P-05-126

Oskarshamn site investigation

Drill hole KLX05A

Thermal properties: heat conductivity and heat capacity determined using the TPS method

Bijan Adl-Zarrabi
SP Swedish National Testing and Research Institute

September 2005

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

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

Abstract

Thermal properties on twenty-four specimens of drill hole KLX05A, Laxemar, were measured at ambient temperature (20°C). The samples were taken from six levels in the drill hole: 220–245 m, 290–300 m, 340–375 m, 405–420 m, 440–465 m and 495–560 m. The rock types of the samples are granite (501058), Ävrö granite, gabbro, fine-grained diorite and quartz monzodiorite. The determination of the thermal properties are based on a direct measurement method, the so called “Transient Plane Source Method” (TPS), Gustafsson, 1991 /1/.

Thermal conductivity and thermal diffusivity at 20°C were in the range of 2.35–3.65 W/(m, K) and 1.01–1.53 mm^2/s respectively.

Sammanfattning

Termiska egenskaper hos tjugofyra provkroppar från borrhål KLX05A, Laxemar, bestämdes vid rumstemperatur (20 °C). Proverna hade tagits från sex nivåer i borrhålet: 220–245 m, 290–300 m, 340–375 m, 405–420 m, 440–465 m and 495–560 m. De karterade bergarterna är av typen granit (501058), Ävrö granit, gabbro, finkornig dioritoid och kvartsmonzodiorit. TPS-metoden, ”Transient Plane Source”, användes för bestämning av de termiska egenskaperna, Gustafsson 1991 /1/.

Den termiska konduktiviteten och den termiska diffusiviteten hos provkropparna vid 20 °C var 2,35–3,65 W/(m, K) respektive 1,01–1,53 mm^2/s.

Contents

1 Introduction

The objective of this investigation was to measure thermal properties of borehole KLX05A, Laxemar, see Figure 1-1, at ambient temperature (20°C) 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.

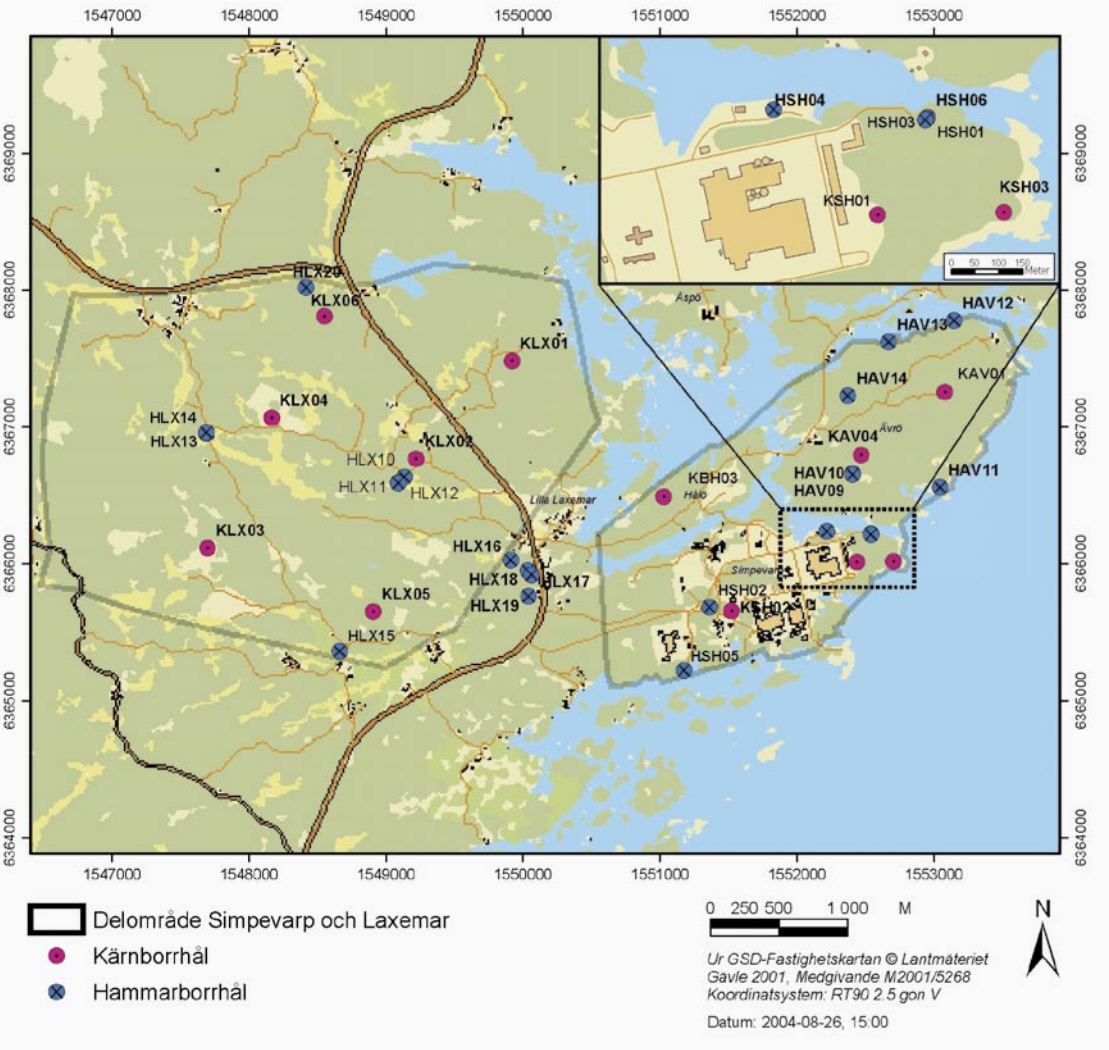

Figure 1-1. *Location of the drill hole KLX05A at the Oskarshamn site investigation area.*

The test programme follows the activity plan AP PS 400–05-028 (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 before testing.

The rock cores arrived to SP in April 2005. The testing was performed during May–June 2005.

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

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 Oskarshamn.

The samples are from the borehole KLX05A in Laxemar. The specimens were sampled from six levels in the drill hole, randomly distributed: 220–245 m, 290–300 m, 340–375 m, 405–420 m, 440–465 m and 495–560 m. The investigated rock type is mapped as granite (501058) (210–290 m), Ävrö granite (290–300 m and 440–460 m), gabbro (340–370 m), fine-grained diorite (410–420 m) and quartz monzodiorite (470–650 m).

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.

Specimen mounting is shown in Figure 3-2.

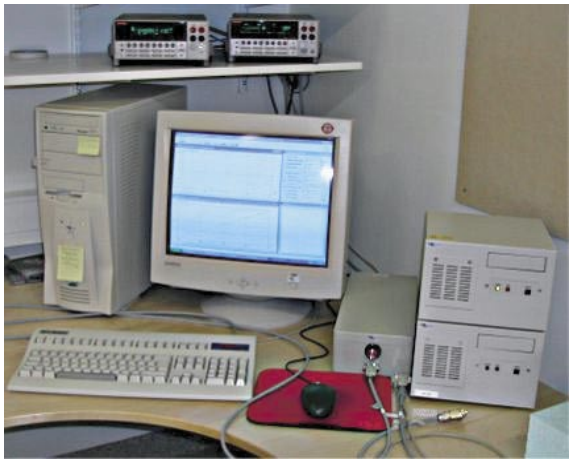

Figure 3-1. *TPS-apparatus with source meter, multi-meter, bridge, and computer.*

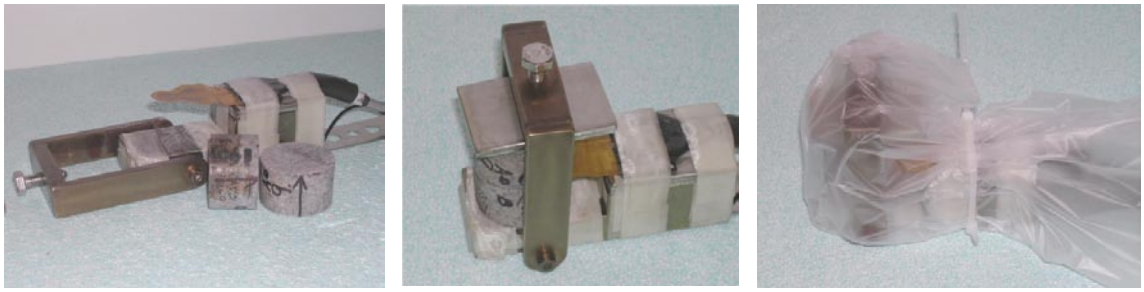

Figure 3-2. *Specimens prior to mounting (left), mounted in stainless sample holder (middle), and sample holder with mounted specimens wrapped in plastic (right).*

4 Execution

Determination of thermal properties was made in accordance to SKB's method description SKB MD 191.001, (SKB internal controlling document) and Hot Disc Instruction Manual /2/ at SGU.

