P-06-72

Oskarshamn site investigation

Borehole KLX12A

Thermal properties of rocks using calorimeter and TPS method

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SP Swedish National Testing and Research Institute

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Keywords: Thermal properties, Thermal conductivity, Thermal diffusivity, Heat capacity, Transient Plane Source method, Calorimeter, AP PS 400-06-044.

Abstract

Thermal properties on eight specimens of drill hole KLX12A, Oskarshamn, Sweden, were measured at ambient temperature (20°C). The samples were taken from the dominant rock type Ävrö granite (501044), at the level 120–305 m, the minority rock type Diorit/gabbro (501033), at the level 440–490 m, and from the rock type Quartz monzodiorite (501036), at the level 530–560 m. 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.

Thermal conductivity and thermal diffusivity measured by TPS at 20°C were in the range of 2.29–2.88 W/(m, K) respectively 0.97–1.31 mm^2/s. The heat capacity, which was calculated from the thermal conductivity and diffusivity, ranged between 2.05 and 2.51 MJ/(m^3, K).

The specific heat capacity that was measured by calorimetric method was in the range of 0.78–0.84 J/(g, K).

Sammanfattning

Termiska egenskaper hos åtta provkroppar från borrhål KLX12A, Oskarshamn, bestämdes vid rumstemperatur (20 °C). Proverna hade tagits från den dominerande bergarten Ävrö granit (501044), vid nivån 120–305 m, minoritetsbergarten diorit/gabbro (501033) vid nivån 440–490 m och från bergarten kvartzmonzodiorit (501036) vid nivå 530–560 m. TPS-metoden, ”Transient Plane Source”, användes för bestämning av de termiska egenskaperna. Specifika värmekapaciteten bestämdes även med en kalorimeter.

Den termiska konduktiviteten och den termiska diffusiviteten mätt med TPS vid 20 °C uppgick till 2,29–2,88 W/(m, K) respektive 0,97–1,31 mm^2/s. Från värdena på dessa parametrar kunde den volymmetriska värmekapaciteten beräknas och befanns ligga i intervallet 2,05 and 2,51 MJ/(m^3, K).

Den specifika värmekapaciteten, som bestämts med kalorimeter, uppgick till 0,78–0,84 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. 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 KLX12A is a conventionally drilled borehole with a length of 602 m. The borehole inclined by 75° against horizontal plane and strikes 316°, see Figure 1-1. This report presents investigations of thermal properties of rock samples from borehole KLX12A at Oskarshamn. 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/.

