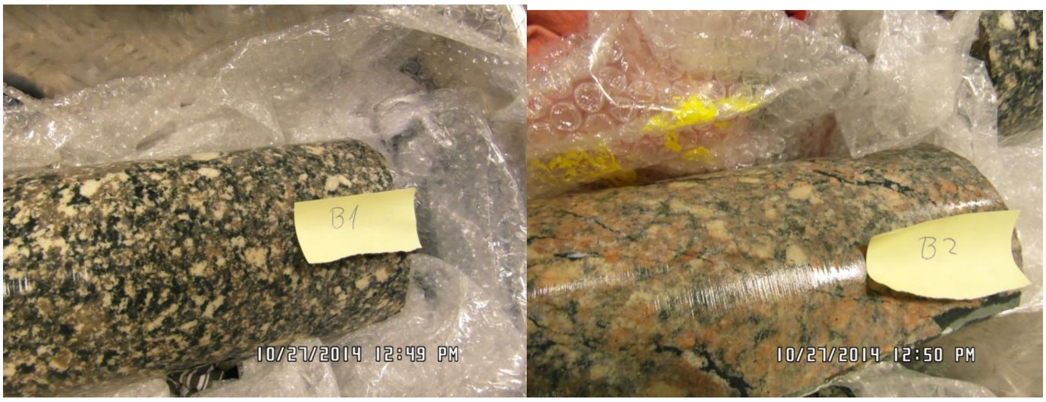

Fig. 8. A) Sample B1, granite. B) Sample B2, red granite with joints filled with chlorite.

Sample C1: The sample is collected at locality 294998E -6560133N, at water depth 179 m, and above the tunnel level. This is a very homogeneous grey phyllite or mica schist. The foliation is rather flat-lying. The quartz content seen to be low, and no carbonate was found, Fig. 9A.
Sample C2: The sample is collected at locality 295089E - 6560038N, at water depth 200 m, and above the tunnel level. It is a grey phyllite or schist like C1, but here the quartz content seems to be a bit higher. No carbonate was found. It seems to be folded in recumbent folds, but the main foliation is rather flat-lying, see Fig. 9B.
Sample D1: The sample was collected at locality 295121E - 6561759N, at a water depth of 52 m, and above the tunnel level. This is the same grey phyllite or schist as sample C1 and C2. The quartz content seems to be low, and no carbonate was found. Here the foliation has about 45^{o} angle to the drill core, Fig 10A.
Sample D2: The sample was collected at locality 295175E - 6561947N at water depth 103 m, and above the tunnel level. It is a strongly foliated granitic gneiss, and it seems to be migmatitic with red feldspar neosome. The gneiss appears to have been strongly deformed after the migmatisation. At the broken end surface of the core a strong lineation is seen, Fig. 10B.

Fig. 9. A) Sample C1, mica schist, sample seen from the end. B) Sample C, phyllite or mica schist, rather quartz rich, with recumbent folds.

Fig. 10A) Sample D1. Phyllite or mica schist. B) Sample D2. Strongly foliated migmatitic granitic gneiss.

3.3 DRILL CORE FROM ARSVÅGEN, BOKN

This core was drilled from Arsvågen on Bokn along an earlier planned trace of the tunnel. It was expected to penetrate the Precambrian basement. As seen from Fig. 1 and confirmed by the logging, the drill core transects a wide variety of granitoid gneisses. Only short comments on the rock types are given here and a more comprehensive log is given in the appendix. The location for the core is shown in Fig. 2.

0-35m: Various types of granitic gneisses with minor aplitic veins and mafic enclaves. The gneiss seems to amphibole bearing and contains a lot of blue quartz. This is a characteristic feature for most of the core length.
35-80m: Red granitic gneiss with only weak foliation, migmatitic.
80-210m: Dominating grey gneiss of supposed monzonitic composition with some gabbros but also sections with red granitic migmatite.

Fig. 11. Arsvågen drill core at interval 247-249 m. Porphyritic granitic gneiss.

210-265m: Porphyritc granitic gneiss, with feldspar augen, commomly about 0.5 cm across. Fig. 11.
265-290m: Red to grey migmatitic gneiss.
290-413m: Porphyritic granitic gneiss as described above with sections of red granitic gneiss and amphibolites.
413-540m: Dark grey migmatitic gneiss of granodioritic to dioritic composition, with minor red granitic veins of leucosome.
540-751m: Strongly foliated red to grey granitic migmatite gneiss see Fig. 12

Fig. 12. Arsvågen drill core, interval 700-705 m. Granitic to granodioritic migmatitic gneiss. This is a typical rock type for a major part of the core from Arsvågen. Photo by Statens Vegvesen.