Density was determined in accordance to SKB MD 160.002, (SKB internal controlling document) and ISRM /3/.

4.1 Description of the samples

Twenty-four pairs of cores were sampled from drill hole KLX05A, Laxemar, Sweden. The cores were randomly sampled at the depth of the five rock types: 220–245 m, 290–300 m, 340–375 m, 405–420 m, 440–465 m and 495–560 m. The forty-eight 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 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 KLX05A and in the SICADA database at SKB.

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

Identification	Rock type	Sampling depth (Sec low)
KLX05A-90V-01	Granite (501058)	223.28
KLX05A-90V-02	Granite (501058)	233.50
KLX05A-90V-04	Granite (501058)	243.06
KLX05A-90V-05	Ävrö granite	292.49
KLX05A-90V-07	Ävrö granite	300.62
KLX05A-90V-08	Gabbro	340.71
KLX05A-90V-09	Gabbro	349.56
KLX05A-90V-10	Gabbro	361.31
KLX05A-90V-11	Gabbro	371.73
KLX05A-90V-12	Fine-grained diorite	408.35
KLX05A-90V-13	Fine-grained diorite	413.55
KLX05A-90V-15	Fine-grained diorite	417.47
KLX05A-90V-16	Ävrö granite	444.32
KLX05A-90V-17	Ävrö granite	450.00
KLX05A-90V-18	Ävrö granite	461.23
KLX05A-90V-19	Quartz monzodiorite	495.56
KLX05A-90V-20	Quartz monzodiorite	508.42
KLX05A-90V-21	Quartz monzodiorite	520.67
KLX05A-90V-22	Quartz monzodiorite	530.79
KLX05A-90V-23	Quartz monzodiorite	543.24
KLX05A-90V-24	Quartz monzodiorite	553.42
KLX05A-90V-25	Quartz monzodiorite	565.74
KLX05A-90V-26	Quartz monzodiorite	574.22
KLX05A-90V-27	Quartz monzodiorite	588.09

4.2 Test procedure

4.2.1 Thermal properties

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 (20°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 May–June 2005.

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

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. 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 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.

5.1.1 Test results, sample by sample

Sample KLX05A-90V-01

Figure 5-1. *Specimens KLX05A-90V-01.*

Table 5-1. Porosity, wet and dry density of specimens KLX05A-90V-01, average values.

Sample	Density, wet (kg/m^3)	Density, dry (kg/m^3)	Porosity (%)
KLX05A-90V-01	2,680	2,680	0.4
Sec low: 223.28			

Table 5-2. Thermal properties of sample KLX05A-90V-01 at ambient temperature.

KLX05A-90V-01 Sec low: 223.28	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity (MJ/(m^3, K))
20°C			
Mean value	2.89	1.53	1.89
Standard deviation	0.004	0.003	0.006

Sample KLX05A-90V-02

Figure 5-2. *Specimens KLX05A-90V-02.*

Table 5-3. Porosity, wet and dry density of specimens KLX05A-90V-02, average values.

Sample	Density, wet (kg/m^3)	Density, dry (kg/m^3)	Porosity (%)
KLX05A-90V-02	2,670	2,670	0.4
Sec low: 233.50			

Table 5-4. Thermal properties of sample KLX05A-90V-02 at ambient temperature.

KLX05A-90V-02 Sec low: 233.50	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity (MJ/(m^3, K))
20°C			
Mean value	3.03	1.30	2.33
Standard deviation	0.004	0.009	0.015

Sample KLX05A-90V-04

Figure 5-3. *Specimens KLX05A-90V-04.*

Table 5-5. Porosity, wet and dry density of specimens KLX05A-90V-04, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-04	2,670	2,670	0.4
Sec low: 243.06			

Table 5-6. Thermal properties of sample KLX05A-90V-04 at ambient temperature.

KLX05A-90V-04 Sec low: 243.06	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	3.11	1.36	2.28
Standard deviation	0.004	0.006	0.008

Sample KLX05A-90V-05

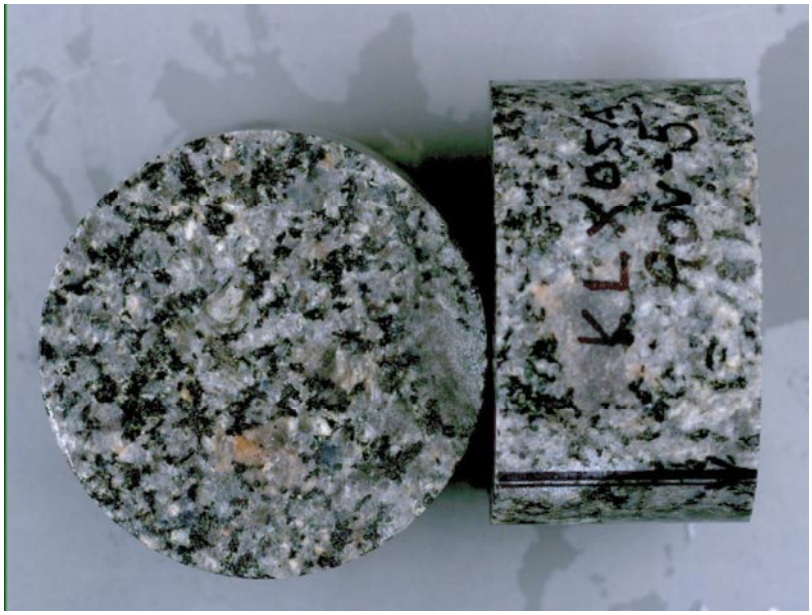

Figure 5-4. *Specimens KLX05A-90V-05.*

Table 5-7. Porosity, wet and dry density of specimens KLX05A-90V-05, average values.

Sample	Density, wet (kg/m^3)	Density, dry (kg/m^3)	Porosity (%)
KLX05A-90V-05	2,720	2,720	0.6
Sec low: 292.49			

Table 5-8. Thermal properties of sample KLX05A-90V-05 at ambient temperature.

KLX05A-90V-05 Sec low: 292.49	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity (MJ/(m^3, K))
20°C			
Mean value	2.38	1.13	2.11
Standard deviation	0.007	0.009	0.022

Sample KLX05A-90V-07

Figure 5-5. *Specimens KLX05A-90V-07.*

Table 5-9. Porosity, wet and dry density of specimens KLX05A-90V-07, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-07	2,720	2,710	0.6
Sec low: 300.62			

Table 5-10. Thermal properties of sample KLX05A-90V-07 at ambient temperature.

