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Oskarshamn site investigation

Drill hole KSH02

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

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March 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 fifteen specimens of drill hole KSH02, Oskarshamn, were measured at ambient and elevated temperature. The rock type of all samples is Fine-grained dioritoid The mineralogical content was determined by using modal analysis.

The determination of the thermal properties are 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 greater than on the conductivity. Thermal conductivity and thermal diffusivity of specimens at different depth at 20°C were in the range of 2.51–3.16 W/(m, K) and 1.12–1.41 mm^2/s respectively. At 80°C, thermal conductivity and thermal diffusivity of specimens were in the range of 2.75–3.09 W/(m, K) and 1.06–1.19 mm^2/s respectively.

Contents

1 Introduction

The objective of this investigation was to measure thermal properties of borehole KSH02, Oskarshamn, 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 properties. 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 follows the activity plan AP PS 400-03-090 (SKB internal controlling document) and is controlled by SP-QD 13.1 (SP quality document).

The samples were water saturated and stored in this condition for 7 days. This yields complete water saturation whereupon the density and the thermal properties were determined. The specimens were photographed when measuring was completed.

Modal analyses, based on point counting using a polarising microscope were performed on 7 specimens that were sampled on the same level as the specimens for thermal properties.

The rock cores arrived to SP in September 2003. The testing was performed during January–February, 2004.

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

Modal analyses are performed according to SKB MD 160.001, version 1.9 (SKB internal controlling document) and BMm-P54 (SP quality document).

Figure 1-1. *Map of Oskarshamn site.*

2 Objective and scope

The purpose of the testing is to determine the thermal properties of rock specimens. The properties are used in the rock thermal model, which will be established for the candidate area selected for site investigations at Oskarshamn.

The samples are from the borehole KSH02 in Oskarshamn. The specimens were sampled on four levels in the drill hole: 320 m, 610 m, and 800 m. The investigated rock type is mapped as Fine–grained dioritoid.

3 Equipment

Technical devices for determination of thermal properties used 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.

More information about the design of the water bath is given in /3/. Specimen mounting is shown in Figure 3-2.

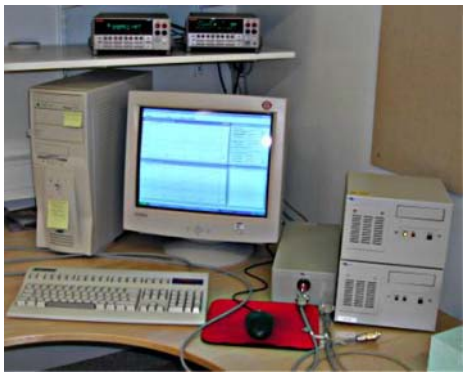

Figure 3-1. *TPS-apparatus with source meter, multi-meter, bridge, and computer.*

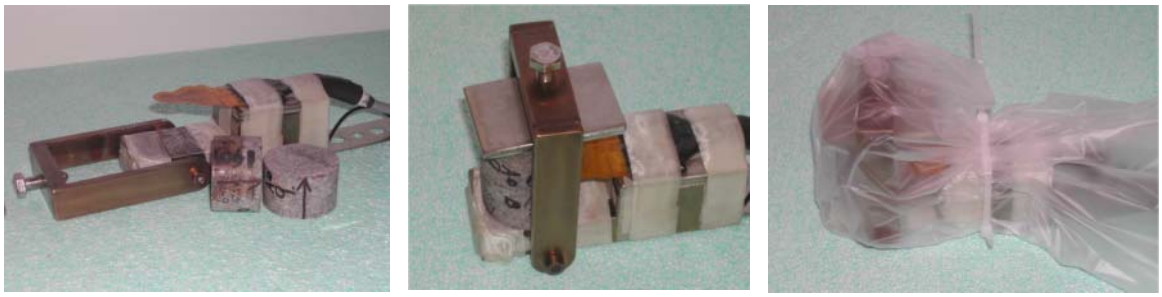

Figure 3-2. *Specimens prior to mounting (left), mounted in stainless sample holder (middle), and sample holder with mounted specimens wrapped in plastic (right).*

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

- Leitz Orthoplan optical microscope (inv nr 100276).

4 Execution

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

Density was determined in accordance to SKB MD 160.002, version 1.9 (SKB internal controlling document) and ISRM /4/. Modal analysis was determined in according to SKB MD 160.001, version 1.9 (SKB internal controlling document) and Chayes /5/, Streckeisen /6,7,8,9/, Le Maitre /10/, Le Bas and Streckeisen /11/ and Sigmond and Gjelle /12/ at the department of Building Technology at SP.

4.1 Description of the samples

Eighteen cores were sampled from three levels of drill hole KSH02, Oskarshamn, Sweden. The first level was between 310 and 323, the second level was between 608 m and 610 m, and the third level between 791m and 804 m. The thirty-six specimens, with a thickness of 25 mm each were sampled from the samples at SP, see Figure 3-2. The diameter of the specimens was 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 KSH02 and in the SICADA database (FN 161) at SKB.

Shortened sample identification S02A-90V has been used through out the report.

