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Forsmark site investigation

Overcoring rock stress measurements in borehole KFM02B

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

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Summary

Overcoring stress measurements were conducted in borehole KFM02B at the Forsmark site. The equipment used for the measurements was the three-dimensional *Borre* probe. Measurements were carried out at four measurement levels in the borehole. At the first measurement level only a few partly successful results could be achieved, whereas the following three measurement levels provided usable results for stress determinations. The causes of unsuccessful measurements were drill rig problems, unreliable strain responses and occurrence of fractures parallel with the borehole.

At Level 1, the results from only partly successful measurements performed between 113 and 145 m borehole length (mbl), indicated a maximum horizontal stress of magnitude 9.4 MPa and with orientation NW-SE and a minor horizontal stress of 3.8 MPa. The magnitude of the estimated vertical stress was negative, –0.5 MPa. No unambiguous results were achieved at this level.

From the successful measurements at Level 2 (156 to 180 mbl) the magnitude of the maximum horizontal stress was estimated at 11.8 MPa and the orientated at NNW-SSE, whereas the minor horizontal stress equalled 4.7 MPa. The vertical stress at this level, 5.5 MPa, is considered somewhat high compared with the vertical overburden load.

Also at Level 3, 252 to 256 mbl, the measurements were regarded as successful and indicated a magnitude of the maximum horizontal stress of 17.6 MPa, orientated NW-SE, and a magnitude of the minor horizontal stress of 9.7 MPa. The estimated vertical stress of 3.9 MPa is somewhat low compared with the theoretically determined vertical stress.

Finally, the successful measurements at Level 4 (between 302 and 307 mbl) indicated magnitudes of the maximum and minimum horizontal stresses of 14.1 MPa and 6.5 MPa, respectively. The orientation of the maximum horizontal stress is NW-SE. The magnitude of the vertical stress determination was 4.2 MPa, which is half the theoretically determined vertical stress at this level due to overburden.

Transient strain analysis was conducted for all successful or partly successful measurements. For the majority of the measurements there were indications that the tensile stress exceeded the tensile strength of the rock mass.

From the overcoring strain responses, a temperature effect from drilling of the core sample was indicated, and thereby also on the strain gauges. The significance of this temperature effect on strain responses has not been quantified within the frame of this commission. However, in the analysis of the test results efforts were made to minimize the effects on the resulting state of stress.

Sammanfattning

Bergspänningsmätningar med överborrningsmetoden har genomförts i borrhål KFM02B i Forsmark. Vid mätningarna användes *Borre*-cellen, vilken är en tredimensionell mätmetod. Mätningarna, som utfördes på fyra mätnivåer i borrhålet, resulterade på den första mätnivån i endast ett fåtal fullgoda mätdata, medan testerna på de efterföljande tre nivåerna var mer framgångsrika. Skälen till att vissa mätförsök inte gav fullgoda resultat var bl a problem med borrmaskinen, otillförlitlig töjningsrespons samt förekomst av sprickplan parallella med borrhålet.

På mätnivå nr 1, mellan 113 och 145 m borrhålslängd (mbl), indikerade de endast delvis lyckade mätresultaten en magnitud hos den största horisontalspänningen på 9,4 MPa (medelvärde) med riktning NV-SO, medan magnituden hos den minsta horisontalspänningen (medel) är 3,8 MPa. Den uppmätta vertikalspänningen på denna nivå har negativ magnitud, –0,5 MPa.

De lyckade mätningarna på mätnivå nr 2 (156 till 180 mbl) resulterade i en magnitud på 11,8 MPa för den största horisontella spänningen och en NNV-SSO-lig riktning, medan den minsta horisontalspänningen uppvisade magnituden 4.7 MPa. Vertikalspänningen på denna nivå, 5.5 MPa, är något högre än teoretiskt beräknad vertikalspänning.

På nivå nr 3, med lyckade mätningar mellan 252 och 256 mbl, uppmättes magnituden 17,6 MPa och orienteringen NV-SO för största horisontalspänningen och magnituden 9,7 för minsta horisontalspänningen. Uppmätt vertikalspänning är 3.9 MPa, dvs något lägre än den teoretiskt beräknad vertikalspänningen.

Slutligen indikerade de lyckade mätningarna på mätnivå nr 4 (mellan 302 och 307 mbl) en största horisontalspänning på 14.1 MPa och en motsvarande, minsta horisontalspänning, på 6.5 MPa. Den största horisontalspänningen är orienterad NV-SO. Vertikalspänningen uppmättes till 4.2 MPa, vilket är hälften av teoretiskt beräknad vertikalspänning.

Alla mätdata som bedömts som lyckade eller delvis lyckade har varit föremål för transient-analyser. Vid majoriteten av dessa indikerades uppkomst av dragspänningar som överskred den uppmätta draghållfastheten för bergmassan.

Töjningsresponsen vid överborrningarna indikerade viss temperatureffekt på borrkärnorna orsakad av borrningen och därmed också en påverkan på trådtöjningsgivarna. Temperatur-effektens inverkan på töjningsresponsen har inte kvantifierats inom ramen för denna aktivitet. Däremot har åtgärder vidtagits vid analysen av mätresultaten för att minimera dess inverkan på spänningsberäkningarna.

Contents

1 Introduction

This document reports the data gained from three-dimensional overcoring rock stress measurements in borehole KFM02B, which is one of the activities within the site investigation at Forsmark. The borehole is located in the Forsmark candidate area as shown in Figure 1-1.

