P-06-234

Forsmark site investigation

Borehole KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A

Determination of porosity by water saturation and density by buoyancy technique

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December 2006

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Keywords: Rock mechanics, Petro-physics, Density, Porosity, AP PF 400-06-051.

Abstract

The density and porosity was determined on 20 specimens (each divided into two pieces) from borehole KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A, Forsmark, Sweden. The specimens were sampled at different levels and in 6 different boreholes. The investigated rock types are mapped as granite-tonalite (101051), granite-aplite (101058), medium-grained granite (111058), amphibiolithe (102017), fine-grained granite (101057) and felsic (103076). The results for the dry density varied between 2,610 and 3,010 kg/m^3, and for the wet density between 2,620 and 3,010 kg/m^3. Finally,the porosity results varied between 0.2 and 0.9%.

Sammanfattning

Densiteten och porositeten bestämdes på 20 provkroppar (varje provkropp delad i två delar) från borrhål KFM01A, KFM01C, KFM01D, KFM04A, KFM05A och KFM06A i Forsmark. Proverna togs från flera nivåer i 6 olika borrhål. De undersökta bergarterna är karterade som granit-tonalit (101051), granit-aplit (101058), medelkorning granit (111058), amfibolit (102017), finkornig granit (101057) och felsisk (103076). Resultaten för torrdensiteten varierade mellan 2 610 och 3 010 kg/m^3 och för våtdensiteten mellan 2 620 och 3 010 kg/m^3. För porositeten, slutligen, varierade resultaten mellan 0,2 och 0,9 %.

Contents

1 Introduction

This document reports performance and results of determination of porosity by water saturation and density by buoyancy technique within the site investigation programme at Forsmark, Sweden, /1/. The controlling documents for the activity are listed in Table 1-1. Both Activity Plan and Method Description are SKB's internal controlling documents. The thermal properties conductivity and diffusivity of the specimens were determined within the scope of parallel activity /2/.

Samples were collected from the drill cores of borehole KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A at the Forsmark site investigation area, Sweden, see Figure 1-1, for determination of the water saturated density, dry density and the porosity. Borehole KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A are telescopic drilled boreholes.

The sampling was based on the preliminary core logging with the strategy to primarily investigate the properties of the different rock types. The samples were collected and transported to SP (Swedish National Testing and Research institute), department of Building and Mechanics, where they arrived on June 26, 2006. Testing commenced in July 2006 and was completed in September 2006.

The commission was carried out in compliance with the controlling documents presented in Table 1-1. Activity Plan and Method Descriptions are SKB's (The Swedish Nuclear Fuel and waste Management Company) internal controlling documents, whereas SP-QD 13.1 is an SP internal Quality document.

Table 1-1. Controlling documents for performance of the activity.

Activity Plan	Number	Version
Termiska laboratoriebestämningar på borrkärnor från KFM01A, KFM01C, KFM01D, KFM04A, KFM05A och KFM06A.	AP PF 400-06-051	1.0
Method Description	**Number**	**Version**
Determining density and porosity of intact rock	SKB MD 160.002	2.0
Quality Plan		
SP-QD 13.1		