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

Identification	Rock type	Sampling depth (Sec low)
KSH02-90V-1	Fine–grained dioritoid	311.03
KSH02-90V-2	Fine–grained dioritoid	311.31
KSH02-90V-3	Fine–grained dioritoid	320.66
KSH02-90V-4	Fine–grained dioritoid	321.04
KSH02-90V-5	Fine–grained dioritoid	323.04
KSH02-90V-7	Fine–grained dioritoid	609.68
KSH02-90V-8	Fine–grained dioritoid	609.76
KSH02-90V-9	Fine–grained dioritoid	609.94
KSH02-90V-10	Fine–grained dioritoid	610.12
KSH02-90V-11	Fine–grained dioritoid	610.20
KSH02-90V-13	Fine–grained dioritoid	791.56
KSH02-90V-14	Fine–grained dioritoid	792.84
KSH02-90V-15	Fine–grained dioritoid	793.31
KSH02-90V-16	Fine–grained dioritoid	794.53
KSH02-90V-17	Fine–grained dioritoid	802.17

4.2 Test Procedure

4.2.1 Thermal properties

The following steps were performed:

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

Thermal properties of water-saturated specimens were measured in ambient air (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. These stored files were sent to SKB catalogue at SP network. Further calculations of mean values and standard deviations were performed in the same catalogue.

Thermal properties, density and porosity measurements were performed during February 2004.

Dry weight was measured after the specimens had been dried to constant mass according to ISMR /4/ at 105°C. The drying procedure took seven days.

4.2.2 Modal analysis

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

The analysis was performed 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 (FN 161) at SKB. 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 S02A-90V-01

Figure 5-1. *Specimens S02A-90V-01.*

Table 5-1. Porosity, wet and dry density of specimens S02A-90V-01, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-01			
Sec low: 311.03	2781	2779	0.21

Table 5-2. Thermal properties of sample S02A-90V-01.

S02A-90V-01 Sec low: 311.03	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.75	1.19	2.32
Standard deviation	0.007	0.003	0.013

Sample S02A-90V-02

Figure 5-2. *Specimens S02A-90V-02.*

Table 5-3. Porosity, wet and dry density of specimens S02A-90V-02, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-02			
Sec low: 311.31	2773	2770	0.27

Table 5-4. Thermal properties of sample S02A-90V-02.

S02A-90V-02 Sec low: 311.31	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.81	1.21	2.32
Standard deviation	0.005	0.009	0.019

Sample S02A-90V-03

Figure 5-3 Specimens S02A-90V-03

Table 5-5. Porosity, wet and dry density of specimens S02A-90V-03, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-03			
Sec low: 320.66	2773	2769	0.35

Table 5-6. Thermal properties of sample S02A-90V-03.

S02A-90V-03 Sec low: 320.66	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.76	1.21	2.28
Standard deviation	0.002	0.004	0.010

Sample S02A-90V-04

Figure 5-4. *Specimens S02A-90V-04.*

Table 5-7. Porosity, wet and dry density of specimens S02A-90V-04, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-04			
Sec low: 321.04	2781	2779	0.28

Table 5-8. Thermal properties of sample S02A-90V-04.

S02A-90V-04 Sec low: 321.04	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.63	1.22	2.15
Standard deviation	0.004	0.005	0.009

Sample S02A-90V-05

Figure 5-5. *Specimens S02A-90V-05.*

Table 5-9. Porosity, wet and dry density of specimens S02A-90V-05, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-05			
Sec low: 323.04	2764	2761	0.29

Table 5-10. Thermal properties of sample S02A-90V-05.

S02A-90V-05 Sec low: 323.04	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	3.02	1.41	2.14
Standard deviation	0.008	0.009	0.014

Sample S02A-90V-07

Figure 5-6. *Specimens S02A-90V-07.*

Table 5-11. Porosity, wet and dry density of specimens S02A-90V-07, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-07			
Sec low: 609.68	2773	2769	0.40

Table 5-12. Thermal properties of sample S02A-90V-07 at different temperatures.

S02A-90V-07 Sec low: 609.68	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	3.01	1.35	2.23
Standard deviation	0.013	0.010	0.027
50°C			
Mean value	3.00	1.23	2.45
Standard deviation	0.002	0.001	0.002
80°C			
Mean value	2.96	1.13	2.61
Standard deviation	0.008	0.003	0.001

Sample S02A-90V-08

Figure 5-7. *Specimens S02A-90V-08.*

Table 5-13. Porosity, wet and dry density of specimens S02A-90V-08, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-08			
Sec low: 609.76	2760	2757	0.31

Table 5-14. Thermal properties of sample S02A-90V-08 at different temperatures.

S02A-90V-08 Sec low: 609.76	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	3.16	1.41	2.24
Standard deviation	0.010	0.011	0.025
50°C			
Mean value	3.14	1.29	2.43
Standard deviation	0.003	0.009	0.015
80°C			
Mean value	3.09	1.19	2.59
Standard deviation	0.002	0.003	0.007

Sample S02A-90V-09

Figure 5-8. *Specimens S02A-90V-09.*

Table 5-15. Porosity, wet and dry density of specimens S02A-90V-09, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-09			
Sec low: 609.94	2764	2761	0.28

Table 5-16. Thermal properties of sample S02A-90V-09 at different temperatures.

