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# Oskarshamn site investigation

# Drillhole KSH01A

## Extensometer measurement of the coefficient of thermal expansion of rock (SINTEF)

Lisbeth Alnæs, SINTEF Civil and Environmental Engineering, Rock and Soil Mechanics

October 2006

**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:* Rock mechanics, Coefficient of thermal expansion, Temperature change, Density, Porosity.

# Preface

The results in this report have not been approved and therefore it has not been reported into the SKB's SICADA. The reason for this action is due to the results differ significantly (app. 4 times greater) from previous test performed at the same specimens, i.e. /Åkesson 2004/, other SKB reports at PLU site investigation at Oskarshamn and at the Äspö Hard Rock Laboratory and finally data collected from material hand books.

The report's supplier, SINTEF, has not been able to explain or find the cause to the obtained misleading results.

Anyway, the report is going to be published among the other comparison tests performed at SKB in the field of rock mechanic and thermal properties determination.

All comparison tests are evaluated together with other tests respectively, and therefore needed to be traceable.

Göteborg, 2005-08-16

*Thomas Janson*
Deputy manager, Rock Mechanic and Thermal properties

# Abstract

The coefficient of thermal expansion and the wet density has been determined on 10 specimens from drill hole KSH01A. SINTEF in Trondheim, Norway received the specimens from The Swedish National Testing and Research Institute (SP) in Borås, Sweden and they were all marked with Id. number and had fixing points for extensometer measurement of the coefficient of thermal expansion. According to received document AP-PS-400-03-067 (SKB internal controlling document), the specimens have been sampled from depth 300 m (quartz monzodiorite) and 400 m (fine-grained dioritoid) in the drill hole. The coefficient of thermal expansion has been determined between the temperature interval 20–80°C.

It has been difficult to get reliable results at 80°C, because the glue used detaches from the rock face upon exposure to water and high temperatures (80°C). The data gained at 80°C is therefore not reliable for several of the specimens and has not been used in the calculation of coefficient of thermal expansion and length change.

The results indicate that the thermal expansion was linear to weakly curvilinear for the specimens. The coefficient of thermal expansion is rather similar among the rock samples, ranging from $1.8\times10^{-5}$ mm/mm°C to $3.3\times10^{-5}$ mm/mm°C.

# Sammanfattning

Värmeutvidgningskoefficienten och våtdensiteten bestämdes på 10 bergprover från borrhål KSH01A i Oskarshamn. SINTEF i Trondheim, Norge, fick proverna levererade från SP, Borås. Alla prover var markerade med id-nummer och var försedda med fixeringspunkter för extensometermätning, för bestämning av värmeutvidgningskoefficienten. Alla prover som testades av SINTEF var provtagna på 300- och 400-metersnivån i borrhålet. Bergarten är hanterad som kvartsmonzodiorit (300 m) och finkornig dioritoid (400 m). Värmeutvidgningskoefficienten bestämdes för temperaturintervallet 20–80 °C.

Det visade sig svårt att erhålla tillförlitliga resultat vid 80 °C, därför att limmet lossnar från bergytan då den exponeras för vatten och högre temperatur. Data från 80 °C är därför inte tillförlitliga för flera av proverna och har inte utnyttjats vid beräkningen av värmeutvidgningskoefficienten och längdförändring.

Resultaten indikerar att värmeutvidgningen var linjär till krokiga för proven. Värmeutvidgningskoefficienten varierar från $1{,}8\times10^{-5}$ mm/mm °C till $3{,}3\times10^{-5}$ mm/mm °C.

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# 1 Introduction

This document reports the data from extensometer measurement performed by SINTEF, Trondheim, Norway on 10 specimens received from The Swedish National Testing and Research Institute (SP) and representing rock core samples from the Simpevarp area. This is one of the activities performed as part of the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-03-067 (SKB internal controlling document).

The principle of the measurements is to determine the coefficient of thermal expansion at different temperatures.

