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Oskarshamn site investigation

Borehole KLX16A

Thermal properties of rocks using TPS method

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June 2007

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Abstract

Thermal properties on six pair of specimens of drill hole KLX16A, Oskarshamn, Sweden, were measured at ambient temperature (20°C). The samples were taken from the dominant rock type quartz monzodiorite (501036) at the borehole length 200 m–310 m. The determination of the thermal properties is based on a direct measurement method, the so called "Transient Plane Source Method" (TPS).

Thermal conductivity and thermal diffusivity at 20°C were in the range of 2.63–2.99 W/(m, K) respectively 1.18–1.46 mm^2/s. The volumetric heat capacity, which was calculated from the thermal conductivity and diffusivity, ranged between 2.06 and 2.26 MJ/(m^3, K).

Sammanfattning

Termiska egenskaper hos sex par provkroppar från borrhål KLX16A, Oskarshamn, bestämdes vid rumstemperatur (20°C). Proverna hade tagits från den dominerande bergarten kvartsmonzodiorit (501036) vid borrhålslängderna 200 m–310 m. TPS metoden, ”Transient Plane Source”, användes för bestämning av de termiska egenskaperna.

Den termiska konduktiviteten och den termiska diffusiviteten hos provkropparna vid 20°C uppgick till 2,63–2,99 W/(m, K) respektive 1,18–1,46 mm^2/s. Från värdena på dessa parametrar kunde den volymmetriska värmekapaciteten beräknas och befanns ligga i intervallet 2,06 och 2,26 MJ/(m^3, K).

Contents

1 Introduction

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

Borehole KLX16A is a conventionally drilled cored borehole with a length of approximately 430 m. The borehole is inclined by 65° against horizontal plane and strikes 295°, see Figure 1-1. This report presents investigations of thermal properties of rock samples from borehole KLX16A at Oskarshamn. The thermal properties thermal conductivity and thermal diffusivity have been determined by using the Transient Plane Source Method (TPS), /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/.

Rock samples were selected at Oskarshamn based on the preliminary core logging with the strategy to investigate the properties of the rock type quartz monzodiorite.

