P-04-159

Forsmark site investigation

Drill hole KFM01A

Thermal properties: heat conductivity and heat capacity determined using the TPS method and Mineralogical composition by modal analysis

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December 2004

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Keywords: Thermal properties, Rock mechanics, Thermal conductivity, Thermal diffusivity, Heat capacity, Transient Plane Source method, Modal analysis.

Abstract

Thermal properties on twenty-six specimens from drill hole KFM01A, Forsmark, Sweden, were measured at ambient and elevated temperature. The rock type of all samples is medium-grained metagranodiorite-granite. The mineralogical content was determined by using modal analysis.

The determination of the thermal properties is based on a direct measurement method, the so called “Transient Plane Source Method (TPS)”, Gustafsson, 1991 /1/.

Generally, the influence of temperature on the thermal diffusivity was larger than on the conductivity. Thermal conductivity and thermal diffusivity of specimens at different depths at 20°C were in the range of 3.47–4.00 W/(m, K) and 1.56–1.93 mm^2/s respectively. At 80°C, thermal conductivity and thermal diffusivity of specimens at the depth 492–495 m were in the range of 3.33–3.71 W/(m, K) and 1.28–1.45 mm^2/s respectively.

Contents

1 Introduction

The objective of this investigation was to determine thermal properties of drill core specimens borehole KFM01A, Forsmark, Sweden, see Figure 1-1, at different temperature levels by using the TPS-method /1/. The thermal properties were determined for water-saturated specimens. The specimens, in form of circular discs, were cut from rock cores. The samples were selected based on the preliminary core logging, and with the strategy to primarily investigate the properties of the dominant rock types. The principle of the TPS method is to place a sensor between two rock samples. The sensor consists of a thin metal double spiral, embedded in an insulation material. 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 heat conductivity and diffusivity of a material, and from this the volumetric heat capacity can be determined, if the density is known.

The test programme followed the activity plan AP PF 400 03 18 (SKB internal controlling document) and was controlled by SP-QD 13.1 (SP quality document).

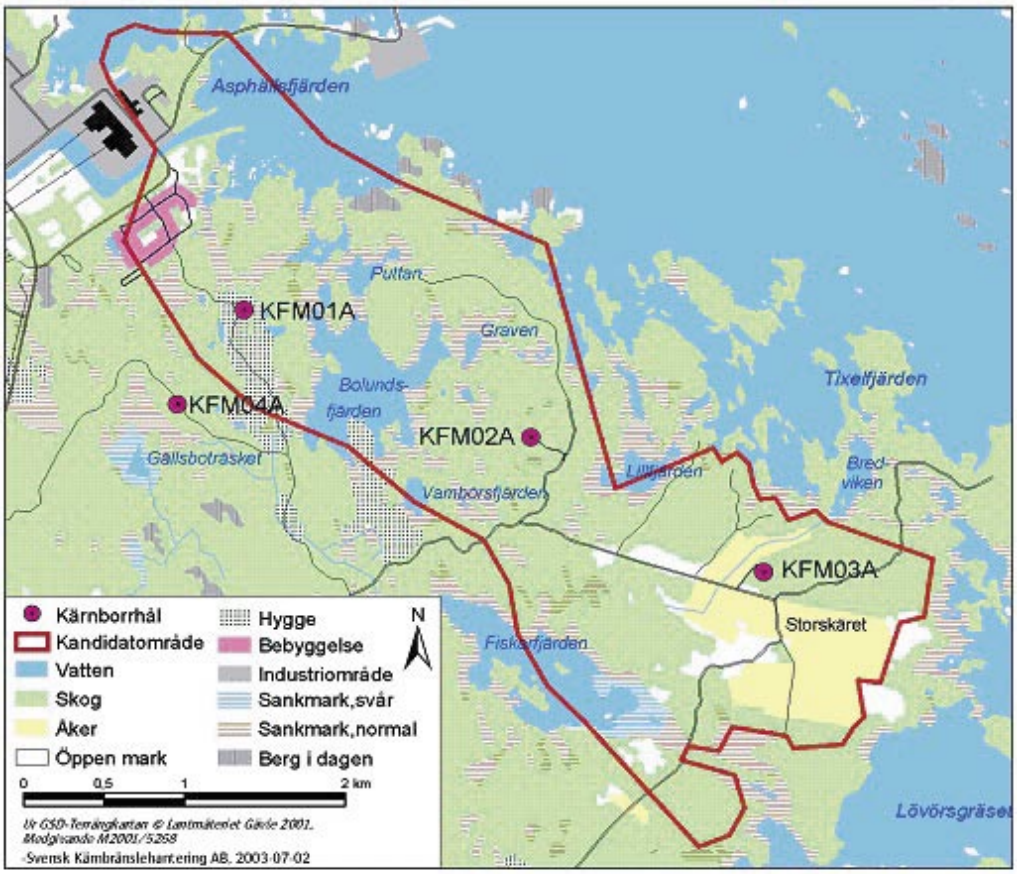

Figure 1-1. *Location of drill hole KFM01A at the Forsmark site.*

The samples were water saturated and stored in 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.

Modal analyses, based on point counting using a polarising microscope were performed on 8 specimens that were sampled on the same level as the specimens for thermal properties.

The rock cores arrived at SP in February 2003. The testing was performed during November and December 2003.

Determination of thermal properties was made in accordance with SKB's method description SKB MD 191.001, version 1.9 (SKB internal controlling document) at SP Fire Technology. Density was determined in compliance with SKB MD 160.002, version 1.9 (SKB internal controlling document), at SP Building Technology and Mechanics.

Modal analysis was performed according to SKB MD 160.001 (SKB internal controlling document) and BMm-P54 (SP quality document).

2 Objective and scope

The purpose of the testing is to determine the thermal properties of rock specimens. The results shall be used for the site descriptive modelling of thermal properties, which will be established for the candidate area selected for site investigations at Forsmark.

The samples derive from borehole KFM01A in Forsmark, which is a near-vertical telescope borehole of SKB-chemistry type with a drilling length of c 1,000 m. The specimens were sampled on four levels in the drill hole: 230, 390, 490 and 690 m. The investigated rock type is mapped as medium-grained metagranodiorite-granite (rock code 101057).

3 Equipment

Technical devices used for determination of thermal properties were:

- Kapton sensor 5501, radius of the sensor was 6.403 mm, and output of power was 0.7 W. The sensor 5501 fulfils the recommended relation between the radius of sensor and geometry of the samples in /2/.
- 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.
- Water bath with immersion heater.
- Immersion heater, Grant, type TD. The accuracy of the thermostat is 0.004°C.
- Hand instrument for control measuring of the water bath temperature.

Specimen mounting is shown in Figure 3-2.

Technical devices used for modal analyses (point counting) were:

- Leitz Orthoplan optical microscope (inv nr 100276).

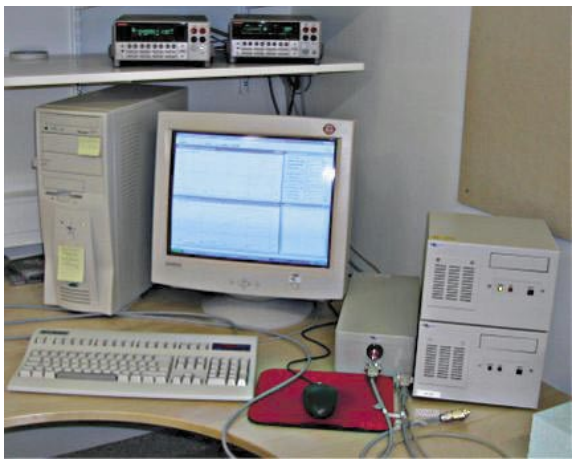

Figure 3-1. *TPS-apparatus with source meter, multi-meter, bridge, and computer.*

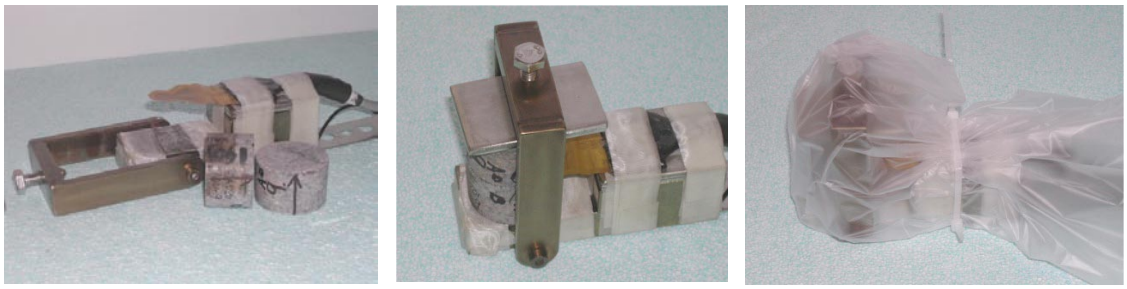

Figure 3-2. *Specimens prior to mounting (left), mounted in stainless sample holder (middle), and sample holder with mounted specimens wrapped in plastic (right).*

4 Execution

Determination of thermal properties was made in accordance with SKB's method description SKB MD 191.001, version 1.9 (SKB internal controlling document), and the Hot Disc Instruction Manual /2/ at SP Fire Technology.

Density was determined in accordance with SKB MD 160.002, version 1.9 (SKB internal controlling document), and ISRM /3/. Modal analysis was determined according to SKB MD 160.001, version 1.9 (SKB internal controlling document), at SP Building Technology and Mechanics.