KLX05A-90V-07 Sec low: 300.62	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.70	1.07	2.52
Standard deviation	0.007	0.005	0.018

Sample KLX05A-90V-08

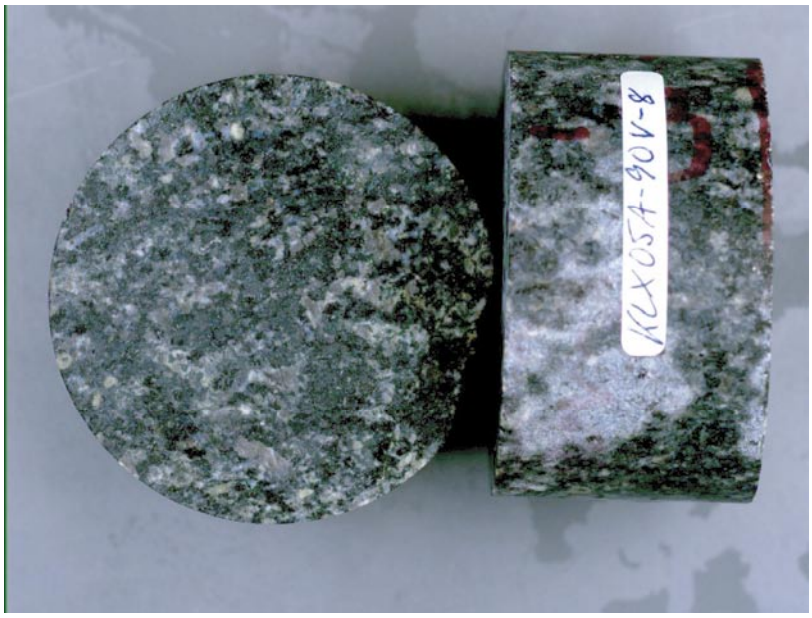

Figure 5-6. *Specimens KLX05A-90V-08.*

Table 5-11. Porosity, wet and dry density of specimens KLX05A-90V-08, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-08	2,910	2,910	0.2
Sec low: 340.71			

Table 5-12. Thermal properties of sample KLX05A-90V-08 at ambient temperature.

KLX05A-90V-08 Sec low: 340.71	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.51	1.08	2.32
Standard deviation	0.002	0.001	0.002

Sample KLX05A-90V-09

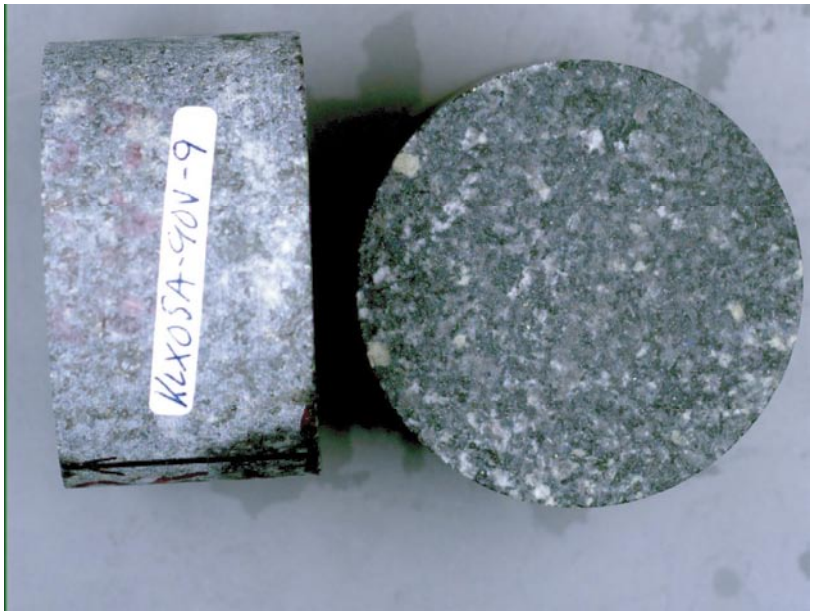

Figure 5-7. *Specimens KLX05A-90V-09.*

Table 5-13. Porosity, wet and dry density of specimens KLX05A-90V-09, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-09	2,910	2,910	0.2
Sec low: 349.56			

Table 5-14. Thermal properties of sample KLX05A-90V-09 at ambient temperature.

KLX05A-90V-09 Sec low: 349.56	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.58	1.06	2.43
Standard deviation	0.001	0.002	0.006

Sample KLX05A-90V-10

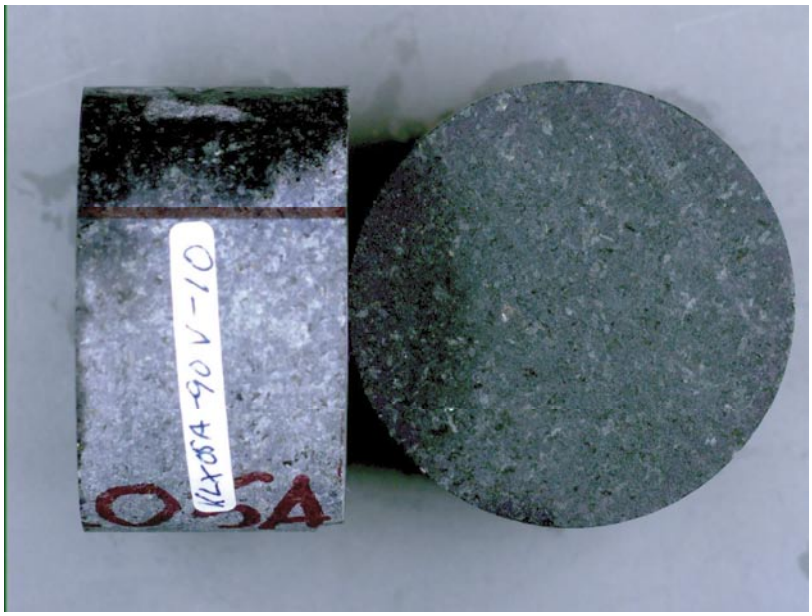

Figure 5-8. *Specimens KLX05A-90V-10.*

Table 5-15. Porosity, wet and dry density of specimens KLX05A-90V-10, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-10	3,020	3,010	0.2
Sec low: 361.31			

Table 5-16. Thermal properties of sample KLX05A-90V-10 at ambient temperature.

KLX05A-90V-10 Sec low: 361.31	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	3.65	1.50	2.43
Standard deviation	0.007	0.009	0.018

Sample KLX05A-90V-11

Figure 5-9. *Specimens KLX05A-90V-11.*

Table 5-17. Porosity, wet and dry density of specimens KLX05A-90V-11, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-11	2,920	2,920	0.2
Sec low: 371.73			

Table 5-18. Thermal properties of sample KLX05A-90V-11 at ambient temperature.

KLX05A-90V-11 Sec low: 371.73	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	3.42	1.30	2.63
Standard deviation	0.006	0.007	0.017

Sample KLX05A-90V-12

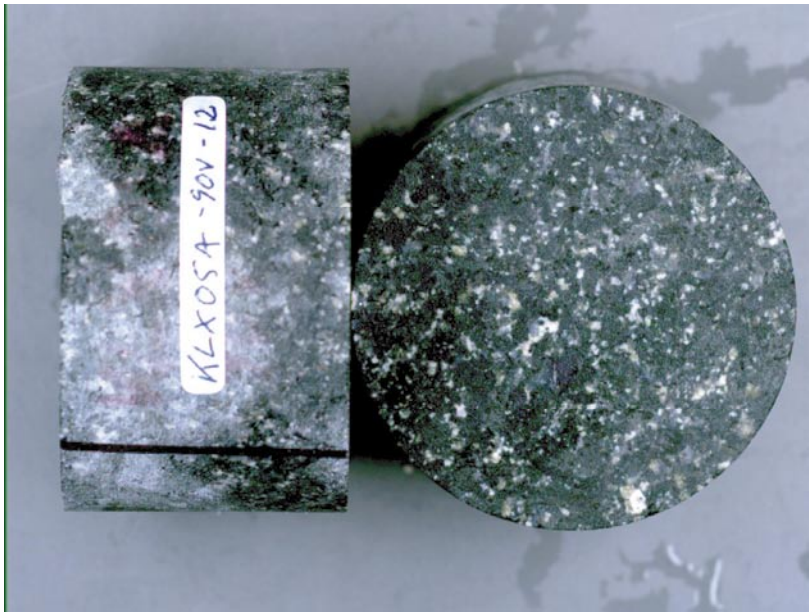

Figure 5-10. *Specimens KLX05A-90V-12.*

Table 5-19. Porosity, wet and dry density of specimens KLX05A-90V-12, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-12	2,960	2,960	0.2
Sec low: 408.35			

Table 5-20. Thermal properties of sample KLX05A-90V-12 at ambient temperature.