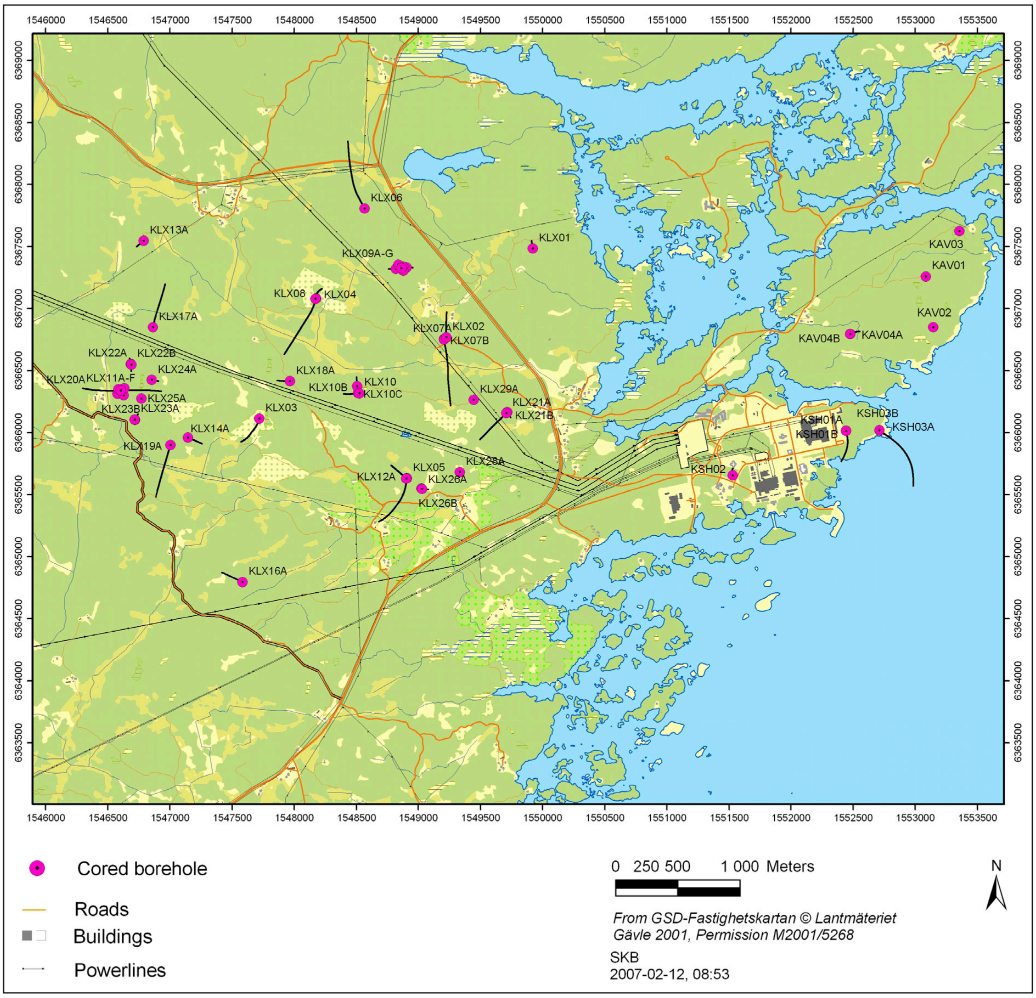

Figure 1-1. Location of cored boreholes up to February 2007.

The specimens to be tested were cut from the rock samples in the shape of circular discs. The rock samples arrived at SP in May 2007. The thermal properties were determined on water-saturated specimens. Testing was performed during June 2007.

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, whereas the Quality Plan (SP-QD 13.1) referred to in the table is an SP (Swedish National Testing and Research Institute) internal controlling document.

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

Activity Plan	**Number**	**Version**
KLX16A. Bergmekaniska och termiska laboratoriebestämningar	AP PS 400-07-041	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 and scope

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 Oskarshamn. The test programme included testing of six pairs of rock samples.

3 Equipment

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 /4/.
- 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.

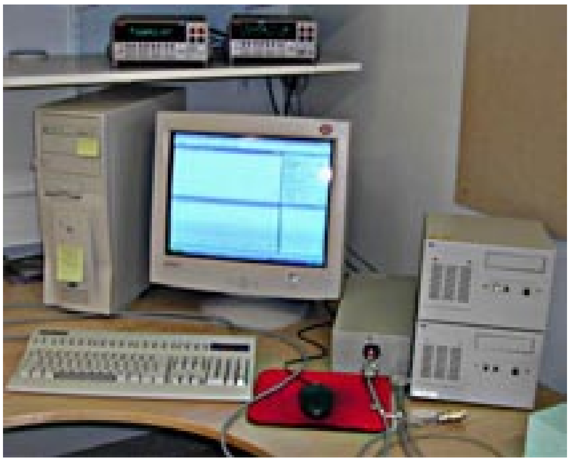

Figure 3-1. *TPS-apparatus with source meter, multi-meter, bridge, and computer.*

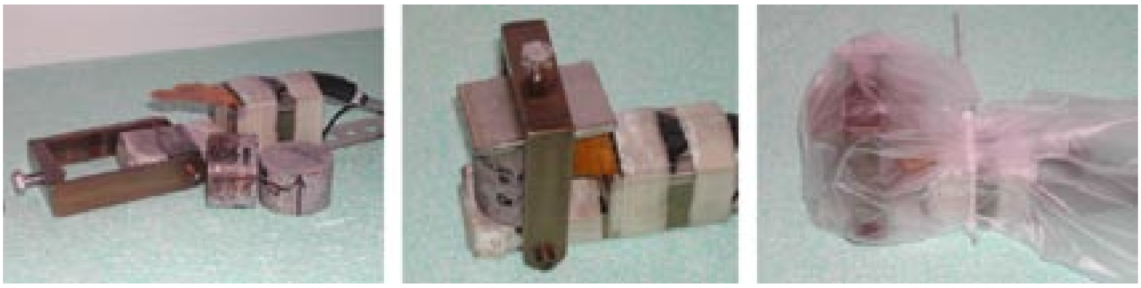

Figure 3-2. *Specimens prior to mounting (left), mounted in stainless sample holder (middle), and sample holder with mounted specimens wrapped in plastic (right).*

4 Execution

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 /4/ 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 /5/ at SP Building Technology and Mechanics.