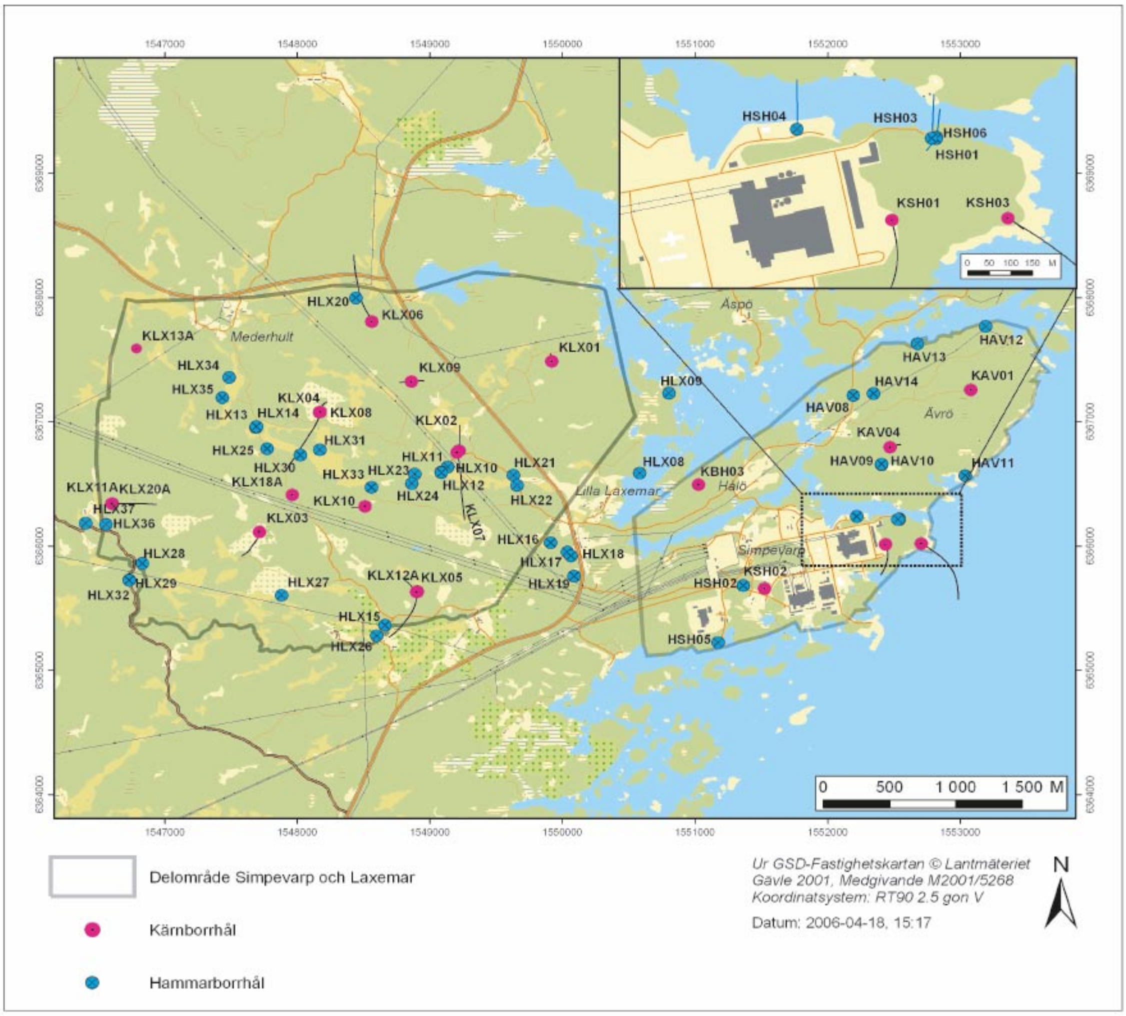

Figure 1-1. Location of boreholes drilled up to April 2006. The projection of each borehole on the horizontal plane at top of casing is also shown in the figure.

Rock samples were selected at Oskarshamn based on the preliminary 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 May 2006. The thermal properties were determined on water-saturated specimens. Testing was performed during June 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**
KLX12A. Bergmekaniska och termiska laboratoriebestämningar	AP PS 400-06-044	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.

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.

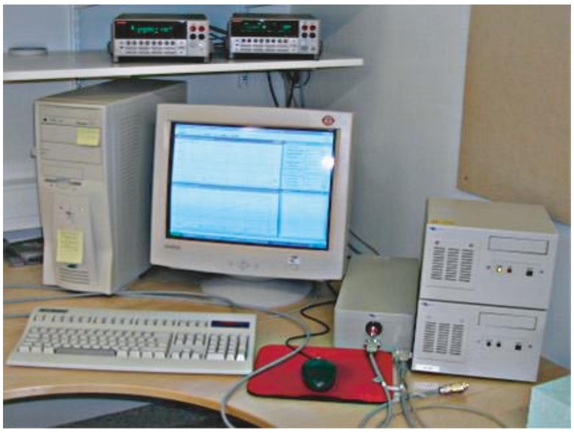

Figure 3-1. *TPS-apparatus with source meter, multi-meter, bridge, and computer.*

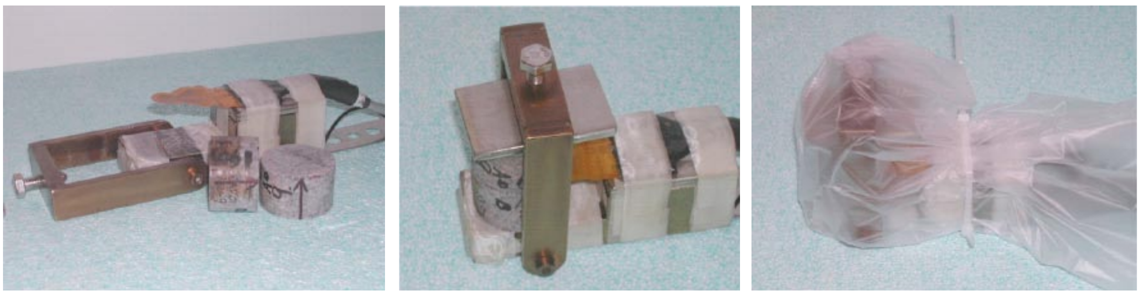

Figure 3-2. *Specimens prior to mounting (left), mounted in stainless sample holder (middle), and sample holder with mounted specimens wrapped in plastic (right).*

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.