The borehole is drilled subvertically (inclined at approximately 80° from the horizon at borehole collar) to a length of 573.87 metres, corresponding to a vertical depth of c 566 m below ground surface. The hole is of "telescopic" type with varying diameter (339–86 mm) down to 88.61 m borehole length (mbl) and with the diameter 75.8 mm from 88.61 mbl down to the borehole bottom at 573.87 mbl. Overcoring rock stress measurements were planned to be conducted at approximately 100, 150, 190–210, 240–250 and 350 m borehole length during drilling of the hole but were in the end restricted to four levels, see Chapter 5.

Controlling documents for performance of the activity are listed in Table 1-1. Both Activity Plan and Method description are SKB's internal controlling document.

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the Activity Plan number (AP PF 400-05-122). Only data in SKB's databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

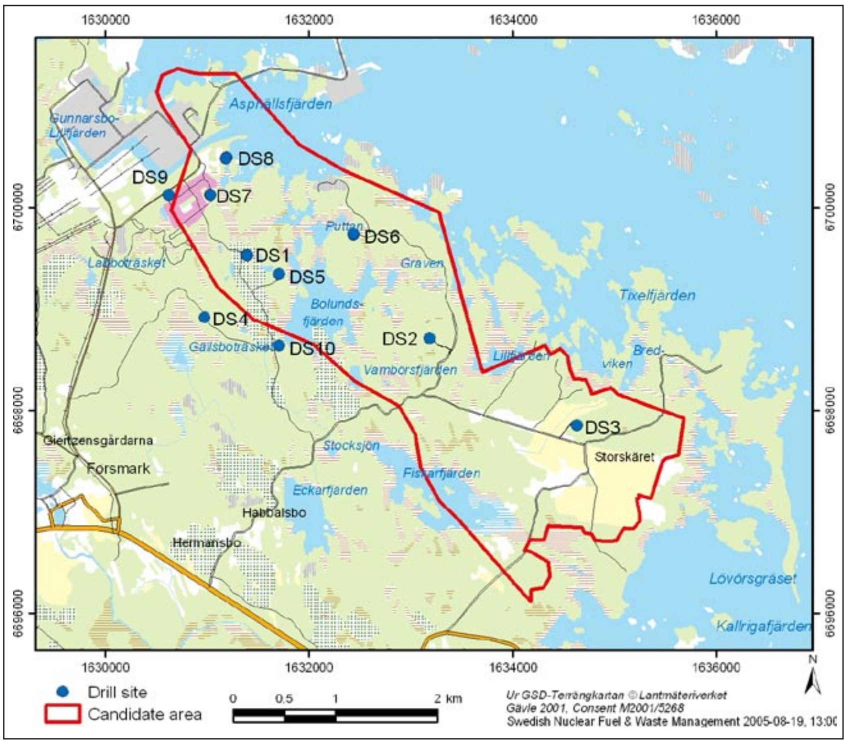


Figure 1-1. *Location of drill sites (DS) 1–10 within the Forsmark area. The telescopic borehole KFM02B is located at DS2.*

Table 1-1. Controlling documents for performance of the activity.

Activity Plan	Number	Version
Kärnborrning av och Bergspänningsmätningar i KFM02B	AP PF 400-05-122	1.0
Method Description		
Method Description for Rock Stress Measurements with the Overcoring Method	SKB MD 181.001	1.0

2 Objective and scope

The objectives of the overcoring rock stress measurements were to: (i) determine the stress gradient through the fractured shallow rock mass to the more low-fractured rock mass at greater depth, (ii) decrease the uncertainty in stress magnitude at larger depth, and (iii) collect more data about when ring disking occurs. This was to be achieved by 3–4 successful test results from each level at approximately 100, 150, 190–210 and 350 mbl.

All measurements were conducted using the three-dimensional *Borre* probe for overcoring (developed and used by Vattenfall Power Consultant AB). The method is described in detail in Chapter 3 of this report.

Field measurements were done in three periods during 2006, see Table 2-1. The first period included Level 1 as well as Level 2. Execution of field measurements and data analysis is presented in Chapter 4 of this report, whereas all measurement results are presented in Chapter 5, along with a brief discussion of the test results. Measurement and analysis data from the tests are reported in Appendices A through H.

All stresses presented in this report are denoted using a geomechanical sign convention with compressive stresses taken as positive. Compressive strains are, however, defined as negative. All stress orientations are given with respect to geographic North (based on borehole orientation measurements), using a right-hand rule notation. Measurement positions are given as the borehole length at the gauge position of the measurement probe.

The presentation of this report is restricted to the work done and the results obtained, as such. It is neither attempted to put the data into a geological/tectonic context, nor to discuss the implications of the results for future work.

Table 2-1. Duration of the field measurement periods during 2006.

Level no	From	To	Period
1	June 15	October 3	1
2	June 15	October 3	1
3	October 6	November 22	2
4	November 25	December 13	3

3 Equipment

Three-dimensional overcoring rock stress measurements are based on measuring strains when a sample of rock is released from the rock mass and the stresses are acting upon it. The in situ stresses can be calculated from the measured strains and with knowledge of the elastic properties of the rock. The complete, three-dimensional, stress tensor is determined from a single measurement, under the assumption of continuous, homogeneous, isotropic and linear-elastic rock behaviour /Leeman and Hayes 1966, Leeman 1968/.