Bengt Bogren and Ingrid Wetterlund at SP Fire Technology conducted the thermal property measurements and preparation of the report.

4.1 Description of the samples

Six pairs of cores (designated A and B) were sampled from borehole KLX16A, Oskarshamn, Sweden. The cores were collected within the borehole length interval 200 m–310 m. The twelve 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, rock type and sampling levels of the specimens are presented in Table 4-1. Detailed geological description of the entire core of KLX16A is given in SKB's database SICADA (Boremap data).

Table 4-1. Rock type and identification marks (Rock-type classification according to Boremap). Sampling level refers to borehole length.

Identification	Rock type/occurence	Sampling level (m borehole length) (Adjsec low)
KLX16A-90V-01	Quartz monzodiorite (501036)	203.71
KLX16A-90V-02	Quartz monzodiorite (501036)	220.69
KLX16A-90V-03	Quartz monzodiorite (501036)	239.48
KLX16A-90V-04	Quartz monzodiorite (501036)	269.30
KLX16A-90V-05	Quartz monzodiorite (501036)	291.73
KLX16A-90V-06	Quartz monzodiorite (501036)	313.69

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/.

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 Fire Technology.
5. Thermal properties were determined by SP Fire Technology.
6. Specimens were sent from SP Fire Technology to SP Building Technology and Mechanics.
7. 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 May–June 2007.

The dry weight was measured after the specimens had been dried to constant mass according to ISMR /5/ at 105°C. The drying procedure took seven days.

4.2.1 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.

5 Results

The results of the 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 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 are 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.

5.1 Test results of individual specimens

Specimens KLX16A-90V-01A and B

Figure 5-1. *Specimens KLX16A-90V-01A and B.*

Table 5-1. Porosity, wet and dry density of specimens KLX16A-90V-01A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX16A-90V-01 Adjsec low: 203.71	2,780	2,780	0.4

Table 5-2. Thermal properties of specimens KLX16A-90V-01A and B at ambient temperature, average values.

KLX16A-90V-01 Adjsec low: 203.71	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
Mean value	2.63	1.18	2.23
Standard deviation	0.002	0.004	0.008

Specimens KLX16A-90V-02A and B

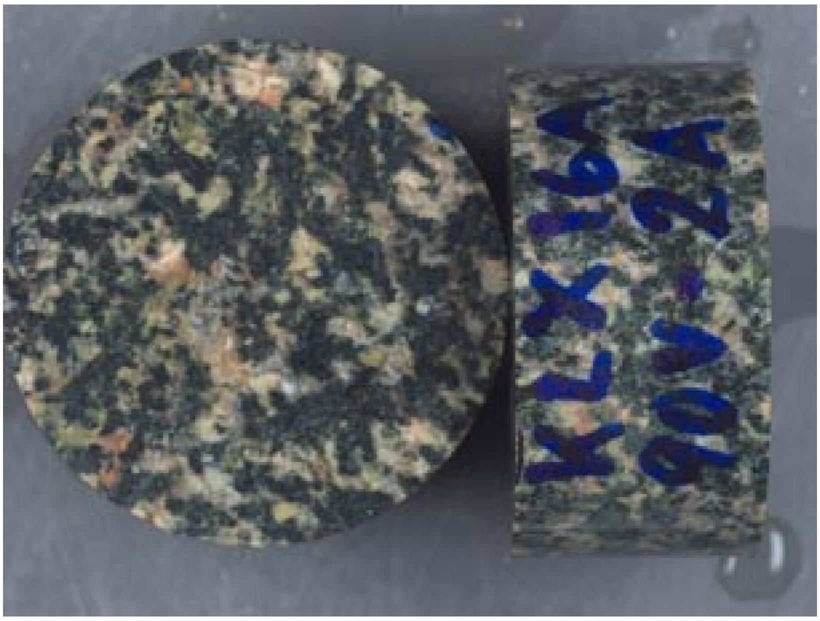

Figure 5-2. *Specimens KLX16A-90V-02A and B.*

Table 5-3. Porosity, wet and dry density of specimens KLX16A-90V-02A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX16A-90V-02 Adjsec low: 220.71	2,830	2,820	0.3

Table 5-4. Thermal properties of specimens KLX16A-90V-02A and B at ambient temperature, average values.