SINTEF has received the following information from SP about sampling: The cores are sampled from borehole KSH01A in the Simpevarp area, see Figure 1-1. It was sampled 13 May 2003 by Rolf Christiansson (SKB) and Urban Åkesson (SP). Specimens were taken from four levels in the rock core: level 1 between 297 and 303 m (SINTEFs specimens), level 2 between 399 and 412 m (SINTEFs specimens), level 3 between 480 and 492 m, and level 4 between 701 and 713. 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 rock cores were transported by SP from Simpevarp and arrived to SP 14 May 2003.

SINTEF received the specimens at 27th of February 2004. Testing at SINTEF was conducted in the period 3rd of March to 27th of March.


***Figure 1-1.*** *Location of the drill hole KSH01A at the Oskarshamn site.*

# 2 Objective and scope

The purpose is to determine the linear coefficient of thermal expansion for rock cores in water-saturated condition between +20°C and +80°C. SP has determined the linear coefficient of thermal expansion on the rock cores and an evaluation of these results in comparison to each other will be performed in a separate report.

These parameters will be included in site descriptive rock mechanical and thermal model for the Simplevarp area, performed by SKB. The specimens and the results will be presented in tables, diagrams and spreadsheets.

# 3 Equipment

The following equipment has been used for the analyses:

- Extensometer (MERCER) for measurements of the thermal expansion. Calibrations of the instrument were done by measurement on the reference bar before and after every measuring day.
- Reference bar in invar steel for calibrate the extensometer.
- Oven (Termaks) for heating up the specimens.
- A covered stainless steel box filled with water for keeping the specimens water saturated.
- Temperature measuring device and termocouples from Jenway (producer) for water temperature recording.
- SINTEF has during the last year not made calculation of the uncertainty of the equipment used.

# 4 Execution

Determination of the coefficient of thermal expansion was made in accordance with SKB's method description SKB MD 191.002-version 1.9 (SKB internal controlling document). SINTEF Civil and Environmental Engineering, Dep. of Rock and Soil Mechanics performed the test in co-operation with Dep. of Cement and Concrete.

## 4.1 Description of the samples

All 10 specimens received from SP were marked with Id. Number as shown in Table 4-1 and had measuring points (Demec) fixed with glue, type HBM X60 to the surface. The specimens have a diameter of 50 mm and a length of 250 mm. The fixing points give a measuring distance of around 200 mm.

Several of the fixings had detached from the surface, and on the rest of the specimens all of these could easily be removed by hand. All measuring points on the specimens had to be re-fixed, see section 4.2.

The identification reported by SP will be used in the following. The rocks investigated represent quartz monzodiorite from level 1 between 297 and 303 m, and a fine-grained dioritoid from level 2 between 399 and 412 m.

In order to secure stability in the temperature of the specimens at each measurement, the box with the specimens was kept in the oven, and the specimens were taken out one by one for measurement.

**Table 4-1. Identification marks and informed sampling depth.**

| ID. Number on specimens received from SP | Identificationreported by SP | Sampling depth, according to the marks on the drill-core boxes (Sec up) |
|---|---|---|
| **Quartz monzodiorite** | | |
| SO1A-90L-1 | KSH01A-90L-1 | 297.59 |
| SO1A-90L-2 | KSH01A-90L-2 | 297.86 |
| SO1A-90L-3 | KSH01A-90L-3 | 300.75 |
| SO1A-90L-4 | KSH01A-90L-4 | 301.39 |
| SO1A-90L-5 | KSH01A-90L-5 | 302.19 |
| **Fine-grained dioritoid** | | |
| SO1A-90L-7 | KSH01A-90L-7 | 399.00 |
| SO1A-90L-8 | KSH01A-90L-8 | 400.10 |
| SO1A-90L-9 | KSH01A-90L-9 | 400.37 |
| SO1A-90L-10 | KSH01A-90L-10 | 400.64 |
| SO1A-90L-11 | KSH01A-90L-11 | 401.21 |