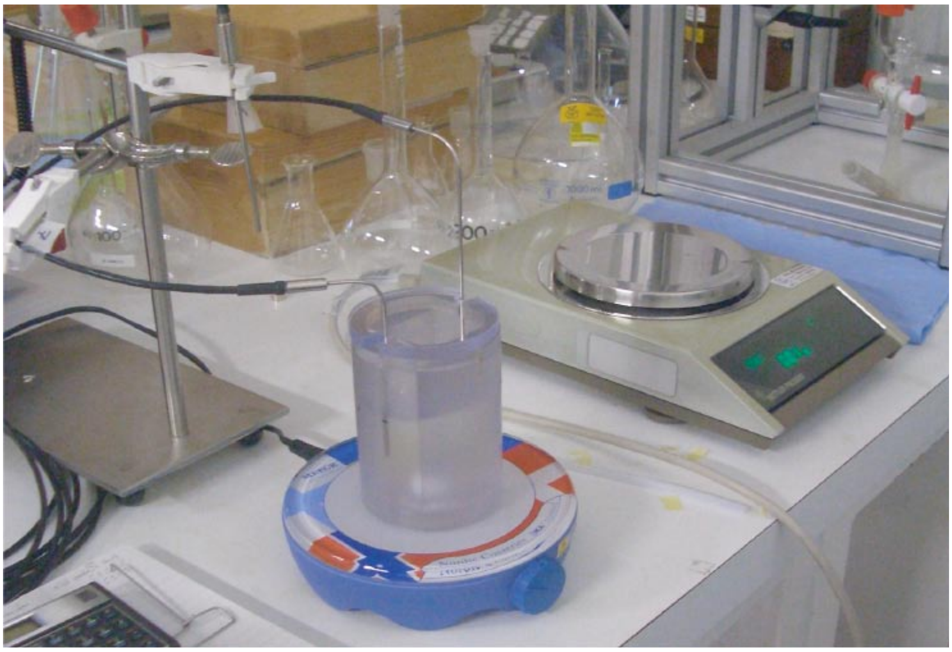

Figure 3-3. *Calorimeter with two temperature sensors on magnetic stirrers.*

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

Nine pairs of cores (designated A and B) were sampled from borehole KLX12A, Oskarshamn, Sweden. The cores were collected within the interval 120–560 m. The eighteen 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 KLX12A is given in SKB's database SICADA (Boremap data).

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

Identification	Rock type/occurence	Sampling level (m borehole length) (Sec low)
KLX12A-90V-01	Ävrö granite (501044)	127.92
KLX12A-90V-02	Ävrö granite (501044)	221.59
KLX12A-90V-03	Ävrö granite (501044)	251.58
KLX12A-90V-04	Ävrö granite (501044)	305.29
KLX12A-90V-06	Diorite/gabbro (501033)	440.15
KLX12A-90V-07	Diorite/gabbro (501033)	450.86
KLX12A-90V-08	Diorite/gabbro (501033)	489.89
KLX12A-90V-09	Quartz monzodiorite (501036)	532.87
KLX12A-90V-10	Quartz monzodiorite (501036)	560.75

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 June 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 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.