3.4 CONCLUSIONS FROM THE LOGGING

1) *Drill core 1*, *drill core 2* and seafloor *samples A1 and A2* all belong to lithologies well known from the drill cores from Sauholmen on Kvitsøy (Saintot & Solli 2011). The dominating lithology is a black shale/schist that can contain a rather high concentration of graphite. It is nearly always carbonate bearing, and may grade into chloritic schist or phyllite. Core 1 also contains a green sandstone intermingled in the schist. Sample A1 is greenstone. As mentioned in Saintot & Solli (2011), the black shale is not a prominent lithology either on Kvitsøy or Karmøy, where the the Torvastad and Vistnes Group occur, but is well known from the island Stord that hosts a sediment sequence above the ophiolite of the same age as here (Færseth 1982).

2) *Drill core 2*, *Sample B2* and *Sample B3* all seem to belong to the same type of slightly foliated granite. With regard to the regional picture presented in Chapter 2, the position of the granite can be considered in different ways:

   a) The most reasonable explanation is that this granite belongs to the Precambrian basement. Within the basement east of Gandsfjorden and further north beneath the Caledonian nappes east of Boknafjorden, there are large areas of a similar type of granite. Age determinations have shown that it has intruded at about 1030 Ma, which is late in the Sveconorwegian phase, and it is therefore less foliated than most of the Precambrian gneisses.

   b) The granite could belong to the Storheia Nappe. However, all the granites known in this nappe are strongly deformed and foliated with a flat-lying foliation. It seems unlikely that a relatively undeformed granite should occur in the nappes in this area.

c) It could also be a possibility that this granite belongs to the Vest-Karmøy Suite and has an intrusive or tectonic boundary to the sediments and greenstone on Kvitsøy. However, no granitic rocks of this type are known in the Vest-Karmøy Suite.

3) *Sample C1*, *Sample C2* and *sample D1* all belong to the same type of mica schist or phyllite. The rocks could in principle be a variety of the schist found on Kvitsøy, and belong to the Torvastad Group. However, the most likely interpretation is that these samples belong to the Ryfylke schist. They have the typical recumbent folds found in the Ryfylke schist, and they do not contain any carbonate, in contrast to the 'Kvitsøy type' schists. From magnetic maps it is also clear that anomalies found in the Precambrian on Bokn can be followed beneath this schist, so therefore it seems likely that this schist occurs as thin cover units as suggested in the profile, see Fig.15A.

4) Sample D2. This is a granitic gneiss with a strong lineation. Based on its texture and general appearance, it could be interpreted as part of the Caledonian nappes (e.g. Storheia Nappe). However, from Fig. 2 and Fig. 15C, it is clear that this sample is collected in a 'valley' on the seafloor below Sample D1, which is interpreted as the Ryfylke schist. It is therefore concluded that Sample D2 must belong to the Precambrian basement. As mentioned earlier, there are examples of a sedimentary contact between undisturbed basement and the schist. In other places a strong foliation hampers the exact identification of the boundary between the gneisses and the schist. The gneiss represented by sample D2 is therefore interpreteted to belong to the Precambrian basement just beneath the contact to the Ryfylke schist.

4. REVISED GEOLOGICAL MODEL AND DISCUSSION

Although previous reports left a white area with uncertain bedrock geology between Kvitsøy and Bokn (Fig. 1), it was expected that most of the bedrock in that area would be a continuation of the Torvastad and Vistnes Group on Kvitsøy, and probably also rocks belonging to the Karmøy Ophiolite (Ragnhildstveit et al. 1995, Saintot & Solli, 2011). This assumption has been confirmed by the new samples reported here (see below). Nevertheless, the new sampling and drilling has revealed a completely new picture of the geological relations along the planned tunnel. A detailed map with a revised interpretation of the geology along the tunnel, with bottom topography, is shown in Fig. 13. In Fig 14 a regional overview is shown that includes the revised interpretation of the white area from previous reports (cf Fig 1). In the following the revised model is presented. Possible alternative models are also briefly discussed.

For the southernmost area near Kvitsøy, where sample A1, A 2 and Drill core 1 and 2 have been collected, the litohologies belong to the Torvastad and Vistnes Group. There is little greenstone compared to what is found on land on Kvitsøy, but the lithology corresponds very well with the drill cores from Sauholmen (Saintot & Solli 2011). Black shale occurs over a considerable length, also in the near vertical Drill core 2. This could indicate that the black shale is part of the stratigraphical sequence, and not necessarily linked to tectonic activity, as suggested earlier. Drill core 2 is not supposed/does not appear to intersect any known fault or lineament, but still seems to have considerable loss of core.