## 4.2 Testing

The following steps were performed:

| Item | Date | Activity |
|---|---|---|
| 1 | 2/3-04 | The specimens received from SP were photographed in JPEG-format. |
| 2 | 3/3–8/3-04 | All measuring points (Demec) already glued on the specimens by SP were taken off. The rock surface for the measuring points was rubbed by the use of sand paper and then cleaned with acetone before the two Demec points were re-glued by use of HBM X60 on the specimens, giving a measuring distance of 200 mm. The glue was allowed to dry/cure for one week. |
| 3 | 8/3–15/3-04 | The specimens were water saturated (temperature 19,5°C) for one week. |
| 4 | 15/3 | The wet density was determined. |
| 5 | 15/3–27/3-04 | The coefficient of thermal expansion was determined. The length/thermal expansion was measured at 20, 40, 60 and 80°C. On each temperature level was three measurements done with 24 h intervals in order to know that the expansion was completed for each temperature level. The coeffiient of thermal expansion was determined between 20–80°C. Calibration of the instrument was done before the measurements on every new temperature by the use of invar steel bar. |

# 5 Results

## 5.1 Description of the specimen and presentation of test results

The temperature of water for water saturation was 19,5°C and the density of the water was 998 kg/m$^3$. The coefficient of thermal expansion was determined between +20°C and +80°C.

There has been difficult to get reliable results at 80°C, because the glue used detaches from the rock face upon exposure to water and high temperatures (80°C). The data gained at 80°C is therefore not reliable for some of the specimens and has not been used in the calculation of coefficient of thermal expansion and length change. This has been remarked in the below description of each sample.

***KSH01A-90L-1 (297.59 m)***

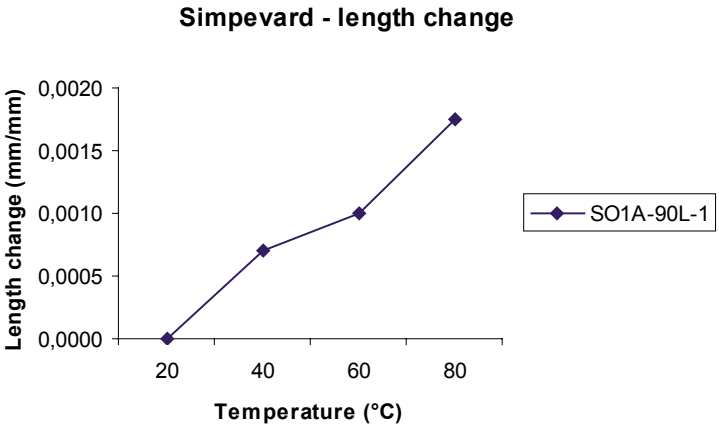


***Figure 5-1.*** *Specimen KSH01A-90L-1.*

The 3rd measurement at 80°C is uncertain and not included in the data set for calculation. The coefficient of thermal expansion for specimen KSH01A-90L-1 was calculated to be 2.9×10$^{-5}$ mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,723 kg/m$^3$.