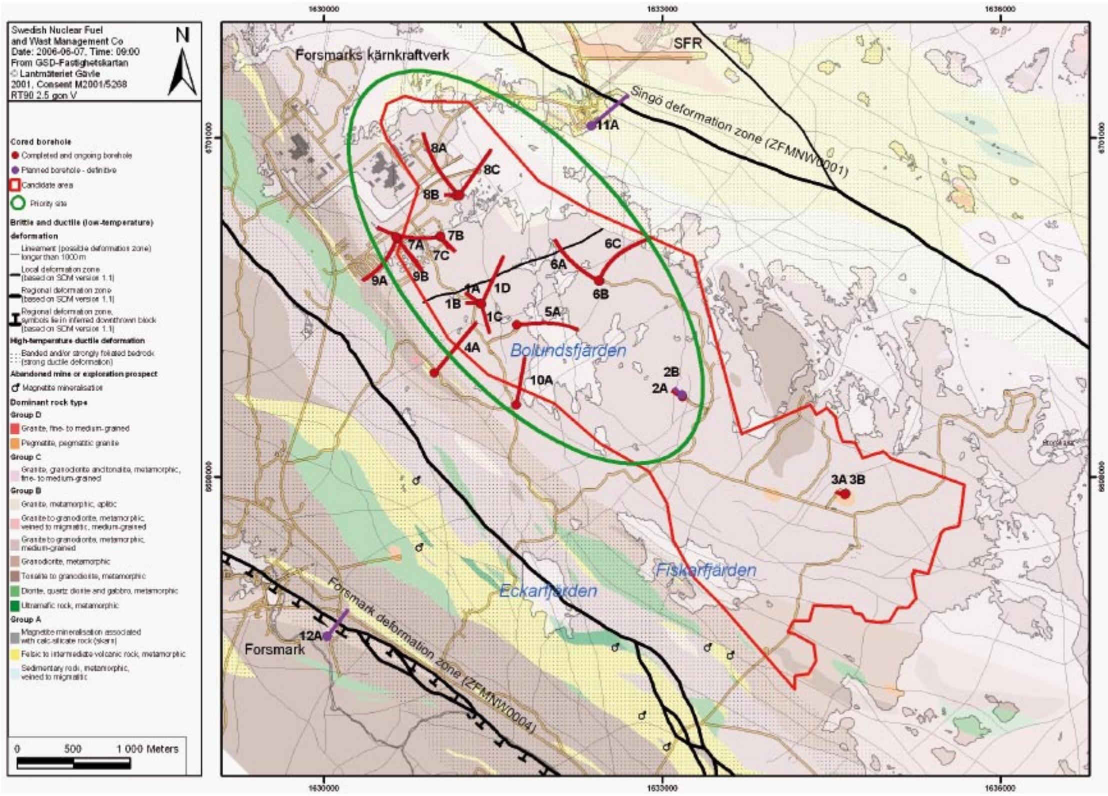

Figure 1-1. *Geological map over Forsmark candidate area with location of telescopic boreholes and conventional drilled boreholes drilled or started up to April 2006 (marked in red) and planned to be drilled (marked in violet).*

2 Objective and scope

The purpose of determining density and porosity of intact rock cores is to use these parameters in the rock mechanics and thermal site descriptive model, which will be established for the candidate area selected for site investigations at Forsmark.

The testing comprised of 20 rock samples from boreholes KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A.

3 Equipment

The following equipment was used for the density and porosity determinations:

- Thermometer (inv no 102185) for measurement of water temperature. Calibrated 2006-01-17. Measurement accuracy ± 0.4°C.
- Scale (inv no 102291) for weight measurement. Calibrated in 2006-03-10. Measurement accuracy ± 0.2 g.
- Heating chamber (inv no 102284) for drying the specimens. Calibrated 2006-01-17. Measurement accuracy ± 5°C.
- A covered plastic box filled with water for water saturation of the samples.
- A desiccator for cooling samples.

Uncertainty of method as expanded uncertainty with covering factor 2 (95% confidence interval):

Density	± 4 kg/m^3
Porosity	± 0.09%.
Water absorption	± 0.05%.

4 Execution

Determination of the porosity and density was made in accordance with SKB's method description SKB MD 160.002, (SKB internal controlling document). This includes determination of density in accordance to ISRM 1979 /3/ and water saturation by EN 13755 /4/ and in compliance with Activity Plan AP PF 400-06-051 (internal controlling document of SKB). The department of Building Technology and Mechanics (BM) at SP performed the test.

4.1 Description of the specimens

The specimens from borehole KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A were sampled at different levels. Table 4-1 shows the identification mark, sampling level and rock type/occurrence of each specimen.