KLX16A-90V-02 Adjsec low: 220.71	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
Mean value	2.99	1.46	2.06
Standard deviation	0.004	0.006	0.010

Specimens KLX16A-90V-03A and B

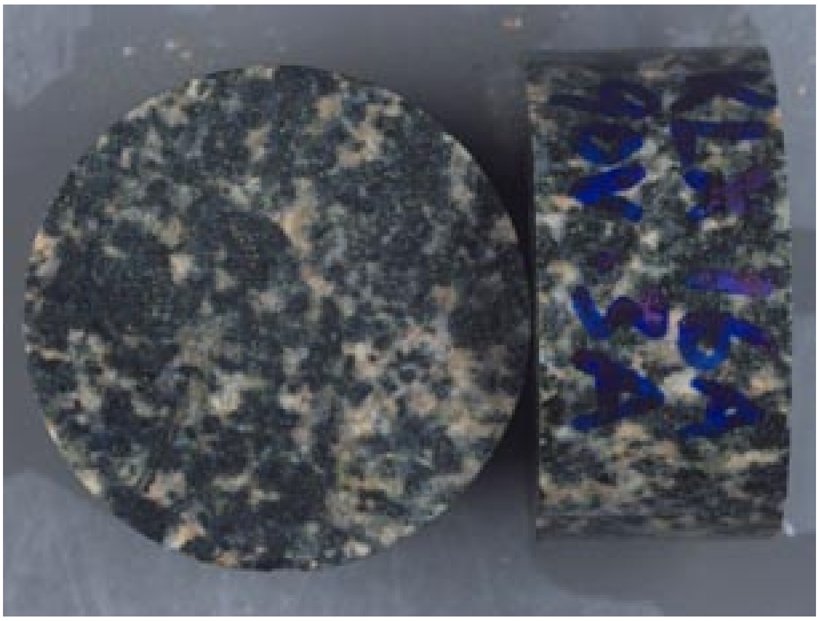

Figure 5-3. *Specimens KLX16A-90V-03A and B.*

Table 5-5. Porosity, wet and dry density of specimens KLX16A-90V-03A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX16A-90V-03 Adjsec low: 239.48	2,830	2,820	0.3

Table 5-6. Thermal properties of specimens KLX16A-90V-03A and B at ambient temperature, average values.

KLX16A-90V-03 Adjsec low: 239.48	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
Mean value	2.87	1.28	2.24
Standard deviation	0.003	0.004	0.005