5.1 Test results of individual specimens

Specimens KLX12A-90V-01A and B

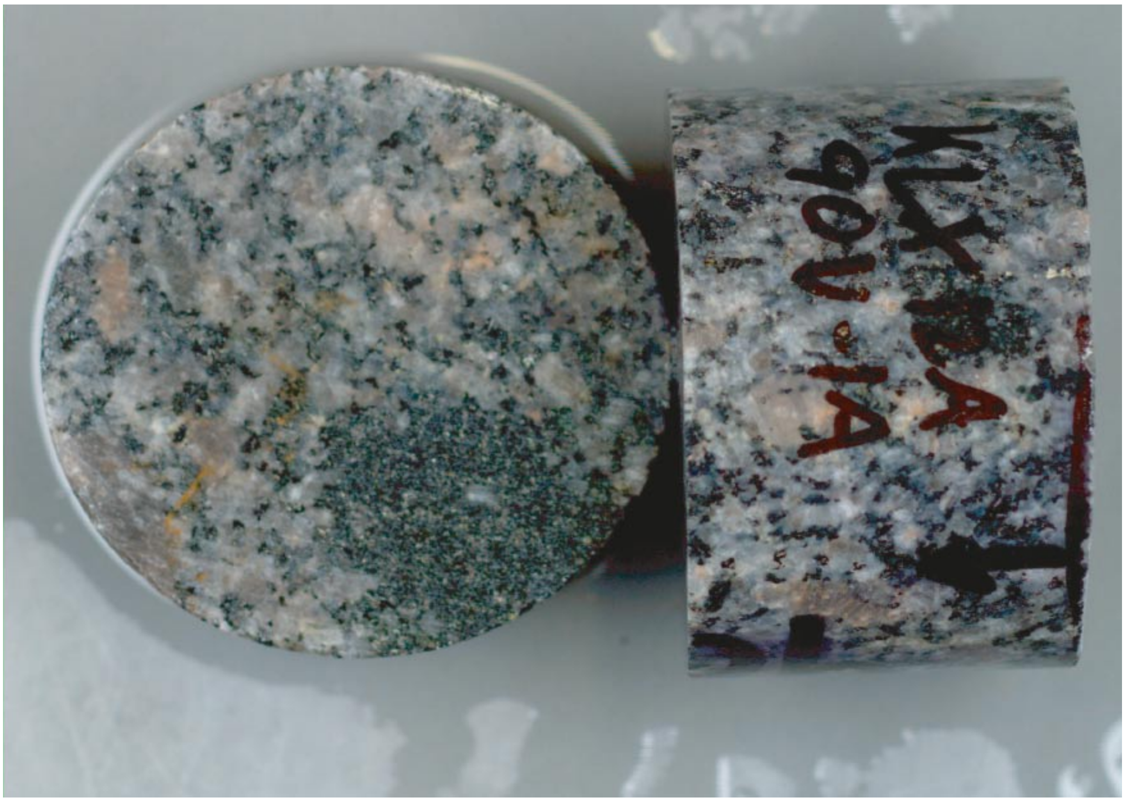

Figure 5-1. *Specimens KLX12A-90V-01A and B.*

Table 5-1. Porosity, wet and dry density of specimens KLX12A-90V-01A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX12A-90V-01 Sec low: 127.92	2,770	2,770	0.4

Table 5-2. Thermal properties of specimens KLX12A-90V-01A and B at ambient temperature, average values.

Sample KLX12A-90V-01 Sec low: 127.92	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	2.29	0.97	2.36	2.21	0.797
Standard deviation	0.001	0.002	0.006	–	–

Specimens KLX12A-90V-02A and B

Figure 5-2. *Specimens KLX12A-90V-02A and B.*

Table 5-3. Porosity, wet and dry density of specimens KLX12A-90V-02A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX12A-90V-02 Sec low: 221.59	2,700	2,700	0.6

Table 5-4. Thermal properties of specimens KLX12A-90V-02A and B at ambient temperature, average values.

Sample KLX12A-90V-02 Sec low: 221.59	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	1.16	2.42	2.10	0.777
Standard deviation	0.001	0.006	0.013	–	–

Specimens KLX12A-90V-03A and B

Figure 5-3. *Specimens KLX12A-90V-03A and B.*

Table 5-5. Porosity, wet and dry density of specimens KLX12A-90V-03A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX12A-90V-03 Sec low: 251.58	2,770	2,760	0.7

Table 5-6. Thermal properties of specimens KLX12A-90V-03A and B at ambient temperature, average values.

Sample KLX12A-90V-03 Sec low: 251.58	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	2.50	1.07	2.34	2.20	0.795
Standard deviation	0.006	0.003	0.011	–	–

Specimens KLX12A-90V-04A and B

Figure 5-4. *Specimens KLX12A-90V-04A and B.*

Table 5-7. Porosity, wet and dry density of specimens KLX12A-90V-04A and B, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
KLX12A-90V-04 Sec low: 305.29	2,750	2,740	0.7

Table 5-8. Thermal properties of specimens KLX12A-90V-04A and B at ambient temperature, average values.