Table 4-1. Identification mark, sampling level and rock type/occurance of each specimen (rock-type classification according to Boremap).

Identification	Sampling level (m borehole length, Adj seclow)	Rock type/occurance
KFM-ST-90V-1	588.64	Granite-tonalite (101051)
KFM-ST-90V-2	594.88	Granite-tonalite (101051)
KFM-ST-90V-3	640.72	Granite-aplite (101058)
KFM-ST-90V-4	659.97	Granite-aplite (101058)
KFM-ST-90V-5	651.81	Granite-aplite (101058)
KFM-ST-90V-6	989.43	Granite-aplite (101058)
KFM-ST-90V-7	356.24	Amphibolite (102017)
KFM-ST-90V-8	687.13	Granite-tonalite (101051)
KFM-ST-90V-9	695.70	Granite-tonalite (101051)
KFM-ST-90V-10	708.40	Granite-tonalite (101051)
KFM-ST-90V-11	741.34	Medium-grained granite (111058)
KFM-ST-90V-12	874.90	Medium-grained granite (111058)
KFM-ST-90V-13	287.10	Fine-grained granite (101057)
KFM-ST-90V-14	330.89	Felsic to intermediate metavolcanite (103076)
KFM-ST-90V-15	739.54	Amphibolite (102017)
KFM-ST-90V-16	184.09	Fine-grained granite (101057)
KFM-ST-90V-17	838.42	Granite-tonalite (101051)
KFM-ST-90V-18	845.56	Amphibolite (102017)
KFM-ST-90V-19	691.77	Amphibolite (102017)
KFM-ST-90V-20	771.33	Fine-grained granite (101057)

4.2 Testing

The temperature of the water used for water saturation was 20°C and the density was 998 kg/m^3.The specimens were dried in 105°C for six days after water saturation. The execution procedure followed the prescription in SKB MD 160.002, see Table 4-2.

The present activity was performed in parallel with other activities /2/, conducted by the Fire technology at SP and Measurement Technology at SP that determined different thermal properties. The following logistic sequence was applied for the three activities.

Table 4-2. The sequence of activities applied for execution of the commission.

Activity No	Activity
1	The specimens were cut according to the marks on the rock cores. Every specimen was cut into two pieces, marked A and B and about 25 mm thick each. The same specimens were used in a parallel activity to determine the thermal properties thermal conductivity and thermal diffusivity by applying the TPS method /2/.
2	The specimens were photographed in JPEG-format.
3	The specimens were water saturated in normal air pressure for at least seven days.
4	The specimens were weighed in tapwater. The temperature of the water was 20°C and the density 998 kg/m^3.
5	The specimens were surface dried with a towel and weighed.
6	The water saturated density was determined.
7	The samples were sent from SP Building Technology and Mechanics to SP Fire Technology for measurement of thermal properties /2/.
8	The samples were sent back from SP Fire Technology to SP Building Technology and Mechanics.
9	The specimens were dried in a heating chamber during six days at 105°C.
10	The specimens were transported to a desiccator for cooling.
11	The dry density and porosity were determined.
12	The specimens were water saturated in normal air pressure for at least seven days.
13	The samples were sent from SP Building Technology and Mechanics to SP Measurement technology for measurement of thermal properties, calorimetric method.
14	The samples were returned from SP Measurement technology to SP Building Technology and Mechanics.

4.3 Nonconformities

The tests were performed in accordance with the Method Description. The Activity Plan was followed without deviations.

An exception from the method was the statement of significant numbers in Appendix 1. The precision in the method for density gives only three significant digits the fourth digit given here is thus not significant. The precision in the method for porosity gives only one significant digit the second digit given here is thus not significant. It is important that this is kept in mind when the results are used for further calculation. However in Chapter 5 only significant digits are presented.

5 Results

The results of the porosity and density determinations of core samples from KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A are stored in SKB's database SICADA, where they are traceable by the Activity Plan number.

