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Overcoring of pilot hole in KFM24

Evaluation of the required conditions for future overcoring stress measurements

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Keywords: Overcoring, Forsmark, KFM24, Ring disking.

Abstract

The objective of this study was to investigate the conditions for conducting new overcoring stress measurements in Forsmark where the current stress model is uncertain regarding the stress magnitudes at depth. In the bottom of the existing borehole KFM24, at about 550 meters depth, a short standard drill core was first drilled followed by two trials of overcoring. They include first a 0.6 m long slim pilot hole (36 mm in diameter) and thereafter overcored with a 0.8 m long core. These hollow drill cores have an outer diameter of 62 mm. The results show that both trials gave solid rock cores without any signs of developing ring disking. The drilling operation and geological circumstances are thoroughly documented.

The overcoring survey concludes that KFM24 meets the required conditions for stress measurements using the overcoring technique. This report also suggests further related studies to explain the presence and variation of ring disking occurrence in Forsmark.

Sammanfattning

Syftet med denna studie var att undersöka förutsättningar för att göra nya bergspänningsmätningar i Forsmark där nuvarande spänningsmodell har stor osäkerhet vad gäller spänningsmagnituder på djupet. I botten på ett redan befintligt kärnborrhål, KFM24, på ca 550 m djup, borrades först en kortare vanlig kärna och sedan gjordes två överborningsförsök. Dessa innebar först borrning av ett ca 0,6 m långt smalt pilothål (36 mm i diameter) som sedan överborrades med en 0,8 m lång överborrningskrona. Denna ihåliga borrkärna har 62 mm yttre diameter. Resultatet visar att båda överborrningsförsöken gav kärnor som är intakta utan några tendenser till ring disking i något av fallen. Borrningsförfarandet vid överborrningen och de geologiska förutsättningarna är väl dokumenterade.

Slutsatsen från undersökningen är att det finns förutsättningar för att mäta bergspänningar med överborrningsteknik i KFM24. Rekommendationer till ytterligare relaterade undersökningar för att förklara varierande förekomst av ring disking i Forsmark ges också i rapporten.

Contents

1 Introduction

The in situ rock stress condition is one of the most important factors for a relevant site description concerning mechanical stability of excavations and concerning the long-term behaviour of a deep repository at the Forsmark site. The site description in the SDM-Site stage showed that the rock stress orientation is quite well understood in Forsmark but that there is a large uncertainty in the model for rock stress magnitudes (SKB 2008). The reason for this is that there have been difficulties in performing direct measurements at the site, and the obtained results also show a large spread.

Therefore, there was a desire to develop and find new opportunities for additional measurements. The general steps of the overcoring stress measurement method with the Borre Probe are shown in Figure 1-1. The overcoring measurements with this tool performed in the borehole KFM07C had resulted in repeated ring disking (Step 6 in Figure 1-1), i.e., the hollow core cracked regularly to make rings of rock (Lindfors et al. 2007), making further efforts with this method at depth in Forsmark questionable.