4.1 Description of the samples

Twenty-six pairs of cores were sampled from four levels of drill hole KFM01A. The first level was between 227 m and 236 m, the second at 389 m, the third between 492 m and 495 m, and the fourth level between 691 m and 699 m. The fifty-two specimens, with a thickness of 25 mm each, were prepared from the samples at SP, see Figure 3-2. The diameter of the specimens was about 50 mm. The rock type, identification marks and depth of the specimens are presented in Table 4-1. Detailed geological description of the rock is given in SKB's BOREMAP of KFM01A within the SICADA database at SKB.

Each sample is assigned an identification number composed of the combination KFM01A-90V (in some figures and tables abbreviated F01A-90), followed by the serial numbers -1, -2, -3 etc for thermal properties respectively KFM01A-200, followed by selected serial numbers for modal analysis.

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

Identification	Rock type	Sampling depth (Sec low)
KFM01A-90V-1	Metagranodiorite-granite	235.23
KFM01A-90V-2	Metagranodiorite-granite	235.35
KFM01A-90V-3	Metagranodiorite-granite	231.28
KFM01A-90V-4	Metagranodiorite-granite	226.80
KFM01A-90V-5	Metagranodiorite-granite	227.02
KFM01A-90V-6	Metagranodiorite-granite	389.04
KFM01A-90V-7	Metagranodiorite-granite	389.15
KFM01A-90V-8	Metagranodiorite-granite	389.27
KFM01A-90V-9	Metagranodiorite-granite	389.38
KFM01A-90V-10	Metagranodiorite-granite	389.68
KFM01A-90V-11	Metagranodiorite-granite	492.51
KFM01A-90V-12	Metagranodiorite-granite	493.85
KFM01A-90V-13	Metagranodiorite-granite	493.97
KFM01A-90V-14	Metagranodiorite-granite	494.09
KFM01A-90V-15	Metagranodiorite-granite	494.20
KFM01A-90V-16	Metagranodiorite-granite	494.32
KFM01A-90V-17	Metagranodiorite-granite	494.43
KFM01A-90V-18	Metagranodiorite-granite	494.62
KFM01A-90V-19	Metagranodiorite-granite	494.74
KFM01A-90V-20	Metagranodiorite-granite	494.94
KFM01A-90V-21	Metagranodiorite-granite	691.79
KFM01A-90V-22	Metagranodiorite-granite	691.90
KFM01A-90V-23	Metagranodiorite-granite	692.02
KFM01A-90V-24	Metagranodiorite-granite	692.14
KFM01A-90V-25	Metagranodiorite-granite	698.47
KFM01A-90V-26	Metagranodiorite-granite	698.58

4.2 Test procedure

The following steps were performed:

1. Samples were cut and polished by SP Building Technology and Mechanics.
2. Samples were photographed by SP Building Technology and Mechanics.
3. Samples were water saturated and wet density was determined by SP Building Technology and Mechanics.
4. Samples were sent from SP Building Technology and Mechanics to SP Fire Technology.
5. Thermal properties were determined.
6. Samples were sent from SP Fire Technology to SP Building Technology and Mechanics.
7. Dry density of samples determined at SP Building Technology and Mechanics.

Thermal properties of water-saturated specimens were measured in ambient air temperature (20°C) as well as at 50°C and 80°C. In order to remain water saturation and obtain desired temperature, the samples and the sensor were kept in a plastic bag during the measurement, see Figure 3-2.

Each core pair 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.

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

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

Thermal properties, density and porosity measurements were carried out during November–December, 2003.

Dry weight was measured after the specimens had been dried to constant mass according to ISRM /3/ at 105°C. The drying procedure took seven days.

4.2.1 Modal analysis

Modal analysis, based on point counting with at least 500 points counted in each sample, was performed by SP Building Technology and Mechanics.

The analysis was conducted on 8 specimens that were sampled on the same level as the specimens for thermal properties (see Sec low in Table 4-1). The modal analysis was done in order to calculate the thermal properties based on the specimen's mineralogical composition.

5 Results

5.1 Thermal properties

Mean values of measured data, five repeated measurements, are reported in 5.1.1 and 5.1.2 and in the SICADA database at SKB under field note no Forsmark 96. Values of each separate measurement as described in 4.2 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.

5.1.1 Test results, sample by sample

Sample F01A-90V-1

Figure 5-1. *Specimens F01A-90V-1.*

Table 5-1. Porosity, wet and dry density of specimens F01A-90V-1, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-1			
Sec low: 235.23	2,663	2,660	0.38

Table 5-2. Thermal properties of sample F01A-90V-1 at ambient temperature.

F01A-90V-1 Sec low: 235.23	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.54	1.77	2.00
Standard deviation	0.006	0.015	0.020

Sample F01A-90V-2

Figure 5-2. *Specimens F01A-90V-2.*

Table 5-3. Porosity, wet and dry density of specimens F01A-90V-2, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-2			
Sec low: 235.35	2,660	2,657	0.36

Table 5-4. Thermal properties of sample F01A-90V-2 at ambient temperature.

F01A-90V-2 Sec low: 235.35	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
		20°C	
Mean value	3.50	1.77	1.97
Standard deviation	0.015	0.018	0.027

Sample F01A-90V-3

Figure 5-3. *Specimens F01A-90V-3.*

Table 5-5. Porosity, wet and dry density of specimens F01A-90V-3, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-3			
Sec low: 231.28	2,658	2,655	0.35

Table 5-6. Thermal properties of sample F01A-90V-3 at ambient temperature.

F01A-90V-3 Sec low: 231.28	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
	20°C		
Mean value	3.69	1.56	2.36
Standard deviation	0.008	0.004	0.008

Sample F01A-90V-4

Figure 5-4. *Specimens F01A-90V-4.*

Table 5-7. Porosity, wet and dry density of specimens F01A-90V-4, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-4			
Sec low: 226.80	2,658	2,655	0.36

Table 5-8. Thermal properties of sample F01A-90V-4 at ambient temperature.

F01A-90V-4 Sec low: 226.80	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
		20°C	
Mean value	3.59	1.60	2.24
Standard deviation	0.004	0.004	0.007

Sample F01A-90V-5

Figure 5-5. *Specimens F01A-90V-5.*

Table 5-9. Porosity, wet and dry density of specimens F01A-90V-5, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-5			
Sec low: 227.02	2,660	2,658	0.16

Table 5-10. Thermal properties of sample F01A-90V-5 at ambient temperature.

F01A-90V-5 Sec low: 227.02	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
	20°C		
Mean value	3.86	1.72	2.24
Standard deviation	0.002	0.002	0.002

Sample F01A-90V-6

Figure 5-6. *Specimens F01A-90V-6.*

Table 5-11. Porosity, wet and dry density of specimens F01A-90V-6, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-6			
Sec low: 389.04	2,654	2,652	0.14

Table 5-12. Thermal properties of sample F01A-90V-6 at ambient temperature.

F01A-90V-6 Sec low: 389.04	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.64	1.68	2.17
Standard deviation	0.005	0.007	0.011

Sample F01A-90V-7

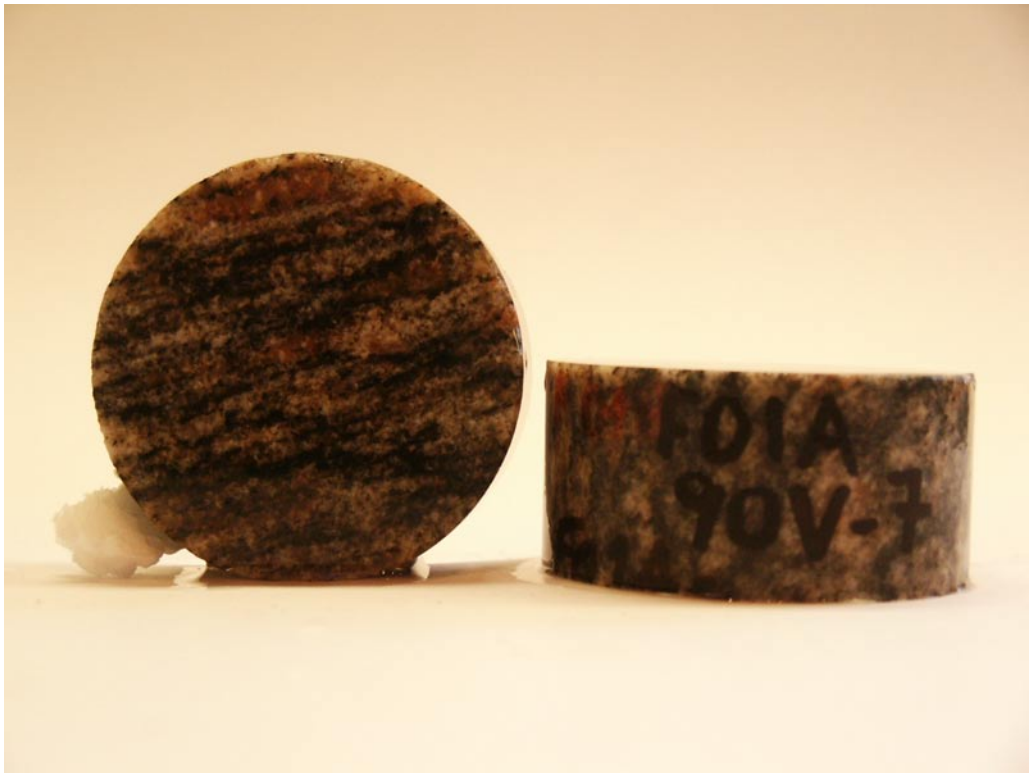

Figure 5-7. *Specimens F01A-90V-7.*

Table 5-13. Porosity, wet and dry density of specimens F01A-90V-7, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-7			
Sec low: 389.15	2,658	2,657	0.15

Table 5-14. Thermal properties of sample F01A-90V-7 at ambient temperature.