Minutes and photos are presented in Appendix 1.

5.1 Summarized results of KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A

Table 5-1 summarizes the results of the porosity and density determinations of the specimens.

5.2 Results for the entire test series

Results for the entire test series are shown in the diagrams below. They are divided into three diagrams; see Figures 5-1 to 5-3, illustrating dry density, wet density and porosity.

Table 5-1. Summary of the results for porosity, dry density and wet density. The result for each specimen is a mean value of sub samples A and B.

Specimen	Sampling level (m borehole length), (Adj seclow)	Porosity (%)	Dry density (kg/m^3)	Wet density (kg/m^3)
KFM-ST-90V-1	588.64	0.3	2,710	2,710
KFM-ST-90V-2	594.88	0.4	2,710	2,710
KFM-ST-90V-3	640.72	0.4	2,650	2,650
KFM-ST-90V-4	659.97	0.3	2,640	2,650
KFM-ST-90V-5	651.81	0.3	2,640	2,640
KFM-ST-90V-6	989.43	0.4	2,620	2,630
KFM-ST-90V-7	356.24	0.3	2,950	2,950
KFM-ST-90V-8	687.13	0.3	2,690	2,690
KFM-ST-90V-9	695.70	0.3	2,720	2,720
KFM-ST-90V-10	708.40	0.3	2,710	2,720
KFM-ST-90V-11	741.34	0.7	2,610	2,620
KFM-ST-90V-12	874.90	0.5	2,620	2,620
KFM-ST-90V-13	287.10	0.9	2,630	2,640
KFM-ST-90V-14	330.89	0.2	2,900	2,900
KFM-ST-90V-15	739.54	0.2	2,920	2,930
KFM-ST-90V-16	184.09	0.6	2,640	2,650
KFM-ST-90V-17	838.42	0.3	2,670	2,670
KFM-ST-90V-18	845.56	0.3	3,010	3,010
KFM-ST-90V-19	691.77	0.6	3,000	3,010
KFM-ST-90V-20	771.33	0.4	2,620	2,630