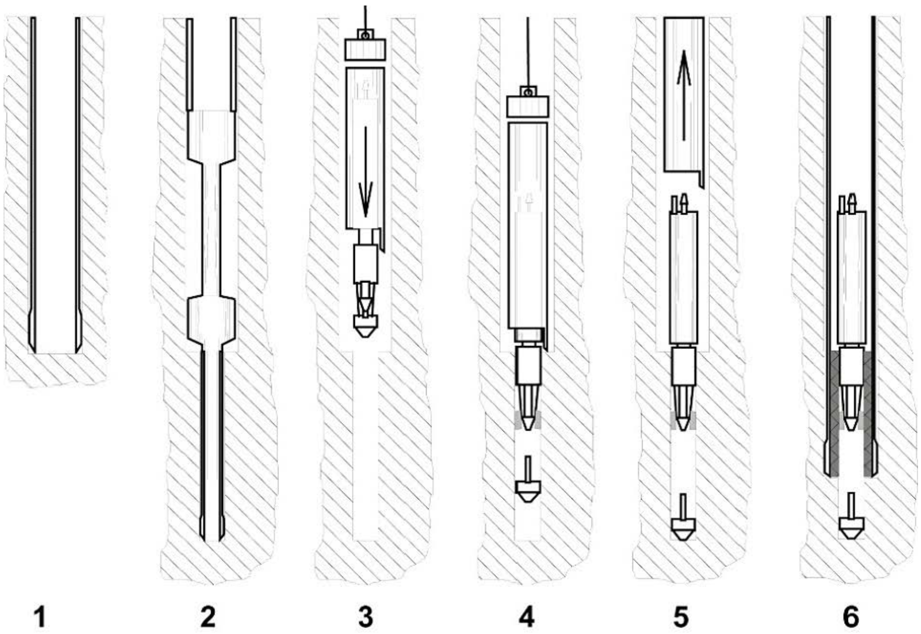

Figure 1-1. *Installation and measurement procedure with the Borre probe (Lindfors et al. 2007):*

1. *Advance 76 mm-diameter main borehole to measurement depth. Grind the hole bottom using the planing tool.*
2. *Drill 36 mm-diameter pilot hole and recover core for appraisal. Flush the borehole to remove drill cuttings.*
3. *Prepare the Borre probe for measurement and apply glue to strain gauges. Insert the probe in installation tool into hole.*
4. *Tip of probe with strain gauges enters the pilot hole. Probe releases from installation tool through a latch, which also fixes the compass, thus recording the installed probe orientation. Gauges bonded to pilot hole wall under pressure from the nose cone.*
5. *Allow glue to harden (usually overnight). Pull out installation tool and retrieve to surface. The probe is bonded in place.*
6. *Overcore the Borre probe and record strain data using the built-in data logger. Break the core after completed overcoring and recover in core barrel to surface.*

In 2013, a new cored drill hole was drilled at the location of the future skip shaft to the repository and the drilling activities for this borehole were reported in Nilsson (2017). This borehole is almost vertical (inclination 82 deg.) and ends at about 550 m depth, which is about the same depth as the deepest planned excavation level. From this reason, this was a borehole that was judged to be desirable to make stress measurement in, but the possibility of doing so was uncertain considering the previous experience at depth in KFM07C, which is located not far from KFM24.

Drillcon Scandinavia AB, Nora was employed for the drilling operations.

Table 1-1. Controlling documents for performance.

Activity plan	Number	Version
Förlängning och överborrning i KFM24	AP SFK-20-050	1.0
Method description		
Method Description for Rock Stress Measurements with the Overcoring Method (applicable parts)	SKB MD 181.001	1.0

2 Objective

The objective of this study was to try the overcoring step of the stress measurement procedure, to understand whether it was possible to get intact hollow cores after overcoring the smaller pilot hole. An intact thick-walled hollow core is an absolute prerequisite for successful stress measurements with any overcoring technique. If the rock during overcoring would experience too high tensile stresses compared to tensile strength, it would show signs of ring disking, indicating that overcoring measurements would not be possible.

By doing first the overcoring test in the bottom of the KFM24 borehole, the aim was to have a better ground for the decision of performing actual stress measurements, which are time-consuming and costly investigations. This study thus concerns only "empty" overcoring trials without any measurement devise installed in the pilot borehole.

3 Site description

This study took place within the tectonic lens in Forsmark, bordered by the Singö deformation zone at the northeast and by the Forsmark deformation zone at the southwest (Figure 3-1). The lens is the target area for the future repository, and it is dominated by metamorphic biotite bearing granite to locally granodiorite (SKB Rock type ID code 101057) dated to 1.87 Ga, with subordinate amphibolite occurring as dykes and/or enclaves as well as younger intrusions of pegmatite. The dominant granite was subjected to ductile deformation under amphibolite facies conditions (SKB 2008). Sporadic occurrence of more granodioritic composition of this rock type could be related to an early stage of albitization (Petersson et al. 2012, SKB 2008). Interpretation and distribution of albitization and its influence concerning mechanical properties in the granite to granodiorite (SKB Rock type ID code 101057) is under investigation. The current state of knowledge about the stress state at Forsmark is reported in SKB (2008).

3.1 Borehole description

The existing borehole KFM24 is located towards the northeast border within the tectonic lens in Forsmark (Figure 3-1), close to the planned skip shaft (Figure 3-2). The borehole was drilled in 2013, basic technical parameters described in Table 3-1. The drilling operations of are reported in Nilsson (2017).