S02A-90V-09 Sec low: 609.94	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.92	1.28	2.29
Standard deviation	0.008	0.008	0.020
50°C			
Mean value	2.90	1.19	2.44
Standard deviation	0.003	0.004	0.011
80°C			
Mean value	2.86	1.10	2.60
Standard deviation	0.006	0.014	0.038

Sample S02A-90V-10

Figure 5-9. *Specimens S02A-90V-10.*

Table 5-17. Porosity, wet and dry density of specimens S02A-90V-10, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-10			
Sec low: 610.12	2762	2756	0.57

Table 5-18. Thermal properties of sample S02A-90V-10 at different temperatures.

S02A-90V-10 Sec low: 610.12	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.83	1.24	2.29
Standard deviation	0.009	0.011	0.027
50°C			
Mean value	2.81	1.13	2.48
Standard deviation	0.003	0.006	0.012
80°C			
Mean value	2.78	1.06	2.62
Standard deviation	0.005	0.005	0.014

Sample S02A-90V-11

Figure 5-10. *Specimens S02A-90V-11.*

Table 5-19. Porosity, wet and dry density of specimens S02A-90V-11, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-11			
Sec low: 610.20	2759	2755	0.42

Table 5-20. Thermal properties of sample S02A-90V-11 at different temperatures.

S02A-90V-11 Sec low: 610.20	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.78	1.28	2.18
Standard deviation	0.009	0.006	0.012
50°C			
Mean value	2.77	1.16	2.38
Standard deviation	0.003	0.004	0.011
80°C			
Mean value	2.75	1.08	2.55
Standard deviation	0.003	0.003	0.008

Sample S02A-90V-13

Figure 5-11. *Specimens S02A-90V-13.*

Table 5-21. Porosity, wet and dry density of specimens S02A-90V-13, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-13			
Sec low: 791.56	2791	2789	0.24

Table 5-22. Thermal properties of sample S02A-90V-13 at different temperatures.

S02A-90V-13 Sec low: 791.56	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.54	1.16	2.18
Standard deviation	0.005	0.008	0.019

Sample S02A-90V-14

Figure 5-12. *Specimens S02A-90V-14.*

Table 5-23. Porosity, wet and dry density of specimens S02A-90V-14, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-14			
Sec low: 792.84	2816	2814	0.15

Table 5-24. Thermal properties of sample S02A-90V-14 at different temperatures.

S02A-90V-14 Sec low: 792.84	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.51	1.12	2.24
Standard deviation	0.003	0.003	0.007

Sample S02A-90V-15

Figure 5-13. *Specimens S02A-90V-15.*

Table 5-25. Porosity, wet and dry density of specimens S02A-90V-15, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-15			
Sec low: 793.31	2816	2814	0.17

Table 5-26. Thermal properties of sample S02A-90V-15 at different temperatures.

S02A-90V-15 Sec low: 793.31	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.56	1.15	2.23
Standard deviation	0.008	0.007	0.019

Sample S02A-90V-16

Figure 5-14. *Specimens S02A-90V-16.*

Table 5-27. Porosity, wet and dry density of specimens S02A-90V-16, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-16			
Sec low: 794.53	2770	2767	0.28

Table 5-28. Thermal properties of sample S02A-90V-16 at different temperatures.

S02A-90V-16 Sec low: 794.53	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.85	1.31	2.17
Standard deviation	0.004	0.005	0.011

Sample S02A-90V-17

Figure 5-15. *Specimens S02A-90V-17.*

Table 5-29. Porosity, wet and dry density of specimens S02A-90V-17, average values.

Sample	Density, wet [kg/m^3]	Density, dry [kg/m^3]	Porosity [%]
S02A-90V-17			
Sec low: 802.17	2775	2773	0.16

Table 5-30. Thermal properties of sample S02A-90V-17 at different temperatures.

S02A-90V-17 Sec low: 802.17	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
20°C			
Mean value	2.58	1.27	2.03
Standard deviation	0.012	0.018	0.037

5.1.2 Results for the entire test series

Table 5-31–Table 5-33 show the mean value of five repeated measurements of the thermal properties. Standard deviation at different temperature levels is shown in Table 5-34–Table 5-36.

Thermal conductivity and thermal diffusivity of specimens at different depth at 20°C were in the range of 2.51–3.16 W/(m, K) and 1.12–1.41 mm^2/s respectively. At 50°C, thermal conductivity and thermal diffusivity of specimens at different depth were in the range of 2.77–3.14 W/(m, K) and 1.13–1.29 mm^2/s respectively and finally at 80°C, thermal conductivity and thermal diffusivity of specimens were in the range of 2.75–3.09 W/(m, K) and 1.06–1.19 mm^2/s respectively.