KLX05A-90V-12 Sec low: 408.35	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	3.02	1.24	2.43
Standard deviation	0.010	0.009	0.024

Sample KLX05A-90V-13

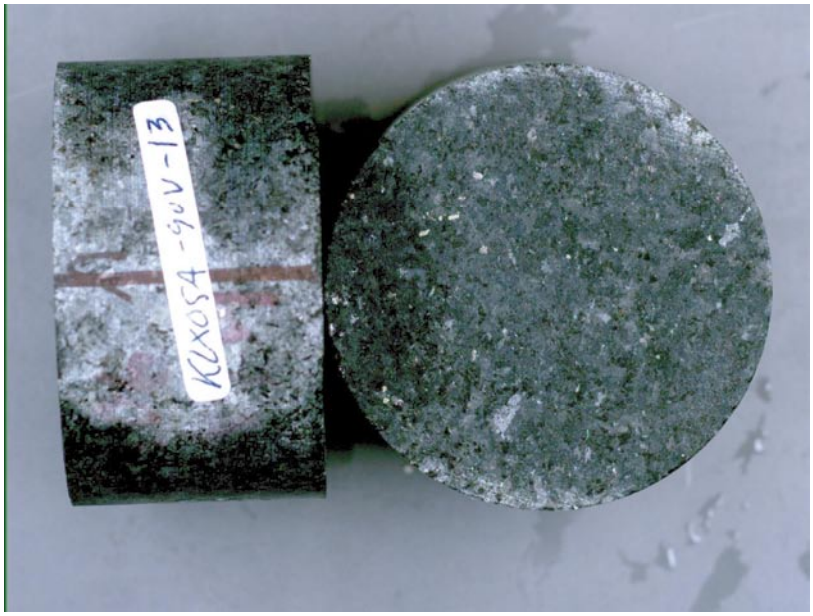

Figure 5-11. *Specimens KLX05A-90V-13.*

Table 5-21. Porosity, wet and dry density of specimens KLX05A-90V-13, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-13	3,010	3,010	0.2
Sec low: 413.55			

Table 5-22. Thermal properties of sample KLX05A-90V-13 at ambient temperature.

KLX05A-90V-13 Sec low: 413.55	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	3.61	1.45	2.49
Standard deviation	0.006	0.014	0.028

Sample KLX05A-90V-15

Figure 5-12. *Specimens KLX05A-90V-15.*

Table 5-23. Porosity, wet and dry density of specimens KLX05A-90V-15, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-15	2,970	2,970	0.3
Sec low: 417.47			

Table 5-24. Thermal properties of sample KLX05A-90V-15 at ambient temperature.

KLX05A-90V-15 Sec low: 417.47	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	3.07	1.16	2.65
Standard deviation	0.010	0.008	0.025

Sample KLX05A-90V-16

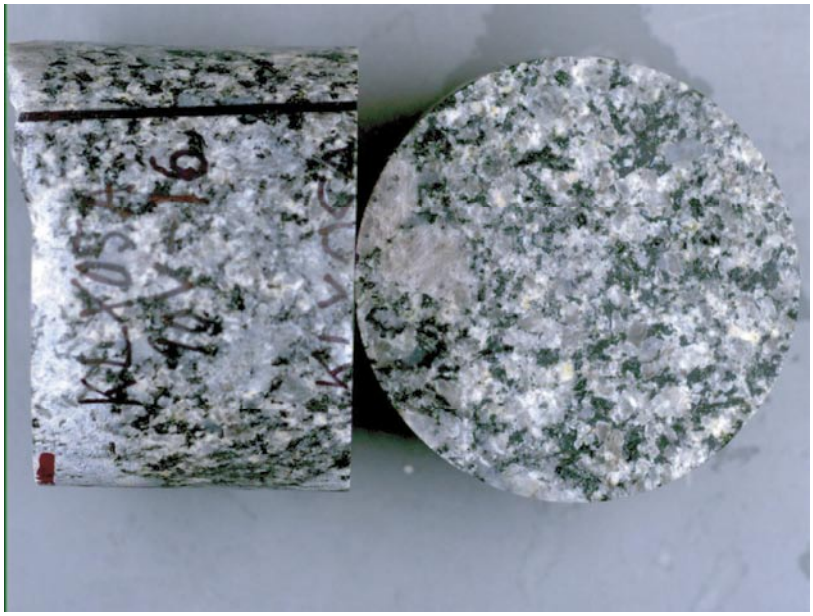

Figure 5-13. *Specimens KLX05A-90V-16.*

Table 5-25. Porosity, wet and dry density of specimens KLX05A-90V-16, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-16	2,740	2,730	0.5
Sec low: 444.32			

Table 5-26. Thermal properties of sample KLX05A-90V-16 at ambient temperature.

KLX05A-90V-16 Sec low: 444.32	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.39	1.14	2.09
Standard deviation	0.005	0.006	0.014

Sample KLX05A-90V-17

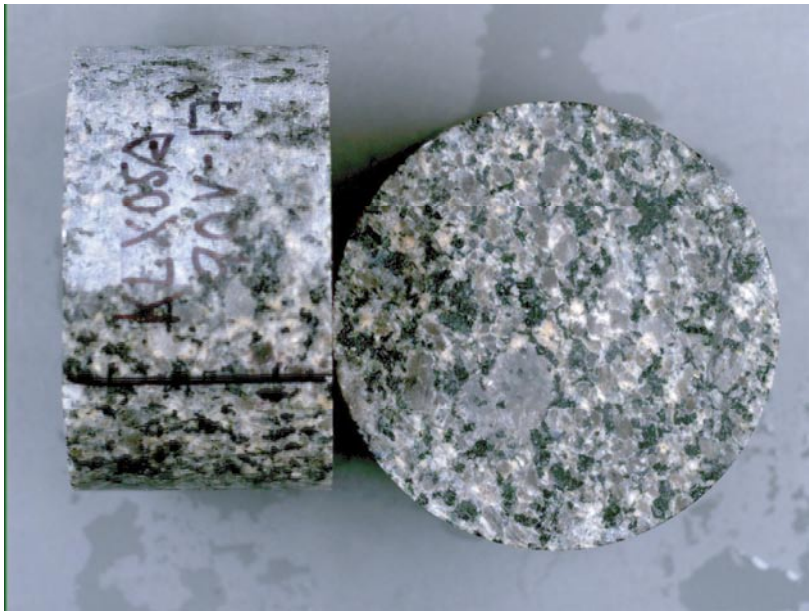

Figure 5-14. *Specimens KLX05A-90V-17.*

Table 5-27. Porosity, wet and dry density of specimens KLX05A-90V-17, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-17	2,750	2,740	0.4
Sec low: 450.00			

Table 5-28. Thermal properties of sample KLX05A-90V-17 at ambient temperature.

KLX05A-90V-17 Sec low: 450.00	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.39	1.01	2.36
Standard deviation	0.001	0.004	0.009

Sample KLX05A-90V-18

Figure 5-15. *Specimens KLX05A-90V-18.*

Table 5-29. Porosity, wet and dry density of specimens KLX05A-90V-18, average values.

Sample	Density, wet (kg/m^3)	Density, dry (kg/m^3)	Porosity (%)
KLX05A-90V-18	2,730	2,720	0.4
Sec low: 461.23			

Table 5-30. Thermal properties of sample KLX05A-90V-18 at ambient temperature.

KLX05A-90V-18 Sec low: 461.23	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity (MJ/(m^3, K))
20°C			
Mean value	2.35	1.06	2.22
Standard deviation	0.002	0.005	0.011

Sample KLX05A-90V-19

Figure 5-16. *Specimens KLX05A-90V-19.*

Table 5-31. Porosity, wet and dry density of specimens KLX05A-90V-19, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-19	2,900	2,900	0.2
Sec low: 495.56			

Table 5-32. Thermal properties of sample KLX05A-90V-19 at ambient temperature.