The seafloor samples C1, C2 and D1 (see Fig 13 for location) are for several reasons assigned to the Ryfylke nappe: No graphite was observed in these samples , nor were there any carbonate, which is present nearly everywhere in the samples of the Kvitsøy rocks. From new, detailed geophysical surveys (Rønning et al. 2006) it is also clear that magnetic anomalies in the Precambrian basement on Bokn can be followed along the seafloor nearly as far south as the sites where samples C1 and C2 were collected. This strengthens the argument that the schist is occurring as a sub-horizontal layer on top of the Precambrian basement, as shown in Fig. 15A. The seafloor topography also seems to allow such a solution, and from what is known from mapping of the Ryfylke schist elsewhere on land, it occurs as a rather flat-lying sequence. The maps shown in Fig. 13 and Fig. 14 are draw in accordance with this interpretation. The termination of the schist to the west is mainly based on the seafloor topography, but it might well be that it continues further west to the fault that is located at the east side of the Karmsundet Mesozoic basin (Fig 14).

Over most of its area the Ryfylke schist is characterized by folded quartz lenses of both hydrothermal and sedimentary origin. None of the schist samples grabbed from the seafloor have these pronounced quartz lenses. It could therefore be argued that these samples belong to different unit, and the schist in the Torvastad Group that also occurs on Kvitsøy, could be an alternative. The fact that Sample D1 resembles the gneisses that occur in the crystalline nappes (e.g. Storheia Nappe), and is situated in a structural position below the schist (see Fig. 15C), could support this interpretation. A visit on the small island Kråka (also spelled Kråga) just north of the locality where Sample D1 was collected, could have confirmed or ruled out this possibility. Unfortunately no observations exist from this island.