Sample KLX12A-90V-04 Sec low: 305.29	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	2.67	1.31	2.05	2.26	0.822
Standard deviation	0.002	0.002	0.004	–	–

Specimens KLX12A-90V-06A and B

Figure 5-5. *Specimens KLX12A-90V-06A and B.*

Table 5-9. Porosity, wet and dry density of specimens KLX12A-90V-06A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX12A-90V-06 Sec low: 440.15	2,960	2,960	0.2

Table 5-10. Thermal properties of specimens KLX12A-90V-06A and B at ambient temperature, average values.

Sample KLX12A-90V-06 Sec low: 440.15	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	2.59	1.04	2.51	2.44	0.822
Standard deviation	0.003	0.002	0.004	–	–

Specimens KLX12A-90V-07A and B

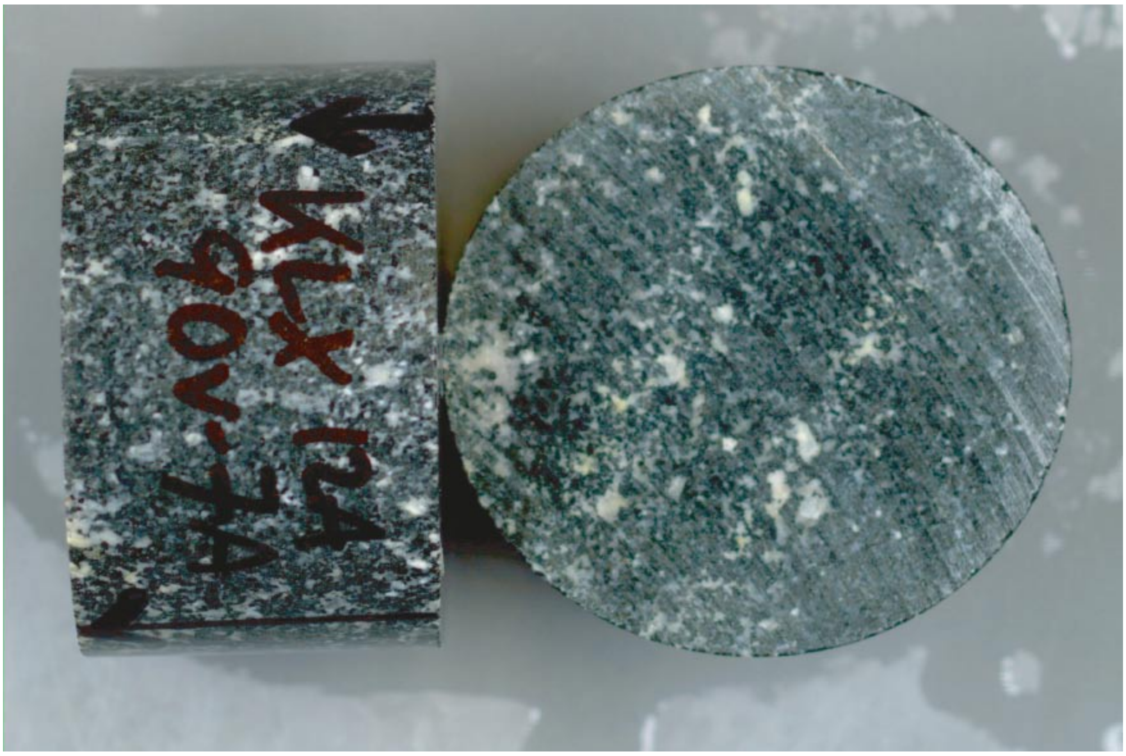

Figure 5-6. *Specimens KLX12A-90V-07A and B.*

Table 5-11. Porosity, wet and dry density of specimens KLX12A-90V-07A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX12A-90V-07 Sec low: 450.86	3,050	3,050	0.2

Table 5-12. Thermal properties of specimens KLX12A-90V-07A and B at ambient temperature, average values.

Sample KLX12A-90V-07 Sec low: 450.86	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	2.77	1.12	2.48	2.48	0.813
Standard deviation	0.005	0.009	0.025	–	–

Specimens KLX12A-90V-08A and B

Figure 5-7. *Specimens KLX12A-90V-08A and B.*

Table 5-13. Porosity, wet and dry density of specimens KLX12A-90V-08A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX12A-90V-08 Sec low: 489.89	3,020	3,020	0.3

Table 5-14. Thermal properties of specimens KLX12A-90V-08A and B at ambient temperature, average values.