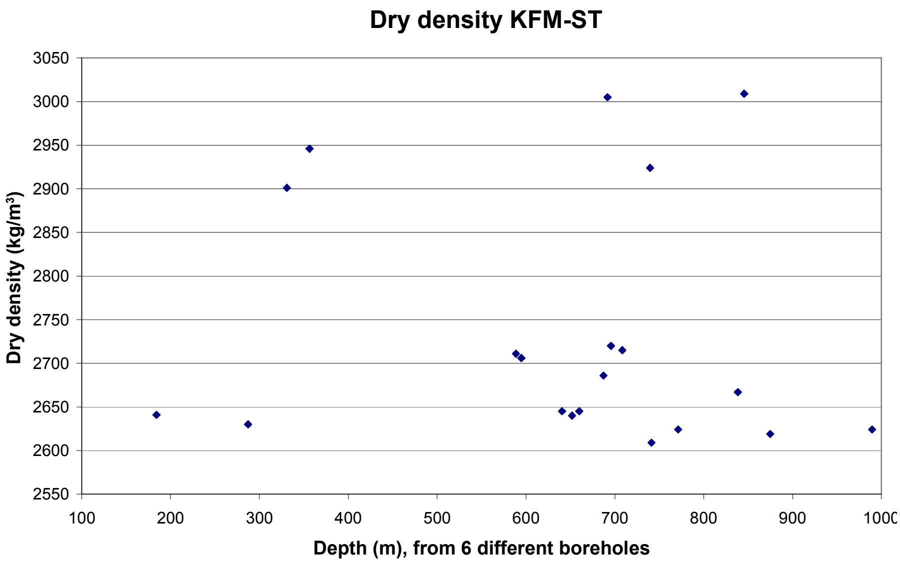

***Figure 5-1**. Density (dry) versus sampling level (borehole length), from 6 different boreholes.*

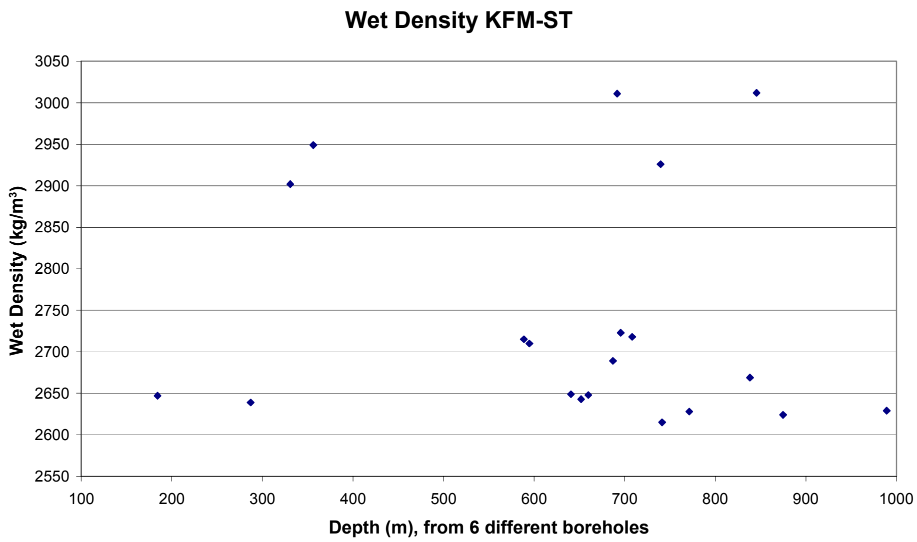

***Figure 5-2.** Density (wet) versus sampling level (borehole length), from 6 different boreholes.*

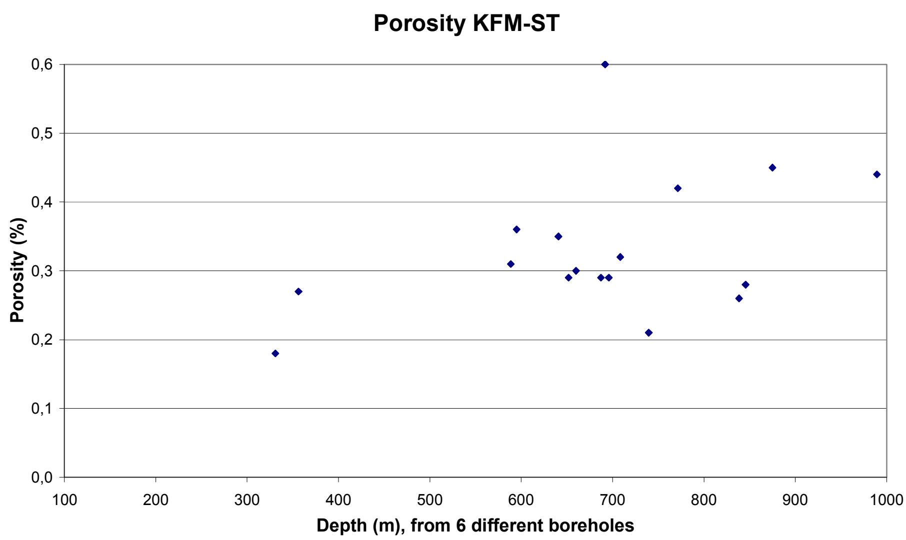

***Figure 5-3.** Porosity versus sampling level (borehole length), from 6 different boreholes.*

References

/1/ **SKB, 2001.** Site investigations. Investigation methods and general execution programme. SKB TR-01-29, Svensk Kärnbränslehantering AB.

/2/ **Adl-Zarrabi, B, 2006.** Drill hole KFM01A, KFM01C, KFM01D, KFM04A and KFM06A: Thermal properties of rocks using calorimeter and TPS method and mineral composition by modal analysis. SKB P-06-233, Svensk Kärnbränslehantering AB.

