P-06-233

Forsmark site investigation

Borehole KFM01A, KFM01C, KFM01D, KFM04A, KFM05A, KFM06A and KFM09A

Thermal properties of rocks using calorimeter and TPS method, and mineralogical composition by modal analysis

Bijan Adl-Zarrabi

SP Swedish National Testing and Research Institute

October 2006

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Keywords: Thermal properties, Thermal conductivity, Thermal diffusivity, Heat capacity, Transient Plane Source method, Calorimeter, AP PF 400-06-051.

Update notice

The original report, dated October 2006, was found to contain factual errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2024-09

Location	Original text	Corrected text
Page 13, Table 4-1, row KFM-ST-90V-17, column Rock type/occurrence	Granite, granodiorite and tonalite (101051)	Granit-granodiorite (101057)
Page 53, Table D-1, row Rock code, column KFM01A (KFM-ST-90V-17)	101051	101057

Abstract

Thermal properties on twenty specimens of drill holes KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A, Forsmark, Sweden, were measured at ambient temperature (20°C). Selective rock samples were taken from earlier investigations in the mentioned drill holes. The determination of the thermal properties is based on a direct measurement method, the so called "Transient Plane Source Method" (TPS). The specific heat capacity of the samples was also measured by a calorimeter. The mineralogical content was determined by using modal analysis.

Thermal conductivity and thermal diffusivity measured by TPS at 20°C were in the range of 2.09–3.96 W/(m, K) respectively 0.88–1.94 mm^2/s. The heat capacity, which was calculated from the thermal conductivity and diffusivity, ranged between 1.79 and 2.53 MJ/(m^3, K).

The specific heat capacity that was measured by calorimetric method was in the range of 0.75–0.86 J/(g, K).

Sammanfattning

Termiska egenskaper hos tjugo provkroppar från borrhålen KFM01A, KFM01C, KFM01D, KFM04A, KFM05A och KFM06A, Forsmark, bestämdes vid rumstemperatur (20 °C). Selektiva bergartsprover hade tagits från tidigare undersökningar av de nämnda borrhålen. TPS metoden, ”Transient Plane Source”, användes för bestämning av de termiska egenskaperna. Specifika värmekapaciteten bestämdes även med en kalorimeter. Det mineralogiska innehållet bestämdes med hjälp av modalanalys.

Den termiska konduktiviteten och den termiska diffusiviteten mätt med TPS vid 20 °C uppgick till 2,09–3,96 W/(m, K) respektive 0,88–1,94 mm^2/s. Från värdena på dessa parametrar kunde den volymmetriska värmekapaciteten beräknas och befanns ligga i intervallet 1,79 till 2,53 MJ/(m^3, K).

Den specifika värmekapaciteten, som bestämts med kalorimeter, uppgick till 0,75–0,86 J/(g, K).

Contents

1 Introduction

SKB is planning to build a final repository for nuclear waste in bedrock. A final repository for nuclear waste demands knowledge about thermal properties of the rock. Forsmark, Sweden, is one of the areas selected for site investigations. The activity presented in this report is part of the site investigation program at Forsmark /1/.

Several boreholes at Forsmark have previously been investigated with respect to the thermal properties. This report presents investigations of thermal properties of rock samples from boreholes KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A at Forsmark. The location of the telescopic as well as the conventionally drilled core boreholes is shown in Figure 1-1. The thermal properties thermal conductivity and thermal diffusivity have been determined by using the Transient Plane Source Method (TPS), (Gustafsson, 1991) /2/. The method determines thermal conductivity and diffusivity of a material. The volumetric heat capacity can be calculated if the density is known. The dry and wet densities, as well as porosity of the samples, were determined within the scope of a parallel activity /3/. In addition, specific heat capacity of samples was measured by calorimetric method /4/.

Modal analysis, based on point counting using a polarising microscope, was performed on four specimens that were sampled quite close to four specimens for thermal properties (TPS) (boreholes KFM01A, KFM05A and KFM06A) and on six specimens that were sampled from borehole KFM09A. The modal analysis was done in order to calculate the thermal properties based on the mineralogical composition of the specimens. The analysis was performed by Jesper Peterson, Vattenfall Power Consultant AB. No description of the analysis is presented in this report, only the results.

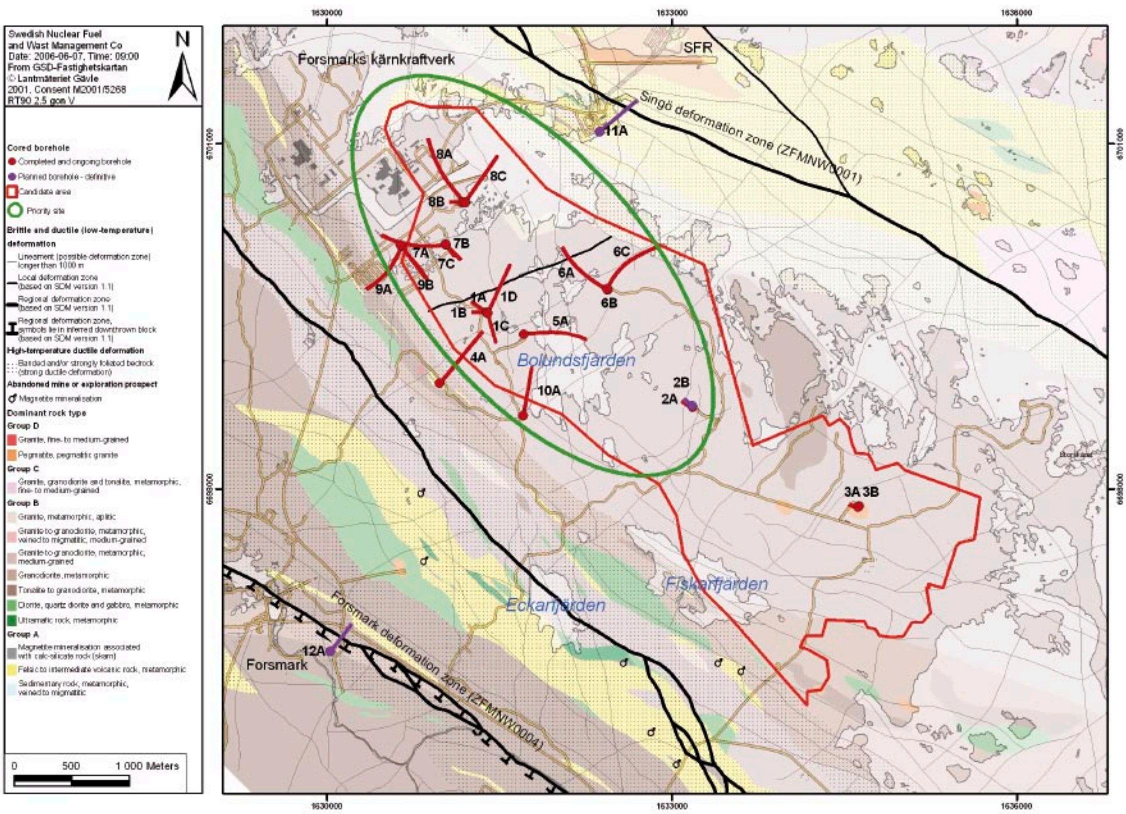

Figure 1-1. Location of all telescopic and conventionally core drilled boreholes completed up to April 2006 within and close to the Forsmark candidate area (marked red).

Rock samples were selected at Forsmark based on the Boremap core logging with the strategy to investigate the properties of the dominant rock types as well as of a number of minority rock types.

The specimens to be tested were cut from the rock samples in the shape of circular discs. The rock samples arrived at SP in June 2006. The thermal properties were determined on water-saturated specimens. Testing was performed during August–September 2006.

The controlling documents for the activity are listed in Table 1-1. Activity Plan and Method Descriptions are SKB's (The Swedish Nuclear Fuel and waste Management Company) internal controlling documents. Also SP's (Swedish National Testing and Research Institute) Quality Plan (SP-QD 13.1) served as controlling document.