3.1 Description of field equipment

The *Borre* probe /Sjöberg and Klasson 2003/ is owned and used by Vattenfall Power Consultant AB for stress measurements in deep, water-filled boreholes. The equipment for overcoring rock stress measurements using the *Borre* probe comprises:

- pilot hole drilling equipment for wireline core drilling, including planing tool,
- inspection tool (test probe) with built-in borehole cleaning brush,
- *Borre* probe with built-in data logger,
- set of strain gauges (to be mounted on the *Borre* probe),
- glue (for bonding strain gauges to the borehole wall),
- cell adapter (installation tool),
- biaxial test equipment including load cell, pressure gauge, hydraulic pump and strain indicator,
- portable computer.

A new pilot hole wireline drilling equipment was developed for use with two of the major wireline systems utilized in Sweden – the Hagby WL76 Metric Thinwall Wireline System, and the Atlas Copco CORAC N3/50 System. Both systems produce a c 76 mm overall hole diameter (albeit with slight differences in drill bit diameter for the two systems), whereas the obtained pilot hole diameter is 36 mm using the developed pilot hole equipment. In this project, the Atlas Copco CORAC N3/50 equipment was used for drilling.

The developed wireline pilot hole equipment is fitted to the wireline drill string. Thrusting of the pilot hole drill is controlled through water pressure in the drill string, whereas rotation is transferred through the drill string itself. The unique design of the equipment ensures that the pilot hole is always drilled for a length of 75 cm. The pilot core is recovered through the wireline drill string in the normal fashion for wireline systems. The drilling equipment also includes a planing tool attached to the wireline equipment, which is used to grind the base of the borehole to ensure that it is planar. Overcoring equipment includes a specially manufactured, thinwall, core barrel and coring bit producing a nominal core diameter of 61.7 mm, i.e. equal to that produced by using conventional Craelius T2-76 equipment. The latter is a requirement for being able to fit overcored samples into the biaxial test cell.

The most vital part of the equipment is the *Borre* probe, which is shown in Figure 3-1. The instrument carries nine electrical resistance strain gauges mounted in three rosettes. Each rosette comprises three strain gauges oriented (i) parallel (axial or longitudinal gauges), (ii) perpendicular (circumferential or tangential gauges), and (iii) at a 45° angle, to the borehole axis, respectively, see Figure 3-2. The strain-gauge rosettes are bonded to three plastic cantilever arms at the lower end of the probe, which is the only part of the instrument that enters into the

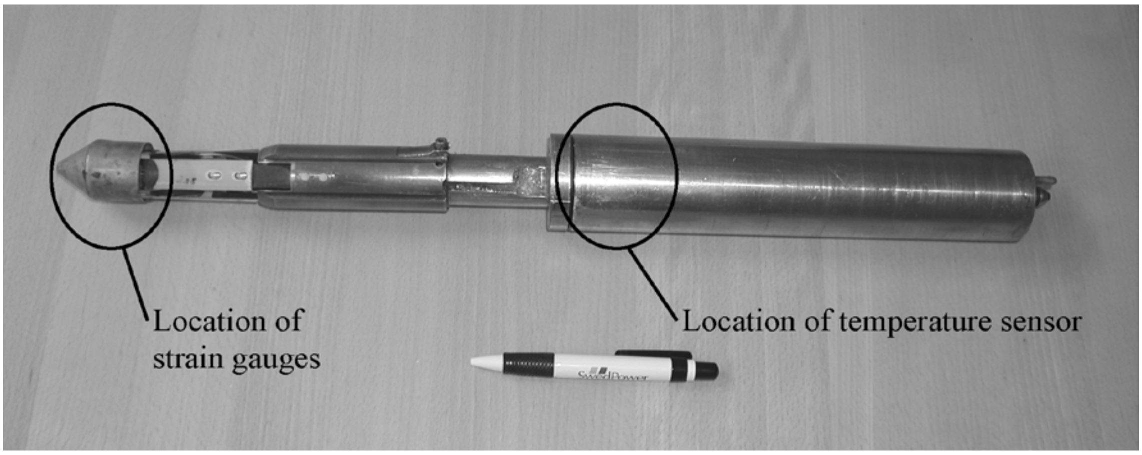


Figure 3-1. *The Borre probe.*

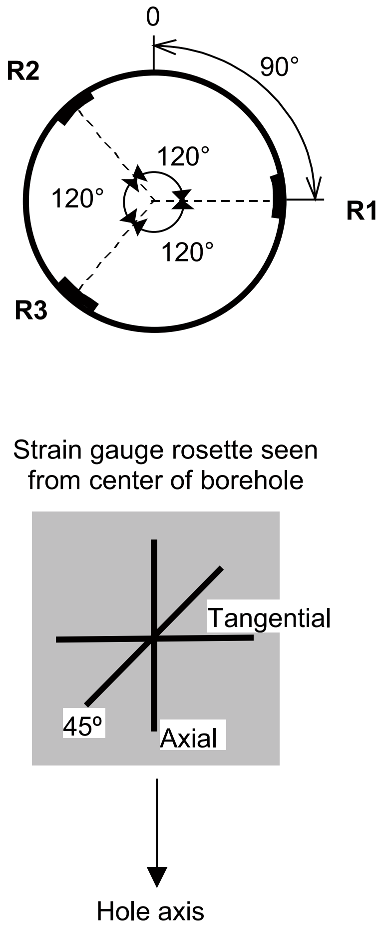


Figure 3-2. *Strain gauge configuration of the Borre probe. Axial strain gauges are denoted L1, L2, and L3 (gauge nos. 1, 4, 7), tangential gauges are denoted T1, T2, and T3 (gauge nos. 2, 5, 8), and inclined gauges are denoted 45-1, 45-2, and 45-3 (gauge nos. 3, 6, 9).*

pilot hole. The arms are located 120° apart with a known orientation to the main body of the instrument. Thus, the nine strain gauges of the *Borre* probe form an array representing seven spatially different directions. All strain gauges are mounted at a depth of 160 mm in the pilot hole. The temperature sensor is located inside the front end (metal shell) of the Borre cell.