F01A-90V-7 Sec low: 389.15	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
		20°C	
Mean value	3.94	1.79	2.21
Standard deviation	0.006	0.012	0.016

Sample F01A-90V-8

Figure 5-8. *Specimens F01A-90V-8.*

Table 5-15. Porosity, wet and dry density of specimens F01A-90V-8, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-8			
Sec low: 389.27	2,662	2,660	0.15

Table 5-16. Thermal properties of sample F01A-90V-8 at ambient temperature.

F01A-90V-8 Sec low: 389.27	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.74	1.63	2.30
Standard deviation	0.005	0.004	0.008

Sample F01A-90V-9

Figure 5-9. *Specimens F01A-90V-9.*

Table 5-17. Porosity, wet and dry density of specimens F01A-90V-9, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-9			
Sec low: 389.38	2,656	2,654	0.21

Table 5-18. Thermal properties of sample F01A-90V-9 at ambient temperature.

F01A-90V-9 Sec low: 389.38	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
		20°C	
Mean value	3.67	1.90	1.93
Standard deviation	0.009	0.013	0.017

Sample F01A-90V-10

Figure 5-10. *Specimens F01A-90V-10.*

Table 5-19. Porosity, wet and dry density of specimens F01A-90V-10, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-10			
Sec low: 389.68	2,658	2,656	0.22

Table 5-20. Thermal properties of sample F01A-90V-10 at ambient temperature.

F01A-90V-10 Sec low: 389.68	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.47	1.93	1.80
Standard deviation	0.007	0.017	0.019

Sample F01A-90V-11

Figure 5-11. *Specimens F01A-90V-11.*

Table 5-21. Porosity, wet and dry density of specimens F01A-90V-11, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-11			
Sec low: 492.51	2,657	2,654	0.27

Table 5-22. Thermal properties of sample F01A-90V-11 at different temperatures.

F01A-90V-11 Sec low: 492.51	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
		20°C	
Mean value	3.80	1.66	2.30
Standard deviation	0.010	0.009	0.010
		50°C	
Mean value	3.67	1.50	2.45
Standard deviation	0.010	0.010	0.022
		80°C	
Mean value	3.62	1.34	2.71
Standard deviation	0.017	0.015	0.021

Sample F01A-90V-12

Figure 5-12. *Specimens F01A-90V-12.*

Table 5-23. Porosity, wet and dry density of specimens F01A-90V-12, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-12			
Sec low: 493.85	2,660	2,657	0.30

Table 5-24. Thermal properties of sample F01A-90V-12 at different temperatures.

F01A-90V-12 Sec low: 493.85	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.67	1.59	2.31
Standard deviation	0.005	0.007	0.010
		50°C	
Mean value	3.58	1.45	2.47
Standard deviation	0.003	0.010	0.016
		80°C	
Mean value	3.49	1.28	2.74
Standard deviation	0.017	0.028	0.057

Sample F01A-90V-13

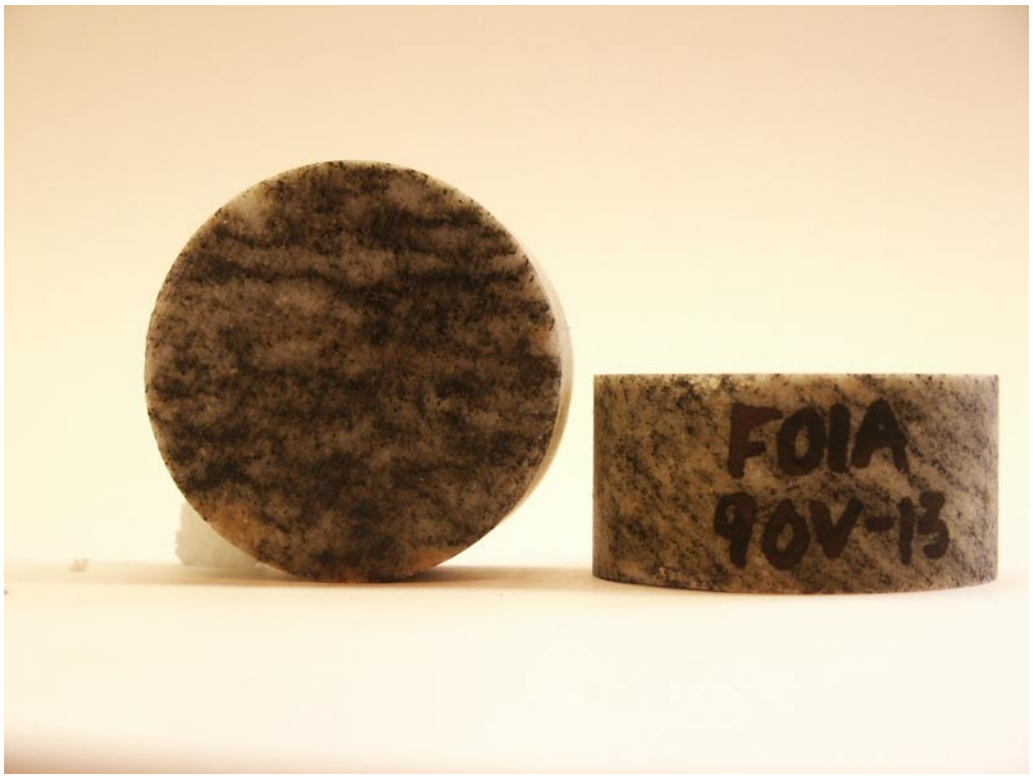

Figure 5-13. *Specimens F01A-90V-13.*

Table 5-25. Porosity, wet and dry density of specimens F01A-90V-13, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-13			
Sec low: 493.97	2,656	2,653	0.29

Table 5-26. Thermal properties of sample F01A-90V-13 at different temperatures.

F01A-90V-13 Sec low: 493.97	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
		20°C	
Mean value	3.54	1.69	2.09
Standard deviation	0.008	0.020	0.029
		50°C	
Mean value	3.49	1.48	2.36
Standard deviation	0.008	0.013	0.024
		80°C	
Mean value	3.33	1.41	2.36
Standard deviation	0.015	0.018	0.033

Sample F01A-90V-14

Figure 5-14. *Specimens F01A-90V-14.*

Table 5-27. Porosity, wet and dry density of specimens F01A-90V-14, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-14			
Sec low: 494.09	2,660	2,657	0.27

Table 5-28. Thermal properties of sample F01A-90V-14 at different temperatures.

F01A-90V-14 Sec low: 494.09	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.89	1.60	2.43
Standard deviation	0.005	0.013	0.021
		50°C	
Mean value	3.76	1.47	2.56
Standard deviation	0.014	0.019	0.030
		80°C	
Mean value	3.62	1.36	2.67
Standard deviation	0.004	0.010	0.021

Sample F01A-90V-15

Figure 5-15. *Specimens F01A-90V-15.*

Table 5-29. Porosity, wet and dry density of specimens F01A-90V-15, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-15			
Sec low: 494.20	2,663	2,660	0.25

Table 5-30. Thermal properties of sample F01A-90V-15 at different temperatures.

F01A-90V-15 Sec low: 494.20	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.89	1.64	2.37
Standard deviation	0.003	0.005	0.008
		50°C	
Mean value	3.69	1.58	2.33
Standard deviation	0.008	0.010	0.015
		80°C	
Mean value	3.61	1.30	2.77
Standard deviation	0.015	0.018	0.042

Sample F01A-90V-16

Figure 5-16. *Specimens F01A-90V-16.*

Table 5-31. Porosity, wet and dry density of specimens F01A-90V-16, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-16			
Sec low: 494.32	2,652	2,649	0.31

Table 5-32. Thermal properties of sample F01A-90V-16 at different temperatures.

F01A-90V-16 Sec low: 494.32	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.68	1.88	1.96
Standard deviation	0.012	0.012	0.018
		50°C	
Mean value	3.57	1.66	2.15
Standard deviation	0.007	0.011	0.019
		80°C	
Mean value	3.50	1.35	2.60
Standard deviation	0.014	0.047	0.093

Sample F01A-90V-17

Figure 5-17. *Specimens F01A-90V-17.*

Table 5-33. Porosity, wet and dry density of specimens F01A-90V-17, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-17			
Sec low: 494.43	2,654	2,651	0.31

Table 5-34. Thermal properties of sample F01A-90V-17 at different temperatures.

F01A-90V-17 Sec low: 494.43	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.75	1.61	2.33
Standard deviation	0.006	0.010	0.016
		50°C	
Mean value	3.69	1.45	2.55
Standard deviation	0.008	0.008	0.017
		80°C	
Mean value	3.61	1.28	2.82
Standard deviation	0.010	0.008	0.024

Sample F01A-90V-18

Figure 5-18. *Specimens F01A-90V-18.*

Table 5-35. Porosity, wet and dry density of specimens F01A-90V-18, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-18			
Sec low: 494.62	2,656	2,654	0.27

Table 5-36. Thermal properties of sample F01A-90V-18 at different temperatures.