Table 5-31. Mean value of thermal properties of samples at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
S02A-90V-01	2.75	1.19	2.32
S02A-90V-02	2.81	1.21	2.32
S02A-90V-03	2.76	1.21	2.28
S02A-90V-04	2.63	1.22	2.15
S02A-90V-05	3.02	1.41	2.14
Mean value, level 320	**2.79**	**1.25**	**2.24**
S02A-90V-07	3.01	1.35	2.23
S02A-90V-08	3.16	1.41	2.24
S02A-90V-09	2.92	1.28	2.29
S02A-90V-10	2.83	1.24	2.29
S02A-90V-11	2.78	1.28	2.18
Mean value, level 610	**2.94**	**1.31**	**2.24**
S02A-90V-13	2.54	1.16	2.18
S02A-90V-14	2.51	1.12	2.24
S02A-90V-15	2.56	1.15	2.23
S02A-90V-16	2.85	1.31	2.17
S02A-90V-17	2.58	1.27	2.03
Mean value, level 800	**2.61**	**1.20**	**2.17**

Table 5-32. Mean value of thermal properties of samples at 50°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
S02A-90V-07	3.00	1.23	2.45
S02A-90V-08	3.14	1.29	2.43
S02A-90V-09	2.90	1.19	2.44
S02A-90V-10	2.81	1.13	2.48
S02A-90V-11	2.77	1.16	2.38
Mean value, level 610	**2.92**	**1.20**	**2.43**

Table 5-33. Mean value of thermal properties of samples at 80°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
S02A-90V-07	2.96	1.13	2.61
S02A-90V-08	3.09	1.19	2.59
S02A-90V-09	2.86	1.10	2.60
S02A-90V-10	2.78	1.06	2.62
S02A-90V-11	2.75	1.08	2.55
Mean value, level 610	**2.89**	**1.11**	**2.59**

Table 5-34. Standard deviation of measured values at 20°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
S02A-90V-01	0.007	0.003	0.013
S02A-90V-02	0.005	0.009	0.019
S02A-90V-03	0.002	0.004	0.010
S02A-90V-04	0.004	0.005	0.009
S02A-90V-05	0.008	0.009	0.014
S02A-90V-07	0.013	0.010	0.027
S02A-90V-08	0.010	0.011	0.025
S02A-90V-09	0.008	0.008	0.020
S02A-90V-10	0.009	0.011	0.027
S02A-90V-11	0.009	0.006	0.012
S02A-90V-13	0.005	0.008	0.019
S02A-90V-14	0.003	0.003	0.007
S02A-90V-15	0.008	0.007	0.019
S02A-90V-16	0.004	0.005	0.011
S02A-90V-17	0.012	0.018	0.037

Table 5-35. Standard deviation of measured values at 50°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
S02A-90V-07	0.002	0.001	0.002
S02A-90V-08	0.003	0.009	0.015
S02A-90V-09	0.003	0.004	0.011
S02A-90V-10	0.003	0.006	0.012
S02A-90V-11	0.003	0.004	0.011

Table 5-36. Standard deviation of measured values at 80°C.

Sample identification	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [MJ/(m^3, K)]
S02A-90V-07	0.008	0.003	0.001
S02A-90V-08	0.002	0.003	0.007
S02A-90V-09	0.006	0.014	0.038
S02A-90V-10	0.005	0.005	0.014
S02A-90V-11	0.003	0.003	0.008

5.1.2.1 Graphical presentation of results

Variation of the thermal conductivity and heat capacity in relation to depth of the sampling at different temperatures are shown in Figure 5-16–Figure 5-20.

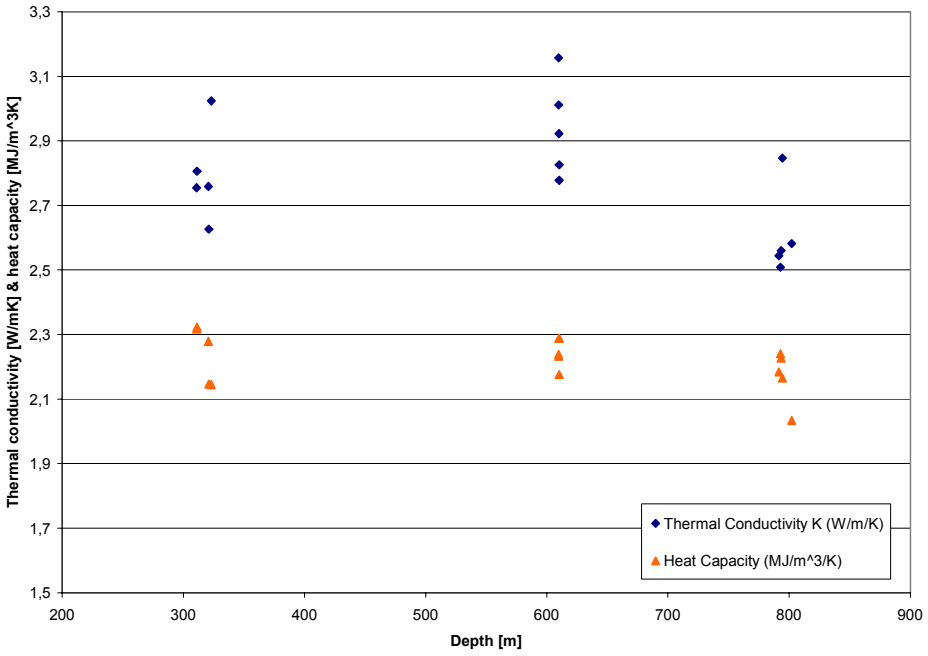

Figure 5-16. *Thermal conductivity and heat capacity at different depth at 20°C.*