KLX05A-90V-19 Sec low: 495.56	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.91	1.12	2.60
Standard deviation	0.010	0.008	0.024

Sample KLX05A-90V-20

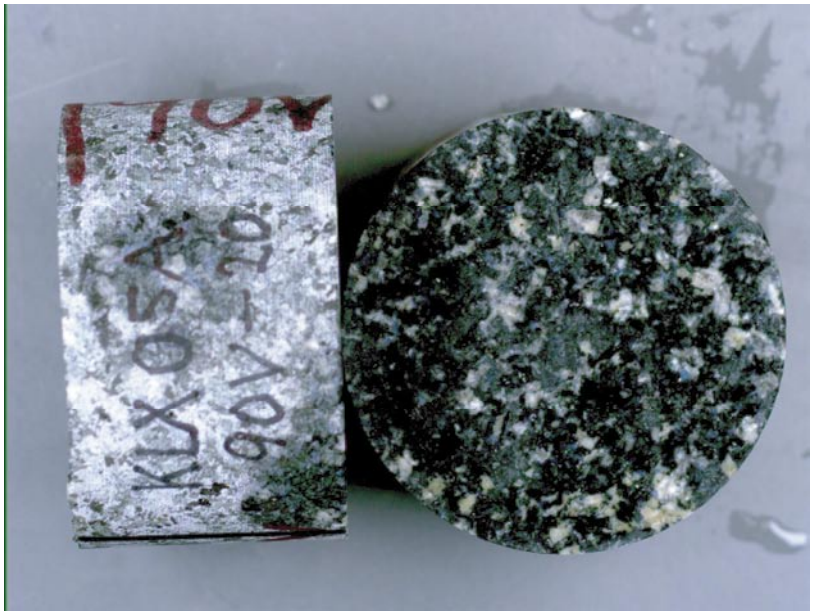

Figure 5-17. *Specimens KLX05A-90V-20.*

Table 5-33. Porosity, wet and dry density of specimens KLX05A-90V-20, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-20	2,890	2,880	0.1
Sec low: 508.42			

Table 5-34. Thermal properties of sample KLX05A-90V-20 at ambient temperature.

KLX05A-90V-20 Sec low: 508.42	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.76	1.20	2.31
Standard deviation	0.004	0.011	0.025

Sample KLX05A-90V-21

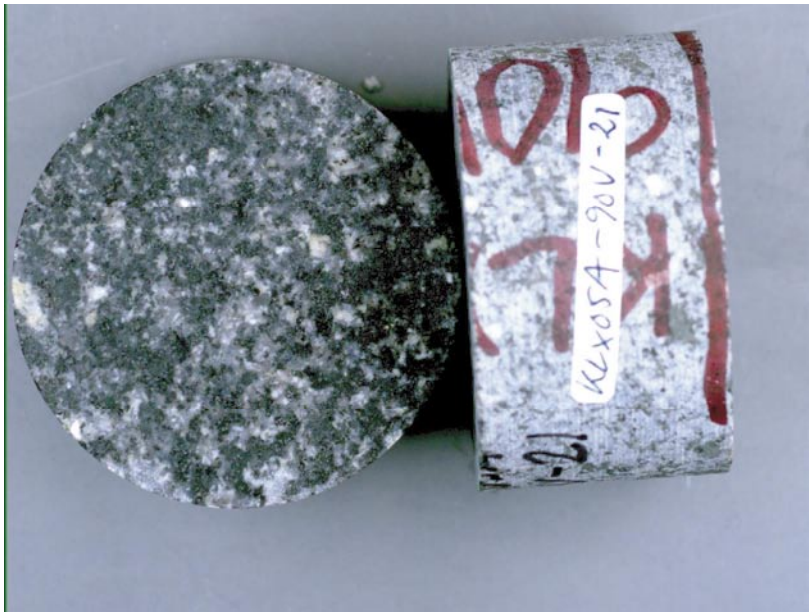

Figure 5-18. *Specimens KLX05A-90V-21.*

Table 5-35. Porosity, wet and dry density of specimens KLX05A-90V-21, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-21	2,790	2,790	0.2
Sec low: 520.67			

Table 5-36. Thermal properties of sample KLX05A-90V-21 at ambient temperature.

KLX05A-90V-21 Sec low: 520.67	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.77	1.24	2.23
Standard deviation	0.005	0.009	0.018

Sample KLX05A-90V-22

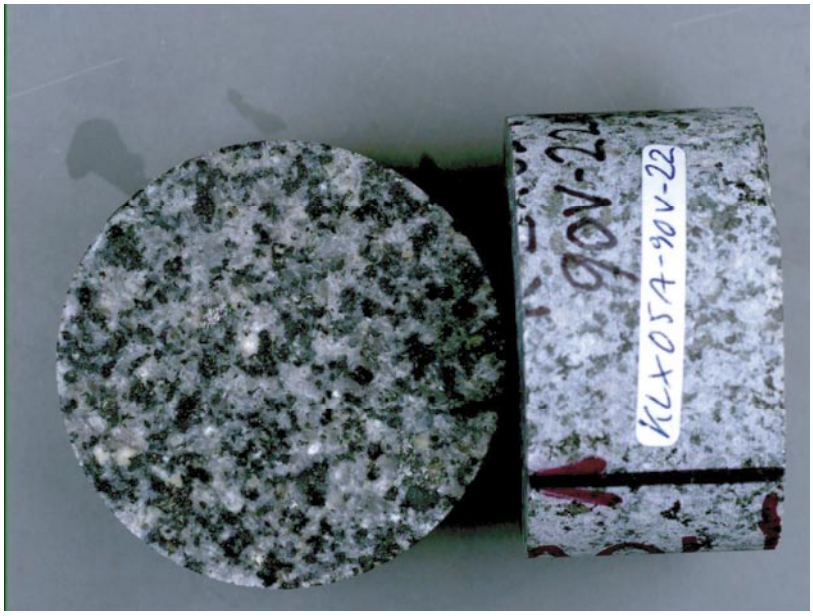

Figure 5-19. *Specimens KLX05A-90V-22.*

Table 5-37. Porosity, wet and dry density of specimens KLX05A-90V-22, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-22	2,780	2,780	0.2
Sec low: 530.79			

Table 5-38. Thermal properties of sample KLX05A-90V-22 at ambient temperature.

KLX05A-90V-22 Sec low: 530.79	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.74	1.26	2.18
Standard deviation	0.013	0.015	0.030

Sample KLX05A-90V-23

Figure 5-20. *Specimens KLX05A-90V-23.*

Table 5-39. Porosity, wet and dry density of specimens KLX05A-90V-23, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-23	2,780	2,770	0.2
Sec low: 543.24			

Table 5-40. Thermal properties of sample KLX05A-90V-23 at ambient temperature.

KLX05A-90V-23 Sec low: 543.24	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.68	1.12	2.39
Standard deviation	0.006	0.012	0.030

Sample KLX05A-90V-24

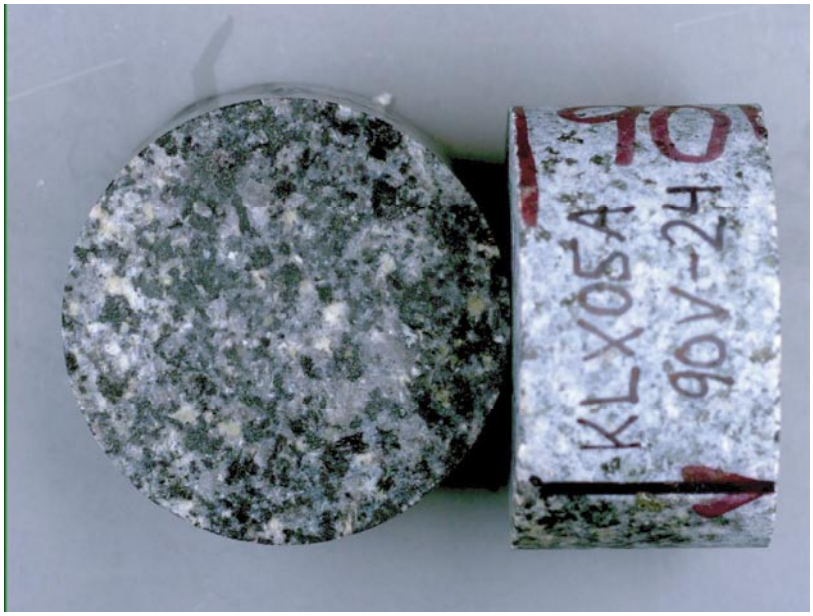

Figure 5-21. *Specimens KLX05A-90V-24.*

Table 5-41. Porosity, wet and dry density of specimens KLX05A-90V-24, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-24	2,780	2,780	0.3
Sec low: 553.42			

Table 5-42. Thermal properties of sample KLX05A-90V-24 at ambient temperature.