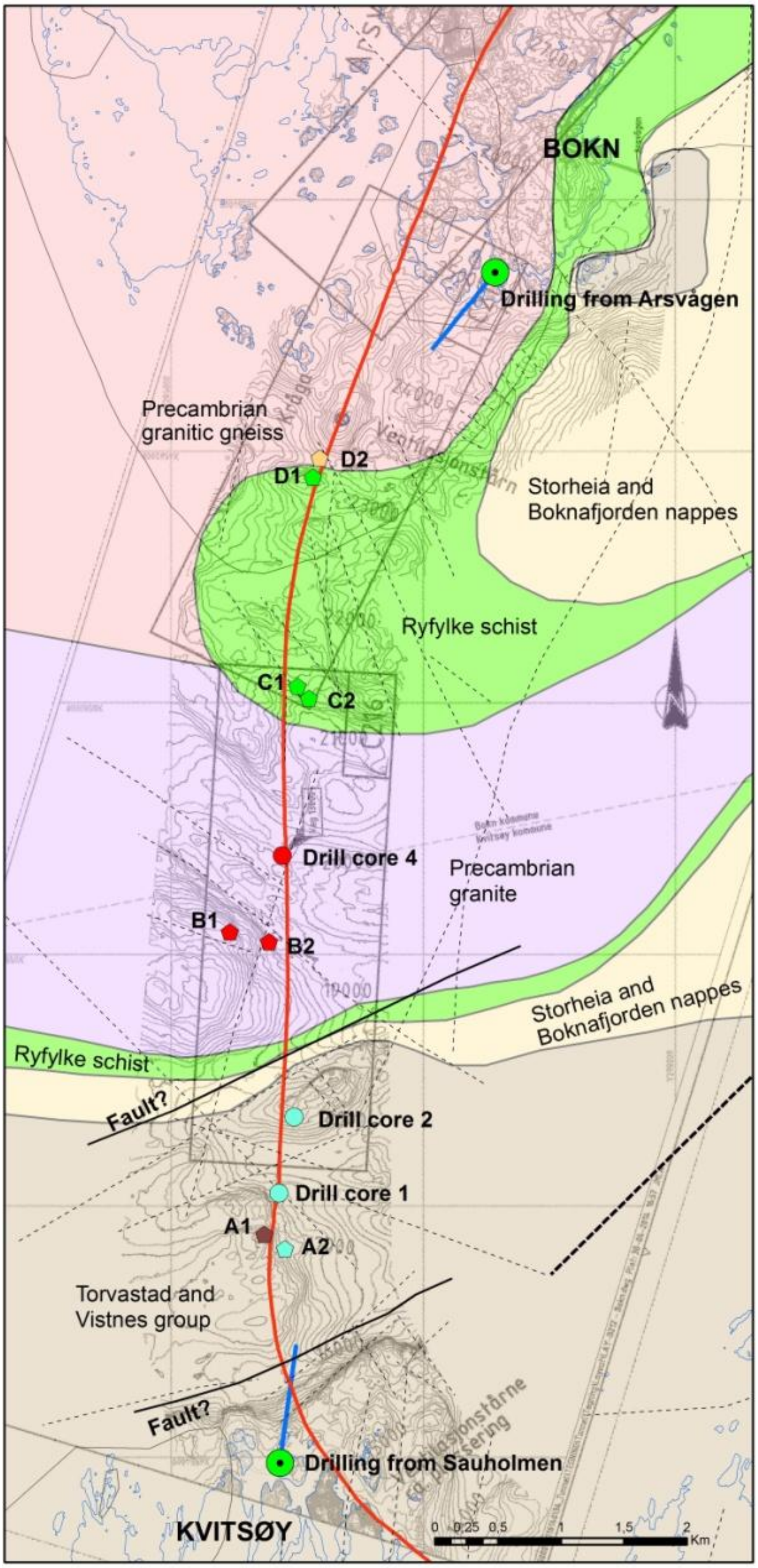

Fig.13 . Detailed geological map along the tunnel trace between Kvitsøy and Bokn. The colors are pale compared to Fig.14 in order to show the seafloor topography. The stippled line are lineaments taken from earlier reports. Some possible faults are indicated. See legend in Fig.2 for explanation of drill cores (circles) and seafloor samples (pentagons).

Sample B1, B2 and Drill core 4 all seems to belong to the same type of slightly foliated granite. Both from the appearance of the rocks and from the seafloor topography it seems to be highly unlikely that this granite should belong to the crystalline nappes (e.g. Storheia Nappe). Another possibility is that it belongs to the Vest-Karmøy Suite that consists of a wide variety of granitoid rocks. However, from the aeromagnetic map (Rønning et al. 2006) it is clear that the Vest-Karmøy Suite has a strong negative magnetic anomaly, while this granite has a weak positive anomaly. It is therefore concluded that this granite belongs to c. 1030 Ma old porphyritic granite and has a wide distribution below the Caledonian nappes east of Stavanger and Boknafjord.

The nature of the contact between this granite and the Torvastad Group on Kvitsøy is uncertain. In our interpretation the Ryfylke schist and the Storheia nappe are present below the Torvastad Group. However, it is possible that there is a fault between the Precambrian granite and the Torvastad Group (cf Fig. 16). This interpretation is indicated in Fig. 13 and Fig. 15B and C, where tentative faults are drawn. The Karmøy Ophiolite is in our interpretation thought to terminate along a NW-SE oriented fault parallel to the deep trench along Boknafjord (Fig. 14). It might well be that the problematic conditions encountered at the end of the drill hole from Sauholmen reflect the continuation of this fault, see Fig. 13 and 14. The boundary between the Precambrian granite and the Torvastad Group could therefore be a fault with about the same orientation.