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

Activity Plan	**Number**	**Version**
Termiska laboratoriebestämningar på borrkärnor från borrhål KFM01A, KFM01C, KFM01D, KFM04A, KFM05A och KFM06A.	AP PF 400-06-051	1.0
Method Description	**Number**	**Version**
Determining thermal conductivity and thermal capacity by the TPS method.	SKB MD 191.001	2.0
Quality Plan		
SP-QD 13.1		

2 Objective

The purpose of this activity is to determine the thermal properties of rock specimens. The obtained thermal properties will be used as input data for mechanical and thermal analysis in a site descriptive model that will be established for the candidate area selected for site investigation at Forsmark.

3 Equipment

3.1 Transient Plane Source

Technical devices for determination of the thermal properties in question were:

- Kapton sensor 5501, with a radius of 6.403 mm, and a power output of 0.7 W. The sensor 5501 fulfils the recommended relation between sensor radius and sample geometry of the samples in /5/.
- TPS-apparatus, Source meter Keithley 2400, Multi-meter Keithley 2000 and bridge, see Figure 3-1.
- PC + Microsoft Office and Hot Disk version 5.4.
- Stainless Sample holder.

Function control of TPS instrumentation was performed according to BRk-QB-M26-02 (SP quality document), see Appendix A.

The experimental set-up is shown in Figure 3-2.

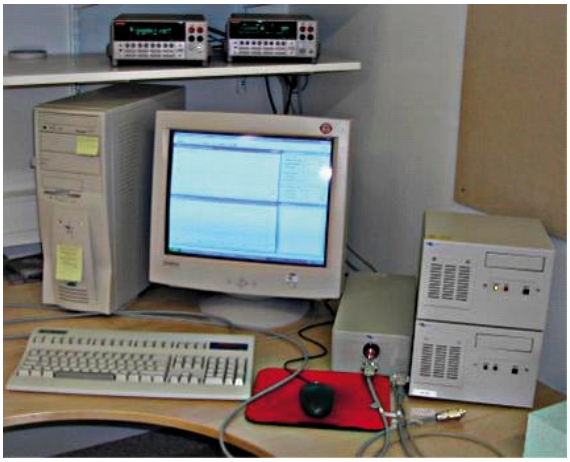

Figure 3-1. *TPS-apparatus with source meter, multi-meter, bridge, and computer.*

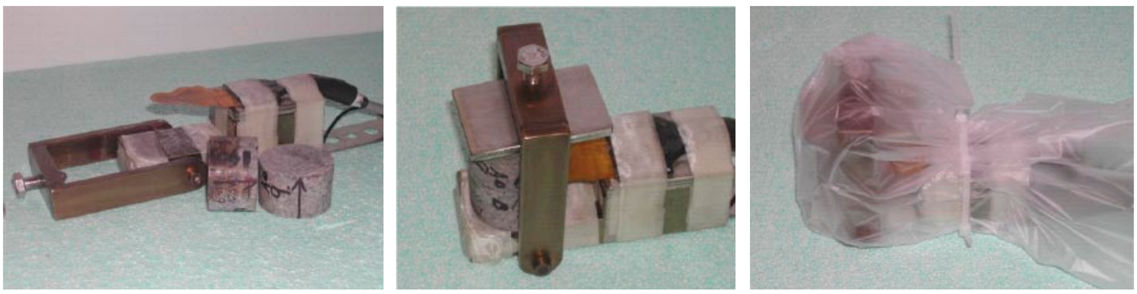

Figure 3-2. *Specimens prior to mounting (left), mounted in stainless sample holder (middle), and sample holder with mounted specimens wrapped in plastic (right).*

3.2 Calorimetric method

The measurement equipment used for the calorimetric determination of the specific heat capacity is shown in Figure 3-3 and consisted of:

- Calorimeter, made of Macrolon with low heat capacity and very low heat conductivity.
- Magnetic stirrer, IKA type BigSquid.
- Temperature logger, Keithley 2000 multimeter with scanner Keithley 7700 (temperature resolution 0.01 mK, accuracy 5 mK).
- Temperature controlled bath, Heto Thermostat 13 DT-1 (resolution 0.1°C).
- Three temperature sensors, Pt-100 Pentronic (2 for calorimeter, 1 for temperature controlled bath).
- Thermometer for Air, Pentronic CRL 206, s/n 270210 (resolution 0.01°C).
- Balance Mettler PM 2000 (resolution 0.01 g, accuracy 0.02 g).
- Air conditioning equipment, µAC Carel, Essén Company.
- Laptop computer Toshiba programmed on Visual Basic 6 for the temperature monitoring of three channels per three seconds.
- Pure and de-aerated water, crushed ice for fast preparation of a "steady state" condition.
- Various accessories (stand, holder, clamps, hoses, dewar, syringe, timer, etc.).

All measurement instruments are traceable via in-house calibration to national and international standards. The three temperature sensors connected to respective logger channel were calibrated immediately before the measurements. The balance was several times checked using relevant weight pieces.

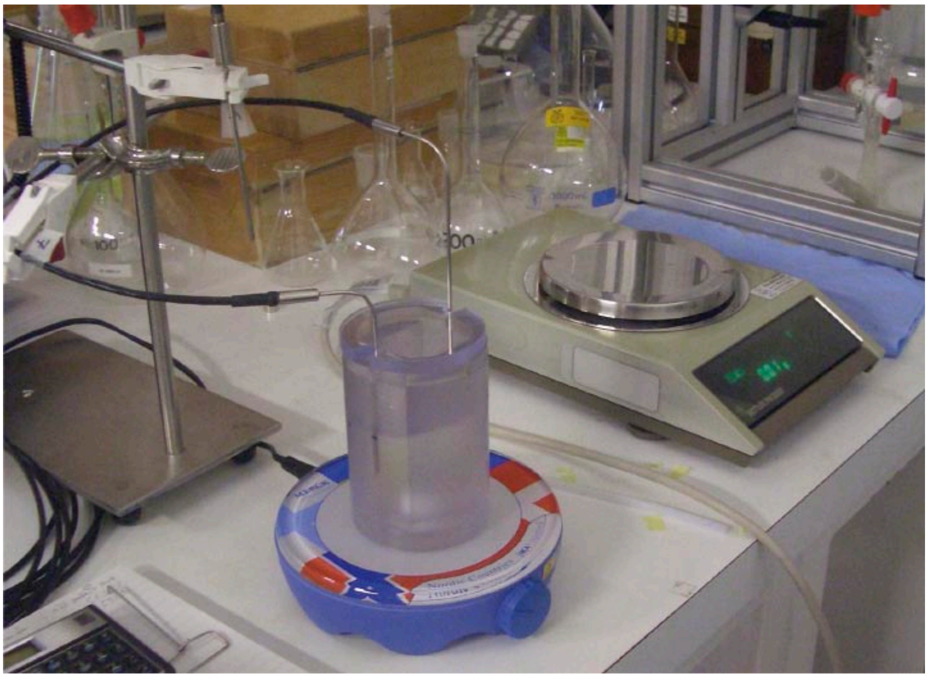

Figure 3-3. *Calorimeter with two temperature sensors on magnetic stirrer.*

4 Execution

Specific heat capacity was determined according to /4/ at SP Measurement Technology. The procedure of temperature measurement in conjunction with the determination of specific heat was modified in this project. The modification is explained in 4.3.

Determination of thermal properties conductivity and diffusivity was made in compliance with SKB's method description SKB MD 191.001 (SKB internal controlling document) and Hot Disc Instruction Manual /5/ at SP Fire Technology.

The density determinations, which were performed in a parallel activity at SP /3/, were carried out in accordance with SKB MD 160.002 (SKB internal controlling document) and ISRM /6/ at SP Building Technology and Mechanics.

Peter Lau at SP Measurement Technology conducted the specific heat capacity measurements, Patrik Nilsson and Ingrid Wetterlund at SP Fire Technology conducted the thermal property measurements and preparation of the report.