KLX05A-90V-24 Sec low: 553.42	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.64	1.22	2.17
Standard deviation	0.008	0.014	0.028

Sample KLX05A-90V-25

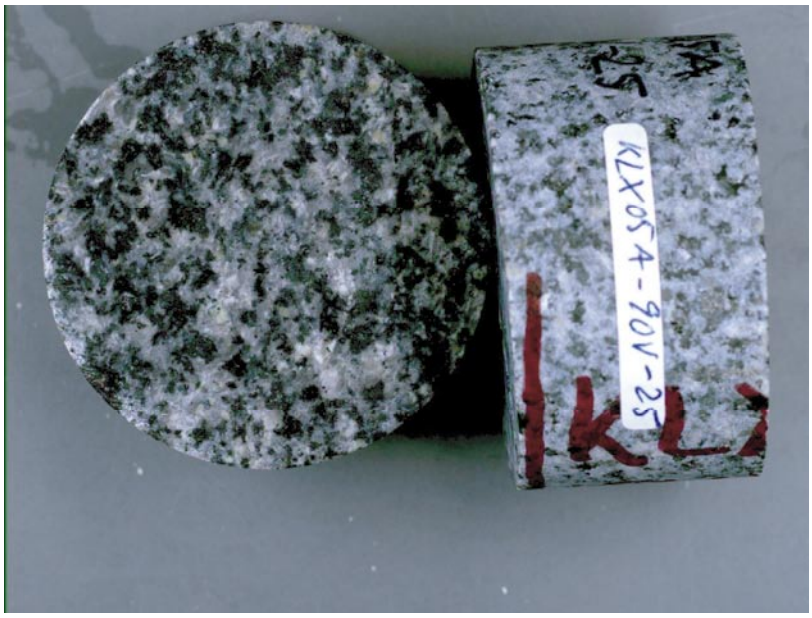

Figure 5-22. *Specimens KLX05A-90V-25.*

Table 5-43. Porosity, wet and dry density of specimens KLX05A-90V-25, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-25	2,780	2,770	0.4
Sec low: 565.74			

Table 5-44. Thermal properties of sample KLX05A-90V-25 at ambient temperature.

KLX05A-90V-25 Sec low: 565.74	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.76	1.16	2.39
Standard deviation	0.002	0.002	0.005

Sample KLX05A-90V-26

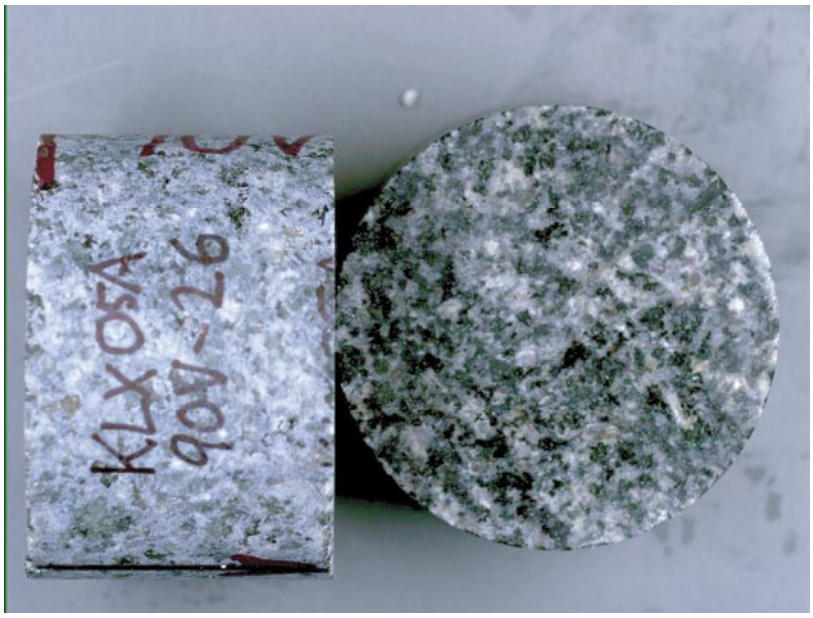

Figure 5-23. *Specimens KLX05A-90V-26.*

Table 5-45. Porosity, wet and dry density of specimens KLX05A-90V-26, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-26	2,780	2,780	0.3
Sec low: 574.22			

Table 5-46. Thermal properties of sample KLX05A-90V-26 at ambient temperature.

KLX05A-90V-26 Sec low: 574.22	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.68	1.24	2.17
Standard deviation	0.002	0.008	0.015

Sample KLX05A-90V-27

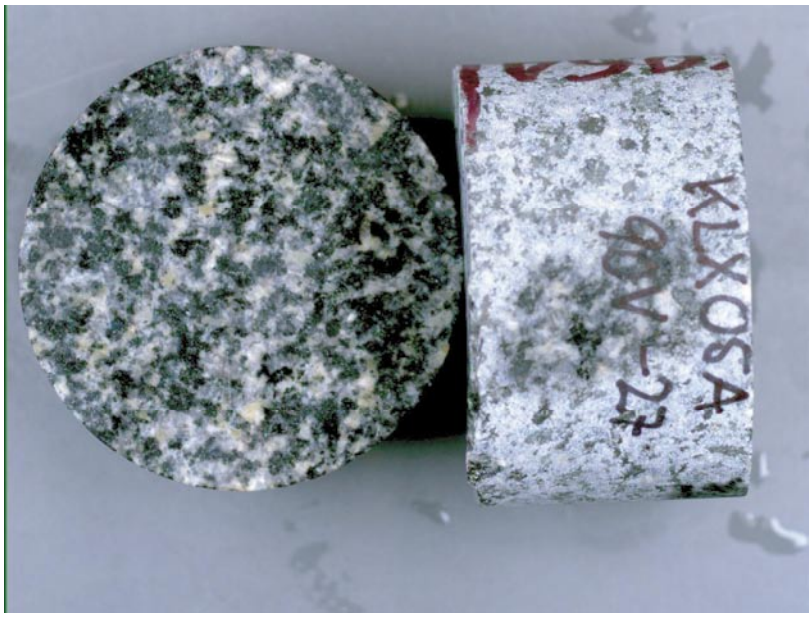

Figure 5-24. *Specimens KLX05A-90V-27.*

Table 5-47. Porosity, wet and dry density of specimens KLX05A-90V-27, average values.

Sample	Density, wet (kg/m³)	Density, dry (kg/m³)	Porosity (%)
KLX05A-90V-27	2,800	2,790	0.3
Sec low: 588.09			

Table 5-48. Thermal properties of sample KLX05A-90V-27 at ambient temperature.

KLX05A-90V-27 Sec low: 588.09	Conductivity (W/(m, K))	Diffusivity (mm²/s)	Heat capacity (MJ/(m³, K))
20°C			
Mean value	2.81	1.21	2.32
Standard deviation	0.004	0.005	0.012

5.1.2 Results for the entire test series

Table 5-49 shows the mean value of five repeated measurements of the thermal properties of all samples. The values are grouped level by level. Standard deviation is shown in Table 5-50.