Table 3-1. Technical information about KFM24.

Borehole depth (m)	550.17
Borehole lengths (m)	**Borehole diameter (m)**
0.14–5.88	0.3390
5.88–35.41	0.2480
35.41–35.64	0.1980
35.64–35.68	0.164
35.68–37.25	0.0860
37.25–550.17	0.0765
Position at top of casing	**SWEREF 99 18 00 RH 2000**
Northing	6 698 770.31
Easting	160 182.04
Elevation (m a.s.l.)	1.21
Azimuth (0–360°)	314.45
Inclination (0–90°)	83.44
Position at bottom of borehole	**SWEREF 99 18 00 RH 2000**
Northing	6 698 822.49
Easting	160 141.20
Elevation (m a.s.l.)	−544.91
Azimuth (0–360°)	320.61
Inclination (0–90°)	82.27

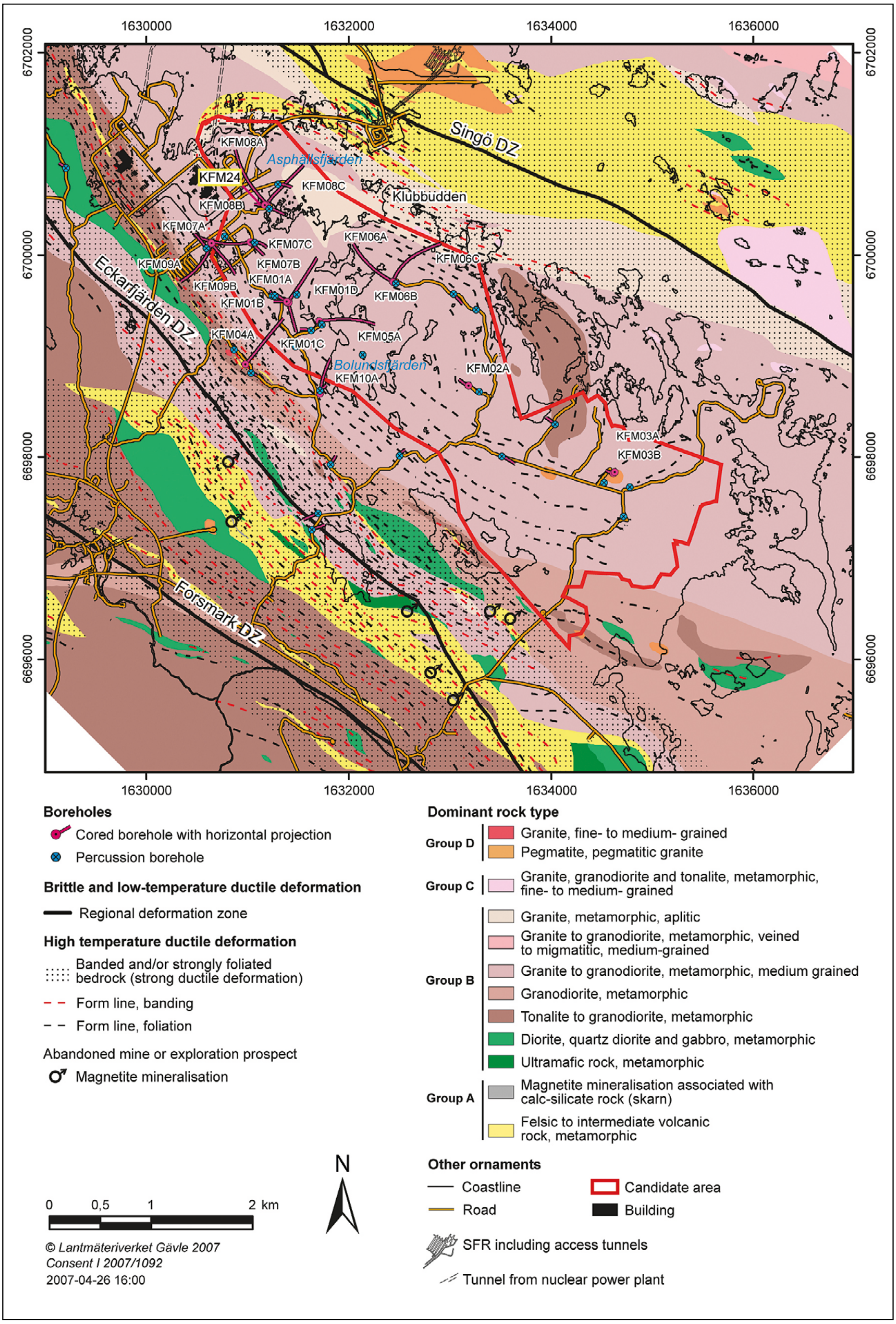

Figure 3-1. *Bedrock geological map of the Forsmark site including borehole positions, where the location of KFM24 is highlighted in yellow frame. Modified after Stephens et al. (2007).*