/3/ **ISRM, 1979.** Volume 16, Number 2.

/4/ **EN 13755.** Natural stone test methods – Determination of water absorption at atmospheric pressure.

Appendix

Result minutes and photos

Table A-1. KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A. Specimens KFM-ST-90V-1 to KFM-ST-90V-20.

KFM-ST-90V-1 (588.644 m)

Dry density of specimen KFM-ST-90V-1A 2,713 kg/m^3 and porosity 0.31%.

Dry density of specimen KFM-ST-90V-1B 2,710 kg/m^3 and porosity 0.30%

***Figure A-1.** KFM-ST-90V-1 A and B.*

KFM-ST-90V-2 (594.876 m)

Dry density of specimen KFM-ST-90V-2A 2,710 kg/m^3 and porosity 0.32%.

Dry density of specimen KFM-ST-90V-2B 2,702 kg/m^3 and porosity 0.39%.

***Figure A-2.** Specimens KFM-ST-90V-2 A and B.*

KFM-ST-90V-3 (640.717 m)

Dry density of specimen KFM-ST-90V-3A 2,645 kg/m^3 and porosity 0.34%.

Dry density of specimen KFM-ST -90V-3B 2,646 kg/m^3 and porosity 0.37%.

***Figure A-3.** Specimens KFM-ST-90V-3 A and B.*

KFM-ST-90V-4 (659.975 m)

Dry density of specimen KFM-ST-90V-4A 2,649 kg/m^3 and porosity 0.28%.

Dry density of specimen KFM-ST-90V-4B 2,641 kg/m^3 and porosity 0.32%.

Figure A-4. *Specimens KFM-ST-90V-4 A and B.*

KFM-ST-90V-5 (651.813 m)

Dry density of specimen KFM-ST-90V-5A 2,639 kg/m^3 and porosity 0.30%.

Dry density of specimen KFM-ST-90V-5B 2,641 kg/m^3 and porosity 0.28%.

Figure A-5. *Specimens KFM-ST-90V-5 A and B.*

KFM-ST-90V-6 (989.426 m)

Dry density of specimen KFM-ST-90V-6A 2,622 kg/m^3 and porosity 0.47%.

Dry density of specimen KFM-ST-90V-6B 2,626 kg/m^3 and porosity 0.41%.

Figure A-6. *Specimens KFM-ST-90V-6 A and B.*

KFM-ST-90V-7 (356.244 m)

Dry density of specimen KFM-ST-90V-7A 2,957 kg/m^3 and porosity 0.26%.

Dry density of specimen KFM-ST-90V-7B 2,936 kg/m^3 and porosity 0.28%.

Figure A-7. *KFM-ST-90V-7 A and B.*

KFM-ST-90V-8 (687.129 m)

Dry density of specimen KFM-ST-90V-8A 2,686 kg/m³ and porosity 0.30%.

Dry density of specimen KFM-ST-90V-8B 2,686 kg/m³ and porosity 0.28%.

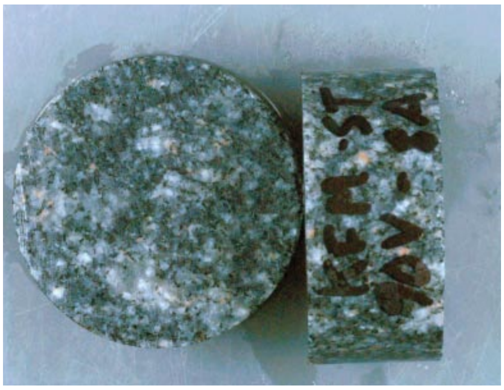

Figure A-8. Specimens KFM-ST-90V-8 A and B.

KFM-ST-90V-9 (695.703 m)

Dry density of specimen KFM-ST-90V-9A 2,720 kg/m³ and porosity 0.28%.