Sample KLX12A-90V-08 Sec low: 489.89	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	1.19	2.43	2.52	0.835
Standard deviation	0.003	0.001	0.004	–	–

Specimens KLX12A-90V-9A and B

Figure 5-8. *Specimens KLX12A-90V-9A and B.*

Table 5-15. Porosity, wet and dry density of specimens KLX12A-90V-9A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX12A-90V-9 Sec low: 532.87	2,810	2,800	0.3

Table 5-16. Thermal properties of specimens KLX12A-90V-9A and B at ambient temperature, average values.

Sample KLX12A-90V-9 Sec low: 532.87	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	2.52	1.15	2.20	2.21	0.786
Standard deviation	0.003	0.004	0.009	–	–

Specimens KLX12A-90V-10A and B

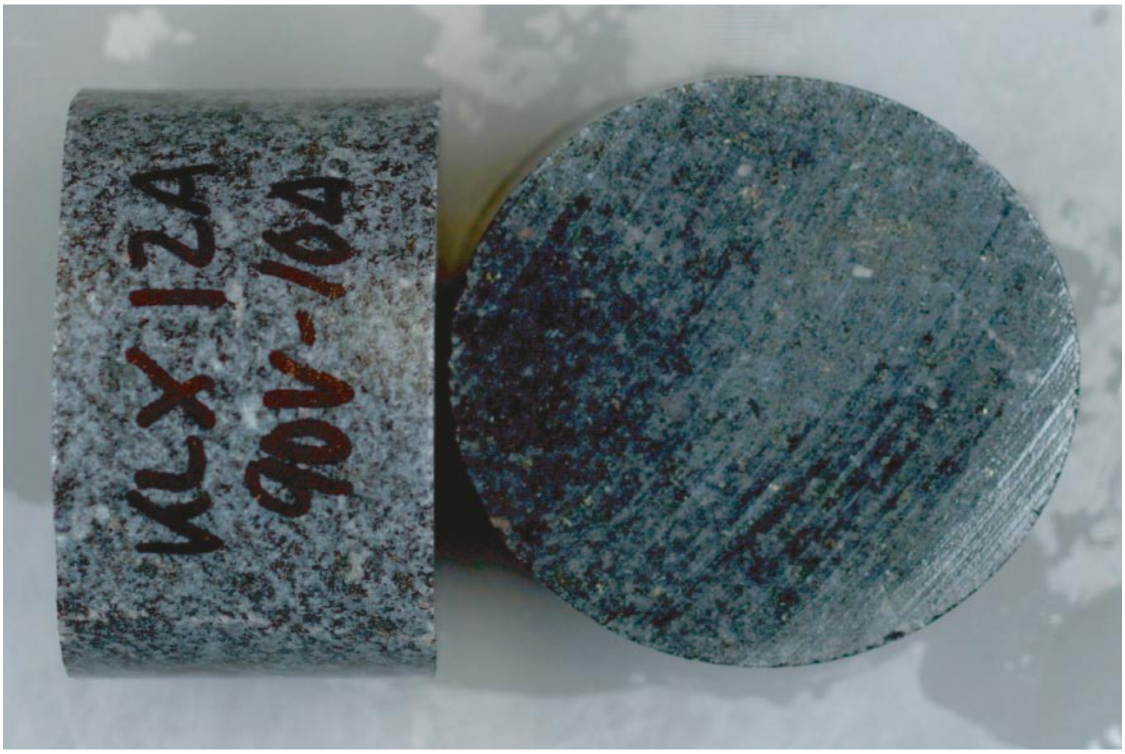

Figure 5-9. *Specimens KLX12A-90V-10A and B.*

Table 5-17. Porosity, wet and dry density of specimens KLX12A-90V-10A and B, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
KLX12A-90V-10 Sec low: 560.75	2,820	2,810	0.2

Table 5-18. Thermal properties of specimens KLX12A-90V-10A and B at ambient temperature, average values.

Sample KLX12A-90V-10 Sec low: 560.75	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	2.50	1.14	2.19	2.21	0.784
Standard deviation	0.002	0.004	0.009	–	–

5.2 Results for the entire test series

Table 5-19 displays the mean value of five repeated measurements of the thermal properties. Standard deviation is shown in Table 5-20. The results are in both tables grouped according to rock type. Thus the mean values are in this report given "per rock type" instead of as in previous reports "per level".

Table 5-21 displays specific heat capacity of the samples measured by calorimetric method. The specific heat capacity ranged between 0.78 and 0.84 J/(g, K).