***KSH01A-90L-2 (297.86 m)***


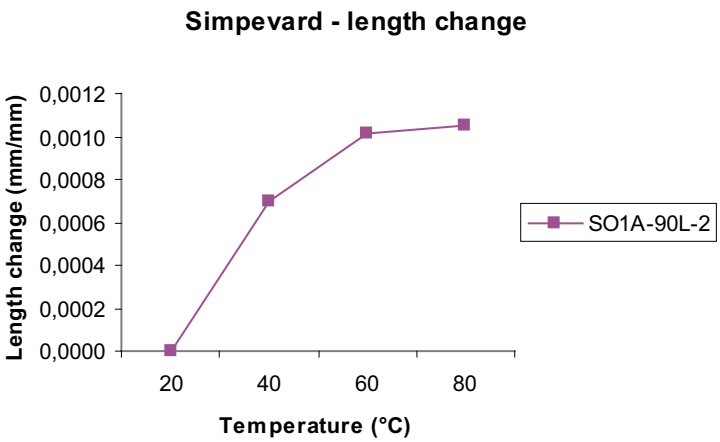


***Figure 5-2.*** *Specimen KSH01A-90L-2.*

The 3rd measurement at 80°C is uncertain and not included in the data set for calculation. The coefficient of thermal expansion for specimen KSH01A-90L-2 was calculated to be $1.8\times10^{-5}$ mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,765 kg/m$^3$.

***KSH01A-90L-3 (300.75 m)***

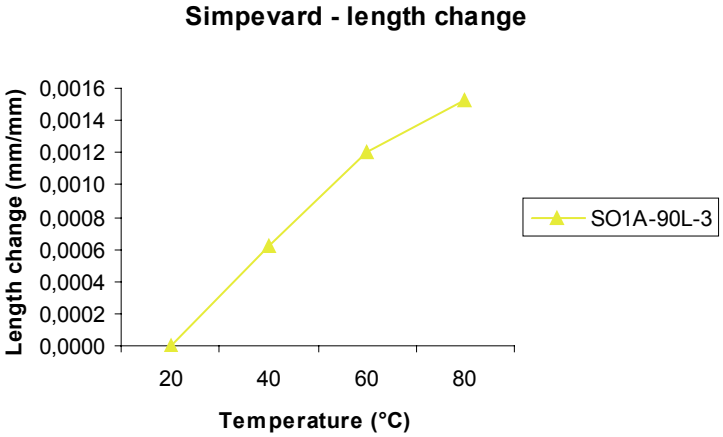


***Figure 5-3.*** *Specimen KSH01A-90L-3.*

The coefficient of thermal expansion for specimen KSH01A-90L-3 was calculated to be $2.5\times10^{-5}$ mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,779 kg/m$^3$.

***KSH01A-90L-4 (301.39 m)***


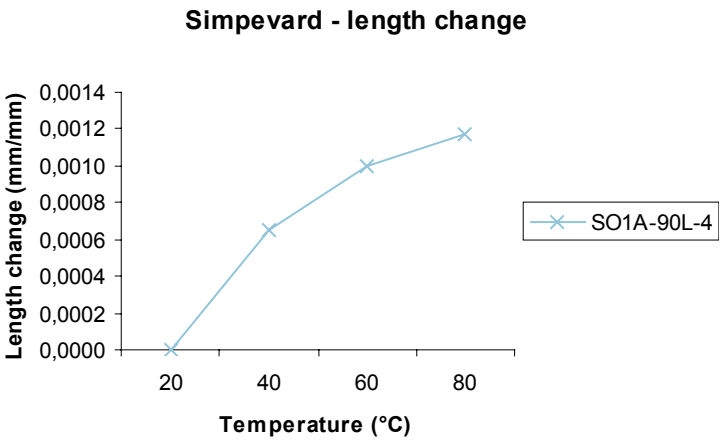


***Figure 5-4.*** *Specimen KSH01A-90L-4.*

The 3rd measurement at 80°C is uncertain and not included in the data set for calculation. The coefficient of thermal expansion for specimen KSH01A-90L-4 was calculated to be $2.0\times10^{-5}$ mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,771 kg/m$^3$.