Thermal conductivity and thermal diffusivity of specimens at different depth at 20°C were in the range of 2.35–3.65 W/(m, K) and 1.01–1.53 mm^2/s respectively.

Table 5-49. Value of thermal properties of all samples at 20°C.

Sample identification	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity ($MJ/(m^3, K)$)
Level 210–290 m			
KLX05A-90V-01	2.89	1.53	1.89
KLX05A-90V-02	3.03	1.30	2.33
KLX05A-90V-04	3.11	1.36	2.28
Level 290–300 m			
KLX05A-90V-05	2.38	1.13	2.11
KLX05A-90V-07	2.70	1.07	2.52
Level 340–370 m			
KLX05A-90V-08	2.51	1.08	2.32
KLX05A-90V-09	2.58	1.06	2.43
KLX05A-90V-10	3.65	1.50	2.43
KLX05A-90V-11	3.42	1.30	2.63
Level 410–420 m			
KLX05A-90V-12	3.02	1.24	2.43
KLX05A-90V-13	3.61	1.45	2.49
KLX05A-90V-15	3.07	1.16	2.65
Level 440–460 m			
KLX05A-90V-16	2.39	1.14	2.09
KLX05A-90V-17	2.39	1.01	2.36
KLX05A-90V-18	2.35	1.06	2.22
Level 470–650 m			
KLX05A-90V-19	2.91	1.12	2.60
KLX05A-90V-20	2.76	1.20	2.31
KLX05A-90V-21	2.77	1.24	2.23
KLX05A-90V-22	2.74	1.26	2.18
KLX05A-90V-23	2.68	1.12	2.39
KLX05A-90V-24	2.64	1.22	2.17
KLX05A-90V-25	2.76	1.16	2.39
KLX05A-90V-26	2.68	1.24	2.17
KLX05A-90V-27	2.81	1.21	2.32

Table 5-50. Standard deviation of measured values at 20°C.

Sample identification	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity ($MJ/(m^3, K)$)
KLX05A-90V-01	0.004	0.003	0.006
KLX05A-90V-02	0.004	0.009	0.015
KLX05A-90V-04	0.004	0.006	0.008
KLX05A-90V-05	0.007	0.009	0.022
KLX05A-90V-07	0.007	0.005	0.018
KLX05A-90V-08	0.002	0.001	0.002
KLX05A-90V-09	0.001	0.002	0.006
KLX05A-90V-10	0.007	0.009	0.018
KLX05A-90V-11	0.006	0.007	0.017
KLX05A-90V-12	0.010	0.009	0.024
KLX05A-90V-13	0.006	0.014	0.028
KLX05A-90V-15	0.010	0.008	0.025
KLX05A-90V-16	0.005	0.006	0.014
KLX05A-90V-17	0.001	0.004	0.009
KLX05A-90V-18	0.002	0.005	0.011
KLX05A-90V-19	0.010	0.008	0.024
KLX05A-90V-20	0.004	0.011	0.025
KLX05A-90V-21	0.005	0.009	0.018
KLX05A-90V-22	0.013	0.015	0.030
KLX05A-90V-23	0.006	0.012	0.030
KLX05A-90V-24	0.008	0.014	0.028
KLX05A-90V-25	0.002	0.002	0.005
KLX05A-90V-26	0.002	0.008	0.015
KLX05A-90V-27	0.004	0.005	0.012

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 5-25.

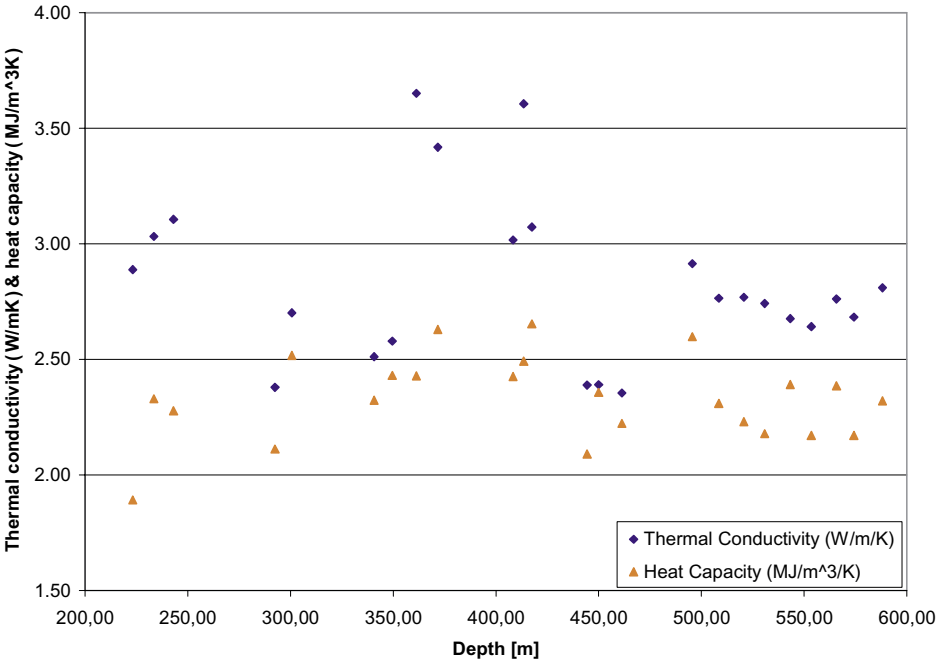

Figure 5-25. *Thermal conductivity and heat capacity at different depth at 20°C.*

5.2 Discussion

The following deviation to the plans occurred:

For sample no 7 the diffusivity and the specific heat in the second measurement deviated substantially from earlier recorded values. Thus it was decided to perform seven measurements instead of the normal number of five. The reported results are from measurements 3–7. For control purposes one additional measurement with another sensor was performed. It showed that the equipment worked well. The data from the additional measurements are available but not reported here.

6 References

/1/ **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.

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

/3/ **ISRM, 1979.** Commission on Testing Methods.

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:	13.44 W/(m, K)	± 0.06%
Thermal Diffusivity:	3,510 mm^2/s	± 0.35%
Heat Capacity:	3,837 $MJ/(m^3, K)$	± 0.36%

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

Borås 25/04 2005

Patrik Nilsson

Appendix B

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

Measurement number	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity ($MJ/(m^3, K)$)
KLX05A-90V-01			
1	2.88	1.53	1.89
2	2.90	1.52	1.90
3	2.89	1.53	1.88
4	2.89	1.53	1.89
5	2.89	1.53	1.89
KLX05A-90V-02			
1	3.04	1.32	2.31
2	3.04	1.29	2.35
3	3.03	1.30	2.33
4	3.03	1.31	2.32
5	3.03	1.30	2.34
KLX05A-90V-04			
1	3.11	1.37	2.27
2	3.11	1.37	2.27
3	3.10	1.36	2.27
4	3.10	1.36	2.28
5	3.10	1.35	2.29
KLX05A-90V-05			
1	2.39	1.11	2.15
2	2.38	1.13	2.11
3	2.37	1.13	2.11
4	2.37	1.13	2.10
5	2.37	1.13	2.10
KLX05A-90V-07			
3	2.71	1.07	2.52
4	2.71	1.07	2.53
5	2.70	1.07	2.52
6	2.69	1.08	2.49
7	2.70	1.07	2.53
KLX05A-90V-08			
1	2.51	1.08	2.32
2	2.51	1.08	2.32
3	2.51	1.08	2.32
4	2.51	1.08	2.32
5	2.51	1.08	2.33