F01A-90V-18 Sec low: 494.62	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.67	1.79	2.05
Standard deviation	0.008	0.011	0.017
		50°C	
Mean value	3.55	1.61	2.21
Standard deviation	0.005	0.018	0.028
		80°C	
Mean value	3.44	1.45	2.38
Standard deviation	0.016	0.017	0.036

Sample F01A-90V-19

Figure 5-19. *Specimens F01A-90V-19.*

Table 5-37. Porosity, wet and dry density of specimens F01A-90V-19, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-19			
Sec low: 494.74	2,657	2,655	0.27

Table 5-38. Thermal properties of sample F01A-90V-19 at different temperatures.

F01A-90V-19 Sec low: 494.74	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
		20°C	
Mean value	3.72	1.68	2.21
Standard deviation	0.006	0.007	0.009
		50°C	
Mean value	3.53	1.55	2.29
Standard deviation	0.009	0.016	0.029
		80°C	
Mean value	3.45	1.35	2.55
Standard deviation	0.015	0.028	0.059

Sample F01A-90V-20

Figure 5-20. *Specimens F01A-90V-20.*

Table 5-39. Porosity, wet and dry density of specimens F01A-90V-20, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-20			
Sec low: 494.94	2,655	2,652	0.29

Table 5-40. Thermal properties of sample F01A-90V-20 at different temperatures.

F01A-90V-20 Sec low: 494.94	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	4.00	1.72	2.32
Standard deviation	0.008	0.011	0.019
		50°C	
Mean value	3.88	1.57	2.47
Standard deviation	0.007	0.010	0.018
		80°C	
Mean value	3.71	1.45	2.56
Standard deviation	0.006	0.005	0.013

Sample F01A-90V-21

Figure 5-21. *Specimens F01A-90V-21.*

Table 5-41. Porosity, wet and dry density of specimens F01A-90V-21, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-21			
Sec low: 691.79	2,662	2,659	0.29

Table 5-42. Thermal properties of sample F01A-90V-21 at ambient temperature.

F01A-90V-21 Sec low: 691.79	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
		20°C	
Mean value	3.72	1.78	2.09
Standard deviation	0.010	0.011	0.018

Sample F01A-90V-22

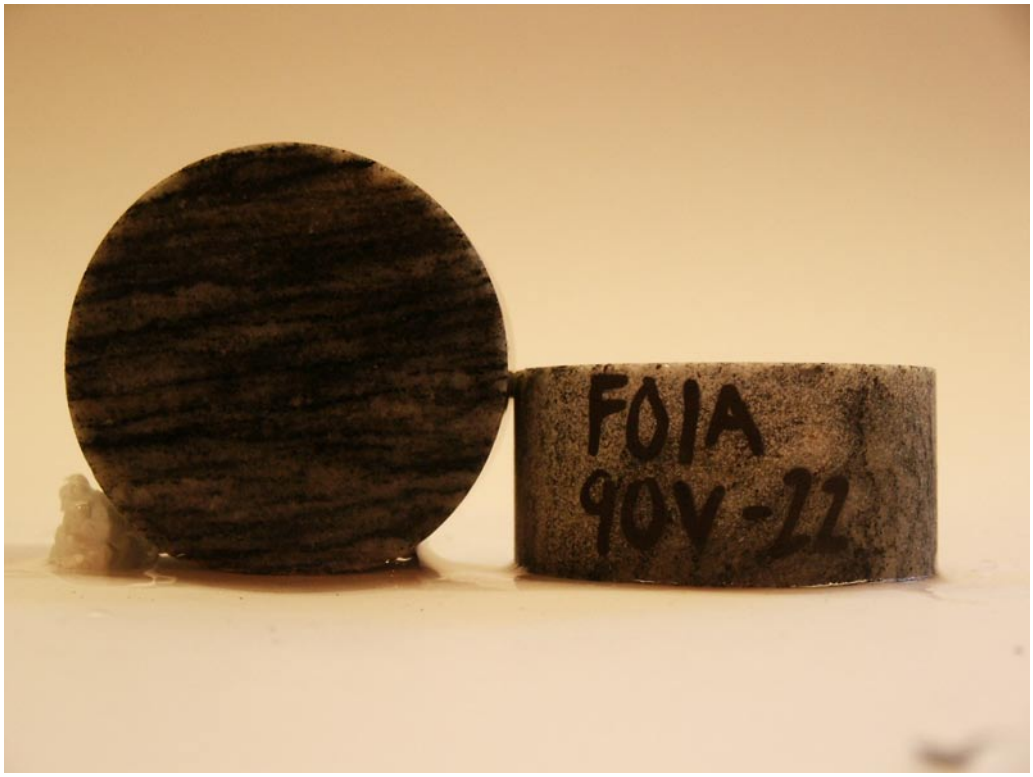

Figure 5-22. *Specimens F01A-90V-22.*

Table 5-43. Porosity, wet and dry density of specimens F01A-90V-22, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-22			
Sec low: 691.90	2,660	2,657	0.25

Table 5-44. Thermal properties of sample F01A-90V-22 at ambient temperature.

F01A-90V-22 Sec low: 691.90	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.63	1.70	2.13
Standard deviation	0.009	0.013	0.016

Sample F01A-90V-23

Figure 5-23. *Specimens F01A-90V-23.*

Table 5-45. Porosity, wet and dry density of specimens F01A-90V-23, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-23			
Sec low: 692.02	2,663	2,660	0.25

Table 5-46. Thermal properties of sample F01A-90V-23 at ambient temperature.

F01A-90V-23 Sec low: 692.02	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
		20°C	
Mean value	3.96	1.56	2.54
Standard deviation	0.005	0.009	0.017

Sample F01A-90V-24

Figure 5-24. *Specimens F01A-90V-24.*

Table 5-47. Porosity, wet and dry density of specimens F01A-90V-24, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-24			
Sec low: 692.14	2,659	2,656	0.25

Table 5-48. Thermal properties of sample F01A-90V-24 at ambient temperature.

F01A-90V-24 Sec low: 692.14	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.85	1.59	2.43
Standard deviation	0.014	0.008	0.019

Sample F01A-90V-25

Figure 5-25. *Specimens F01A-90V-25.*

Table 5-49. Porosity, wet and dry density of specimens F01A-90V-25, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
F01A-90V-25			
Sec low: 698.47	2,659	2,656	0.30

Table 5-50. Thermal properties of sample F01A-90V-25 at ambient temperature.

F01A-90V-25 Sec low: 698.47	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
		20°C	
Mean value	3.92	1.70	2.31
Standard deviation	0.007	0.011	0.018

Sample F01A-90V-26

Figure 5-26. *Specimens F01A-90V-26.*

Table 5-51. Porosity, wet and dry density of specimens F01A-90V-26, average values.

Sample	Density, wet [kg/m³]	Density, dry [kg/m³]	Porosity [%]
F01A-90V-26			
Sec low: 698.58	2,657	2,654	0.33

Table 5-52. Thermal properties of sample F01A-90V-26 at ambient temperature.

F01A-90V-26 Sec low: 698.58	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
		20°C	
Mean value	3.66	1.73	2.11
Standard deviation	0.014	0.011	0.022

5.1.2 Summary of results

Table 5-53 – Table 5-55 show the mean value of five repeated measurements of the thermal properties. Standard deviation at different temperature levels is presented in Table 5-56 – Table 5-58.

Thermal conductivity and thermal diffusivity of specimens at different depths at 20°C were in the range of 3.47–4.00 W/(m, K) and 1.56–1.93 mm^2/s respectively. At 50°C, thermal conductivity and thermal diffusivity of specimens at different depths were in the range of 3.49–3.88 W/(m, K) and 1.45–1.66 mm^2/s respectively and, finally, at 80°C, thermal conductivity and thermal diffusivity of specimens at the depth 492–495 m were in the range of 3.33–3.71 W/(m, K) and 1.28–1.45 mm^2/s respectively.