***KSH01A-90L-5 (302.19 m)***

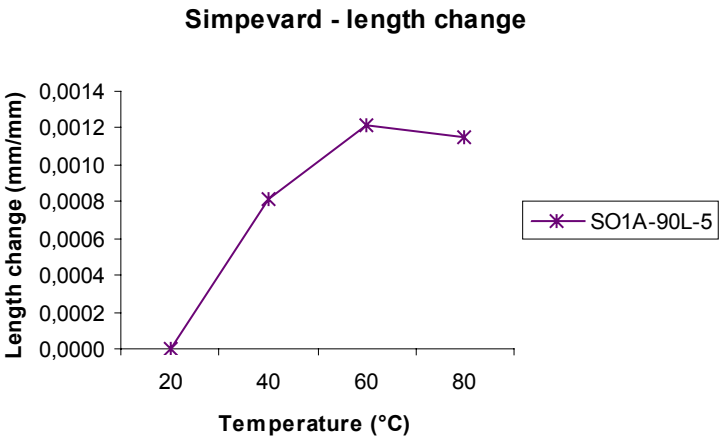


***Figure 5-5.*** *Specimen KSH01A-90L-5.*

The 2nd measurement at 80°C is uncertain and not included in the data set for calculation. The coefficient of thermal expansion for specimen KSH01A-90L-5 was calculated to be $1.9\times10^{-5}$ mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,766 kg/m$^3$.

***KSH01A-90L-7 (399.00 m)***


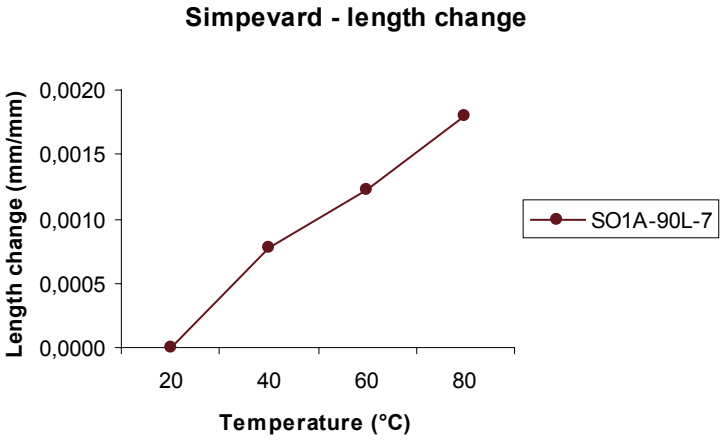


***Figure 5-6.*** *Specimen KSH01A-90L-7.*

The coefficient of thermal expansion for specimen KSH01A-90L-7 was calculated to be $3.0\times10^{-5}$ mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,778 kg/m$^3$.

***KSH01A-90L-8 (400.10 m)***

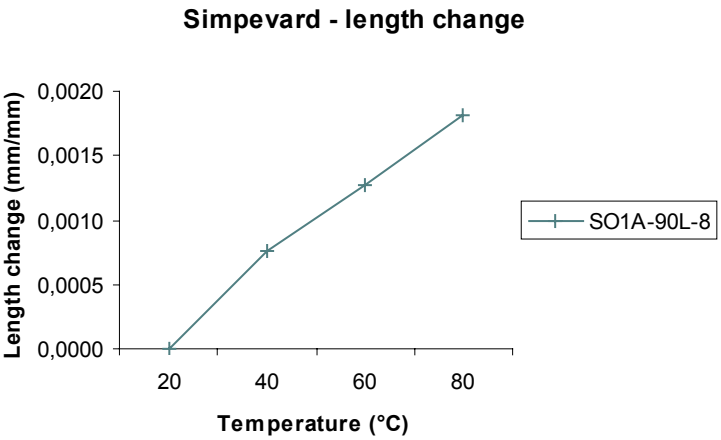


***Figure 5-7.*** *Specimen KSH01A-90L-8.*

The 3rd measurement at 80°C is uncertain and not included in the data set for calculation. The coefficient of thermal expansion for specimen KSH01A-90L-8 was calculated to be $3.0\times10^{-5}$ mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,772 kg/m$^3$.