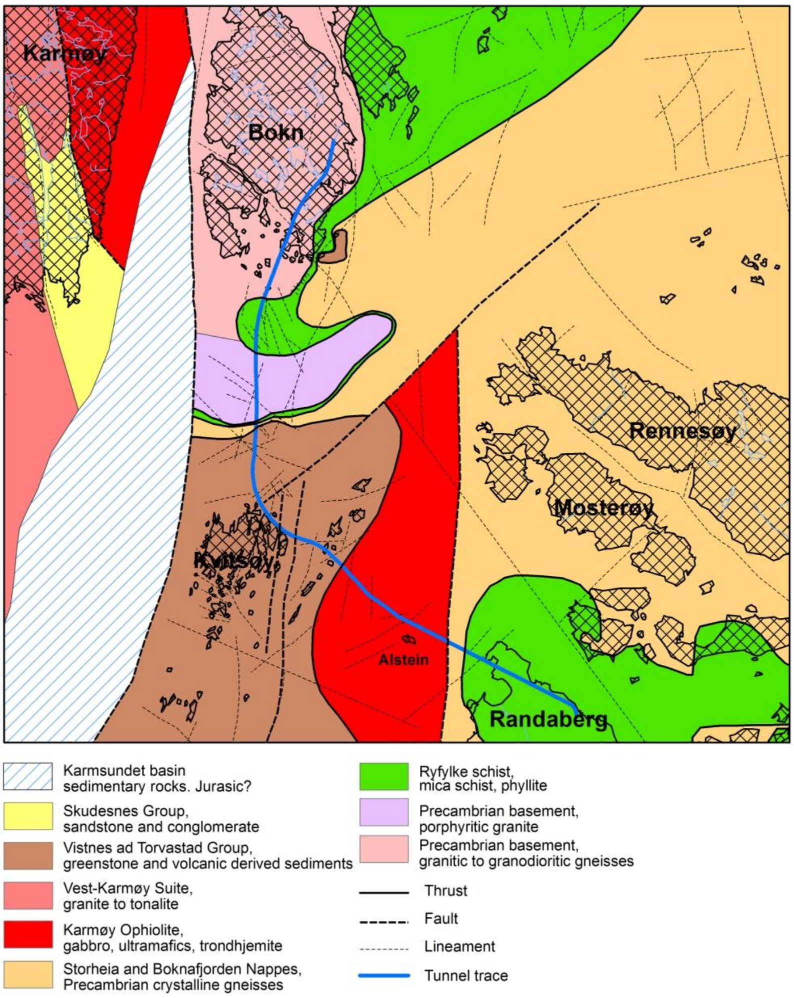

Fig. 14. Revised interpretation of the geology between Randaberg and Bokn.