Table 5-53. Thermal properties with mean values of samples at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
F01A-90V-1	3.54	1.77	2.00
F01A-90V-2	3.50	1.77	1.97
F01A-90V-3	3.69	1.56	2.36
F01A-90V-4	3.59	1.60	2.24
F01A-90V-5	3.86	1.72	2.24
Mean value, level 230	**3.64**	**1.68**	**2.17**
F01A-90V-6	3.64	1.68	2.17
F01A-90V-7	3.94	1.79	2.21
F01A-90V-8	3.74	1.63	2.30
F01A-90V-9	3.67	1.90	1.93
F01A-90V-10	3.47	1.93	1.80
Mean value, level 390	**3.69**	**1.78**	**2.08**
F01A-90V-11	3.80	1.66	2.30
F01A-90V-12	3.67	1.59	2.31
F01A-90V-13	3.54	1.69	2.09
F01A-90V-14	3.89	1.60	2.43
F01A-90V-15	3.89	1.64	2.37
F01A-90V-16	3.68	1.88	1.96
F01A-90V-17	3.75	1.61	2.33
F01A-90V-18	3.67	1.79	2.05
F01A-90V-19	3.72	1.68	2.21
F01A-90V-20	4.00	1.72	2.32
Mean value, level 490	**3.76**	**1.69**	**2.24**
F01A-90V-21	3.72	1.78	2.09
F01A-90V-22	3.63	1.70	2.13
F01A-90V-23	3.96	1.56	2.54
F01A-90V-24	3.85	1.59	2.43
F01A-90V-25	3.92	1.70	2.31
F01A-90V-26	3.66	1.73	2.11
Mean value, level 690	**3.79**	**1.68**	**2.27**

Table 5-54. Thermal properties with mean values of samples at 50°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
F01A-90V-11	3.67	1.50	2.45
F01A-90V-12	3.58	1.45	2.47
F01A-90V-13	3.49	1.48	2.36
F01A-90V-14	3.76	1.47	2.56
F01A-90V-15	3.69	1.58	2.33
F01A-90V-16	3.57	1.66	2.15
F01A-90V-17	3.69	1.45	2.55
F01A-90V-18	3.55	1.61	2.21
F01A-90V-19	3.53	1.55	2.29
F01A-90V-20	3.88	1.57	2.47
Mean value, level 490	**3.64**	**1.53**	**2.38**

Table 5-55. Thermal properties with mean values of samples at 80°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
F01A-90V-11	3.62	1.34	2.71
F01A-90V-12	3.49	1.28	2.74
F01A-90V-13	3.33	1.41	2.36
F01A-90V-14	3.62	1.36	2.67
F01A-90V-15	3.61	1.30	2.77
F01A-90V-16	3.50	1.35	2.60
F01A-90V-17	3.61	1.28	2.82
F01A-90V-18	3.44	1.45	2.38
F01A-90V-19	3.45	1.35	2.55
F01A-90V-20	3.71	1.45	2.56
Mean value, level 490	**3.54**	**1.36**	**2.62**

Table 5-56. Standard deviation of measured values at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
F01A-90V-1	0.006	0.015	0.020
F01A-90V-2	0.015	0.018	0.027
F01A-90V-3	0.008	0.004	0.008
F01A-90V-4	0.004	0.004	0.007
F01A-90V-5	0.002	0.002	0.002
F01A-90V-6	0.005	0.007	0.011
F01A-90V-7	0.006	0.012	0.016
F01A-90V-8	0.005	0.004	0.008
F01A-90V-9	0.009	0.013	0.017
F01A-90V-10	0.007	0.017	0.019
F01A-90V-11	0.010	0.009	0.010
F01A-90V-12	0.005	0.007	0.010
F01A-90V-13	0.008	0.020	0.029
F01A-90V-14	0.005	0.013	0.021
F01A-90V-15	0.003	0.005	0.008
F01A-90V-16	0.012	0.012	0.018
F01A-90V-17	0.006	0.010	0.016
F01A-90V-18	0.008	0.011	0.017
F01A-90V-19	0.006	0.007	0.009
F01A-90V-20	0.008	0.011	0.019
F01A-90V-21	0.010	0.011	0.018
F01A-90V-22	0.009	0.013	0.016
F01A-90V-23	0.005	0.009	0.017
F01A-90V-24	0.014	0.008	0.019
F01A-90V-25	0.007	0.011	0.018
F01A-90V-26	0.014	0.011	0.022

Table 5-57. Standard deviation of measured values at 50°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
F01A-90V-11	0.010	0.010	0.022
F01A-90V-12	0.003	0.010	0.016
F01A-90V-13	0.008	0.013	0.024
F01A-90V-14	0.014	0.019	0.030
F01A-90V-15	0.008	0.010	0.015
F01A-90V-16	0.007	0.011	0.019
F01A-90V-17	0.008	0.008	0.017
F01A-90V-18	0.005	0.018	0.028
F01A-90V-19	0.009	0.016	0.029
F01A-90V-20	0.007	0.010	0.018

Table 5-58. Standard deviation of measured values at 80°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm²/s]	Heat capacity [MJ/(m³, K)]
F01A-90V-11	0.017	0.015	0.021
F01A-90V-12	0.017	0.028	0.057
F01A-90V-13	0.015	0.018	0.033
F01A-90V-14	0.004	0.010	0.021
F01A-90V-15	0.015	0.018	0.042
F01A-90V-16	0.014	0.047	0.093
F01A-90V-17	0.010	0.008	0.024
F01A-90V-18	0.016	0.017	0.036
F01A-90V-19	0.015	0.028	0.059
F01A-90V-20	0.006	0.005	0.013

5.1.3 Graphical presentation of results

Variations of the thermal conductivity and heat capacity in relation to sampling depth of the at different temperatures are shown in Figure 5-27 – Figure 5-31.

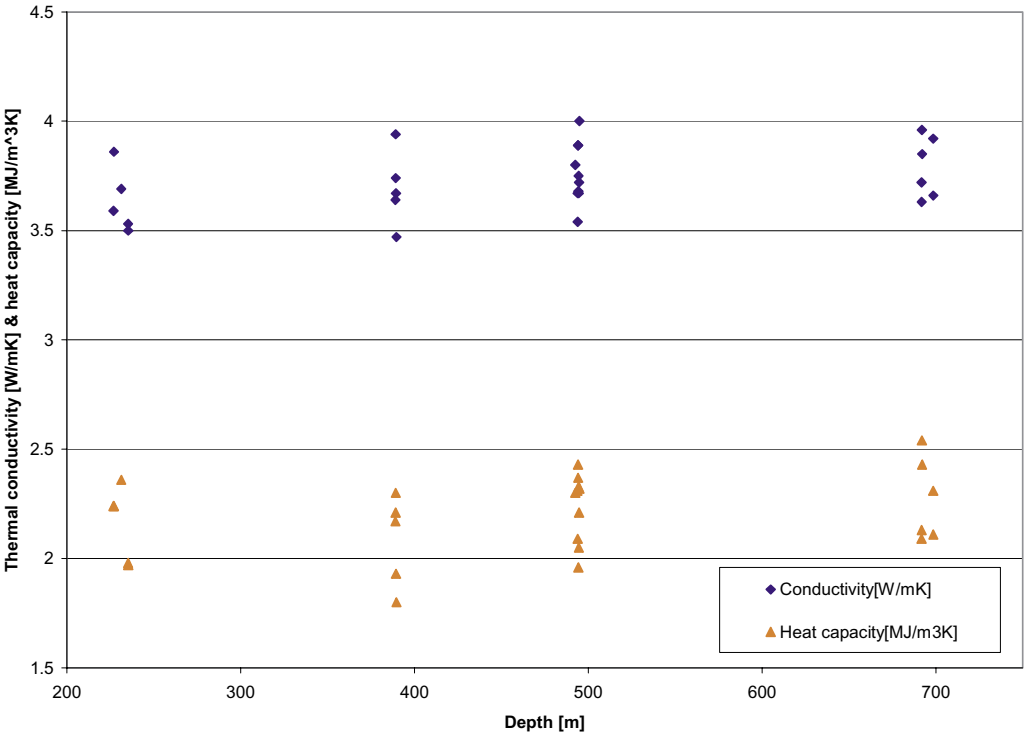

Figure 5-27. *Thermal conductivity and heat capacity at different depths at 20°C.*

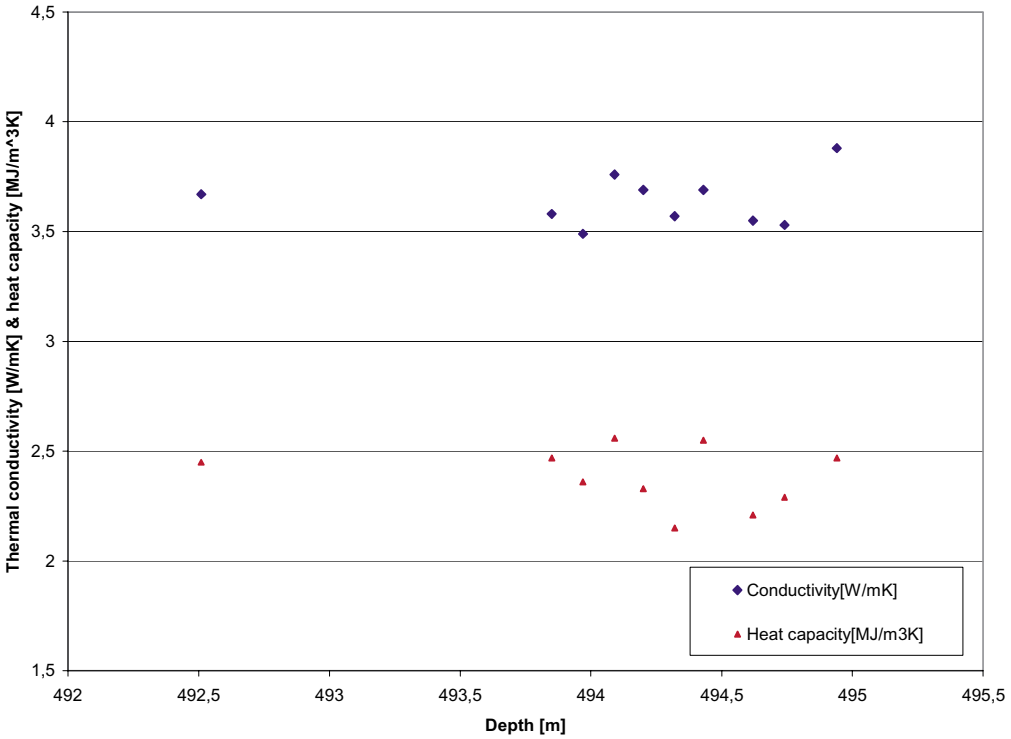

Figure 5-28. *Thermal conductivity and heat capacity at different depths at 50°C.*