Dry density of specimen KFM-ST-90V-9B 2,719 kg/m³ and porosity 0.30%.

Figure A-9. Specimens KFM-ST-90V-9 A and B.

KFM-ST-90V-10 (708.404 m)

Dry density of specimen KFM-ST-90V-10A 2,714 kg/m³ and porosity 0.30%.

Dry density of specimen KFM-ST-90V-10B 2,716 kg/m³ and porosity 0.34%.

Figure A-10. KFM-ST-90V-10 A and B.

KFM-ST-90V-11 (741.342 m)

Dry density of specimen KFM-ST-90V-11A 2,608 kg/m³ and porosity 0.69%.

Dry density of specimen KFM-ST-90V-11B 2,609 kg/m³ and porosity 0.65%.

Figure A-11. Specimens KFM-ST-90V-11 A and B.

KFM-ST-90V-12 (874.901 m)

Dry density of specimen KFM-ST-90V-12A 2,619 kg/m³ and porosity 0.43%.

Dry density of specimen KFM-ST-90V-12B 2,619 kg/m³ and porosity 0.47%.

Figure A-12. *Specimens KFM-ST-90V-12 A and B.*

KFM-ST-90V-13 (287.103 m)

Dry density of specimen KFM-ST-90V-13A 2,628 kg/m³ and porosity 0.95%.

Dry density of specimen KFM-ST-90V-13B 2,633 kg/m³ and porosity 0.77%.

Figure A-13. *KFM-ST-90V-13 A and B.*

KFM-ST-90V-14 (330.895 m)

Dry density of specimen KFM-ST-90V-14A 2,902 kg/m³ and porosity 0.18%.

Dry density of specimen KFM-ST-90V-14B 2,900 kg/m³ and porosity 0.18%.

Figure A-14. *Specimens KFM-ST-90V-14 A and B.*

KFM-ST-90V-15 (739.540 m)

Dry density of specimen KFM-ST-90V-15A 2,925 kg/m³ and porosity 0.22%.

Dry density of specimen KFM-ST-90V-15B 2,923 kg/m³ and porosity 0.21%.

Figure A-15. *Specimens KFM-ST-90V-15 A and B.*

KFM-ST-90V-16 (184.093 m)

Dry density of specimen KFM-ST-90V-16A 2,642 kg/m^3 and porosity 0.60%.

Dry density of specimen KFM-ST-90V-16B 2,639 kg/m^3 and porosity 0.67%.

Figure A-16. *KFM-ST-90V-16 A and B.*

KFM-ST-90V-17 (838.425 m)

Dry density of specimen KFM-ST-90V-17A 2,670 kg/m^3 and porosity 0.24%.

Dry density of specimen KFM-ST-90V-17B 2,663 kg/m^3 and porosity 0.28%.

Figure A-17. *Specimens KFM-ST-90V-17 A and B.*

KFM-ST-90V-18 (845.565 m)

Dry density of specimen KFM-ST-90V-18A 3,009 kg/m^3 and porosity 0.28%.

Dry density of specimen KFM-ST-90V-18B 3,010 kg/m^3 and porosity 0.28%.

Figure A-18. *Specimens KFM-ST-90V-18 A and B.*

KFM-ST-90V-19 (691.77 m)

Dry density of specimen KFM-ST-90V-19A 3,011 kg/m^3 and porosity 0.58%.

Dry density of specimen KFM-ST-90V-19B 2,999 kg/m^3 and porosity 0.62%.

Figure A-19. *KFM-ST-90V-19 A and B.*

KFM-ST-90V-20 (771.33 m)

Dry density of specimen KFM-ST-90V-20A 2,623 kg/m^3 and porosity 0.46%.

Dry density of specimen KFM-ST-90V-20B 2,626 kg/m^3 and porosity 0.37%.

Figure A-20. *Specimens KFM-ST-90V-20 A and B.*