Specimens KLX16A-90V-04A and B

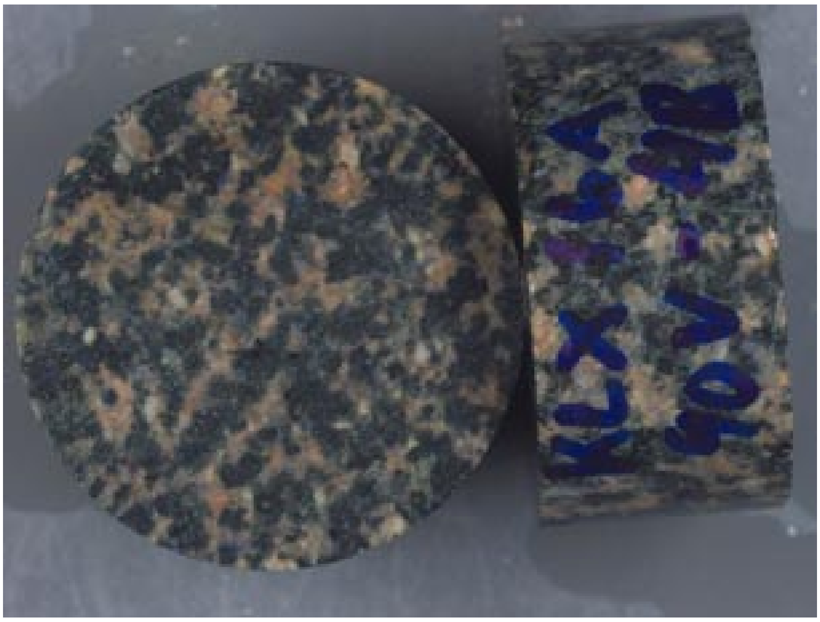

Figure 5-4. *Specimens KLX16A-90V-04A and B.*

Table 5-7. Porosity, wet and dry density of specimens KLX16A-90V-04A and B, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
KLX16A-90V-04 Adjsec low: 269.30	2,810	2,810	0.2

Table 5-8. Thermal properties of specimens KLX16A-90V-04A and B at ambient temperature, average values.

KLX16A-90V-04 Adjsec low: 269.30	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
Mean value	2.82	1.25	2.26
Standard deviation	0.002	0.002	0.005

Specimens KLX16A-90V-05A and B

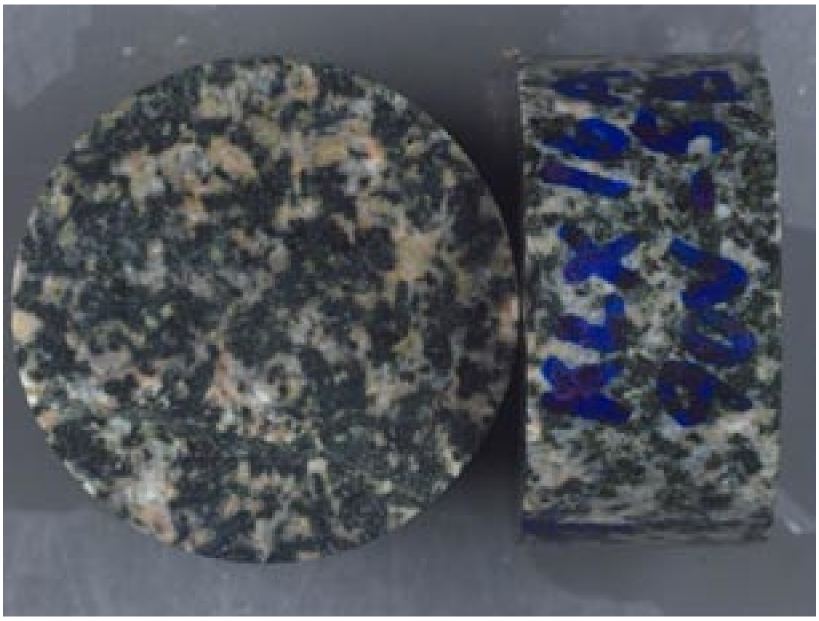

Figure 5-5. *Specimens KLX16A-90V-05A and B.*

Table 5-9. Porosity, wet and dry density of specimens KLX16A-90V-05A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX16A-90V-05 Adjsec low: 291.73	2,830	2,830	0.2

Table 5-10. Thermal properties of specimens KLX16A-90V-05A and B at ambient temperature, average values.

KLX16A-90V-05 Adjsec low: 291.73	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
Mean value	2.72	1.27	2.14
Standard deviation	0.006	0.008	0.018