***KSH01A-90L-9 (400.37 m)***


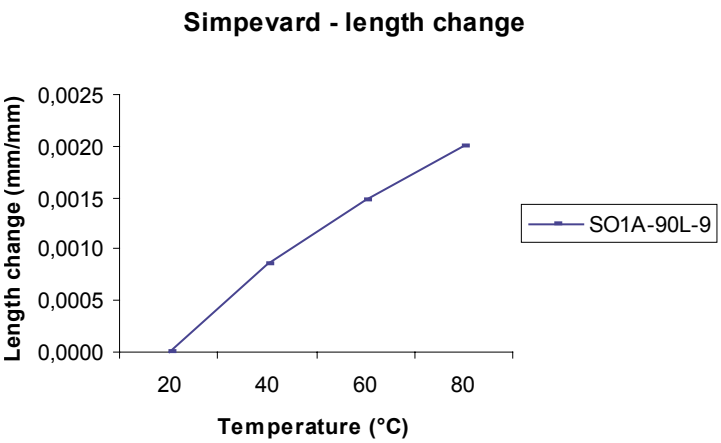


***Figure 5-8.*** *Specimen KSH01A-90L-9.*

The coefficient of thermal expansion for specimen KSH01A-90L-9 was calculated to be $3.3\times10^{-5}$ mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,761 kg/m$^3$.

***KSH01A-90L-10 (400.64 m)***


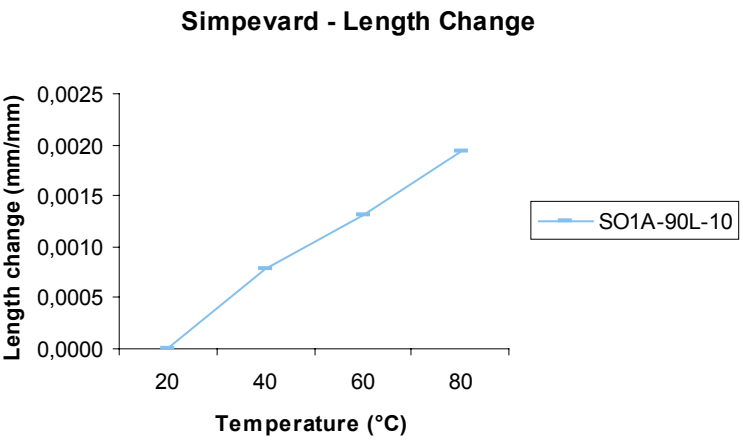


***Figure 5-9.*** *Specimen KSH01A-90L-10.*

The coefficient of thermal expansion for specimen KSH01A-90L-10 was calculated to be $3.2\times10^{-5}$ mm/mm°C in the interval (20–80°C) and the specimen had a wet density of 2,781 kg/m$^3$.

***KSH01A-90L-11 (401.21 m)***


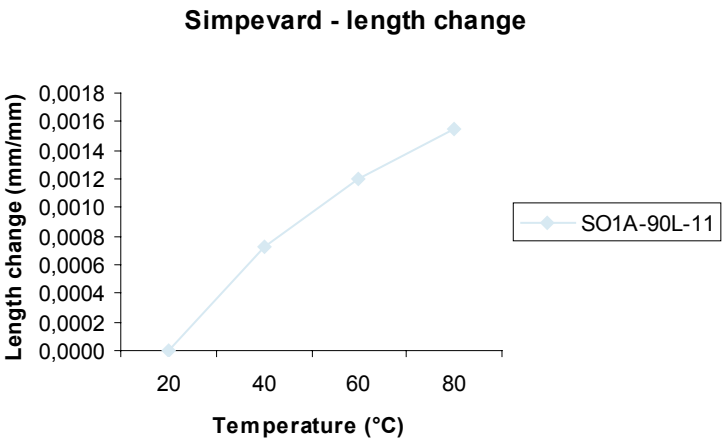


***Figure 5-10.*** *Specimen KSH01A-90L-11.*

The coefficient of thermal expansion for specimen KSH01A-90L-11 was calculated to be $2.6\times10^{-5}$ mm/mm°C and the specimen had a wet density to 2,780 kg/m$^3$.