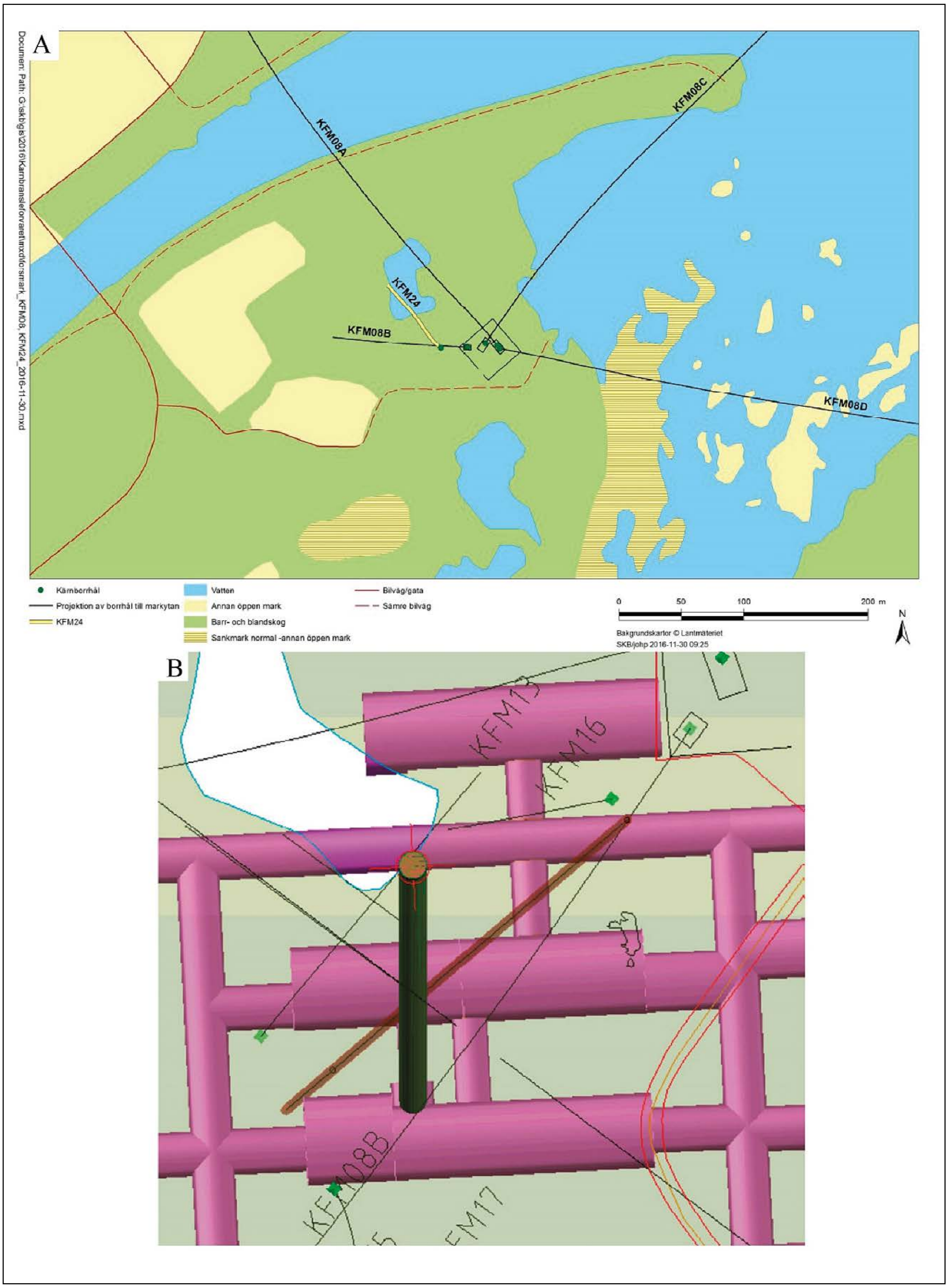

Figure 3-2. *Location of Borehole KFM24 (Nilsson 2017). A) Shows the location of KFM24 with respect to drill site 8 and B) shows a closer view of KFM24 (highlighted in brown) in a 3D model including the planned vertical skip shaft and the excavations in the central area of the repository.*

4 Drilling operations

Drillcon Scandinavia AB was contracted for the drilling operations (Table 4-1), performed during April 2021.

Table 4-1. List of Drillcon personnel involved in the activity.

Name	Role
Svante Berglund	Manager
Jan Arvid Petterson	Driller on-site
Jonny Skagerstam	Driller on-site

4.1 Drilling equipment

During the drilling operations a drilling rig of type Sandvik DE130 was employed.

For the pilot core drilling, a T36 mm core barrel was used together with a wireline 76 system. A steering was mounted above the drill bit to centralise the core pipes. The pilot drilling generates a 0.6 m long drill core with a diameter of 22 mm.

For the overcore drilling, a T2-76 core barrel was used, which gives a drill core with a diameter of 61.7 mm and borehole diameter of 75.7 mm.

4.2 Execution

The first operation was to drill a standard core for a fresh cut at the very bottom of the borehole KFM24, followed by two trials of pilot drilling and overcoring.

The pre-installed transition cone (from larger to smaller diameter) starting at 32.59 m depth down in KFM24 (see Nilsson 2017) probably had some damages, which caused problems to reach the bottom of the cone with the support casing. Reaching the bottom is critical in order to stabilise the drill pipe string during the drilling operations. However, the support casing reached about half down the transition cone and was then welded to be attached to the top of the casing (at ground surface) for stabilization.

The standard drill core was not retrieved from the bottom of the borehole which resulted in a longer drill core (0.45 m) than planned (0.20 m) (Figure 5-1). This was also the case for the first pilot drilling (it was not possible to retrieve the pilot core since it was intact at the bottom), which resulted in overcoring with the pilot core still attached inside (Figure 5-3). This means that the pilot core was not studied before overcoring, but the high quality could be inferred from the unbroken condition. The first standard diameter drill core part also indicated healthy bedrock without microcracks.