The strain gauges are connected to a data logger inside the probe. The probe also measures the temperature in the borehole to assess the temperature effects on the readings during the overcoring phase. An extra wire is used, which is wired directly into the wheatstone measuring bridge, thus providing automatic temperature compensation for wire resistance during actual strain recording.

The present version of the logger is termed *Borre III* and has two recording modes – sparse and dense recording. Sparse recording – every 15 minutes – is conducted from the time of activation to a selected start time for dense recording. The sparse recording provides a quality check of glue hardening and possible disturbances prior to overcoring. Dense recording is done in user-specified intervals of between 3 and 60 seconds, from the pre-set start time (set to just before anticipated start of actual overcoring) until the core is recovered and logging terminated. The data logger is programmed through connection to a portable computer before installation of the probe in the borehole. No further connection to the ground surface is required after this programming.

Description of the details of the *Borre* probe and other components of the equipment is further presented in /Sjöberg and Klasson 2003/ and in SKB MD 181.001 (SKB internal controlling document).

4 Execution

4.1 General

In the following, the execution of overcoring measurements is briefly described. Measurements were conducted in accordance with extensive quality operating procedures for the method used. A list of the constituent procedures is given in Appendix I, see also SKB MD 181.001 (SKB internal controlling document).

4.2 Borehole data

The details of the core drilling of borehole KFM02B are not covered in this report. However, a brief description is given below. The borehole was drilled with 339 mm diameter to a length of 3.23 m, and from there with stepwise decreasing diameter down to 88.61 mbl. For the remainder of the hole, a 75.8 mm hole diameter applies (final hole length of 573.87 m corresponding to c 566 m vertical depth). A steel casing with an inner diameter of 200 mm was installed down to a borehole length of 86.55 m, below which there is a stainless steel transition cone to the narrower part of the borehole at 88.55 mbl. The gap between the casing and the borehole wall was grouted with a total amount of 1,548 kg (1,575 l) cement ("Aalborg Portland Cement/ microsilica") down to 87.10 mbl. This action was taken on January 26, 2006, i.e. well in advance of the commencement of the overcoring campaign.

The hole was also grouted between 90–127.20 m depth with 910 kg Lafarge cement without reaching a stop pressure. This was carried out on September 4, 2006, to seal a zone at about 100 mbl that had a major water yield.

4.3 Preparations

Preparations before measurement start include (according to the method description):

- functional checks of strain gauges and data logger in the probe,
- calibration of biaxial test equipment,
- glue test on every new glue purchase,
- functional checks of drilling and installation equipment.

4.4 Execution of measurements

Overcoring stress measurement using the *Borre* probe involves:

1. Pilot hole drilling and examination.
2. Preparation and installation of the *Borre* probe.
3. Overcoring and recovery of the probe.
4. Biaxial testing of the overcore sample.

The procedure for stress measurement using the *Borre* probe is briefly summarized in Figure 4-1. Each stage is succinctly described below.

4.4.1 Pilot hole drilling

The 76 mm borehole is advanced to the target test depth, specified in advance. Once at this depth, a decision as to whether attempt pilot hole drilling is made. The main criterion for attempting a pilot hole is that the 76 mm drill core shall carry homogeneous rock close to the hole bottom. Discrete fractures may be accepted if the overall fracture frequency and/or orientation of discontinuities indicate that the pilot hole core shall be homogeneous and free of open fractures. If these requirements are not met, the 76 mm borehole is extended another 1–3 m.

Once a decision on pilot hole drilling is taken, the bottom of the 76 mm hole is grinded to ensure that it is planar. Using wireline pilot hole drilling, a 0.75 m long pilot hole is drilled. The borehole is flushed and the return water checked for cleanness (free of debris). The retrieved pilot core is inspected to determine whether the hole location is suitable for testing. The criteria on the pilot hole core for the decision to go on with the test are the following:

- 3–25 cm: (length) Continuous core, mechanical fractures accepted. No healed fracture that can be extrapolated to cross close to the gauge position at 16 cm during the subsequent overcoring process.
- 15–17 cm: No larger and/or different mineral crystals than elsewhere on the core (length) shall be present around 16 cm. Pegmatite shall be avoided if possible.
- Any direct or indirect information on core damage (ring disking, microcracking, etc) on the pilot core surface is an evidence of non-linear and inelastic behaviour, which renders the core unacceptable.

As the hollow overcored core is more vulnerable to core damage, there is no reason to proceed with measurement if there is any core damage or any features present as described above. If these criteria are not met, but conditions appear to be better at a slightly deeper location in the pilot hole, planing and grinding of the bottom of the 76 mm hole may be performed to reach a more suitable location for the strain gauges (always installed 16 cm from the bottom of the 76 mm hole). Planing of up to 10 cm can normally be achieved in practice. If planing is not possible within the above limits, a new pilot hole is instead drilled.

If the pilot hole is judged acceptable for installation, a test probe is lowered down the borehole to check that the pilot hole is open and free from debris.

4.4.2 Preparation and installation

If the conditions for a suitable pilot hole are satisfied, and the pilot hole is open and free from debris, the *Borre* probe is prepared for installation into the pilot borehole. The preparations include:

- attaching strain gauges to the probe and connecting them to the logger,
- programming of the data logger with start time and sampling interval,
- attaching the probe and the compass to the installation tool,
- mixing and applying glue to the strain gauges.