4.1 Description of the samples

Twenty pairs of cores (designated A and B) were sampled from boreholes KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A, Forsmark, Sweden. Selective rock samples were taken from earlier investigations in the mentioned boreholes. The forty specimens with a thickness of 25 mm each (see Figure 3-2) were cut from the rock samples at SP. The diameter of the specimens was about 50 mm. The identification marks, borehole numbers, rock type, and sampling levels of the specimens are presented in Table 4-1. Detailed geological description of the entire core of the boreholes is given in SKB's database SICADA (Boremap data).

Table 4-1. Rock type and identification marks (Rock-type classification according to Boremap).

Identification	Borehole	Rock type/occurence	Sampling level (m borehole length) (Sec low)
KFM-ST-90V-01	KFM06A	Granite, granodiorite and tonalite (101051)	586.64
KFM-ST-90V-02	KFM06A	Granite, granodiorite and tonalite (101051)	592.85
KFM-ST-90V-03	KFM06A	Aplitic granite (101058)	638.47
KFM-ST-90V-04	KFM06A	Aplitic granite (101058)	657.65
KFM-ST-90V-05	KFM06A	Aplitic granite (101058)	649.52
KFM-ST-90V-06	KFM06A	Granite (111058)	985.22
KFM-ST-90V-07	KFM05A	Amfibolite (102017)	355.29
KFM-ST-90V-08	KFM05A	Granite, granodiorite and tonalite (101051)	684.14
KFM-ST-90V-09	KFM05A	Granite, granodiorite and tonalite (101051)	692.67
KFM-ST-90V-10	KFM05A	Granite, granodiorite and tonalite (101051)	705.31
KFM-ST-90V-11	KFM05A	Granite (111058)	738.13
KFM-ST-90V-12	KFM04A	Granite (111058)	870.79
KFM-ST-90V-13	KFM01C	Granit-granodiorite (101057)	286.23
KFM-ST-90V-14	KFM01C	Vulcanite (103076)	329.86
KFM-ST-90V-15	KFM01A	Amfibolite (102017)	736.08
KFM-ST-90V-16	KFM01A	Granit-granodiorite (101057)	183.59
KFM-ST-90V-17	KFM01A	Granit-granodiorite (101057)	834.44
KFM-ST-90V-18	KFM01A	Amfibolite (102017)	841.54
KFM-ST-90V-19	KFM01D	Amfibolite (102017)	689.54
KFM-ST-90V-20	KFM01D	Granit-granodiorite (101057)	768.74

4.2 Test procedure

The present activity was performed parallel to other activities, conducted by SP Building Technology and Mechanics, by which the wet and dry density as well as the porosity of the specimens were determined /3/ and by SP Measurement Technology, by which specific heat capacity was determined /4/.

The following logistic sequence was applied for the activities:

1. Specimens were cut and polished by SP Building Technology and Mechanics.
2. Specimens were photographed by SP Building Technology and Mechanics.
3. Specimens were water saturated and wet density was determined by SP Building Technology and Mechanics /3/.
4. Specimens were sent from SP Building Technology and Mechanics to SP Measurement Technology.
5. Specific heat was determined by SP Measurement Technology /4/.
6. Specimens were sent from SP Measurement Technology to SP Fire Technology.
7. Thermal properties were determined by SP Fire Technology.
8. Specimens were sent from SP Fire Technology to SP Building Technology and Mechanics.
9. Dry density of the specimens was determined at SP Building Technology and Mechanics.

The rock samples were water saturated and stored under this condition for 7 days. This yielded complete water saturation, whereupon the density and the thermal properties were determined. The specimens were photographed before testing.

Determinations of the thermal properties as well as density and porosity measurements were performed during August–September 2006.

The dry weight was measured after the specimens had been dried to constant mass according to ISMR /6/ at 105°C. The drying procedure took seven days.

4.2.1 Principle of the calorimetric method

The calorimetric technique involves heating the samples after mass determination to a well defined temperature. The samples are placed in a temperature controlled water bath long enough to stabilize.

The calorimeter is filled with prepared water (pure and de-aerated of 17°C) to a predefined level and stirred to produce nearly steady state conditions. Thereafter it is placed on the balance and excessive water is extracted with a syringe to reach a nominal mass, chosen with respect to the sample volume.

The so prepared calorimeter is stirred and the temperature logging program is started. After 90 to 150 seconds the sample is quickly moved (3 to 5 seconds) from the bath into the calorimeter. The temperature rise of water can be followed graphically during the equalization process, which typically takes 150 seconds and the experiment is terminated after another 300 to 600 seconds.

The calorimeter, water and sample are weighed again to determine the amount of water that unavoidably did follow with the sample into the calorimeter. This amount is typically 0.28 to 0.36% of the water contained in the calorimeter. If accidentally a water splash happens during the sample insertion, those droplets are absorbed with a small piece of prepared tissue that is weighed dry and wet. The corresponding mass is subtracted from the initial water mass. In extreme cases it has amounted to 0.03% of the total water mass.

All mass values for the determination of the specific heat were manually documented in a prepared form that was a printout of the corresponding Excel calculation sheet.

With the termination of the logging program each experiment was saved as raw data in an Excel file on the SP network. The main information was the bath temperature and two calorimeter temperatures as function of time.

4.2.2 Principle of Transient Plane Source

The principle of the TPS-method is to install a sensor consisting of a thin metal double spiral, embedded in an insulation material, between two rock samples. During the measurement the sensor works both as a heat emitter and a heat receptor. The input data and results of the direct measurement are registered and analysed by the same software and electronics that govern the measurement. The method gives information on the thermal conductivity and diffusivity of a material.

The thermal properties of the water-saturated specimens were measured in ambient air (20°C). In order to remain water saturation and obtain desired temperature, the specimens and the sensor were kept in a plastic bag during the measurements, see Figure 3-2.

Each pair of specimens (A and B) was measured five times. The time lag between two repeated measurements was at least 20 minutes. The result of each measurement was evaluated separately. The average value of these five measurements was calculated.

Measured raw data were saved as text files and analysed data as Excel files. These files were stored on the hard disc of the measurement computer and sent to the SKB catalogue at the SP network. Further calculations of mean values and standard deviations were performed in the same catalogue.

4.3 Nonconformities

Thermal conductivity and thermal diffusivity were measured and there were no deviations to the plan.

However, the measurement of specific heat according to the suggested procedure in /4/ was modified as follows:

- The sample temperature was measured inside a drilled hole in a dummy specimen that was positioned between specimens in the prepared bath.
- Despite a relative low temperature rise (≈ 2°C) and low thermal conductivity and heat capacitivity of Macrolon, the calorimeter is not passive in the heat exchange process. Furthermore the stirrer, which is very important for supporting the temperature equalization, generates both thermal and mechanical energy that overlays the measured heat transfer process in the calorimeter. Therefore the time and the temperature dependent influence were studied in separate experiments simulating all conditions except the existence of the sample. From these a suitable correction technique was worked out and applied to each measurement record in order to compensate for the overlaid effects.

5 Results

The results of activity are stored in SKB´s database SICADA, where they are traceable by the Activity Plan number.

Mean values of measured data, five repeated measurements, are reported in 5.1 and in 5.2. Values of each separate measurement as described in Section 5.1 are reported in Appendix B. Furthermore, the total measuring time, the ratio between total measuring time and characteristic time, and the number of analysed points is presented in Appendix C. In a correct measurement the ratio between the total measuring time and the characteristic time should be between 0.4 and 1.

The results from the modal analysis are reported in Appendix D. The results in Appendix D also include specimens from borehole KFM09A.