After the second pilot drilling, the pilot core was retrieved through the wireline system, following standard overcoring procedures, and studied before overcoring. The second and last overcoring also went according to the protocol.

Drillers from Drillcon experienced that the bedrock was hard to drill and especially challenging since the load should be kept constant at a minimum level to not induce any impact on the stress field. Flushing of water down the drill string was kept at maximum level (40–50 L/min) during the whole overcoring operation, to reduce the frictional heat on the drill bit and thereby also the bedrock. Overall subsidence of drilling was between 5 to 8 cm/min using constant pressure supply about 30 bars. To reach the depth of 550, meters a total amount of 184 drill pipes were connected. In addition, a time-consuming operation since withdrawal of the whole set up (drill string) was necessary between pilot drilling and overcore drilling in order to change the drill bit and also pipe systems.

The drilling operation occupied altogether about 80 hours of work. Approximately 10 hours where spent on various complications, such as difficulties to install the support casing, small repairs on the hydraulic system in the drill rig, frozen water and drillcores left in the borehole. Most of the time is required for the work to bring the drill string down and up in the 550 m deep borehole and the actual drilling time for all five drillcores occupied about 1.5 hours.

5 Results

Because the pilot cores are represented and situated in the overcores, detailed descriptions from drill core logging, in this chapter, will focus on the overcores. Dimensions of all drilled cores are presented in Table 5-1 and a collected view of all drill cores from the survey are presented in Figure 5-1.

Table 5-1. Technical information of retrieved drill cores within the study.