## 5.2 Results for the entire test series

Table 5-1 and 5-2 and Figure 5-11 and 5-12 gives a summary of the results.

## 5.3 Discussion

The execution procedure followed the prescription in SKB MD 191.002-version 1.9 and SKB MD 160.002-version 2.0. (SKB internal controlling document).

In order to secure stability in the temperature of the specimens at each measurement, the box with the specimens was kept in the oven, and the specimens were taken out one by one for measurement.

Measurement of expansion during heating on fully water immersed specimens is challenging especially because of the difficulty to achieve a permanent attachment of the measuring points when exposed to cyclic heating in water. Both SP and SINTEF have had problems with this. Typically the measuring point detached from the glue at the third cycle, the adhesion between the glue and the rock face was more stabile, but yet also here problems arose. Several of SINTEFs measurement at 80°C is for this reason uncertain. Thus, the measurement of specimens KSH01A-90L-2, -4, -5 and -7 at the interval from 60–80°C behaved strange, without any clear detachment of the measuring points. A comment to the test is that the glue used (type HBM X60) is not fully stable upon heating in water.

**Table 5-1. Summary of the results for the coefficient of thermal expansion, length changes and wet density of the specimens from Simpevarp area, level 1 (297–303 m) and level 2 (399–412 m).**

| Specimen | Measurements between between 20 and 80°C | | | |
|---|---|---|---|---|
| | Coefficient of thermal expansion (mm/mm°C) | Length change (mm) | Length change (mm/mm) | Wet density (kg/m$^3$) |
| **Level 1, 297–303 m** | | | | |
| KSH01A-90L-1 | $2.9\times10^{-5}$ | 0.350 | $1.75\times10^{-3}$ | 2,723 |
| KSH01A-90L-2 | $1.8\times10^{-5}$ | 0.210 | $1.05\times10^{-3}$ | 2,765 |
| KSH01A-90L-3 | $2.5\times10^{-5}$ | 0.305 | $1.52\times10^{-3}$ | 2,779 |
| KSH01A-90L-4 | $2.0\times10^{-5}$ | 0.235 | $1.17\times10^{-3}$ | 2,771 |
| KSH01A-90L-5 | – | – | – | 2,766 |
| **Level 2, 399–412 m** | | | | |
| KSH01A-90L-7 | $3.0\times10^{-5}$ | 0.360 | $1.80\times10^{-3}$ | 2,778 |
| KSH01A-90L-8 | $3.0\times10^{-5}$ | 0.362 | $1.82\times 0^{-3}$ | 2,772 |
| KSH01A-90L-9 | $3.3\times10^{-5}$ | 0.400 | $2.00\times10^{-3}$ | 2,761 |
| KSH01A-90L-10 | $3.2\times10^{-5}$ | 0.385 | $1.93\times10^{-3}$ | 2,781 |
| KSH01A-90L-11 | $2.6\times10^{-5}$ | 0.310 | $1.55\times10^{-3}$ | 2,781 |

**Table 5-2. Summary of the results for the coefficient of thermal expansion (mm/mm°C) in the temperature interval (20–80)°C for the whole sample set.**

| Depth (m) | Coefficient of variation (mm/mm°C) | | |
|---|---|---|---|
| | Min. value | Median value | Max. value |
| 300 | $1.8\times10^{-5}$ | $2.3\times10^{-5}$ | $2.9\times10^{-5}$ |
| 400 | $2.6\times10^{-5}$ | $3.0\times10^{-5}$ | $3.3\times10^{-5}$ |