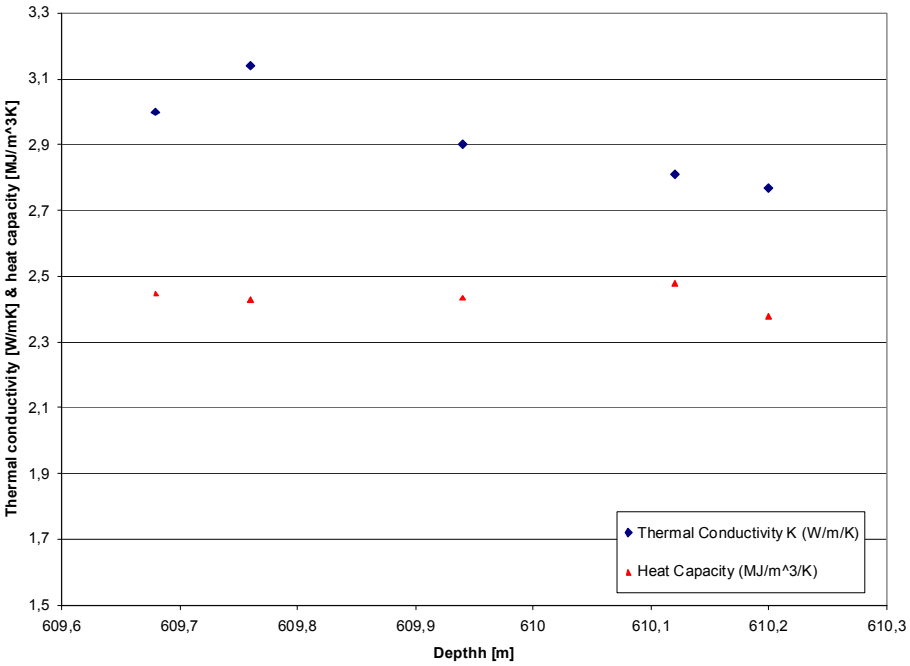

Figure 5-17. *Thermal conductivity and heat capacity at different depth at 50°C.*

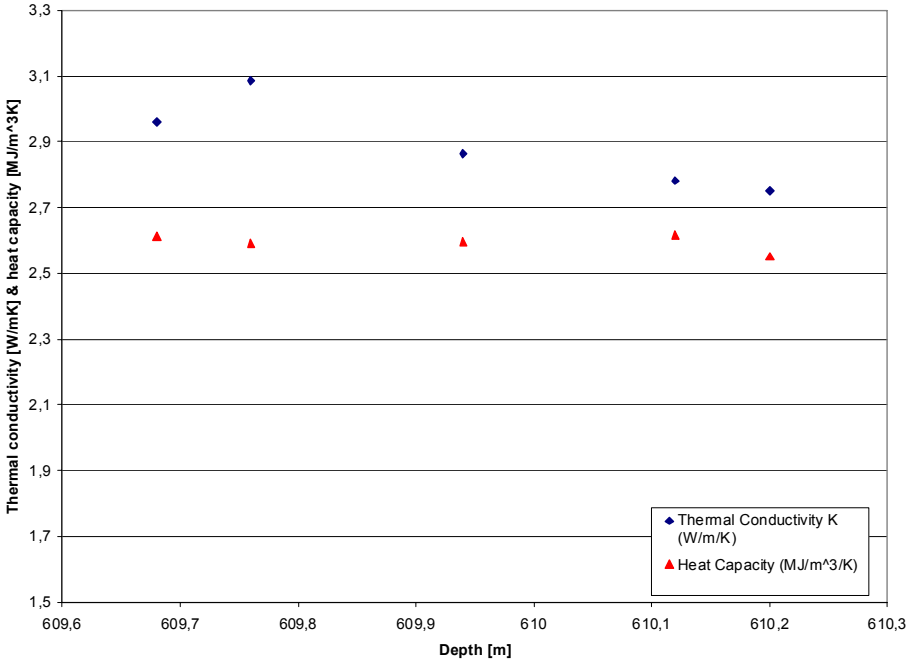

Figure 5-18. *Thermal conductivity and heat capacity at different depth at 80°C.*