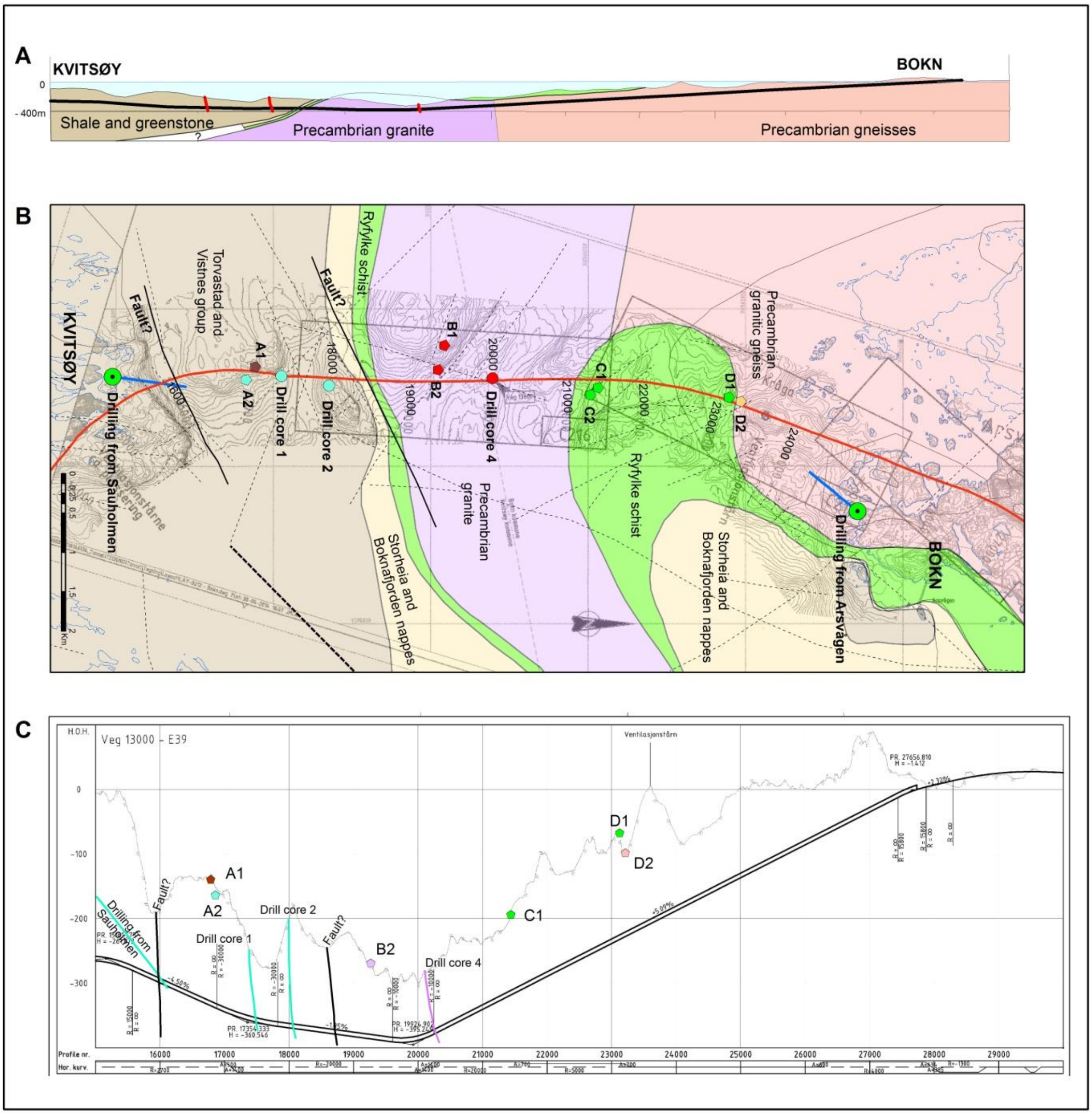

Fig. 15. A) Section along the tunnel trace nearly at the correct proportions. The tunnel trace is shown as a thick black line, and the drilled cores as short red lines. B) Detailed geology along the tunnel as shown in Fig 13. C) Seafloor samples and drill cores along the tunnel profile. The vertical axis is about ten times exaggerated. The drilling from Sauholmen is indicated. Topography provided by Statens Vegvesen. The three sections are not quite to scale.

From mapping on land no faults of this orientation are known, and the termination of the Karmøy Ophiolite east of Kvitsøy could at least partly be explained by topographic effects. In that area the seafloor drops from about 200 m in the south to about 500 m along Boknafjorden, and this trench seems to be filled with Quaternary sediments. Therefore, the map shown in Fig. 14 does not require a substatial fault to explain the bedrock map in Fig 14.

A brief discussion should also be given for other possible interpretations of the geological condition along the tunnel trace.

One alternative model is presented in Fig. 16. Here, the granite in the deepest part of the fjord north of Kvitsøy is interpreted as a part of the Vest-Karmøy Suite, and the schist (sample C1, C2 and D1) is assigned to the Torvastad Group. This interpretation would imply that the planned tunnel would probably intersect the Ryfylke schist, The Storheia Nappe and the Torvastad Group north of the granite (see Fig. 16). A model like this would almost certainly imply that the island Kråka consists of gneisses belonging to the Storheia Nappe. As stated earlier, a field check on Kråka is recommended to verify this alternative model.

Another possibility is that the granite belongs to the Storheia Nappe. A simple geometric model for this is rather difficult to see, but it is known from elsewhere in Rogaland that rocks from the Storheia Nappe and the Ryfylke schist may occur in several thrust sheets on top of each other.

It is, however, concluded that the model presented in Fig. 15 is by far the most plausible.

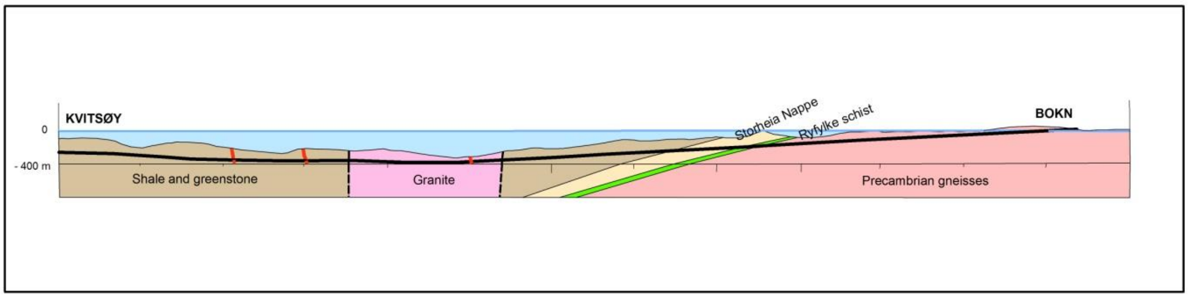

Fig. 16. Alternative section, (cf. Fig. 15 A) where the granite in the central part of the tunnel is interpreted as part of the Vest-Karmøy Suite and separated by fault from the Torvastad Group. Other symbols as in Fig. 15A.

5. CONCLUSION

Sampling from the seafloor and three drill cores extending down to the tunnel trace has made it possible to construct a more reliably model for the lithologic conditions in the area between Kvitsøy and Bokn. The sampling has shown that a phyllite or schist most likely belonging to the Ryfylke schist, occurs on the seafloor, but does not extend down to the tunnel level. This implies that most of the tunnel will run through Precambrian gneiss and granite, as shown in Fig. 15A.