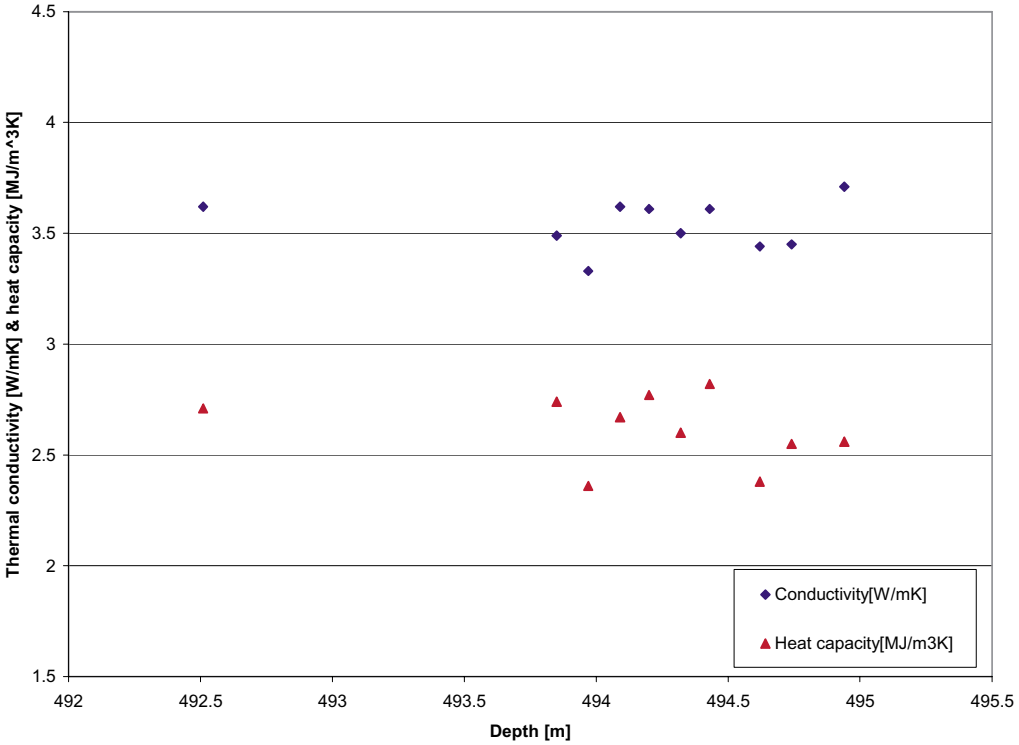

Figure 5-29. *Thermal conductivity and heat capacity at different depths at 80°C.*

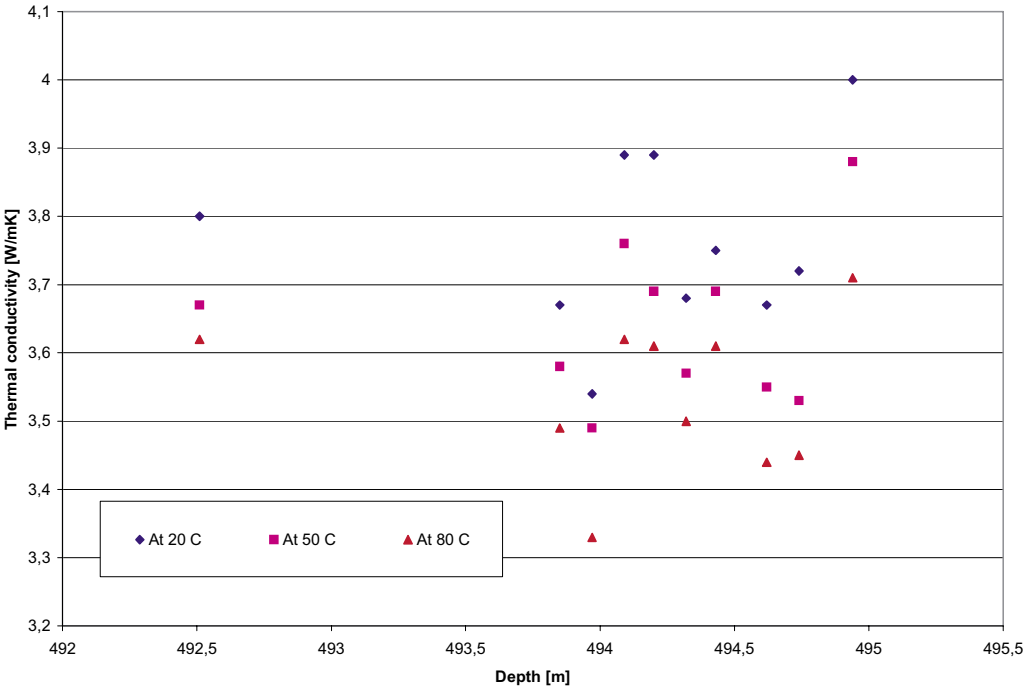

Figure 5-30. *Thermal conductivity at different depths and at different temperatures.*

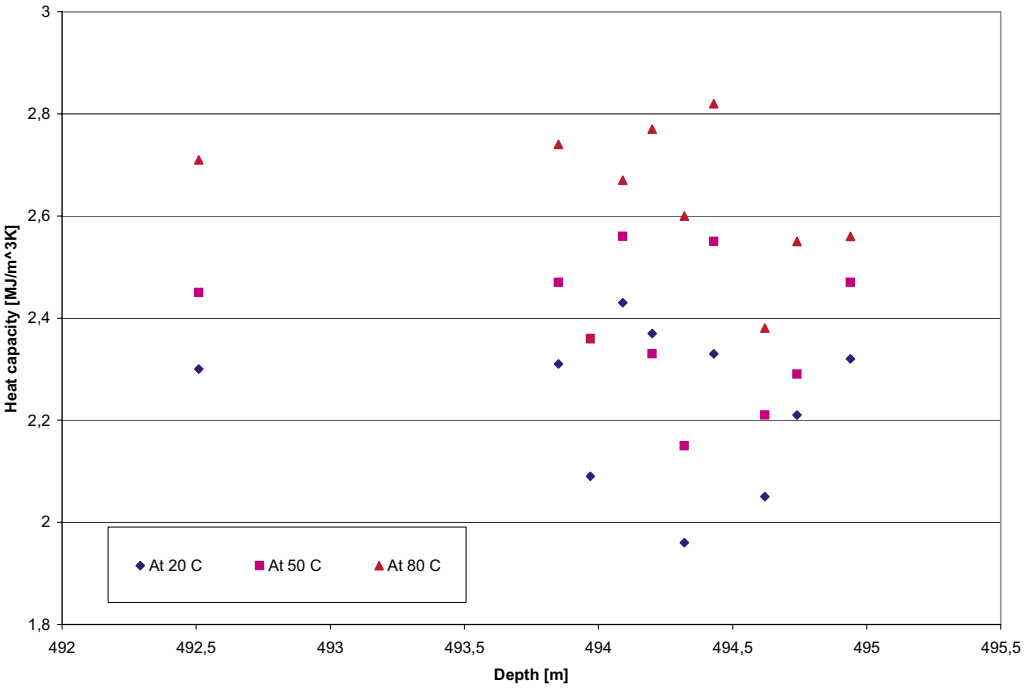

Figure 5-31. *Heat capacity at different depths and at different temperatures.*

The maximum variation of thermal conductivity in the temperature range 20ºC to 80ºC was 8% for sample F01A-90V-20 (494.94 m) and the maximum variation of heat capacity in the same temperature range was about 25% for sample F01A-90V-18 (494.62 m).

5.2 Modal analysis

Modal analyses, based on point counting using a polarising microscope were performed on 8 specimens that were sampled on the same level as the specimens for thermal properties (see Sec up in Table 5-59 and Sec low in Table 4-1). The modal analyses were carried out in order to calculate the thermal properties based on the specimen's mineralogical composition.

Table 5-59. Mineralogical composition (in vol. %) of the investigated specimens from KFM01A. 500 points are counted on each specimen.

Identification	Sampling depth (Sec up)	Quartz	K-feldspar	Plagioclase	Biotite	Amphibole	Opaque
KFM01A-200-1	235.11	40.4	19	35.6	4	0.4	0.6
KFM01A-200-3	231.15	42.2	24	28.6	4.8	0.2	0.2
KFM01A-200-9	389.27	39.8	15.6	37.6	5.8	0.2	1
KFM01A-200-10	389.57	37	17.6	36.6	8	0.2	0.6
KFM01A-200-17	494.32	34.2	21.4	40.2	3.2	0.4	0.6
KFM01A-200-20	494.82	30.8	25.8	36.2	6.2	0.8	0.2
KFM01A-200-24	692.02	37	16.2	39	6.8	0.8	0.2
KFM01A-200-25	698.35	38.6	19.4	37.6	4.2		0.2

The mineral mode is based on point counting using a polarising microscope. Assessory minerals are amphibole, epidote and sphene.

5.3 Nonconformities

None.

6 References

/1/ Gustafsson, S E: “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.

/2/ Instruction Manual Hot Disc Thermal Constants Analyser Windows 95 Version 5.0, 2001.