5.1 Test results of individual specimens

Specimens KFM-ST-90V-01A and B

Figure 5-1. *Specimens KFM-ST-90V-01A and B.*

Table 5-1. Porosity, wet and dry density of specimens KFM-ST-90V-01A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-01 Sec low: 586.64	2,710	2,710	0.3

Table 5-2. Thermal properties of specimens KFM-ST-90V-01A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	2.88	1.34	2.14	2.13	0.785
Standard deviation	0.006	0.005	0.009	–	–

Specimens KFM-ST-90V-02A and B

Figure 5-2. *Specimens KFM-ST-90V-02A and B.*

Table 5-3. Porosity, wet and dry density of specimens KFM-ST-90V-02A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-02 Sec low: 592.85	2,710	2,710	0.4

Table 5-4. Thermal properties of specimens KFM-ST-90V-02A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	2.81	1.34	2.10	2.26	0.833
Standard deviation	0.006	0.008	0.018	_	_

Specimens KFM-ST-90V-03A and B

Figure 5-3. *Specimens KFM-ST-90V-03A and B.*

Table 5-5. Porosity, wet and dry density of specimens KFM-ST-90V-03A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-03 Sec low: 638.47	2,650	2,650	0.4

Table 5-6. Thermal properties of specimens KFM-ST-90V-03A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	3.70	1.83	2.02	1.99	0.753
Standard deviation	0.006	0.019	0.020	–	–

Specimens KFM-ST-90V-04A and B

Figure 5-4. *Specimens KFM-ST-90V-04A and B.*

Table 5-7. Porosity, wet and dry density of specimens KFM-ST-90V-04A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-04	2,650	2,640	0.3
Sec low: 657.65			

Table 5-8. Thermal properties of specimens KFM-ST-90V-04A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	3.95	1.87	2.11	2.00	0.757
Standard deviation	0.005	0.008	0.011	–	–

Specimens KFM-ST-90V-05A and B

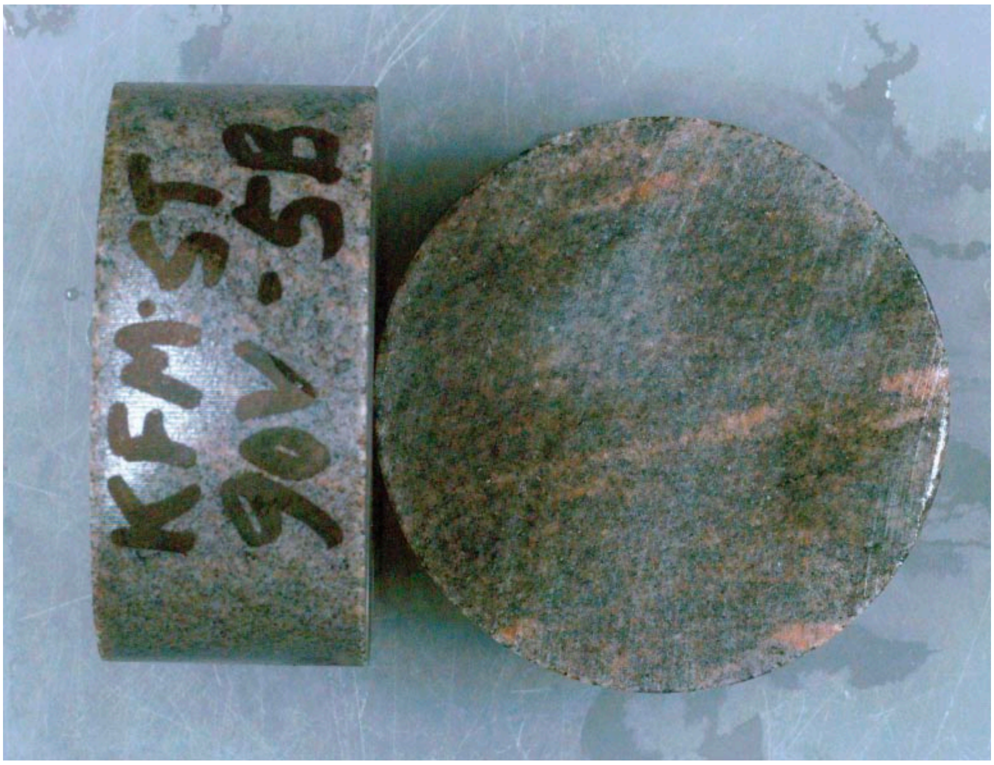

Figure 5-5. *Specimens KFM-ST-90V-05A and B.*

Table 5-9. Porosity, wet and dry density of specimens KFM-ST-90V-05A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-05	2,640	2,640	0.3
Sec low: 649.52			

Table 5-10. Thermal properties of specimens KFM-ST-90V-05A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	3.68	1.82	2.03	2.03	0.769
Standard deviation	0.017	0.028	0.040	–	–

Specimens KFM-ST-90V-06A and B

Figure 5-6. *Specimens KFM-ST-90V-06A and B.*

Table 5-11. Porosity, wet and dry density of specimens KFM-ST-90V-06A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-06	2,630	2,620	0.4
Sec low: 985.22			

Table 5-12. Thermal properties of specimens KFM-ST-90V-06A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	3.55	1.68	2.11	2.01	0.765
Standard deviation	0.010	0.008	0.012	–	–

Specimens KFM-ST-90V-07A and B

Figure 5-7. *Specimens KFM-ST-90V-07A and B.*

Table 5-13. Porosity, wet and dry density of specimens KFM-ST-90V-07A and B, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
KFM-ST-90V-07	2,950	2,950	0.3
Sec low: 355.29			

Table 5-14. Thermal properties of specimens KFM-ST-90V-07A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]	Calorimeter Heat capacity [MJ/(m^3, K)]	Heat capacity [J/(g, K)]
Mean value	2.36	0.98	2.40	2.32	0.786
Standard deviation	0.002	0.002	0.005	–	–

Specimens KFM-ST-90V-08A and B

Figure 5-8. *Specimens KFM-ST-90V-08A and B.*

Table 5-15. Porosity, wet and dry density of specimens KFM-ST-90V-08A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-08 Sec low: 684.14	2,690	2,690	0.3

Table 5-16. Thermal properties of specimens KFM-ST-90V-08A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	3.07	1.36	2.26	2.12	0.789
Standard deviation	0.006	0.010	0.020	–	–

Specimens KFM-ST-90V-09A and B

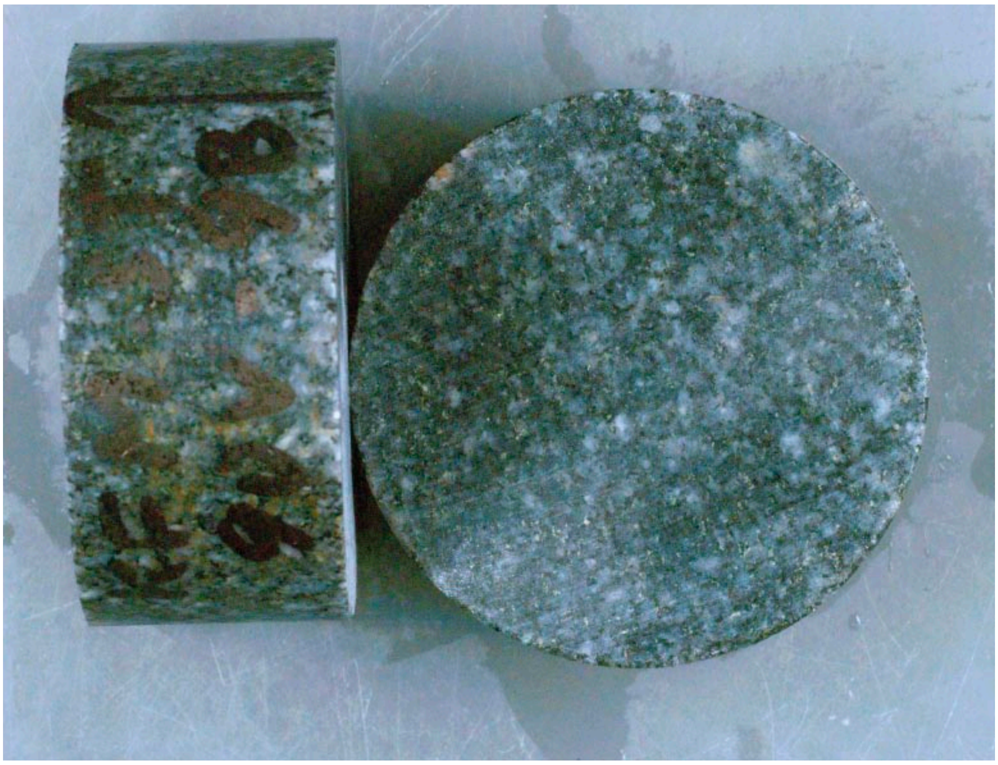

Figure 5-9. *Specimens KFM-ST-90V-09A and B.*

Table 5-17. Porosity, wet and dry density of specimens KFM-ST-90V-09A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-09 Sec low: 692.67	2,720	2,720	0.3