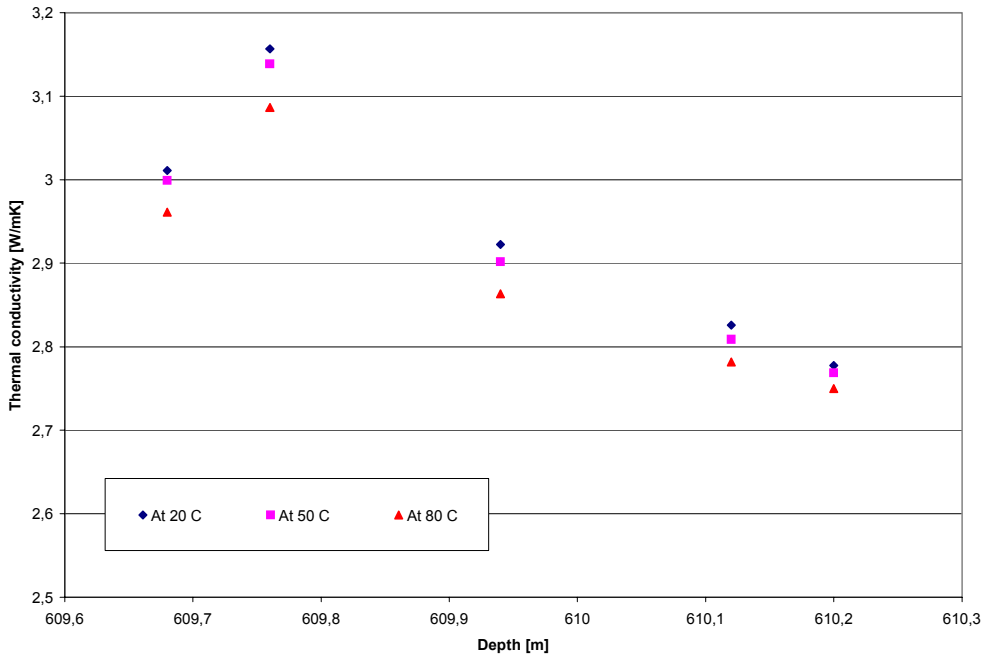

Figure 5-19. *Thermal conductivity at different depth and at different temperatures.*

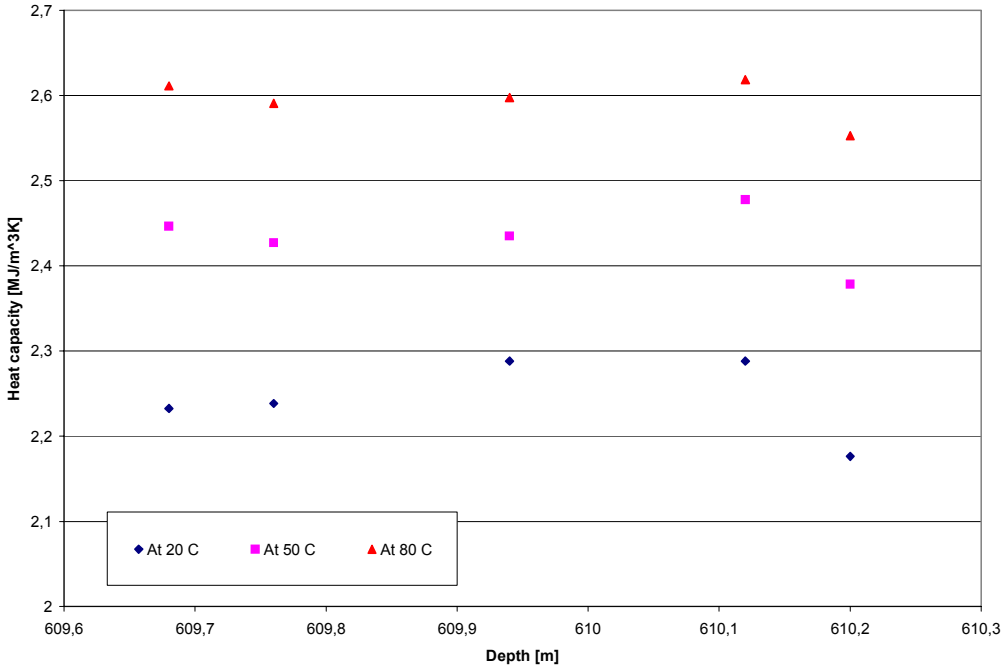

Figure 5-20. *Thermal conductivity at different depth and at different temperatures.*

Maximum variation of thermal conductivity in the temperature range 20°C to 80°C was 2.3% for sample S02A-90V-8 and maximum variation of heat capacity in the same temperature range was about 15% for sample S02A-90V-11.

5.2 Modal analysis

Modal analyses, based on point counting using a polarising microscope were performed on 6 specimens that were sampled on the same level as the specimens for thermal properties (see Sec low in Table 4-1). The modal analyses were done in order to calculate the thermal properties based on the specimen's mineralogical composition. The primary mineralogy are to a large extent altered and the feldspars are to a large extent altered to zoisite and sericite. The latter are mainly composed of muscovite.

Table 5-37. Mineralogical composition (in vol. %) of the investigated specimens from KSH02, 500 points are counted on each specimen.

Identification	Sampling depth (Sec up)	Qtz	Kfs	Pl	Bt	Ch	Amp	Zoi	Ser	Cc	Op
KSH02-200-1	310.93	21	25	26	5	7	1	14	0	0	1
KSH02-200-2	322.94	11	23	21	0.4	9	1	8	22	4	0.4
KSH02-200-3	609.68	19	15	12	0	16	2	7	26	2	1
KSH02-200-4	610.12	20	38	21	11	2	2	3	0	0	3
KSH02-200-5	792.74	17	29	25	6	0	1	2	10	9	0
KSH02-200-6	794.43	22	16	15	18	0	3	5	6	15	0

The mineral mode is based on point counting using a polarising microscope.

Qtz= Quartz, Kfs= K-feldspar, Pl= Plagioclase, Bt= Biotite, Ch=chlorite, Amp=amphibole, Zoi=zoisite, Ser=sericite, Cc=calcite, Op=opaque minerals.