/3/ 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 1.4.2
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:	13.98 W/(m, K)	±0.11 %
Thermal Diffusivity:	3.535 mm^2/s	±0.20 %
Heat Capacity:	3.955 $MJ/(m^3, K)$	±0.19 %

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

Borås 01/10 2003

Bijan Adl-Zarrabi

Appendix B

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

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
F01A-90V-1			
1	3.54	1.77	1.99
2	3.54	1.75	2.02
3	3.54	1.75	2.02
4	3.54	1.77	2.00
5	3.53	1.79	1.98
F01A-90V-2			
1	3.51	1.76	1.99
2	3.48	1.79	1.94
3	3.50	1.79	1.96
4	3.52	1.75	2.01
5	3.50	1.78	1.96
F01A-90V-3			
1	3.68	1.56	2.36
2	3.69	1.56	2.37
3	3.70	1.56	2.37
4	3.69	1.57	2.36
5	3.69	1.56	2.36
F01A-90V-4			
1	3.59	1.60	2.25
2	3.59	1.60	2.24
3	3.59	1.60	2.24
4	3.60	1.60	2.25
5	3.59	1.61	2.23
F01A-90V-5			
1	3.86	1.72	2.24
2	3.87	1.72	2.24
3	3.86	1.72	2.25
4	3.86	1.72	2.24
5	3.86	1.72	2.24
F01A-90V-6			
1	3.64	1.68	2.17
2	3.64	1.68	2.17
3	3.64	1.68	2.17
4	3.65	1.67	2.18
5	3.63	1.69	2.15
F01A-90V-7			
1	3.93	1.80	2.19
2	3.95	1.77	2.23
3	3.94	1.79	2.20
4	3.94	1.77	2.22
5	3.95	1.79	2.20

Table B-1 (continues) Thermal properties of samples at 20 °C

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
F01A-90V-8			
1	3.74	1.63	2.30
2	3.74	1.62	2.30
3	3.73	1.63	2.29
4	3.73	1.63	2.29
5	3.74	1.62	2.31
F01A-90V-9			
1	3.67	1.89	1.94
2	3.69	1.88	1.96
3	3.67	1.91	1.92
4	3.67	1.90	1.93
5	3.67	1.91	1.92
F01A-90V-10			
1	3.47	1.92	1.81
2	3.47	1.91	1.82
3	3.46	1.94	1.79
4	3.47	1.92	1.81
5	3.46	1.95	1.77
F01A-90V-11			
1	3.81	1.67	2.28
2	3.81	1.65	2.31
3	3.80	1.65	2.30
4	3.79	1.65	2.30
5	3.79	1.65	2.30
F01A-90V-12			
1	3.68	1.59	2.32
2	3.67	1.59	2.31
3	3.67	1.60	2.30
4	3.67	1.59	2.30
5	3.67	1.58	2.32
F01A-90V-13			
1	3.53	1.72	2.05
2	3.53	1.71	2.07
3	3.55	1.68	2.11
4	3.54	1.70	2.08
5	3.55	1.67	2.12
F01A-90V-14			
1	3.88	1.61	2.41
2	3.90	1.60	2.44
3	3.89	1.61	2.42
4	3.89	1.60	2.44
5	3.89	1.58	2.46

Table B-1 (continues) Thermal properties of samples at 20 °C

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
F01A-90V-15			
1	3.89	1.64	2.37
2	3.89	1.64	2.37
3	3.88	1.65	2.35
4	3.89	1.64	2.37
5	3.88	1.64	2.37
F01A-90V-16			
1	3.70	1.87	1.98
2	3.68	1.88	1.95
3	3.67	1.89	1.94
4	3.68	1.87	1.97
5	3.66	1.89	1.94
F01A-90V-17			
1	3.75	1.62	2.31
2	3.75	1.61	2.32
3	3.76	1.60	2.35
4	3.74	1.61	2.33
5	3.75	1.60	2.33
F01A-90V-18			
1	3.68	1.79	2.06
2	3.68	1.78	2.07
3	3.66	1.81	2.03
4	3.67	1.79	2.04
5	3.68	1.78	2.07
F01A-90V-19			
1	3.72	1.69	2.21
2	3.71	1.68	2.21
3	3.72	1.67	2.22
4	3.72	1.67	2.22
5	3.71	1.68	2.21
F01A-90V-20			
1	3.99	1.74	2.29
2	4.00	1.72	2.33
3	4.00	1.72	2.32
4	4.01	1.72	2.33
5	4.01	1.71	2.34
F01A-90V-21			
1	3.72	1.78	2.09
2	3.73	1.77	2.11
3	3.72	1.76	2.11
4	3.70	1.79	2.06
5	3.72	1.78	2.09

Table B-1 (continues) Thermal properties of samples at 20 °C

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
F01A-90V-22			
1	3.64	1.72	2.11
2	3.63	1.70	2.13
3	3.62	1.70	2.13
4	3.63	1.70	2.14
5	3.64	1.69	2.16
F01A-90V-23			
1	3.96	1.57	2.52
2	3.96	1.56	2.53
3	3.96	1.56	2.55
4	3.96	1.55	2.55
5	3.97	1.55	2.57
F01A-90V-24			
1	3.87	1.58	2.44
2	3.87	1.58	2.44
3	3.86	1.58	2.44
4	3.83	1.60	2.40
5	3.85	1.59	2.43
F01A-90V-25			
1	3.91	1.71	2.29
2	3.92	1.70	2.31
3	3.93	1.68	2.34
4	3.92	1.70	2.30
5	3.93	1.70	2.32
F01A-90V-26			
1	3.64	1.74	2.10
2	3.65	1.73	2.11
3	3.65	1.74	2.10
4	3.66	1.73	2.11
5	3.68	1.71	2.15

Table B-2 Thermal properties of samples at 50 °C

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
F01A-90V-11			
1	3.66	1.50	2.45
2	3.68	1.50	2.46
3	3.68	1.50	2.45
4	3.68	1.49	2.47
5	3.66	1.52	2.41
F01A-90V-12			
1	3.58	1.45	2.46
2	3.57	1.46	2.45
3	3.58	1.46	2.45
4	3.58	1.44	2.48
5	3.57	1.44	2.48
F01A-90V-13			
1	3.50	1.49	2.34
2	3.49	1.47	2.37
3	3.50	1.47	2.38
4	3.49	1.46	2.39
5	3.48	1.49	2.34
F01A-90V-14			
1	3.75	1.46	2.56
2	3.74	1.47	2.54
3	3.75	1.44	2.60
4	3.77	1.49	2.52
5	3.77	1.47	2.57
F01A-90V-15			
1	3.68	1.59	2.32
2	3.69	1.59	2.33
3	3.67	1.58	2.33
4	3.69	1.57	2.36
5	3.69	1.59	2.32
F01A-90V-16			
1	3.55	1.67	2.12
2	3.57	1.65	2.17
3	3.57	1.66	2.15
4	3.56	1.65	2.16
5	3.57	1.66	2.15
F01A-90V-17			
1	3.70	1.44	2.58
2	3.69	1.46	2.54
3	3.70	1.45	2.54
4	3.69	1.45	2.54
5	3.68	1.45	2.54

Table B-2 (continues) Thermal properties of samples at 50 °C

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
F01A-90V-18			
1	3.55	1.58	2.25
2	3.56	1.60	2.22
3	3.55	1.61	2.20
4	3.55	1.62	2.19
5	3.54	1.62	2.19
F01A-90V-19			
1	3.54	1.52	2.32
2	3.53	1.56	2.25
3	3.53	1.56	2.26
4	3.54	1.54	2.30
5	3.53	1.54	2.29
F01A-90V-20			
1	3.87	1.56	2.48
2	3.89	1.57	2.47
3	3.88	1.57	2.48
4	3.87	1.59	2.44
5	3.89	1.56	2.49

Table B-3 Thermal properties of samples at 80 °C

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
F01A-90V-11			
1	3.65	1.36	2.68
2	3.61	1.33	2.72
3	3.63	1.33	2.73
4	3.61	1.34	2.71
5	3.60	1.33	2.72
F01A-90V-12			
1	3.51	1.29	2.73
2	3.46	1.25	2.78
3	3.50	1.26	2.77
4	3.50	1.26	2.77
5	3.49	1.32	2.64
F01A-90V-13			
1	3.34	1.43	2.33
2	3.35	1.40	2.39
3	3.31	1.42	2.33
4	3.32	1.41	2.36
5	3.33	1.39	2.40
F01A-90V-14			
1	3.62	1.36	2.66
2	3.61	1.36	2.66
3	3.62	1.37	2.64
4	3.62	1.35	2.69
5	3.62	1.35	2.68
F01A-90V-15			
1	3.60	1.28	2.81
2	3.59	1.31	2.74
3	3.60	1.33	2.71
4	3.63	1.30	2.80
5	3.61	1.31	2.77
F01A-90V-16			
1	3.51	1.37	2.55
2	3.50	1.42	2.47
3	3.52	1.32	2.66
4	3.50	1.29	2.71
5	3.48	1.33	2.61
F01A-90V-17			
1	3.61	1.27	2.85
2	3.59	1.29	2.78
3	3.61	1.28	2.83
4	3.61	1.28	2.83
5	3.61	1.28	2.83

Table B-3 (continues) Thermal properties of samples at 80 °C

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
F01A-90V-18			
1	3.46	1.42	2.43
2	3.43	1.46	2.34
3	3.42	1.46	2.35
4	3.44	1.45	2.38
5	3.42	1.44	2.38
F01A-90V-19			
1	3.46	1.38	2.51
2	3.44	1.37	2.50
3	3.43	1.35	2.55
4	3.46	1.35	2.57
5	3.47	1.31	2.65
F01A-90V-20			
1	3.70	1.46	2.54
2	3.72	1.46	2.55
3	3.72	1.45	2.57
4	3.71	1.45	2.56
5	3.71	1.46	2.55