The probe is then installed into the pilot hole, as shown in Figure 4-1. The probe is left in the hole for a minimum of 8 hours (usually overnight) for proper bonding of strain gauges to the pilot hole wall.

4.4.3 Overcoring

Overcoring of the probe involves flushing before and after overcoring, to stabilize temperatures. A checklist is followed to control drilling rate, rotational speeds, flushing, etc (according to the method description). Coring advance is done at a specified constant rate (normally 3 cm/min).

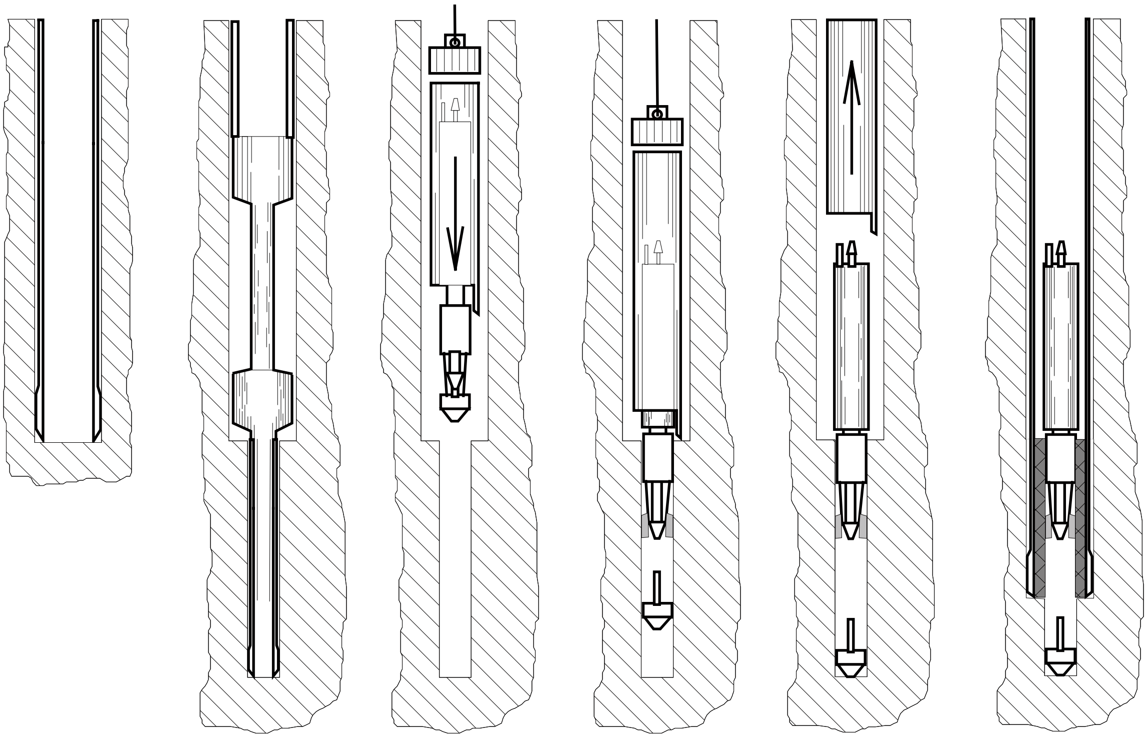


Figure 4-1. *Installation and measurement procedure with the Borre probe:*

1. *Advance 76 mm-diameter main borehole to measurement depth. Grind the hole bottom using the planing tool.*
2. *Drill 36 mm-diameter pilot hole and recover core for appraisal. Flush the borehole to remove drill cuttings.*
3. *Prepare the Borre probe for measurement and apply glue to strain gauges. Insert the probe in installation tool into hole.*
4. *Tip of probe with strain gauges enters the pilot hole. Probe releases from installation tool through a latch, which also fixes the compass, thus recording the installed probe orientation. Gauges bonded to pilot hole wall under pressure from the nose cone.*
5. *Allow glue to harden (usually overnight). Pull out installation tool and retrieve to surface. The probe is bonded in place.*
6. *Overcore the Borre probe and record strain data using the built-in data logger. Break the core after completed overcoring and recover in core barrel to surface.*

In practice, it is difficult for the drilling contractor to maintain a constant rate throughout the overcoring process; hence, variations are almost always present. The coring advance was registered manually using a watch and markers on the drill string for every 4th cm up to 32 cm overcoring length, after as well as before completed overcoring (normally 100 cm length).

The borehole is left with only flushing continuing, for approximately 15 minutes after completed overcoring. After flushing stop, the borehole is left completely without on-going activities before the core is broken loose from the hole. This procedure ensures that sufficient strain data are recorded to assess temperature effects, possible non-ideal rock behaviour, etc, which may affect strain readings and measurement results adversely. After overcoring, the probe is recovered with the overcore sample inside the core barrel. Strain data are transferred from the data logger to a portable computer. The overcore sample is then mapped with respect to length, concentricity, gauge positions, lithology, structures, microcracks and other possible defects.

4.4.4 Biaxial testing

Biaxial testing of the overcored specimens is conducted to determine the elastic constants of the rock at the measurement position. Testing is carried out on-site as soon as possible after overcoring, using the equipment shown in Figure 4-2. The overcore sample must be at least 24 cm long, without fractures, for biaxial testing to be possible.