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APPENDIX

Logging of the drill core from Arsvågen
This core was drilled along an earlier planned trace of the tunnel. It was logged because it is supposed to pass through the types of rocks that the present trace of the tunnel is passing, although not in the same order. The core shows a very varied type of gneisses, mainly of granitic composition.

0-5 m: Granitic gneiss, rather fractured, between 0-3 m red granitic, 3.5-m dark grey. A gabbroic lens at 3.5 m, see Fig. 17A
5-10 m: Grey granitic to monzonitic gneiss, less strongly foliated, amphibole bearing, with characteristic blue quartz, see Fig. 17B
10-12.30 m: Gabbro
12.3-20.5 m: Grey to red granitic gneiss, but not so strong foliation, with characteristic is blue quartz.

Fig. 17. A) Core interval between 0-5m that show a lot of fractures. B) Monzonitic(?) gneiss with characteristic blue quartz at core interval c. 8-8.5 m.

20.5-22 m: Foliated grey fine-grained gneiss that could have supracrustal origin.
22-26.1 m: Aplite, grey fine grained gneiss with few dark minerals.
26.1-35 m: Varied gneisses of granitic composition with dark schlieren.
35-56 m: Red granitic gneiss with weak foliation is the dominating rock, it is rather coarse-grained, see Fig. 18
56-80 m: Dominating red to grey migmatitic granitic gneiss, well foliated, migmatitic, with lots of dark schlieren, can in places grade into dioritic composition.
80-90 m: Grey gneiss of monzonitic(?) composition with characteristic blue quartz. Fig.19 (85-90m)
90-125 m: Red to grey granitic to granodioritic gneiss, migmatitic, well foliated. Gabbroic lenses between 110-113 m.
125-147.2 m: Gneiss of monzonitic composition, only weakly foliated.
147.2-155m: Gabbro
155-164m: Monzonite, or monzonitic gneiss, only weakly foliated see Fig. 20.

Fig 18. Red, rather coarse grained gneiss, core interval c. 36.5-37.5m

Fig. 19. Grey gneiss of monzonitic composition at core interval 85- 90 m. Photo by Statens Vegvesen.

Fig. 20. Monzonite or monzonitic gneiss, only weakly foliated. Core interval 155-160 m. Photo by Statens Vegvesen.

164-165 m: Gabbro
165-188 m: Monzonite or monzonitic gneisses of the same type as between 155-164 m.
188-190 m: Gabbro
190-195 m: Granitic gneiss

195-210 m: Monzonite or monzonitic gneisses as described above.
210-265 m: Granitic gneiss with small augens of K-feldspar is the dominating rock type. Between 249-253.5m foliated granitic gneiss, and between 260-265 m there is a transition zone between the augen gneiss and granitic gneiss, see Fig. 21.

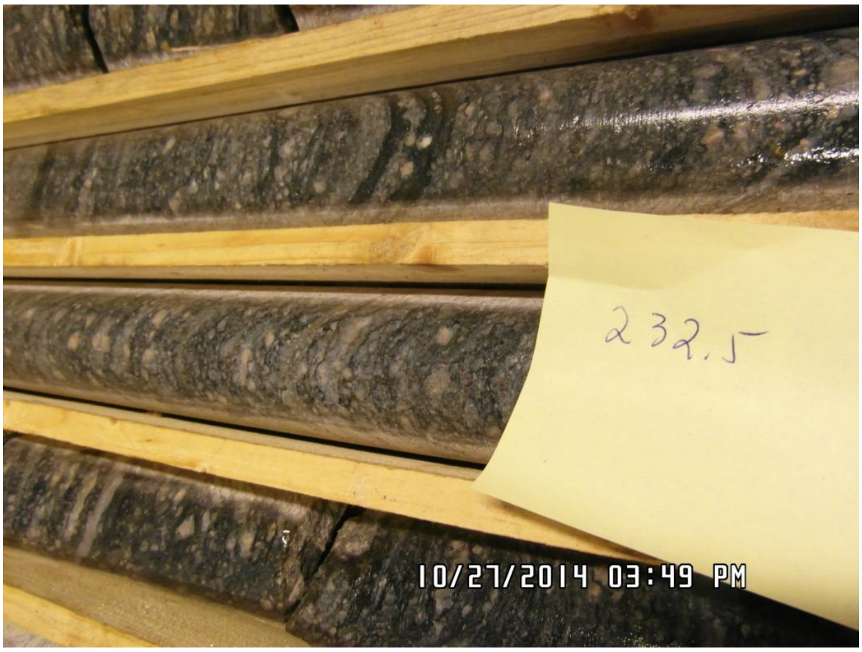

Fig. 21. Close up of the granitic gneiss with small augens that dominate the core between 210-399 m. The photo it taken at core interval 331-333 m.