	First core (*fresh cut*)	Pilot cores	Overcore 1	Overcore 2
Borehole length (m) – *start*	550.17	550.62	550.62	551.62
Length (m)	0.45	0.6	1.00	0.95
Outer diameter (mm)	50	22	62	62
Inner diameter (mm)	-	-	36	36
Wall thickness (mm)	-	-	13	min 10 max 15

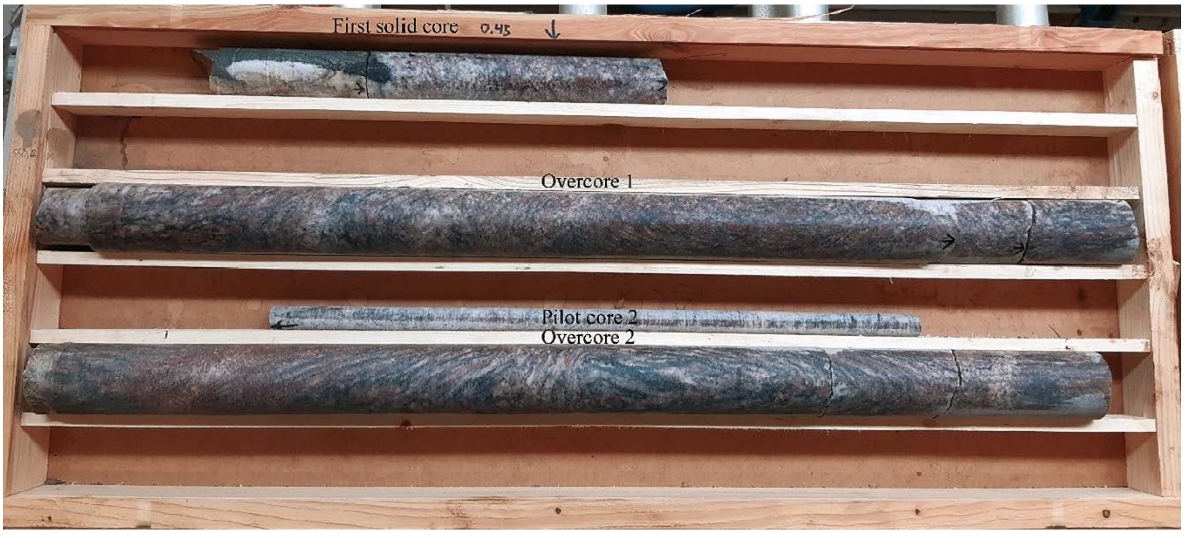

Figure 5-1. *Overview of all drilled cores within this study. Note that pilot core 1 is attached inside overcore 1 (not visible).*

5.1 First standard diameter solid core

The first drillcore has the standard diameter of 50 mm and is 0.45 m long. The upper half of the drill-core consist of amphibolite (SKB Rock type ID code 102017), together with coarse grained pegmatite. The bottom part of the drillcore comprise metamorphic medium-grained reddish granite (within the variety span of SKB Rock type ID code 101057, denoted "granite to granodiorite"). This is the most common rock type within the area of the planned repository, see Figure 3-1.

One open fracture with moderate fill of chlorite is noted in the amphibolite at the very top of the core, and one unbroken fracture with minor fill of calcite and chlorite in part where pegmatite and amphibolite co-exist. One sealed fracture without any visible mineral filling is noted in the granite (Figure 5-2).

Figure 5-2. *First solid core comprising amphibolite and pegmatite followed by medium-grained granite (101057).*

5.2 Overcoring test no. 1

The first pilot core was not detached from the bottom of the borehole due to failure of the drilling operation and is therefore still attached inside the first overcore (Figure 5-3). The overcore is about 1 m long were the hollow part is 0.6 m long. The wall is uniform with a thickness of about 13 mm all around (Figure 5-3). The core is solid with no signs of ring disking or micro fractures (Figure 5-4).

Metamorphic medium-grained reddish granite (101057) is the main rock type of the core, with one occurrence of a relatively thin vein of pegmatite (SKB Rock type ID code 101061). The granite 101057 have a medium strong foliation parallel to the drill core. One open fracture with minor filling of chlorite is noted at the bottom non-hollow part of the core (Figure 5-4). Faint albitisation is noted along the whole core, appearing as white-milky areas with less mafic minerals (Figure 5-5).