5.3 Discussion

The following deviation to the plans occurred: The specimens were photographed when measuring was completed.

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

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/3/ Adl-Zarrabi, B: "Influence of Moisture transport (Drying) on thermal properties of water saturated samples (Äspö KA2599) obtained by the TPS-Method at high temperature", SP Project no P301248, 2003

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/6/ Streckeisen A: "Classification and Nomenclature of Igneous Rocks". Neues Jahrbuch für Mineralogie 107, pp144-214, 1967

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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:	13.48 W/(m, K)	±0.04%
Thermal Diffusivity:	3.528 mm^2/s	±0.16%
Heat Capacity:	3.955 $MJ/(m^3, K)$	±0.15%

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

Borås 07/01 2004

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 [$MJ/(m^3, K)$]
S02A-90V-01			
1	2.74	1.19	2.30
2	2.76	1.19	2.33
3	2.76	1.19	2.32
4	2.76	1.19	2.32
5	2.76	1.19	2.32
S02A-90V-02			
1	2.80	1.20	2.34
2	2.81	1.21	2.32
3	2.81	1.20	2.35
4	2.80	1.21	2.31
5	2.80	1.22	2.30
S02A-90V-03			
1	2.76	1.21	2.29
2	2.76	1.21	2.27
3	2.76	1.21	2.27
4	2.76	1.21	2.29
5	2.76	1.21	2.27
S02A-90V-04			
1	2.62	1.22	2.15
2	2.63	1.22	2.15
3	2.63	1.22	2.15
4	2.63	1.23	2.13
5	2.63	1.22	2.16
S02A-90V-05			
1	3.01	1.41	2.13
2	3.02	1.40	2.15
3	3.03	1.40	2.16
4	3.03	1.42	2.14
5	3.03	1.41	2.14
S02A-90V-07			
1	3.00	1.36	2.21
2	3.02	1.34	2.26
3	3.02	1.35	2.24
4	3.00	1.36	2.20
5	3.02	1.34	2.26
S02A-90V-08			
1	3.14	1.41	2.22
2	3.17	1.39	2.28
3	3.15	1.42	2.22
4	3.16	1.41	2.23
5	3.16	1.41	2.23

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

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
S02A-90V-09			
1	2.91	1.28	2.27
2	2.92	1.28	2.27
3	2.93	1.26	2.32
4	2.92	1.28	2.29
5	2.92	1.28	2.29
S02A-90V-10			
1	2.81	1.24	2.27
2	2.84	1.22	2.33
3	2.83	1.23	2.30
4	2.82	1.24	2.27
5	2.82	1.24	2.27
S02A-90V-11			
1	2.77	1.28	2.17
2	2.77	1.27	2.18
3	2.78	1.27	2.18
4	2.79	1.27	2.19
5	2.77	1.28	2.17
S02A-90V-13			
1	2.54	1.17	2.17
2	2.55	1.15	2.22
3	2.54	1.16	2.18
4	2.54	1.17	2.18
5	2.54	1.17	2.18
S02A-90V-14			
1	2.50	1.12	2.23
2	2.51	1.11	2.25
3	2.51	1.12	2.24
4	2.51	1.12	2.24
5	2.51	1.12	2.24
S02A-90V-15			
1	2.55	1.15	2.21
2	2.56	1.15	2.24
3	2.55	1.16	2.20
4	2.57	1.14	2.25
5	2.56	1.15	2.23
S02A-90V-16			
1	2.84	1.32	2.15
2	2.84	1.32	2.16
3	2.85	1.31	2.18
4	2.85	1.31	2.17
5	2.85	1.31	2.17
S02A-90V-17			
1	2.57	1.28	2.02
2	2.59	1.26	2.06
3	2.60	1.25	2.08
4	2.58	1.27	2.03
5	2.57	1.29	1.98

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

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
S02A-90V-07			
1	3.00	1.23	2.44
2	3.00	1.23	2.45
3	3.00	1.23	2.45
4	3.00	1.23	2.45
5	3.00	1.23	2.44
F01A-90V-08			
1	3.13	1.29	2.43
2	3.14	1.31	2.40
3	3.14	1.29	2.43
4	3.14	1.29	2.44
5	3.14	1.29	2.43
S02A-90V-09			
1	2.90	1.19	2.43
2	2.90	1.20	2.42
3	2.90	1.19	2.44
4	2.90	1.19	2.44
5	2.91	1.19	2.45
S02A-90V-10			
1	2.80	1.12	2.50
2	2.81	1.13	2.48
3	2.81	1.14	2.47
4	2.81	1.14	2.46
5	2.81	1.14	2.47
S02A-90V-11			
1	2.77	1.16	2.40
2	2.77	1.16	2.38
3	2.77	1.17	2.37
4	2.77	1.17	2.37
5	2.77	1.17	2.37