Table 5-18. Thermal properties of specimens KFM-ST-90V-09A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	2.90	1.23	2.37	2.13	0.783
Standard deviation	0.005	0.010	0.018	–	–

Specimens KFM-ST-90V-10A and B

Figure 5-10. *Specimens KFM-ST-90V-10A and B.*

Table 5-19. Porosity, wet and dry density of specimens KFM-ST-90V-10A and B, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
KFM-ST-90V-10	2,720	2,710	0.3
Sec low: 705.31			

Table 5-20. Thermal properties of specimens KFM-ST-90V-10A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]	Calorimeter Heat capacity [MJ/(m^3, K)]	Heat capacity [J/(g, K)]
Mean value	2.98	1.24	2.41	2.11	0.775
Standard deviation	0.002	0.004	0.009	–	–

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

Figure 5-11. *Specimens KFM-ST-90V-11A and B.*

Table 5-21. Porosity, wet and dry density of specimens KFM-ST-90V-11A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-11 Sec low: 738.13	2,620	2,610	0.7

Table 5-22. Thermal properties of specimens KFM-ST-90V-11A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	3.57	1.72	2.08	2.02	0.772
Standard deviation	0.003	0.006	0.008	–	–

Specimens KFM-ST-90V-12A and B

Figure 5-12. *Specimens KFM-ST-90V-12A and B.*

Table 5-23. Porosity, wet and dry density of specimens KFM-ST-90V-12A and B, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
KFM-ST-90V-12 Sec low: 870.79	2,620	2,620	0.5

Table 5-24. Thermal properties of specimens KFM-ST-90V-12A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]	Calorimeter Heat capacity [MJ/(m^3, K)]	Heat capacity [J/(g, K)]
Mean value	3.62	1.69	2.14	2.04	0.779
Standard deviation	0.008	0.013	0.020	–	–

Specimens KFM-ST-90V-13A and B

Figure 5-13. *Specimens KFM-ST-90V-13A and B.*

Table 5-25. Porosity, wet and dry density of specimens KFM-ST-90V-13A and B, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
KFM-ST-90V-13 Sec low: 286.23	2,640	2,630	0.9

Table 5-26. Thermal properties of specimens KFM-ST-90V-13A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]	Calorimeter Heat capacity [MJ/(m^3, K)]	Heat capacity [J/(g, K)]
Mean value	3.84	1.79	2.14	2.12	0.802
Standard deviation	0.007	0.010	0.015	–	–

Specimens KFM-ST-90V-14A and B

Figure 5-14. *Specimens KFM-ST-90V-14A and B.*

Table 5-27. Porosity, wet and dry density of specimens KFM-ST-90V-14A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-14 Sec low: 329.86	2,900	2,900	0.2

Table 5-28. Thermal properties of specimens KFM-ST-90V-14A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	2.09	0.90	2.33	2.42	0.832
Standard deviation	0.002	0.002	0.004	–	–

Specimens KFM-ST-90V-15A and B

Figure 5-15. *Specimens KFM-ST-90V-15A and B.*

Table 5-29. Porosity, wet and dry density of specimens KFM-ST-90V-15A and B, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
KFM-ST-90V-15	2,930	2,920	0.2
Sec low: 736.08			

Table 5-30. Thermal properties of specimens KFM-ST-90V-15A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]	Calorimeter Heat capacity [MJ/(m^3, K)]	Heat capacity [J/(g, K)]
Mean value	2.24	0.88	2.53	2.42	0.828
Standard deviation	0.004	0.003	0.011	–	–

Specimens KFM-ST-90V-16A and B

Figure 5-16. *Specimens KFM-ST-90V-16A and B.*

Table 5-31. Porosity, wet and dry density of specimens KFM-ST-90V-16A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-16	2,650	2,640	0.6
Sec low: 183.59			

Table 5-32. Thermal properties of specimens KFM-ST-90V-16A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	3.25	1.82	1.79	2.03	0.767
Standard deviation	0.008	0.014	0.018	–	–

Specimens KFM-ST-90V-17A and B

Figure 5-17. *Specimens KFM-ST-90V-17A and B.*

Table 5-33. Porosity, wet and dry density of specimens KFM-ST-90V-17A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-17 Sec low: 834.44	2,670	2,670	0.3

Table 5-34. Thermal properties of specimens KFM-ST-90V-17A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	3.39	1.65	2.05	2.09	0.782
Standard deviation	0.010	0.025	0.034	–	–

Specimens KFM-ST-90V-18A and B

Figure 5-18. *Specimens KFM-ST-90V-18A and B.*

Table 5-35. Porosity, wet and dry density of specimens KFM-ST-90V-18A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-18 Sec low: 841.54	3,010	3,010	0.3

Table 5-36. Thermal properties of specimens KFM-ST-90V-18A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	2.38	1.00	2.38	2.25	0.746
Standard deviation	0.001	0.004	0.009	–	–

Specimens KFM-ST-90V-19A and B

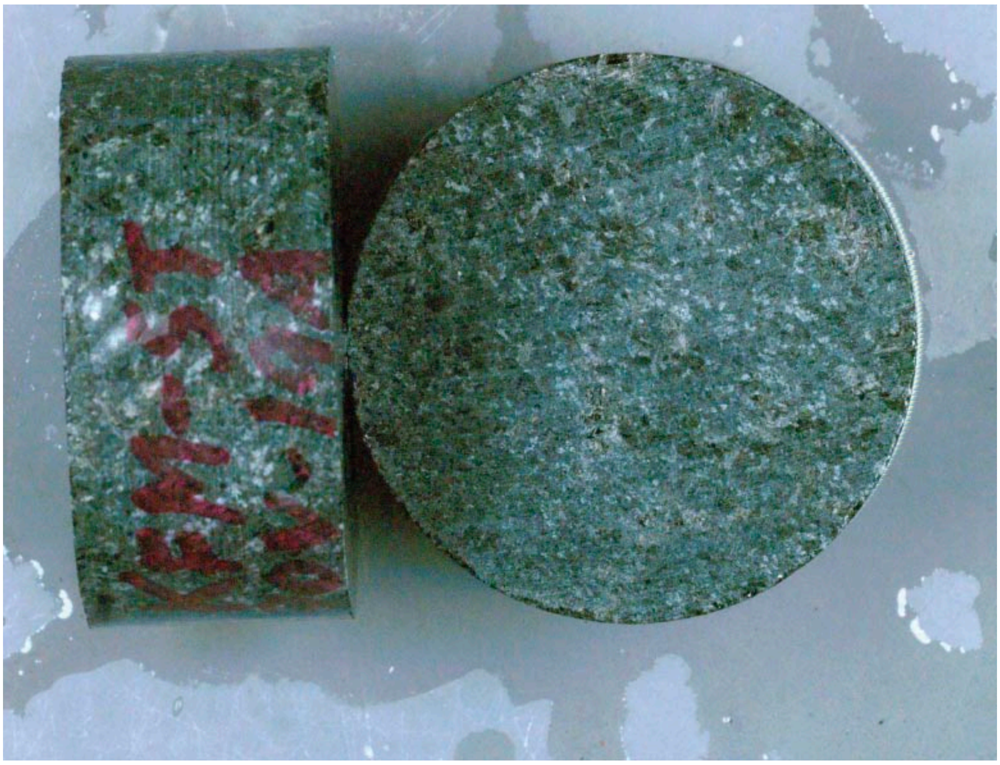

Figure 5-19. *Specimens KFM-ST-90V-19A and B.*

Table 5-37. Porosity, wet and dry density of specimens KFM-ST-90V-19A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-19 Sec low: 689.54	3,010	3,000	0.6

Table 5-38. Thermal properties of specimens KFM-ST-90V-19A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	2.48	1.00	2.47	2.60	0.864
Standard deviation	0.002	0.005	0.013	–	–

Specimens KFM-ST-90V-20A and B

Figure 5-20. *Specimens KFM-ST-90V-20A and B.*

Table 5-39. Porosity, wet and dry density of specimens KFM-ST-90V-20A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KFM-ST-90V-20 Sec low: 768.74	2,630	2,620	0.4

Table 5-40. Thermal properties of specimens KFM-ST-90V-20A and B at ambient temperature, average values.