Measurement number	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity ($MJ/(m^3, K)$)
KLX05A-90V-09			
1	2.58	1.06	2.42
2	2.58	1.06	2.43
3	2.58	1.06	2.44
4	2.58	1.06	2.43
5	2.58	1.06	2.44
KLX05A-90V-10			
1	3.66	1.49	2.45
2	3.66	1.50	2.44
3	3.66	1.50	2.43
4	3.64	1.51	2.40
5	3.65	1.51	2.42
KLX05A-90V-11			
1	3.42	1.31	2.62
2	3.42	1.29	2.65
3	3.42	1.29	2.64
4	3.41	1.31	2.61
5	3.42	1.30	2.63
KLX05A-90V-12			
1	3.03	1.24	2.45
2	3.02	1.23	2.45
3	3.01	1.26	2.40
4	3.01	1.25	2.41
5	3.01	1.25	2.42
KLX05A-90V-13			
1	3.61	1.43	2.53
2	3.61	1.44	2.51
3	3.61	1.45	2.49
4	3.60	1.46	2.47
5	3.60	1.46	2.46
KLX05A-90V-15			
1	3.09	1.15	2.68
2	3.08	1.15	2.68
3	3.06	1.16	2.63
4	3.07	1.16	2.64
5	3.07	1.16	2.64

Measurement number	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity ($MJ/(m^3, K)$)
KLX05A-90V-16			
1	2.39	1.14	2.10
2	2.40	1.14	2.11
3	2.39	1.15	2.08
4	2.38	1.15	2.07
5	2.39	1.14	2.09
KLX05A-90V-17			
1	2.39	1.01	2.36
2	2.39	1.01	2.37
3	2.39	1.02	2.35
4	2.39	1.02	2.35
5	2.39	1.02	2.36
KLX05A-90V-18			
1	2.36	1.06	2.21
2	2.35	1.06	2.22
3	2.35	1.06	2.21
4	2.36	1.05	2.24
5	2.36	1.06	2.23
KLX05A-90V-19			
1	2.93	1.11	2.63
2	2.90	1.12	2.60
3	2.91	1.13	2.58
4	2.92	1.12	2.61
5	2.91	1.13	2.57
KLX05A-90V-20			
1	2.76	1.21	2.28
2	2.77	1.19	2.32
3	2.76	1.20	2.30
4	2.77	1.18	2.35
5	2.76	1.20	2.31
KLX05A-90V-21			
1	2.76	1.24	2.23
2	2.76	1.24	2.22
3	2.77	1.25	2.22
4	2.77	1.25	2.22
5	2.78	1.23	2.26

Measurement number	Conductivity (W/(m, K))	Diffusivity (mm^2/s)	Heat capacity ($MJ/(m^3, K)$)
KLX05A-90V-22			
1	2.75	1.24	2.21
2	2.73	1.25	2.19
3	2.75	1.25	2.19
4	2.72	1.28	2.13
5	2.76	1.27	2.17
KLX05A-90V-23			
1	2.68	1.10	2.44
2	2.68	1.12	2.40
3	2.68	1.12	2.39
4	2.67	1.13	2.37
5	2.67	1.13	2.36
KLX05A-90V-24			
1	2.63	1.20	2.20
2	2.65	1.21	2.20
3	2.64	1.22	2.16
4	2.64	1.22	2.16
5	2.63	1.23	2.13
KLX05A-90V-25			
1	2.76	1.16	2.38
2	2.76	1.16	2.39
3	2.76	1.16	2.39
4	2.76	1.16	2.39
5	2.76	1.16	2.38
KLX05A-90V-26			
1	2.69	1.23	2.18
2	2.68	1.24	2.17
3	2.68	1.24	2.17
4	2.69	1.23	2.19
5	2.68	1.25	2.15
KLX05A-90V-27			
1	2.81	1.20	2.34
2	2.81	1.21	2.32
3	2.81	1.21	2.32
4	2.81	1.21	2.31
5	2.80	1.22	2.31

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
KLX05A-90V-01			
1	20	0.74	74–199
2	20	0.74	78–199
3	20	0.74	77–199
4	20	0.74	74–199
5	20	0.74	77–199
KLX05A-90V-02			
1	20	0.64	65–200
2	20	0.63	80–200
3	20	0.60	63–191
4	20	0.61	65–193
5	20	0.63	66–199
KLX05A-90V-04			
1	20	0.64	29–194
2	20	0.64	29–194
3	20	0.60	29–182
4	20	0.62	29–186
5	20	0.64	29–194
KLX05A-90V-05			
1	20	0.54	44–200
2	20	0.55	75–200
3	20	0.55	71–200
4	20	0.55	75–200
5	20	0.55	79–199
KLX05A-90V-07			
3	20	0.52	92–198
4	20	0.51	96–198
5	20	0.52	91–198
6	20	0.52	92–198
7	20	0.51	91–198
KLX05A-90V-08			
1	20	0.51	24–198
2	20	0.51	24–200
3	20	0.51	27–200
4	20	0.51	26–198
5	20	0.51	25–198

Measurement number	Total times)	Total/Char. time	Points
KLX05A-90V-09			
1	20	0.51	24–198
2	20	0.51	24–200
3	20	0.51	27–200
4	20	0.51	26–198
5	20	0.51	25–198
KLX05A-90V-10			
1	20	0.72	29–200
2	20	0.73	25–200
3	20	0.73	33–200
4	20	0.73	25–200
5	20	0.73	22–200
KLX05A-90V-11			
1	20	0.63	91–200
2	20	0.63	97–200
3	20	0.63	92–200
4	20	0.63	93–200
5	20	0.63	90–200
KLX05A-90V-12			
1	20	0.60	61–200
2	20	0.60	61–200
3	20	0.61	61–200
4	20	0.61	61–200
5	20	0.61	61–200
KLX05A-90V-13			
1	20	0.69	20–200
2	20	0.70	20–200
3	20	0.70	20–200
4	20	0.71	20–200
5	20	0.71	20–200
KLX05A-90V-15			
1	20	0.56	61–199
2	20	0.55	62–199
3	20	0.56	61–199
4	20	0.56	61–200
5	20	0.56	61–199

Measurement number	Total times)	Total/Char. time	Points
KLX05A-90V-16			
1	20	0.55	75–200
2	20	0.55	75–200
3	20	0.56	75–200
4	20	0.56	75–200
5	20	0.56	75–200
KLX05A-90V-17			
1	20	0.49	21–200
2	20	0.38	23–154
3	20	0.44	25–180
4	20	0.46	21–185
5	20	0.37	23–151
KLX05A-90V-18			
1	20	0.52	64–200
2	20	0.51	64–200
3	20	0.52	64–200
4	20	0.51	64–200
5	20	0.51	64–200
KLX05A-90V-19			
1	20	0.50	97–185
2	20	0.54	116–200
3	20	0.54	119–197
4	20	0.54	97–200
5	20	0.55	97–200
KLX05A-90V-20			
1	20	0.57	36–193
2	20	0.56	36–193
3	20	0.56	36–193
4	20	0.55	37–192
5	20	0.56	36–193
KLX05A-90V-21			
1	20	0.60	79–200
2	20	0.60	80–200
3	20	0.60	82–199
4	20	0.61	79–200
5	20	0.60	79–200

Measurement number	Total times)	Total/Char. time	Points
KLX05A-90V-22			
1	20	0.60	78–200
2	20	0.58	78–191
3	20	0.61	78–200
4	20	0.62	78–200
5	20	0.62	78–200
KLX05A-90V-23			
1	20	0.53	38–200
2	20	0.54	38–200
3	20	0.54	38–200
4	20	0.55	38–200
5	20	0.55	38–200
KLX05A-90V-24			
1	20	0.58	95–200
2	20	0.59	95–200
3	20	0.59	95–200
4	20	0.59	95–200
5	20	0.60	95–200
KLX05A-90V-25			
1	20	0.56	37–200
2	20	0.56	37–200
3	20	0.56	37–199
4	20	0.56	37–199
5	20	0.56	37–200
KLX05A-90V-26			
1	20	0.60	54–200
2	20	0.60	56–200
3	20	0.60	57–200
4	20	0.59	56–200
5	20	0.61	68–200
KLX05A-90V-27			
1	20	0.58	33–200
2	20	0.59	33–200
3	20	0.59	33–200
4	20	0.59	33–200
5	20	0.59	33–200