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

Measurement number	Conductivity [W/(m, K)]	Diffusivity [mm^2/s]	Heat capacity [$MJ/(m^3, K)$]
S02A-90V-07			
1	2.95	1.13	2.61
2	2.96	1.13	2.61
3	2.96	1.13	2.61
4	2.96	1.13	2.61
5	2.97	1.14	2.61
F01A-90V-08			
1	3.09	1.20	2.58
2	3.09	1.19	2.60
3	3.08	1.19	2.60
4	3.09	1.19	2.59
5	3.09	1.19	2.59
S02A-90V-09			
1	2.86	1.09	2.62
2	2.86	1.11	2.59
3	2.86	1.12	2.57
4	2.86	1.12	2.56
5	2.87	1.08	2.65
S02A-90V-10			
1	2.78	1.06	2.61
2	2.78	1.06	2.63
3	2.78	1.07	2.60
4	2.79	1.06	2.64
5	2.78	1.06	2.62
S02A-90V-11			
1	2.75	1.07	2.56
2	2.75	1.08	2.55
3	2.76	1.08	2.56
4	2.75	1.08	2.55
5	2.75	1.08	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
S02A-90V-01			
1	20	0.58	56–200
2	20	0.58	46–200
3	20	0.58	40–200
4	20	0.58	32–200
5	20	0.58	34–200
S02A-90V-02			
1	20	0.58	32–200
2	20	0.59	34–200
3	20	0.58	62–200
4	20	0.59	29–200
5	20	0.59	31–199
S02A-90V-03			
1	20	0.59	37–200
2	20	0.59	27–200
3	20	0.59	38–200
4	20	0.59	31–200
5	20	0.59	36–200
S02A-90V-04			
1	20	0.59	57–200
2	20	0.59	55–200
3	20	0.59	64–200
4	20	0.60	72–200
5	20	0.59	81–200
S02A-90V-05			
1	20	0.69	24–200
2	20	0.68	23–200
3	20	0.68	27–200
4	20	0.69	37–200
5	20	0.69	38–200
S02A-90V-07			
1	20	0.66	64–200
2	20	0.65	77–200
3	20	0.65	82–200
4	20	0.66	80–200
5	20	0.65	78–200
S02A-90V-08			
1	20	0.69	39–200
2	20	0.67	52–200
3	20	0.69	67–200
4	20	0.69	55–200
5	20	0.69	49–200

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

Measurement number	Total time(s)	Total/Char. Time	Points
S02A-90V-09			
1	20	0.62	30–200
2	20	0.62	26–200
3	20	0.61	65–200
4	20	0.62	37–200
5	20	0.62	34–200
S02A-90V-10			
1	20	0.60	53–200
2	20	0.59	68–200
3	20	0.60	50–200
4	20	0.60	41–200
5	20	0.60	41–200
S02A-90V-11			
1	20	0.62	30–200
2	20	0.62	28–200
3	20	0.62	38–200
4	20	0.62	86–200
5	20	0.62	62–200
S02A-90V-13			
1	20	0.57	57–200
2	20	0.56	44–200
3	20	0.57	41–200
4	20	0.57	50–200
5	20	0.57	53–200
S02A-90V-14			
1	20	0.54	72–200
2	20	0.54	41–200
3	20	0.54	67–200
4	20	0.54	63–200
5	20	0.54	47–200
S02A-90V-15			
1	20	0.56	45–200
2	20	0.56	47–200
3	20	0.56	51–200
4	20	0.55	50–200
5	20	0.56	53–200
S02A-90V-16			
1	20	0.64	20–200
2	20	0.64	37–200
3	20	0.64	31–200
4	20	0.64	30–200
5	20	0.64	33–200
S02A-90V-17			
1	20	0.62	104–200
2	20	0.61	95–200
3	20	0.61	95–200
4	20	0.62	93–200
5	20	0.63	101–200

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
S02A-90V-07			
1	20	0.59	61–200
2	20	0.59	55–200
3	20	0.59	53–200
4	20	0.59	65–200
5	20	0.60	62–200
S01A-90V-08			
1	20	0.63	60–200
2	20	0.64	60–200
3	20	0.63	67–200
4	20	0.63	72–200
5	20	0.63	64–200
S02A-90V-09			
1	20	0.58	25–200
2	20	0.58	30–200
3	20	0.58	35–200
4	20	0.58	48–200
5	20	0.58	38–200
S02A-90V-10			
1	20	0.55	28–200
2	20	0.55	45–200
3	20	0.55	47–200
4	20	0.55	35–200
5	20	0.55	45–200
S02A-90V-11			
1	20	0.56	39–200
2	20	0.56	44–200
3	20	0.57	35–200
4	20	0.57	37–200
5	20	0.57	39–200

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
S02A-90V-07			
1	20	0.55	45–200
2	20	0.55	57–200
3	20	0.55	56–200
4	20	0.55	60–200
5	20	0.55	70–200
F01A-90V-08			
1	20	0.58	51–200
2	20	0.58	43–200
3	20	0.58	47–200
4	20	0.58	53–200
5	20	0.58	61–200
S02A-90V-09			
1	20	0.53	39–200
2	20	0.54	31–200
3	20	0.54	24–200
4	20	0.54	29–200
5	20	0.53	78–200
S02A-90V-10			
1	20	0.52	56–200
2	20	0.51	40–200
3	20	0.52	47–200
4	20	0.51	58–200
5	20	0.51	47–198
S02A-90V-11			
1	20	0.52	29–200
2	20	0.52	26–200
3	20	0.52	27–200
4	20	0.52	27–200
5	20	0.52	28–200

More details are available in attached Excel files.