Figure 5-3. *First overcore test with the pilot core still attached in the bottom end. Only the first short part has thinner walls until the special overcoring crown is used. The thickness of the hollow core walls is about 12 mm. The rock type of the core is (101057).*

Figure 5-4. *Wet (up) and dry (down) pictures of overcore 1. The open fracture with minor chlorite is marked with a dashed red line, the second fracture at the bottom is induced as a consequence of taking the core out.*

__Figure 5-5.__ Example of appearance of faint albitization in KFM24.

5.3 Overcoring test no. 2

The second overcore has slightly irregular wall thickness because the pilot hole is not fully centered in the overcore. The thickest side has about 15 mm wall and the thinnest side has wall of about 10 mm (Figure 5-6). The overcore is however still solid with no signs of ring disking or micro fractures (Figure 5-7).

Metamorphic medium-grained reddish granite (101057) is the main rock type of the core with one thin vein of medium to coarse grained pegmatite (101061). Faint albitization is noted along the whole core. The foliation is medium-strong generally parallel to the drill core, however it is shifting (Figure 5-7). Three sealed fractures with slightly oxidized walls, one sealed fracture with chlorite, calcite and adularia are noted in the hollow part of the core. One sealed fracture filled with quartz associated with minor chlorite and calcite is found in the bottom and non-hollow part of the core.

__Figure 5-6.__ The pilot hole of overcore no. 2 was not fully centered. Wall thickness of thinnest part is ~10 mm (to the left) and ~15 mm on the thicker side to the right. The foliation is well visible.

***Figure 5-7.** Wet (up) and dry (down) pictures of overcore 2 and pilot core 2. The two open fractures in the bottom are induced as a consequence of taking the core out. Shifting of foliation is visible.*

5.4 Comparison between KFM24 and KFM07C

An ocular comparison between overcores from KFM07C and those from KFM24 described above was done. Compositional difference in the rock type 101057, difference in orientation and intensity of foliation, presence of alteration as well as frequency and character of fractures were considered. To make a fair comparison, the study focused on the five deepest drilled overcores from KFM07C (Figures 5-8 to 5-10), from 418.99 down to 426.38 meters borehole depth. All five with the same dimensions as the overcores from KFM24.

Judgements based on this small investigation are the following:

- The rock type 101057 is considered to be "fresh", i.e., no sign of exceptional alteration or deformation is observed (based on current interpretation standards) at the overcoring points in both KFM07C and KFM24. Though, albitization is noted in both KFM24 and KFM07C. The foliation is slightly more distinctive in cores from KFM24.
- No obvious difference in character or frequency of natural fractures can be seen.
- The rocktype in the three deepest overcores 6:5:2, 6:3:1 and 6:4:1 in KFM07C is more pale in colour compared to the two drill cores from KFM24 (Figures 5-8 and 5-9), which can be due to different feldspar composition (i.e., possibly KFM07C is more "granodioritic" in composition) and/or more albitized. Note, the term granodiorite is confusing since its origin could derive from albitization of the granite. More correctly it should be named as albitized granite.
- Ring disking occurs where KFM07C have less potassium feldspar (Figure 5-9), whereas in the two shallower overcores 6:2:1 and 6:1:2 (Figure 5-10) where the rock composition appears more similar to KFM24 (i.e., higher content of potassium feldspar), no ring disking occurs. Yet, there are fractures in both overcores. Whether this compositional difference is a coincidence or have an effect on rock strength/ring disking occurrence need to be studied in more detail.

***Figure 5-8.** Deepest drilled overcore (6:5:2) in KFM07C down to 426.38 meters borehole depth. Example of more pale 101057, presumably more towards "granodioritic" composition and/or more albitized with little or total absence of potassium feldspar.*

Figure 5-9. *For comparison the image shows overcores from KFM24 (red box) and overcores (6:3:1 and 6:4:1) from KFM07C below. Note the ring disking and the pale colour of 101057 in both overcores from KFM07C.*

Figure 5-10. *For comparison the image shows overcores from KFM24 (red box) and cores from KFM07C below. Note that there are more potassium feldspar in these two cores from KFM07C in this figure compared to those represented in Figure 5-9. Both 6:2:1 and 6:1:2 are more similar to cores from KFM24. 6:2:1 (bottom) is naturally broken in one place (rightmost fracture) and the following joints towards the left in the image are from cutting samples. Overcore 6:1:2 is naturally broken in two places, however, no typical ring disking is observed.*