The test sequence comprises both loading and unloading in order to study possible inelastic behaviour of the rock. The sample is loaded to a maximum radial pressure of 10 MPa, in increments of 1 MPa, and then unloaded in the same manner. The strains induced in the overcore sample are monitored by the strain gauges installed by the *Borre* probe, using the built-in data logger of the probe. After completed test sequence, the *Borre* probe is disconnected from the overcore sample. Supplementary logging of the core is performed to check for potential new fractures. Inner and outer core diameter, as well as the annular thickness of the overcore sample, are also measured.

4.5 Data handling

The raw data include overcoring strain data files, biaxial strain data files, and completed check-lists and QA Report Forms from measurements. Routine data processing of measurement data involves importing the strain data file from overcoring into an in-house developed *Microsoft Excel* application for presenting overcoring strain response. Graphing of the strain response is performed automatically by the software application, and strain differences calculated based on input start- and stop-times for the overcoring process.

Similarly, the strain data file from biaxial testing is imported into the corresponding *Excel* application for presentation of biaxial test response and automatic calculation of elastic constants (Young's modulus and Poisson's ratio).

Calculation of stresses is carried out using another in-house developed *Microsoft Excel* application, with input in the form of strain differences, values on elastic constants, and borehole and recorded strain gauge orientation from the probe installation. The stress calculations are based on the theory presented by /Leeman 1968/. Calculation is performed for a single measurement, or for several successive measurements on one or several test levels, with automatic calculation of mean stresses for each level.

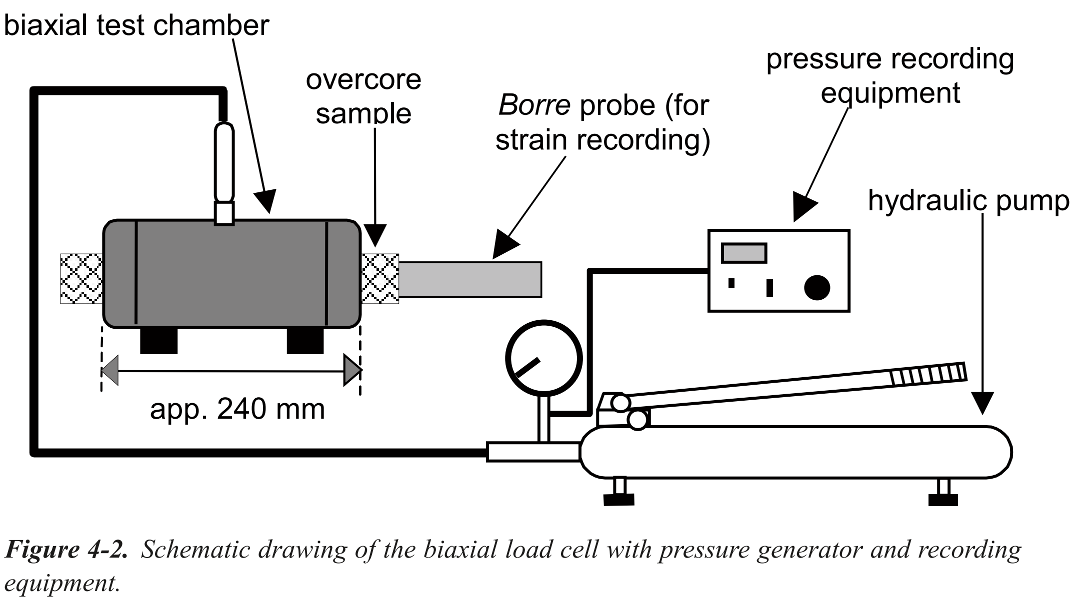


Figure 4-2. *Schematic drawing of the biaxial load cell with pressure generator and recording equipment.*

The primary data reported from the overcoring stress measurements are:

- magnitudes of the three principal stresses,
- orientations of the three principal stresses (bearing and dip),
- magnitudes and orientations of the stresses acting in the horizontal and vertical planes,
- values on elastic constants from biaxial testing.

4.6 Data analyses

4.6.1 Classical overcoring analysis and stress calculation

The *Borre* probe is a "soft" stress cell, which means that the stiffness of the strain gauges is negligible in comparison to the stiffness of the rock. Thus, only the strains induced by overcoring and the elastic constants of the rock, in addition to the orientation of the probe in the borehole (including borehole orientation), are required to determine the complete stress tensor. Calculation of stresses from strain is done under the assumption of continuous, homogeneous, isotropic, and linear-elastic rock behaviour /Leeman 1968/. The stress relief is identical in magnitude to that produced by the in situ stress field but opposite in sign.

The analyses of obtained test data comprise (i) analysis of overcoring strain data, (ii) analysis of biaxial test data, and (iii) stress calculation, using data from the first two tasks. For each task, quality control checks and data assessments are included. Detailed descriptions of each step are given in SKB MD 181.001 (SKB internal controlling document), and are briefly summarized below.

The recorded strain gauge response and temperature are plotted vs. recorded time, and the strain differences due to overcoring and stress relief are calculated for each strain gauge for later use as input to the stress calculation. The overcoring strain change is normally determined as the difference between (i) recorded strain after completed overcoring with flushing on, and (ii) recorded strain at the start of overcoring with flushing on. It is important that all conditions, except the overcoring stress relief itself, are as similar as possible for these two instances (e.g. flushing, water pressures, temperatures, etc). Furthermore, the strain values should be stable (little or negligible strain drift) at these instances. In some cases, stable and ideal strain response can be observed during the first portion (typically 20–30 cm) of the overcoring process, whereas significant strain drifts occur during the rest of the overcoring. In theory, practically all of the strain relief takes place during the first 24 cm of overcoring (with gauge positions at 16 cm), see e.g. /Hakala et al. 2003/. For such cases, strain differences may be determined from stable values of this portion of the strain response curve (corresponding to approximately 20–30 cm drill bit position or more). However, temperature effects (heating of the rock due to drilling) are more prevalent at this stage, which must be considered. It should also be noted that small changes in strains (a few µstrains), which may arise from choosing slightly different start- and stop-times for the overcoring, have very small influence on the calculated magnitudes and orientations of the in situ stress state.