Sample KFM-ST-90V-01 Sec low: 586.64	TPS method Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]	Calorimeter Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Mean value	3.96	1.94	2.05	2.06	0.784
Standard deviation	0.009	0.018	0.023	–	–

5.2 Results for the entire test series

Table 5-41 displays the mean value of five repeated measurements of the thermal properties. Standard deviation is shown in Table 5-42. The results are in both tables grouped according to drill hole.

Table 5-43 displays specific heat capacity of the samples measured by calorimetric method. The specific heat capacity ranged between 0.75 and 0.86 J/(g, K).

Table 5-41. Mean value of thermal properties of samples at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
KFM06A			
KFM-ST-90V-01	2.88	1.34	2.14
KFM-ST-90V-02	2.81	1.34	2.10
KFM-ST-90V-03	3.70	1.83	2.02
KFM-ST-90V-04	3.95	1.87	2.11
KFM-ST-90V-05	3.68	1.82	2.03
KFM-ST-90V-06	3.55	1.68	2.11
KFM05A			
KFM-ST-90V-07	2.36	0.98	2.40
KFM-ST-90V-08	3.07	1.36	2.26
KFM-ST-90V-09	2.90	1.23	2.37
KFM-ST-90V-10	2.98	1.24	2.41
KFM-ST-90V-11	3.57	1.72	2.08
KFM04A			
KFM-ST-90V-12	3.62	1.69	2.14
KFM01C			
KFM-ST-90V-13	3.84	1.79	2.14
KFM-ST-90V-14	2.09	0.90	2.33
KFM01A			
KFM-ST-90V-15	2.24	0.88	2.53
KFM-ST-90V-16	3.25	1.82	1.79
KFM-ST-90V-17	3.39	1.65	2.05
KFM-ST-90V-18	2.38	1.00	2.38
KFM01D			
KFM-ST-90V-19	2.48	1.00	2.47
KFM-ST-90V-20	3.96	1.94	2.05

Table 5-42. Standard deviation of measured values at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
KFM06A			
KFM-ST-90V-01	0.006	0.005	0.009
KFM-ST-90V-02	0.006	0.008	0.018
KFM-ST-90V-03	0.006	0.019	0.020
KFM-ST-90V-04	0.005	0.008	0.011
KFM-ST-90V-05	0.017	0.028	0.040
KFM-ST-90V-06	0.010	0.008	0.012
KFM05A			
KFM-ST-90V-07	0.002	0.002	0.005
KFM-ST-90V-08	0.006	0.010	0.020
KFM-ST-90V-09	0.005	0.010	0.018
KFM-ST-90V-10	0.002	0.004	0.009
KFM-ST-90V-11	0.003	0.006	0.008
KFM04A			
KFM-ST-90V-12	0.008	0.013	0.020
KFM01C			
KFM-ST-90V-13	0.007	0.010	0.015
KFM-ST-90V-14	0.002	0.002	0.004
KFM01A			
KFM-ST-90V-15	0.004	0.003	0.011
KFM-ST-90V-16	0.008	0.014	0.018
KFM-ST-90V-17	0.010	0.025	0.034
KFM-ST-90V-18	0.001	0.004	0.009
KFM01D			
KFM-ST-90V-19	0.002	0.005	0.013
KFM-ST-90V-20	0.009	0.018	0.023

Table 5-43. Specific heat capacity measured by calorimeter.

Sample identification	Heat capacity [MJ/(m^3, K)]	Heat capacity [J/(g, K)]
KFM06A		
KFM-ST-90V-01	2.13	0.785
KFM-ST-90V-02	2.26	0.833
KFM-ST-90V-03	1.99	0.753
KFM-ST-90V-04	2.00	0.757
KFM-ST-90V-05	2.03	0.769
KFM-ST-90V-06	2.01	0.765
KFM05A		
KFM-ST-90V-07	2.32	0.786
KFM-ST-90V-08	2.12	0.789
KFM-ST-90V-09	2.13	0.783
KFM-ST-90V-10	2.11	0.775
KFM-ST-90V-11	2.02	0.772
KFM04A		
KFM-ST-90V-12	2.04	0.779
KFM01C		
KFM-ST-90V-13	2.12	0.802
KFM-ST-90V-14	2.42	0.832
KFM01A		
KFM-ST-90V-15	2.42	0.828
KFM-ST-90V-16	2.03	0.767
KFM-ST-90V-17	2.09	0.782
KFM-ST-90V-18	2.25	0.746
KFM01D		
KFM-ST-90V-19	2.60	0.864
KFM-ST-90V-20	2.06	0.784

The thermal conductivity and thermal diffusivity of specimens measured by TPS representing different depths at 20°C were in the range 2.09–3.96 W/(m, K) respectively 0.88–1.94 mm^2/s. From these results the heat capacity was calculated and appeared to range between 1.79 and 2.53 $MJ/(m^3, K)$. Graphical representations of the heat conductivity and heat capacity versus borehole length of boreholes KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A are given in Figure 5-21 and Figure 5-22.

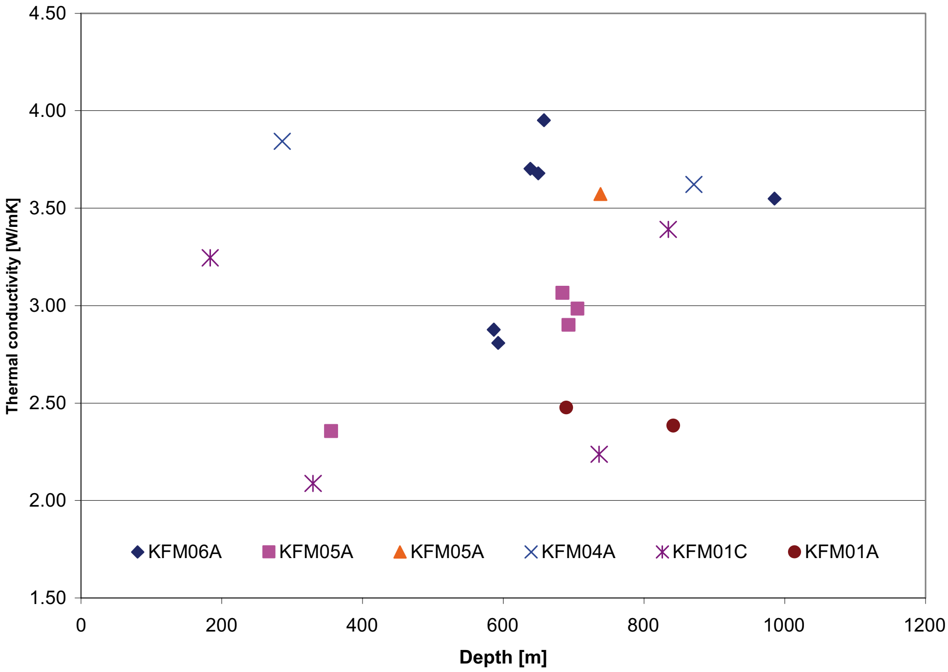

***Figure 5-21.** Thermal conductivity versus length of boreholes KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A measured with TPS method.*