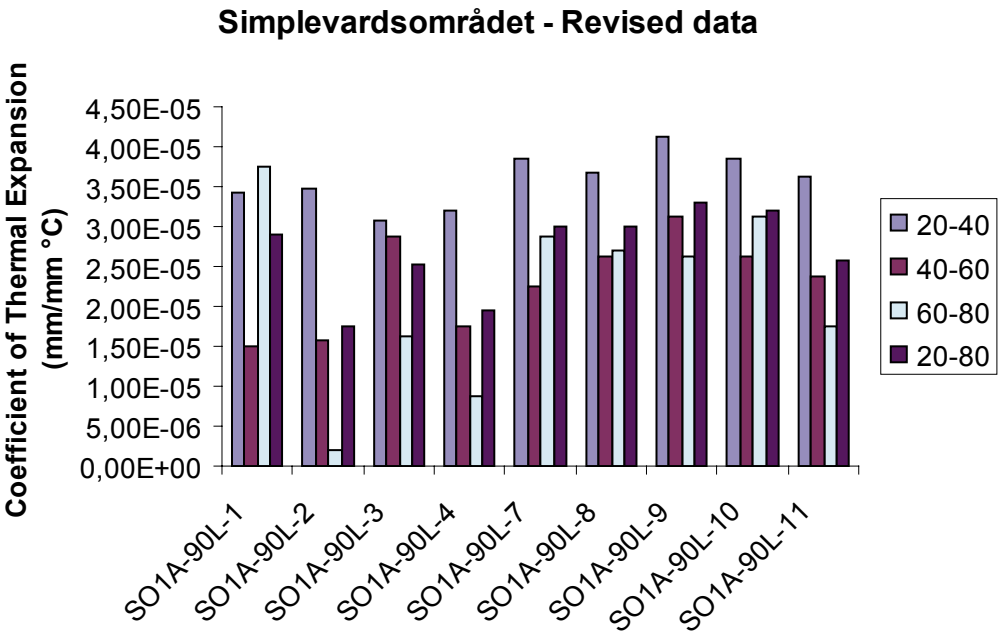


***Figure 5-11.*** *Coefficient of thermal expansion for each specimen in various temperature intervals.*

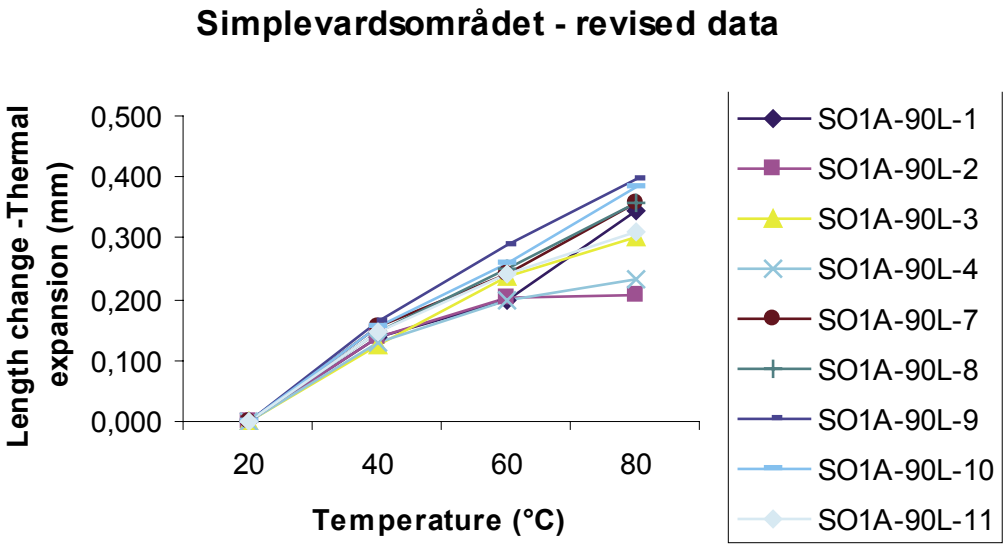


***Figure 5-12.*** *Thermal expansion/length change (mm) for the specimens.*

# References

**NT BUILD 479.** Natural Building stones: Coefficient of thermal expansion.

**Åkesson U, 2004.** Drill hole: KSH01A. Extensometer measurement of the coefficient of thermal expansion of rock. SKB report P-04-59.