Recorded strain and pressure data from biaxial testing are plotted and examined. Elastic constants are determined from recorded strain and pressure data from the biaxial testing. For this, the theory for an infinitely long, thick-walled circular cylinder subjected to uniform external pressure is employed (see e.g. /KTH 1990/). Since the *Borre* probe incorporates three pairs of circumferential and axial strain gauges, three pairs of elastic property-values are obtained from each biaxial test. The aim is to obtain rock parameters that apply to the relaxation experienced by the rock during overcoring. Therefore, the values of E (Young's modulus) and ν (Poisson's ratio) are taken to be secant values, calculated from strain data obtained during unloading of the core specimen. Usually, the secant values between the pressures of 8 and 3 MPa are calculated and averaged for the three strain rosettes. However, elastic constants may be calculated for other pressure intervals, if recorded strain readings are significantly unstable and/or display notable non-linearity for certain pressures.

Calculation of stresses from measured strains is based on the classical theory by /Leeman 1968/. The details of the formulation can also be found in e.g. /Amadei and Stephansson 1997/ and are not repeated here. Strain measurements from at least six independent directions are required to determine the stress tensor (which has six components). When all nine gauges of the *Borre* probe function properly during a measurement, redundant strain data are obtained. A least square regression procedure is used to find the solution best fitting all the strain data, from which the stress tensor components are calculated. For each test, one tangential or inclined gauge and/or two axial gauges may be rejected or recalculated without impairing the determination of the stress tensor. Recalculation is only performed if evidence of malfunctioning gauges exists, see also /Sjöberg and Klasson 2003/ and SKB MD 181.001 (SKB internal controlling document). Subsequently, the magnitude and orientation vector of each of the three principal stresses are calculated, as well as the stresses acting in the horizontal and vertical planes.

For the case of several measurements on one test level, the mean stress state is calculated. This is conducted by first taking the stress tensor components for each of the measurements (defined in a common coordinate system, e.g. the site coordinate system), and averaging each of the stress tensor components. From these mean values, the mean principal stresses, as well as the mean horizontal and vertical stresses, are determined. All calculated data are stored in Sicada, traceable by the Activity Plan number.

4.6.2 Transient strain analysis

A methodology for transient strain analysis of overcoring data was presented by /Hakala et al. 2003/. The methodology involves calculating the theoretical strains corresponding to a given stress field (by using pre-calculations from a three-dimensional numerical model). The theoretical strain response is calculated for the entire overcoring process and can thus subsequently be compared to the actual recorded strain response from the overcoring measurement.

The analysis can be used to assess whether the measured strain differences and calculated stresses are compatible. Larger deviations in terms of measured vs. calculated (theoretical) strains are indications of imperfect conditions at the time of measurements, e.g. debonding, microcracking, heterogeneities, anisotropy, etc. The analysis cannot, however, be used to detect systematic measurement errors.

Transient strain analysis was carried out using the computer code and methodology developed by /Hakala et al. 2003/, and described in more detail in /Hakala 2004, 2006/. For each test (measurement point), the reported stress state and accompanying field parameters were input to the transient strain analysis program. Transient and final strains were calculated and the final strains compared with the measured final strains. The strain differences (measured vs. calculated strains) were evaluated and the maximum difference calculated for each strain gauge as follows:

$$M\_diff_i = \frac{|(\varepsilon_i - \varepsilon\_calc_i)|}{\varepsilon\_amp_i},$$

$$\varepsilon\_amp_i = \varepsilon_{i,max} - \varepsilon_{i,min},$$

where

M_diff_i maximum strain difference for one of the strain gauges (*i*=1, 2,..9) (%),

ε_i measured strain for one of strain gauges (*i*=1, 2,..9),

ε_calc_i back-calculated strain from the calculated stress state for one of the strain gauges (*i*=1, 2,..9),

ε_amp_i amplitude for the calculated transient strain curve for one of strain gauges (*i*=1, 2,..9),

$\varepsilon_{i,max}$ maximum recorded strain value for one of strain gauges (*i*=1, 2,..9),

$\varepsilon_{i,min}$ minimum recorded strain value for one of strain gauges (i=1, 2,..9).

In addition, the amount of unexplained strain was calculated using the program. Initially, the strain differences from the measurement are used to calculate stresses, using the least-square regression procedure described in Section 4.4.1. The resulting stresses were then used to back-calculate the corresponding strains for each of the strain gauges of the probe. The amount of unexplained strain was defined as the sum of absolute differences between measured and calculated strains divided by sum of calculated strains, i.e. /Hakala et al. 2003/

$$AUS = \frac{\sum_{i=1}^{9} \left| \left(\varepsilon_i - \varepsilon\_calc_i \right) \right|}{\sum_{i=1}^{9} \varepsilon\_calc_i} ,$$

where

AUS amount of unexplained strain (%),

ε_i measured strain for each of the strain gauges (i=1, 2,..9), and

ε_calc_i back-calculated strain from the calculated stress state for each of the strain gauges (i=1, 2,..9).