6 Conclusions and recommendations

From this study of overcoring pilot boreholes in the bottom of the pre-existing borehole KFM24 it can be concluded the following:

- Both performed trials starting at 550.62 m borehole depth resulted in intact hollow cores (inner diameter 36 mm and outer diameter 62 mm, wall thickness 13 mm). No signs of ring disking or microcracking were observed on the cores. The hollow parts of the cores are 0.6 m long each.
- The hollow cores consisted of the most common rock type at the Forsmark site, a medium grained granite to granodiorite (SKB Rock type ID code 101057).
- The result of overcoring at depth in KFM24 is different from the result in previous overcoring measurement attempts in KFM07C where ring disking occurred at depth. The difference in results can in principle be related to differences in i) rock strength properties, ii) loading conditions during overcoring from drilling operation and iii) in situ stress magnitudes. The main reason is tentatively judged to be the differences in the rock type strength properties between the locations of the two boreholes. The hollow cores (with ring disking) in KFM07C seem with naked eye to be more "granodioritic" in character and/or experienced stronger albitization compared to the hollow cores in KFM24.
- The conditions at the bottom of KFM24 (552.57 m borehole depth, corresponding to 547.37 m depth below sea level) are suitable for overcoring stress measurements.

Based on the results from this study the following recommendations are given:

- A laboratory determination of uniaxial compressive strength (UCS) of the rock close to the overcoring points in KFM24 is recommended. Such data could be utilized in the comparisons with data from other Forsmark boreholes and constitute valuable data since there is currently no UCS data from KFM24, which is located in the middle of the central area in the planned repository.
- Continuous measurements using Point Load Tester along KFM07C, and other boreholes, could be useful in the attempts to find differences in strength conditions within and between the boreholes. Point Load testing results are already available from borehole KFM24 (SKB 2021b) and they show that drill core from rock type "granite to granodiorite" (101057) has a variation in point load strength along the borehole. This result is supported by results from laboratory tests of tensile strength from different points along this borehole (SKB 2021a).
- A detailed study to confirm i) presence and distribution of albitization in the rock type 101057 and ii) the boundary between granite and "granodiorite" as well as the origin of granodiorite within the rock type 101057 should be considered in order to evaluate differences in rock type strength properties. The origin of "granodiorite" within this rock type and area could be related to an early stage of albitization of granite (Petersson et al. 2012, SKB 2008). If so, it is misleading to call it granodiorite, more accurate naming would be albitized granite.

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.com/publications.

Lindfors U, Perman F, Berg S, Ask M, 2007. Forsmark site investigation. Overcoring rock stress measurements in borehole KFM07C. SKB P-07-130, Svensk Kärnbränslehantering AB.

Nilsson G, 2017. Steered core drilling of borehole KFM24. SKB P-16-32, Svensk Kärnbränslehantering AB.

Petersson J, Stephens M B, Mattson, H, Möller C, 2012. Albitization and quartz dissolution in Paleoproterozoic metagranite, central Sweden – Implications for the disposal of spent nuclear fuel in a deep geological repository. Lithos 148, 10–26.

SKB, 2008. Site description of Forsmark at completion of the site investigation phase. SDM-site Forsmark. SKB TR-08-05, Svensk Kärnbränslehantering AB.

SKB, 2021a. Forsmark – Laboratory tests in borehole KFM24. Thermal properties by TPS method and indirect tensile strength tests with strain measurements of intact rock. SKB P-21-07, Svensk Kärnbränslehantering AB.

SKB, 2021b. Provning av hållfasthet med Point-Load-Tester längs borrkärna KFM24 (över). Metodutvärdering och jämförande laboratorieprovning**.** SKB P-21-08, Svensk Kärnbränslehantering AB. (In Swedish.)

Stephens M, Fox A, La Pointe P, Simeonov A, Isaksson H, Hermansson J, Öhman J, 2007. Geology Forsmark. Site descriptive modelling Forsmark stage 2.2. SKB R-07-45, Svensk Kärnbränslehantering AB.

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