Table 5-19. 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 Ävrö granite			
KLX12A-90V-01	2.29	0.97	2.36
KLX12A-90V-02	2.81	1.16	2.42
KLX12A-90V-03	2.50	1.07	2.34
KLX12A-90V-04	2.67	1.31	2.05
Mean value	**2.57**	**1.13**	**2.29**
Rock type diorite/gabbro			
KLX12A-90V-06	2.59	1.04	2.51
KLX12A-90V-07	2.77	1.12	2.48
KLX12A-90V-08	2.88	1.19	2.43
KLX12A-90V-09	2.52	1.15	2.20
KLX12A-90V-10	2.50	1.14	2.19
Mean value	**2.65**	**1.13**	**2.36**

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

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
Rock type Ävrö granite			
KLX12A-90V-01	0.001	0.002	0.006
KLX12A-90V-02	0.001	0.006	0.013
KLX12A-90V-03	0.006	0.003	0.011
KLX12A-90V-04	0.002	0.002	0.004
Rock type diorite/gabbro			
KLX12A-90V-06	0.003	0.002	0.004
KLX12A-90V-07	0.005	0.009	0.025
KLX12A-90V-08	0.003	0.001	0.004
KLX12A-90V-09	0.003	0.004	0.009
KLX12A-90V-10	0.002	0.004	0.009

Table 5-21. Specific heat capacity measured by calorimeter.

Sample identification	Heat capacity [MJ/(m³, K)]	Heat capacity [J/(g, K)]
Rock type Ävrö granite		
KLX12A-90V-01	2.21	0.797
KLX12A-90V-02	2.10	0.777
KLX12A-90V-03	2.20	0.795
KLX12A-90V-04	2.26	0.822
Mean value	**2.19**	**0.798**
Rock type diorite/gabbro		
KLX12A-90V-06	2.44	0.822
KLX12A-90V-07	2.48	0.813
KLX12A-90V-08	2.52	0.835
KLX12A-90V-09	2.21	0.786
KLX12A-90V-10	2.21	0.784
Mean value	**2.37**	**0.808**

The thermal conductivity and thermal diffusivity of specimens measured by TPS representing different depths at 20°C were in the range 2.29–2.88 W/(m, K) respectively 0.97–1.31 mm^2/s. From these results the heat capacity was calculated and appeared to range between 2.05 and 2.51 MJ/(m^3, K). A graphical representation of the heat conductivity and heat capacity versus borehole length is given in Figure 5-10.

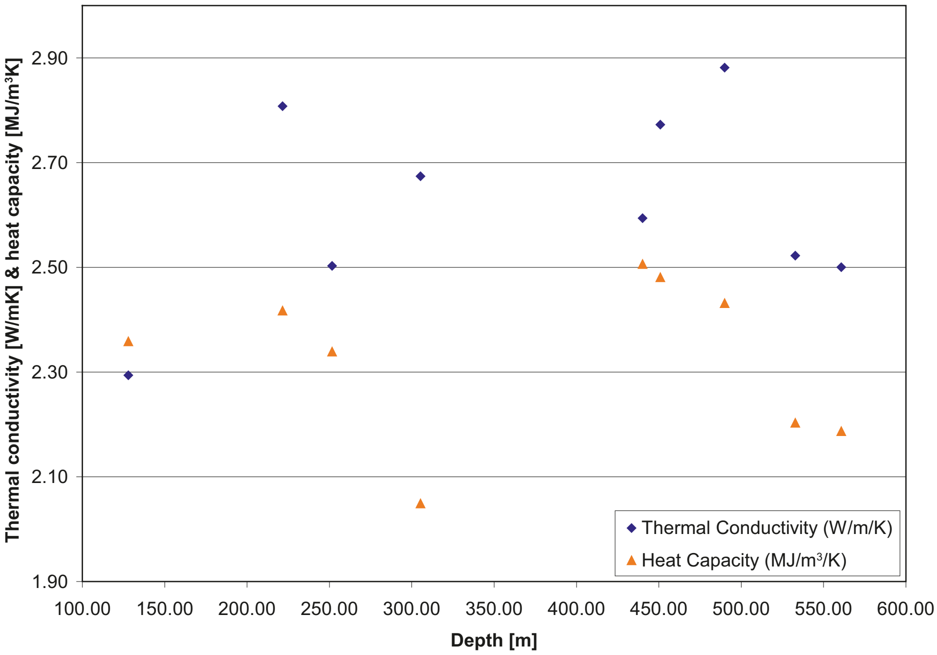

Figure 5-10. *Thermal conductivity and heat capacity versus borehole length measured with TPS method at 20°C.*