Specimens KLX16A-90V-06A and B

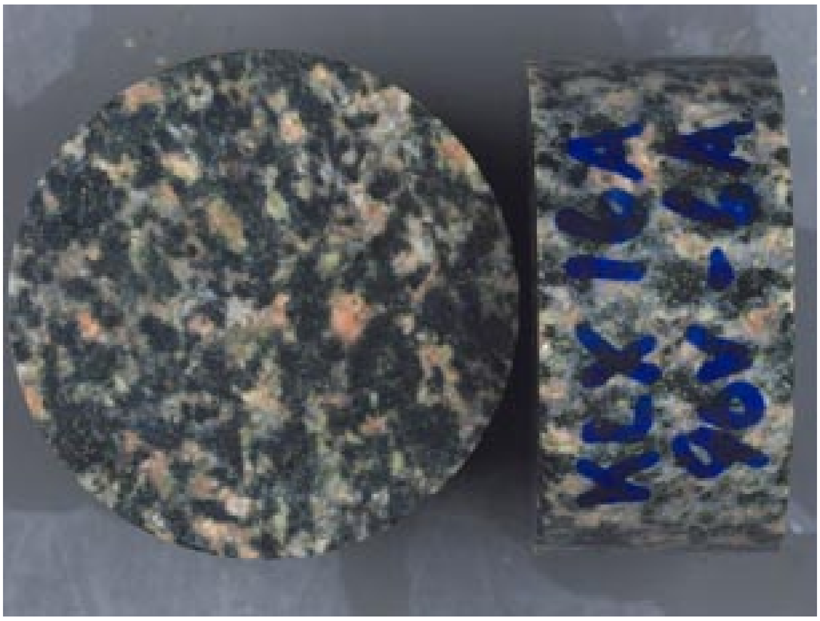

Figure 5-6. *Specimens KLX16A-90V-06A and B.*

Table 5-11. Porosity, wet and dry density of specimens KLX16A-90V-06A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX16A-90V-06 Adjsec low: 313.69	2,810	2,810	0.3

Table 5-12. Thermal properties of specimens KLX16A-90V-06A and B at ambient temperature, average values.

KLX16A-90V-06 Adjsec low: 313.69	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
Mean value	2.90	1.34	2.16
Standard deviation	0.009	0.013	0.024

5.2 Results for the entire test series

Table 5-13 displays the mean value of five repeated measurements of the thermal properties. Standard deviation is shown in Table 5-14.

The thermal conductivity and thermal diffusivity of specimens representing different depths at 20°C were in the range 2.63–2.99 W/(m, K) respectively 1.18–1.46 mm²/s. From these results the heat capacity was calculated and appeared to range between 2.06 and 2.26 MJ/(m³, K). A graphical representation of the thermal conductivity and heat capacity versus borehole length is given in Figure 5-7.

Table 5-13. Mean value of thermal properties of samples at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
Rock type 501036			
KLX16A-90V-01	2.63	1.18	2.23
KLX16A-90V-02	2.99	1.46	2.06
KLX16A-90V-03	2.87	1.28	2.24
KLX16A-90V-04	2.82	1.25	2.26
KLX16A-90V-05	2.72	1.27	2.14
KLX16A-90V-06	2.90	1.34	2.16
Mean value	**2.82**	**1.30**	**2.18**

Table 5-14. Standard deviation of measured values at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
Rock type 501036			
KLX16A-90V-01	0.002	0.004	0.008
KLX16A-90V-02	0.004	0.006	0.010
KLX16A-90V-03	0.003	0.004	0.005
KLX16A-90V-04	0.002	0.002	0.005
KLX16A-90V-05	0.006	0.008	0.018
KLX16A-90V-06	0.009	0.013	0.024