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
F01A-90V-1			
1	20	0.86	85- 200
2	20	0.85	78- 199
3	20	0.85	78- 199
4	20	0.86	95- 200
5	20	0.87	104- 200
F01A-90V-2			
1	20	0.85	81- 200
2	20	0.82	76- 188
3	20	0.87	87- 200
4	20	0.85	77- 200
5	20	0.84	83- 194
F01A-90V-3			
1	20	0.76	61- 200
2	20	0.74	58- 196
3	20	0.68	63- 179
4	20	0.76	28- 200
5	20	0.75	75- 197
F01A-90V-4			
1	20	0.78	30- 200
2	20	0.76	29- 195
3	20	0.78	23- 200
4	20	0.78	32- 200
5	20	0.71	38- 182
F01A-90V-5			
1	20	0.82	47- 197
2	20	0.84	31- 200
3	20	0.83	73- 200
4	20	0.81	27- 194
5	20	0.84	38- 200
F01A-90V-6			
1	20	0.81	30- 200
2	20	0.77	27- 189
3	20	0.81	22- 200
4	20	0.81	26- 200
5	20	0.76	33- 185
F01A-90V-7			
1	20	0.85	85- 195
2	20	0.84	90- 196
3	20	0.85	80- 195
4	20	0.81	88- 188
5	20	0.87	91- 200

Table C-1 (continues) 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
F01A-90V-8			
1	20	0.79	44- 200
2	20	0.76	30- 192
3	20	0.79	41- 200
4	20	0.79	45- 200
5	20	0.76	42- 194
F01A-90V-9			
1	20	0.92	89- 200
2	20	0.91	87- 200
3	20	0.92	100- 199
4	20	0.92	94- 200
5	20	0.93	98- 200
F01A-90V-10			
1	20	0.92	95- 197
2	20	0.93	90- 200
3	20	0.94	106- 200
4	20	0.93	93- 200
5	20	0.95	106- 200
F01A-90V-11			
1	20	0.77	58- 190
2	20	0.80	66- 200
3	20	0.80	72- 199
4	20	0.77	57- 193
5	20	0.77	65- 192
F01A-90V-12			
1	20	0.77	55- 200
2	20	0.74	55- 192
3	20	0.63	44- 163
4	20	0.77	43- 200
5	20	0.71	65- 186
F01A-90V-13			
1	20	0.83	59- 200
2	20	0.81	46- 195
3	20	0.82	45- 200
4	20	0.82	67- 200
5	20	0.75	52- 185
F01A-90V-14			
1	20	0.78	71- 200
2	20	0.77	72- 200
3	20	0.76	65- 195
4	20	0.75	67- 193
5	20	0.77	75- 200

Table C-1 (continues) 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
F01A-90V-15			
1	20	0.79	66- 197
2	20	0.80	68- 200
3	20	0.77	63- 193
4	20	0.77	64- 194
5	20	0.76	68- 190
F01A-90V-16			
1	20	0.83	32- 184
2	20	0.86	24- 189
3	20	0.79	24- 171
4	20	0.87	32- 191
5	20	0.78	21- 170
F01A-90V-17			
1	20	0.72	53- 182
2	20	0.78	60- 200
3	20	0.74	54- 192
4	20	0.78	51- 200
5	20	0.78	60- 200
F01A-90V-18			
1	20	0.87	48- 200
2	20	0.86	34- 200
3	20	0.81	27- 185
4	20	0.74	32- 171
5	20	0.86	42- 200
F01A-90V-19			
1	20	0.82	28- 200
2	20	0.79	25- 194
3	20	0.77	39- 190
4	20	0.81	29- 200
5	20	0.81	65- 200
F01A-90V-20			
1	20	0.83	76- 196
2	20	0.83	85- 200
3	20	0.84	86- 200
4	20	0.82	83- 197
5	20	0.82	88- 196
F01A-90V-21			
1	20	0.86	52- 200
2	20	0.84	35- 196
3	20	0.86	17- 200
4	20	0.87	40- 200
5	20	0.82	34- 190

Table C-1 (continues) 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
F01A-90V-22			
1	20	0.83	55- 198
2	20	0.83	67- 200
3	20	0.82	60- 200
4	20	0.82	55- 200
5	20	0.82	56- 200
F01A-90V-23			
1	20	0.74	86- 195
2	20	0.76	93- 200
3	20	0.75	94- 198
4	20	0.74	97- 197
5	20	0.75	100- 200
F01A-90V-24			
1	20	0.77	84- 200
2	20	0.77	83- 200
3	20	0.76	86- 199
4	20	0.74	78- 191
5	20	0.72	82- 186
F01A-90V-25			
1	20	0.79	45- 191
2	20	0.82	85- 200
3	20	0.82	75- 200
4	20	0.81	45- 196
5	20	0.82	61- 199
F01A-90V-26			
1	20	0.84	33- 200
2	20	0.84	31- 200
3	20	0.77	51- 182
4	20	0.84	33- 200
5	20	0.82	58- 198

Table C-2 Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 50 °C

Measurement number	Total time(s)	Total/Char. Time	Points
F01A-90V-11			
1	20	0.79	66- 197
2	20	0.80	68- 200
3	20	0.77	63- 193
4	20	0.77	64- 194
5	20	0.76	68- 190
F01A-90V-12			
1	20	0.86	52- 192
2	20	0.83	32- 184
3	20	0.86	24- 189
4	20	0.79	24- 171
5	20	0.87	32- 191
F01A-90V-13			
1	20	0.72	53- 182
2	20	0.78	60- 200
3	20	0.74	54- 192
4	20	0.78	51- 200
5	20	0.78	60- 200
F01A-90V-14			
1	20	0.87	48- 200
2	20	0.86	34- 200
3	20	0.81	27- 185
4	20	0.74	32- 171
5	20	0.86	42- 200
F01A-90V-15			
1	20	0.82	28- 200
2	20	0.79	25- 194
3	20	0.77	39- 190
4	20	0.81	29- 200
5	20	0.81	65- 200
F01A-90V-16			
1	20	0.83	76- 196
2	20	0.83	85- 200
3	20	0.84	86- 200
4	20	0.82	83- 197
5	20	0.82	88- 196
F01A-90V-17			
1	20	0.86	52- 200
2	20	0.84	35- 196
3	20	0.86	17- 200
4	20	0.87	40- 200
5	20	0.82	34- 190

Table C-2 (continues) Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 50 °C.

Measurement number	Total time(s)	Total/Char. Time	Points
F01A-90V-18			
1	20	0.76	66- 197
2	20	0.78	68- 200
3	20	0.75	63- 193
4	20	0.79	64- 194
5	20	0.79	68- 190
F01A-90V-19			
1	20	0.74	52- 192
2	20	0.76	32- 184
3	20	0.76	24- 189
4	20	0.75	24- 171
5	20	0.75	32- 191
F01A-90V-20			
1	20	0.76	53- 182
2	20	0.76	60- 200
3	20	0.75	54- 192
4	20	0.73	51- 200
5	20	0.76	60- 200

Table C-3 Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 80 °C

Measurement number	Total time(s)	Total/Char. Time	Points
F01A-90V-11			
1	20	0.65	76- 195
2	20	0.64	97- 200
3	20	0.65	49- 200
4	20	0.65	49- 200
5	20	0.64	88- 200
F01A-90V-12			
1	20	0.62	93- 200
2	20	0.60	82- 198
3	20	0.61	95- 200
4	20	0.61	95- 200
5	20	0.64	86- 200
F01A-90V-13			
1	20	0.70	93- 200
2	20	0.68	54- 200
3	20	0.69	33- 200
4	20	0.68	37- 200
5	20	0.67	90- 200
F01A-90V-14			
1	20	0.62	33- 188
2	20	0.66	34- 200
3	20	0.61	39- 183
4	20	0.65	60- 200
5	20	0.65	56- 200
F01A-90V-15			
1	20	0.62	101- 200
2	20	0.59	75- 186
3	20	0.65	77- 200
4	20	0.63	90- 200
5	20	0.63	85- 200
F01A-90V-16			
1	20	0.64	72- 193
2	20	0.68	29- 199
3	20	0.64	99- 200
4	20	0.63	106- 200
5	20	0.65	95- 200
F01A-90V-17			
1	20	0.62	63- 200
2	20	0.49	25- 157
3	20	0.62	79- 200
4	20	0.62	66- 200
5	20	0.62	69- 200

Table C-3 (continues) Total time of measurement, ratio of total time and characteristic time, and number of analysed points at 80 °C.

Measurement number	Total time(s)	Total/Char. Time	Points
F01A-90V-18			
1	20	0.68	66- 198
2	20	0.71	80- 200
3	20	0.68	68- 193
4	20	0.70	77- 200
5	20	0.70	70- 200
F01A-90V-19			
1	20	0.67	73- 200
2	20	0.67	71- 200
3	20	0.65	99- 200
4	20	0.64	92- 197
5	20	0.63	79- 197
F01A-90V-20			
1	20	0.68	73- 192
2	20	0.68	62- 193
3	20	0.70	79- 200
4	20	0.66	79- 188
5	20	0.66	72- 186