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/ **Liedberg L, 2006.** Oskarshamn site investigation. Borehole KLX12A. Determination of porosity by water saturation and density by buoyancy technique. SKB P-06-71. 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 20/6 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)]
KLX12A 90V-01			
1	2.29	0.97	2.37
2	2.29	0.98	2.35
3	2.29	0.97	2.36
4	2.30	0.97	2.36
5	2.29	0.97	2.35
KLX12A 90V-02			
1	2.81	1.16	2.43
2	2.81	1.16	2.43
3	2.81	1.16	2.42
4	2.81	1.16	2.41
5	2.81	1.17	2.40
KLX12A 90V-03			
1	2.50	1.07	2.34
2	2.51	1.07	2.35
3	2.50	1.07	2.33
4	2.49	1.07	2.32
5	2.51	1.07	2.34
KLX12A 90V-04			
1	2.67	1.30	2.05
2	2.68	1.30	2.05
3	2.67	1.31	2.04
4	2.67	1.31	2.05
5	2.68	1.30	2.05
KLX12A 90V-06			
1	2.59	1.03	2.50
2	2.59	1.04	2.50
3	2.59	1.03	2.51
4	2.60	1.03	2.51
5	2.60	1.04	2.50
KLX12A 90V-07			
1	2.78	1.10	2.52
2	2.77	1.12	2.49
3	2.77	1.12	2.48
4	2.77	1.12	2.47
5	2.77	1.13	2.45
KLX12A 90V-08			
1	2.88	1.19	2.43
2	2.88	1.19	2.43
3	2.88	1.18	2.44
4	2.88	1.19	2.43
5	2.88	1.18	2.44

Measurement number	**Conductivity [W/(m, K)]**	**Diffusivity [mm^2/s]**	**Heat capacity [$MJ/(m^3, K)$]**
KLX12A 90V-09			
1	2.52	1.15	2.20
2	2.52	1.15	2.20
3	2.52	1.15	2.20
4	2.53	1.14	2.22
5	2.52	1.14	2.21
KLX12A 90V-10			
1	2.50	1.14	2.20
2	2.50	1.14	2.19
3	2.50	1.15	2.17
4	2.50	1.14	2.19
5	2.50	1.14	2.19

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
KLX12A 90V-01			
1	20	0.47	(76–200)
2	20	0.47	(76–200)
3	20	0.47	(76–200)
4	20	0.47	(76–200)
5	20	0.47	(76–200)
KLX12A 90V-02			
1	20	0.56	(21–200)
2	20	0.56	(21–200)
3	20	0.56	(21–200)
4	20	0.57	(21–200)
5	20	0.57	(21–200)
KLX12A 90V-03			
1	20	0.52	(74–199)
2	20	0.52	(74–199)
3	20	0.52	(74–199)
4	20	0.52	(74–199)
5	20	0.52	(74–199)
KLX12A 90V-04			
1	20	0.63	(29–200)
2	20	0.63	(29–200)
3	20	0.63	(29–200)
4	20	0.63	(29–200)
5	20	0.63	(29–200)
KLX12A 90V-06			
1	20	0.50	(57–200)
2	20	0.50	(57–200)
3	20	0.50	(57–200)
4	20	0.50	(57–200)
5	20	0.50	(57–200)
KLX12A 90V-07			
1	20	0.54	(30–200)
2	20	0.54	(21–200)
3	20	0.54	(22–200)
4	20	0.54	(22–200)
5	20	0.55	(22–200)
KLX12A 90V-08			
1	20	0.58	(22–200)
2	20	0.58	(22–200)
3	20	0.57	(22–200)
4	20	0.58	(22–200)
5	20	0.57	(22–200)

Measurement number	Total time(s)	Total/Char. time	Points
KLX12A 90V-09			
1	20	0.56	(22–200)
2	20	0.56	(22–200)
3	20	0.56	(22–200)
4	20	0.55	(26–200)
5	20	0.55	(24–200)
KLX12A 90V-10			
1	20	0.55	(28–200)
2	20	0.55	(28–200)
3	20	0.56	(28–200)
4	20	0.55	(28–200)
5	20	0.55	(28–200)