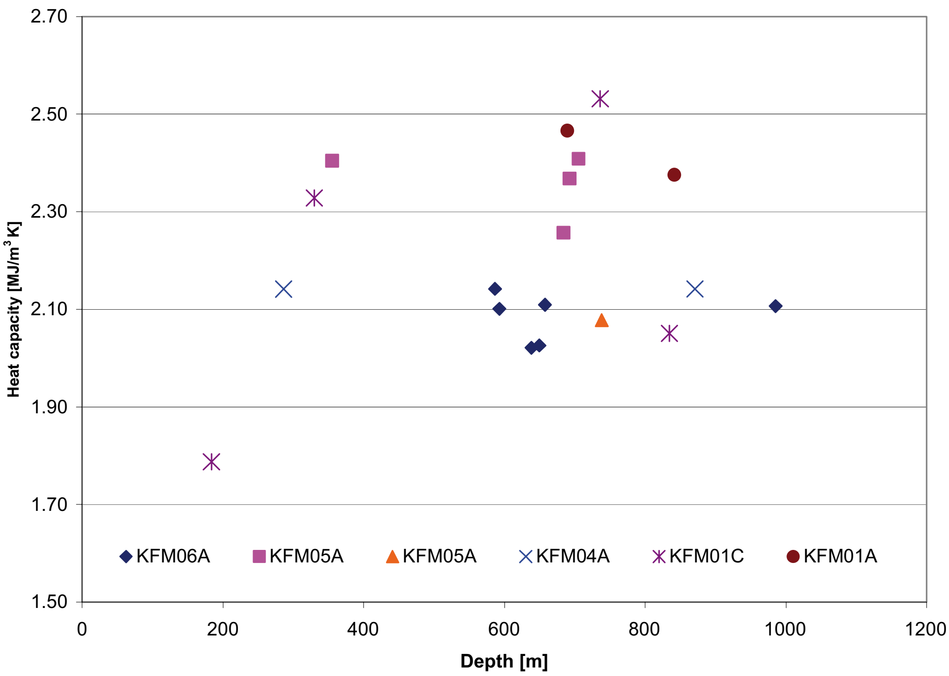

***Figure 5-22.** Heat capacity versus length of boreholes KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A measured with TPS method.*

6 References

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

/2/ **Gustafsson S E, 1991.** "Transient plane source techniques for thermal conductivity and thermal diffusivity measurements of solid materials". Rev. Sci. Instrum. 62 (3), March 1991, American Institute of Physics.

/3/ **Liedberg L, 2006.** Forsmark site investigation. Borehole KFM01A, KFM01C, KFM01D, KFM04A, KFM05A and KFM06A. Determination of porosity by water saturation and density by buoyancy technique. SKB P-06-234. Svensk Kärnbränslehantering AB.

/4/ **Lau P, 2005.** Determination of specific heat capacity of rock samples, P502681-12, SP Swedish National Testing and Research Institute, Measurement Technology.

/5/ Instruction Manual Hot Disc Thermal Constants Analyser Windows 95 Version 5.0, 2001.

/6/ ISRM Commission on Testing Methods, ISRM, 1979.

Appendix A

Calibration protocol for Hot Disk Bridge System

Electronics:	Keithley 2400	Serial No. 0925167
	Keithley 2000	Serial No. 0921454
Hot Disk Bridge:		Serial No. 2003-0004
Computation Device:		Serial No. 2003-0003, ver 1.5
Computer:	Hot Disk computer	Serial No. 2003-0003
Test sample:	SIS2343. mild steel	Serial No. 3.52
Sensor for testing:	C5501	

Test measurement: 10 repeated measurements on the test sample at room temperature.

Conditions: Power 1 W. Measurement time 10 s.

Results

Thermal Conductivity:	13.46 W/(m, K)	± 0.06%
Thermal Diffusivity:	3.499 mm^2/s	± 0.22%
Heat Capacity:	3.847 $MJ/(m^3, K)$	± 0.21%

This instrument has proved to behave according to specifications described in BRk-QB-M26-02.

Borås 20/06 2006

Patrik Nilsson

Appendix B

Table B-1. Thermal properties of samples at 20°C.

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
KFM-ST 90V-01			
1	2.87	1.34	2.14
2	2.88	1.34	2.15
3	2.88	1.35	2.13
4	2.88	1.34	2.15
5	2.88	1.34	2.14
KFM-ST 90V-02			
1	2.80	1.35	2.08
2	2.81	1.33	2.10
3	2.82	1.33	2.12
4	2.81	1.33	2.11
5	2.80	1.34	2.08
KFM-ST 90V-03			
1	3.71	1.86	1.99
2	3.70	1.83	2.02
3	3.71	1.82	2.04
4	3.70	1.84	2.01
5	3.69	1.81	2.04
KFM-ST 90V-04			
1	3.95	1.86	2.12
2	3.94	1.88	2.09
3	3.95	1.88	2.10
4	3.96	1.87	2.12
5	3.95	1.87	2.12
KFM-ST 90V-05			
1	3.69	1.80	2.05
2	3.68	1.82	2.02
3	3.66	1.84	1.99
4	3.66	1.84	1.99
5	3.70	1.78	2.08
KFM-ST 90V-06			
1	3.56	1.68	2.12
2	3.55	1.70	2.09
3	3.56	1.69	2.11
4	3.54	1.68	2.11
5	3.53	1.68	2.10

Table B-1. Continued. Thermal properties of samples at 20°C.

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
KFM-ST 90V-07			
1	2.35	0.98	2.40
2	2.36	0.98	2.41
3	2.36	0.98	2.41
4	2.36	0.98	2.40
5	2.36	0.98	2.40
KFM-ST 90V-08			
1	3.06	1.36	2.25
2	3.07	1.35	2.27
3	3.06	1.37	2.24
4	3.06	1.37	2.24
5	3.07	1.35	2.29
KFM-ST 90V-09			
1	2.90	1.23	2.36
2	2.90	1.24	2.34
3	2.90	1.23	2.37
4	2.91	1.22	2.39
5	2.89	1.22	2.38
KFM-ST 90V-10			
1	2.98	1.24	2.40
2	2.99	1.23	2.42
3	2.98	1.24	2.40
4	2.98	1.24	2.41
5	2.98	1.24	2.41
KFM-ST 90V-11			
1	3.57	1.73	2.07
2	3.57	1.72	2.08
3	3.58	1.71	2.09
4	3.58	1.72	2.08
5	3.57	1.72	2.08
KFM-ST 90V-12			
1	3.62	1.70	2.12
2	3.61	1.70	2.12
3	3.63	1.68	2.16
4	3.62	1.68	2.15
5	3.63	1.68	2.16
KFM-ST 90V-13			
1	3.84	1.80	2.14
2	3.84	1.80	2.14
3	3.84	1.80	2.13
4	3.84	1.80	2.13
5	3.86	1.78	2.17

Table B-1. Continued. Thermal properties of samples at 20°C.

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
KFM-ST 90V-14			
1	2.09	0.90	2.32
2	2.09	0.90	2.33
3	2.09	0.90	2.33
4	2.09	0.89	2.33
5	2.09	0.90	2.33
KFM-ST 90V-15			
1	2.24	0.89	2.52
2	2.24	0.88	2.53
3	2.24	0.88	2.53
4	2.24	0.88	2.55
5	2.23	0.88	2.52
KFM-ST 90V-16			
1	3.25	1.81	1.80
2	3.24	1.82	1.78
3	3.24	1.83	1.78
4	3.23	1.83	1.77
5	3.25	1.79	1.81
KFM-ST 90V-17			
1	3.38	1.69	1.99
2	3.40	1.66	2.05
3	3.40	1.65	2.06
4	3.39	1.63	2.08
5	3.38	1.63	2.07
KFM-ST 90V-18			
1	2.38	1.00	2.38
2	2.38	1.00	2.39
3	2.38	1.00	2.38
4	2.38	1.01	2.37
5	2.39	1.01	2.37
KFM-ST 90V-19			
1	2.48	1.00	2.48
2	2.48	1.00	2.48
3	2.48	1.01	2.46
4	2.48	1.01	2.45
5	2.48	1.01	2.46
KFM-ST 90V-20			
1	3.97	1.91	2.08
2	3.95	1.96	2.02
3	3.96	1.94	2.04
4	3.96	1.93	2.05
5	3.95	1.94	2.04

Appendix C

Table C-1. Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 20°C.