265-290 m: Granitic gneiss, well foliated, dominating leucocratic, migmatitic. Between 156-270 m the foliation is parallel to the core.
290-399 m: Augen gneiss of the same type as described above, is the dominating rock type, see also Fig. 22. The cores are generally very coherent, but between 314-319 m the core is strongly fractured. Between 326 -328.1 m there is loss of core.

Fig 22. Core interval 345-350 m that shows the granitic gneiss with small augens and very coherent cores. Photo by Statens Vegvesen.

399-401.5 m: Leucocratic granitic gneiss.
401.5-405 m: Amfibolite with a aboundant quartz lenses.
405-409 m: Granodioritic to granitic gneiss with the characteristic blue quartz..
409-413 m: Augen gneiss as describe above.

413-435.7 m: Granitic to granodioritic gneiss, with lots of dark paleosome, and well foliated, see Fig. 23.

Fig. 23. Typical grey granitic or granodioritic gneiss that dominates the lower half of the core from Arsvågen. Here at interval 420-425. Photo by Statens Vegvesen.

435.7-445 m: Gabbro with light colored granitic veins.
445-448.5 m: Red gneissic granite, leucocratic.
448.5-641 m: Dark granodioritic gneiss with red granitic veins. The composition varies from granitic to dioritic. The gneiss is moderately foliated, and sometimes the red granite can be the dominating rock over several meters, see Fig. 24.

Fig. 24. Gneiss from the interval 605-610 m. Photo by Statens Vegvesen.

641-650 m: Granodioritic gneiss, grey. This type has less marked foliation compared to the gneisses described above. It also contains a lot of blue quartz. Both biotite and amphibole occur as dark mineral.
650-670 m: Leucocratic granitic to granodioritic gneiss, the foliation is moderate, and characteristic is a lot of blue quartz, see Fig 25.
670-710 m: Dark gneiss of granitic to granodioritic composition with red to grey granitic veins. Blue quartz is present from about 700 m.
710-717.5 m: Nearly unfoliated rock of tonalitic(?) composition with a greenish color, see Fig 26.
717.5-751 m. Well foliated migmatitic gneisses of granitic to granodioritic composition with blue quartz, here probably as veins, see Fig. 27.

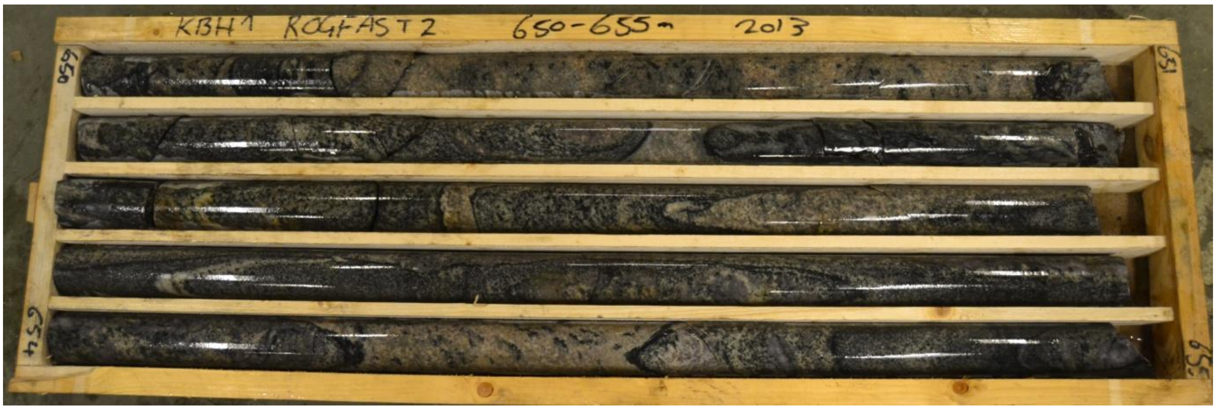

Fig. 25. Relatively leucocratic gneiss of granodioritic composition, core interval 650-655m. Photo by Statens Vegvesen.

Fig 26. Weakly foliated tonalite with a greenish color, core interval c. 712-713 m.

Fig 27. Close-up of migmatitic gneiss with blue quartz at core interval c. 737.5m.

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