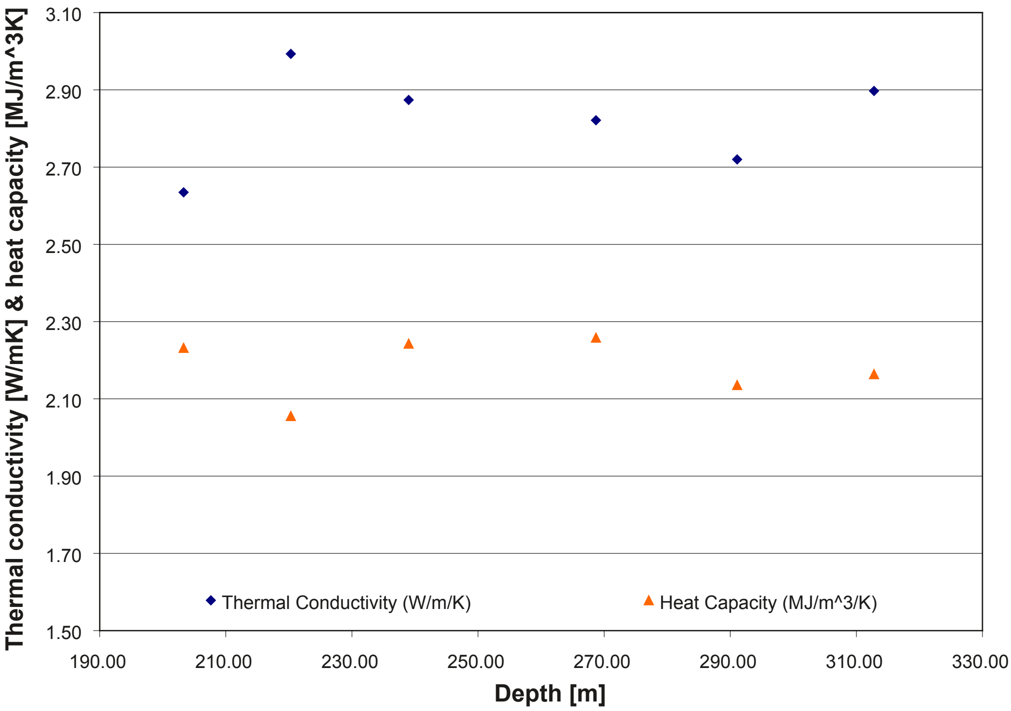

***Figure 5-7.** Thermal conductivity and heat capacity versus borehole length measured with the TPS method at 20°C.*

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/ **Savukoski M, 2007.** Oskarshamn site investigation. Borehole KLX16A. Determination of porosity by water saturation and density by buoyancy technique. SKB P-07-141. Svensk Kärnbränslehantering AB.

/4/ Instruction Manual Hot Disc Thermal Constants Analyser Windows 95 Version 5.0, 2001.

/5/ 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:	13.42 W/(m. K)	±0.06%
Thermal Diffusivity:	3.496 mm^2/s	±0.25%
Heat Capacity:	3.837 $MJ/(m^3. K)$	±0.29%

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

Borås 05/03 2007

Patrik Nilsson

Appendix B

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

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Volumetric heat capacity [MJ/(m³, K)]
KLX16A 90V-01			
1	2.64	1.18	2.24
2	2.64	1.18	2.24
3	2.63	1.18	2.24
4	2.63	1.19	2.22
5	2.64	1.18	2.23
KLX16A 90V-02			
1	2.99	1.45	2.06
2	3.00	1.45	2.07
3	3.00	1.45	2.06
4	2.99	1.46	2.04
5	2.99	1.46	2.05
KLX16A 90V-03			
1	2.87	1.28	2.24
2	2.87	1.28	2.25
3	2.88	1.28	2.24
4	2.87	1.28	2.24
5	2.88	1.29	2.24
KLX16A 90V-04			
1	2.82	1.25	2.26
2	2.82	1.25	2.26
3	2.82	1.25	2.26
4	2.82	1.25	2.26
5	2.82	1.25	2.25
KLX16A 90V-05			
1	2.71	1.28	2.11
2	2.72	1.27	2.15
3	2.73	1.27	2.15
4	2.72	1.28	2.12
5	2.72	1.27	2.14
KLX16A 90V-06			
1	2.89	1.33	2.17
2	2.90	1.34	2.16
3	2.91	1.33	2.19
4	2.89	1.36	2.13
5	2.90	1.34	2.17

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
KLX16A 90V-01			
1	20	0.57	62–199
2	20	0.57	62–200
3	20	0.57	64–200
4	20	0.57	59–199
5	20	0.57	56–200
KLX16A 90V-02			
1	20	0.71	28–200
2	20	0.70	27–200
3	20	0.71	29–200
4	20	0.71	27–200
5	20	0.71	17–200
KLX16A 90V-03			
1	20	0.60	35–194
2	20	0.60	31–195
3	20	0.60	32–194
4	20	0.62	28–200
5	20	0.61	34–194
KLX16A 90V-04			
1	20	0.60	21–200
2	20	0.61	24–200
3	20	0.61	28–200
4	20	0.61	26–200
5	20	0.61	30–200
KLX16A 90V-05			
1	20	0.62	17–200
2	20	0.61	30–200
3	20	0.61	34–200
4	20	0.62	18–200
5	20	0.61	29–199
KLX16A 90V-06			
1	20	0.55	19–170
2	20	0.65	23–200
3	20	0.63	45–195
4	20	0.65	36–198
5	20	0.65	35–200