Measurement number	Total time (s)	Total/Char. Time	Points
KFM-ST 90V-01			
1	20	0.65	46–200
2	20	0.65	49–200
3	20	0.66	49–200
4	20	0.65	52–200
5	20	0.65	52–200
KFM-ST 90V-02			
1	20	0.65	34–200
2	20	0.65	34–200
3	20	0.64	34–200
4	20	0.65	34–200
5	20	0.65	34–200
KFM-ST 90V-03			
1	20	0.90	34–200
2	20	0.89	34–200
3	20	0.88	34–200
4	20	0.89	34–200
5	20	0.88	34–200
KFM-ST 90V-04			
1	20	0.90	42–200
2	20	0.91	42–200
3	20	0.91	42–200
4	20	0.91	42–200
5	20	0.91	42–200
KFM-ST 90V-05			
1	20	0.87	47–200
2	20	0.88	47–200
3	20	0.89	47–200
4	20	0.90	47–200
5	20	0.86	47–200
KFM-ST 90V-06			
1	20	0.81	70–200
2	20	0.82	70–200
3	20	0.82	70–200
4	20	0.81	70–200
5	20	0.82	70–200

Table C-1. Continued. Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 20°C.

Measurement number	Total time (s)	Total/Char. Time	Points
KFM-ST 90V-07			
1	20	0.48	38–200
2	20	0.48	38–200
3	20	0.47	38–200
4	20	0.48	38–200
5	20	0.48	38–200
KFM-ST 90V-08			
1	20	0.66	36–200
2	20	0.66	36–200
3	20	0.66	39–200
4	20	0.66	36–200
5	20	0.65	36–200
KFM-ST 90V-09			
1	20	0.60	37–200
2	20	0.60	37–200
3	20	0.59	37–200
4	20	0.59	37–200
5	20	0.59	37–200
KFM-ST 90V-10			
1	20	0.60	28–200
2	20	0.60	28–200
3	20	0.60	28–200
4	20	0.60	28–200
5	20	0.60	28–200
KFM-ST 90V-11			
1	20	0.84	66–200
2	20	0.84	66–200
3	20	0.83	66–200
4	20	0.83	66–200
5	20	0.84	66–200
KFM-ST 90V-12			
1	20	0.83	43–200
2	20	0.83	43–200
3	20	0.82	43–200
4	20	0.82	43–200
5	20	0.81	43–200
KFM-ST 90V-13			
1	20	0.87	49–200
2	20	0.87	49–200
3	20	0.87	49–200
4	20	0.87	49–200
5	20	0.86	49–200

Table C-1. Continued. Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 20°C.

Measurement number	Total time (s)	Total/Char. Time	Points
KFM-ST 90V-14			
1	20	0.44	45–200
2	20	0.44	45–200
3	20	0.44	45–200
4	20	0.43	45–200
5	20	0.44	45–200
KFM-ST 90V-15			
1	20	0.39	56–181
2	20	0.42	44–197
3	20	0.42	44–197
4	20	0.42	44–197
5	20	0.42	44–197
KFM-ST 90V-16			
1	20	0.88	94–200
2	20	0.88	93–200
3	20	0.89	94–200
4	20	0.89	96–200
5	20	0.87	94–200
KFM-ST 90V-17			
1	20	0.82	35–200
2	20	0.81	35–200
3	20	0.80	35–200
4	20	0.79	35–200
5	20	0.79	35–200
KFM-ST 90V-18			
1	20	0.49	21–200
2	20	0.48	21–200
3	20	0.49	21–200
4	20	0.49	21–200
5	20	0.49	21–200
KFM-ST 90V-19			
1	20	0.49	27–200
2	20	0.48	27–200
3	20	0.49	27–200
4	20	0.49	31–200
5	20	0.49	31–200
KFM-ST 90V-20			
1	20	0.93	28–200
2	20	0.95	28–200
3	20	0.94	28–200
4	20	0.94	28–200
5	20	0.94	28–200

Appendix D

Table D-1. Modal analyses of thin sections of specimens from KFM01A, KFM05A and KFM06A.

Lab ID/core length Adj. length Boremap ID	KFM01A (KFM-ST-90V-17) 838.426–838.466 21	KFM01A (KFM-ST-90V-8) 686.939–686.989 166	KFM05A (KFM-ST-90V-10) 708.404–708.454 170	KFM06A (KFM-ST-90V-1) 588.644–588.684 180
Modal classification	Granodiorite	Tonalite	Tonalite	Granodiorite
Macroscopic classification	Meta-granitoid	Meta-granitoid	Aplitic metagranite	Aplitic metagranite
Rock code	101057	101051	101058	101058
Quartz	31.8	26.6	28.4	30.0
K-feldspar	16.0	3.2	1.4	6.6
Plagioclase[1]	44.6	52.4	56.2	44.2
Biotite	5.6	11.0	12.8	14.2
Chlorite	+	–	–	0.2
Hornblende	–	1.6	–	0.2
Epidote	+	3.6	0.4	2.6
Allanite	–	+	+	0.2
Pumpellyite	0.2	0.2	0.2	–
Sphene	+	0.6	0.2	1.2
Calcite	–	0.2	–	0.2
Apatite	0.4	0.2	0.4	0.2
Zircon	+	0.2	+	–
Magnetite	1.4	0.2	+	0.2
Ilmenite	–	+	–	–
Hematite	+	–	–	–
Pyrite	–	+	+	+
Chalcopyrite	–	+	+	+

+ = Trace amounts.

[1] Including sericitized plagioclase and possible albite.

Table D-2. Modal analyses of thin sections from KFM09A

Lab ID/core length **Adj. length** **Boremap ID**	**443.36–443.39** **443.316–443.346** **398**	**583.00–583.03** **582.916–582.954** **439**	**719.29–719.32** **719.130–719.160** **474**	**762.02–762.05** **761.888–761.918** **483**	**786.91–786.94** **786.789–786.821** **489**	**798.08–798.11** **797.981–798.011** **494**
Modal classification	Monzogranite	Monzogranite	Granodiorite	Granodiorite	Dacite	Tonalite
Macroscopic classification	Aplitic metagranite	Metagranite-granodiorite	Metagranite-granodiorite	Meta-granodi-orite	Felsic to int. Metavolcan.	Metatonalite-granodiorite
Rock code	101058	101057	101057	101056	103076	101054
Quartz	38.4	30.6	19.0	44.4	38.0	15.8
K-feldspar	23.0	28.2	8.2	15.4	17.0	5.6
Plagioclase[1]	31.2	32.6	52.0	28.8	31.2	45.8
Biotite	7.4	6.8	12.4	5.2	12.6	10.8
Chlorite	–	0.2	+	4.6	0.8	0.4
Hornblende	–	+	5.2	–	–	16.6
Epidote	+	0.4	2.6	1.0	0.4	3.4
Allanite	+	0.2	0.2	+	–	0.2
Pumpellyite	–	0.4	–	0.2	–	–
Sphene	–	0.2	0.2	+	–	0.6
Calcite	–	–	–	0.2	–	–
Apatite	+	+	0.2	+	+	0.6
Zircon	+	+	+	+	+	0.2
Magnetite	+	0.4	–	0.2	–	–
Ilmenite	–	–	–	–	–	–
Hematite	–	–	–	–	–	–
Pyrite	–	–	–	–	–	+
Chalcopyrite	–	–	–	–	–	–

+ = Trace amounts.

[1] Including sericitized plagioclase and possible albite.