A higher value on *AUS* indicates larger difference between measured and theoretical strain values. This value can thus be used to estimate the heterogeneity, anisotropy, reliability, or successfulness of measurements.

The stress path developing during the overcoring process was also calculated, including the maximum tensile stress acting on the overcore sample. A high value on the tensile stress is an indicator of high possibility of tensile damage of the rock during overcoring.

At this stage, no strength values have been presented from borehole KFM02B. Previous indirect tensile tests within the site investigation program yielded average tensile strengths of around 14 MPa with a standard deviation of about 2 MPa /SKB 2006/. Similarly, a comprehensive strength of 231 MPa was obtained /SKB 2006/. These values were used to define a failure criterion for the analysis.

It should be noted that only linear-elastic analysis is conducted; hence, very high tensile stresses can develop, which, in reality, would be limited as the strength of the rock is exceeded. The post-peak process and associated stresses and strains cannot be studied with this computer program.

Finally, the developed code has the capability to solve the in situ state of stress based on the measured transient or final strains /Hakala et al. 2003/, following the method presented by /Fouial et al. 1998/. This inverse solution enables, in theory, stresses to be determined from the early, pre-overcoring, strain response. The inverse solution is exact if calculated strain values and coring advance are exact. In reality, there are always errors associated with the measurements. /Hakala et al. 2003/ stated that for the inverse solution to be useful, coring advance must be measured with an accuracy of ± 1 mm, or better. This is clearly difficult to achieve in practice. During overcoring measurements in borehole KFM02B, overcoring was attempted at a constant rate for the different measurements. Manual registration of the coring advance was conducted for every 4th cm up to 32 cm overcoring length. However, the coring rate often proved to be varying due to practical constraints (variations in rock type, drill string extension, etc), thus resulting in varying error in the determination of coring advance. Consequently, in most cases, the local maxima and minima of the measured and theoretical strains, respectively, did not match perfectly. For such cases, the measured strain response curves were corrected to match the theoretical strains with respect to position/core advance, thus resulting in an improved inverse solution. The inverse solution was applied to selected measurements in KFM02B, as described in the following.

5 Results

5.1 Overview

Measurements were planned to be conducted at five measurement levels in borehole KFM02B. Measurement attempts were however restricted to four levels, out of which three measurement levels could be judged as having been completed successfully. Level 1 included measurements between 93 and 151 m borehole length (mbl). For Level 2, measurements were attempted between 156 and 181 mbl and for Level 3 between 217 and 256 mbl. Finally, Level 4 commenced with measurements at 300 m borehole length and stopped at 307 m borehole length. The planned measurements at c 350 mbl were excluded due to time restrictions.

A brief summary of conducted measurements is given in Table 5-1. All tests have been numbered as follows: *measurement level : test no. : pilot hole no.*. Thus, e.g. test 2:5:3 denotes measurement Level 2, test (or measurement) no. 5 at that level, and pilot hole no. 3 (to reach an acceptable measurement location for this test). Each test is presented with a rating reflecting successfulness and reliability of that particular measurement. Ratings were assigned per the following criteria:

Rating	Description and criteria
a	**Successful test** • Geometrical conditions achieved (strain gauges at correct position, etc). • Stable strain response prior to, and during, overcoring with minimal strain drift (strain change less than 10 µstrains per 15 min for undisturbed conditions). • No fractures and/or core disking observed in the overcore sample (at least 24 cm intact core). • Linear and isotropic (20–30% deviation acceptable) strain response during biaxial testing. Minor hysteresis (< 100 µstrains) accepted. • Stress calculation possible with classical analysis (Section 4.6.1). Values on elastic constants may be assumed from nearby tests if biaxial test data are lacking, and all other criteria above are satisfied.
b	**Partly successful test** • Signs of debonding but fairly stable strain response up until peak value (typically at 24–30 cm drill bit position). • Stress calculation possible with classical analysis (Section 4.6.1) but results judged uncertain and/or less reliable. • Additional stress determination may be conducted using inverse solution of transient strain analysis (Section 4.6.2).
c	**Failed test** • Installation failed or incomplete. • Debonding of strain gauges and/or large strain drift. • Fractures/joints detected in overcore sample.

Table 5-1. General test data from measurements in borehole KFM02B, Forsmark.

Test no. (pilot hole no. *)	Hole length [m]	Vertical depth [m] **)	Over-coring	Biaxial testing	Transient strain analysis	Rating	Comments
1:1:1	93.41	92.18	Yes	Yes	No	c	Problems with the wireline system of the drill rig, installation failed.
1:2:1	94.44	93.20	Yes	Yes	No	c	Problems with the wireline system of the drill rig, resulted in indistinct installation.
1:3:1	95.48	93.24	Yes	No	No	c	Successful installation, but biaxial test failed. Somewhat unstable strain response during overcoring.
1:4:1	96.48	95.21	Yes	Yes	No	c	Successful installation, but a lot of drill cuttings preventing good bonding. Somewhat unstable strain response during overcoring and biaxial test.
1:5:1	97.59	96.31	No	No	No	c	The *Borre* probe was damaged due to drill machine problems.
1:6:3	104.05	102.69	No	No	No	c	Drill machine problems.
1:7:1	113.74	112.25	Yes	Yes	Yes	b	Successful installation. Stable strain response during overcoring.
1:8:3	116.75	115.22	No	No	No	c	The adapter did not release. Large amounts of sand and gravel above and inside the pilot hole.
1:9:5	126.48	124.82	Yes	Yes	No	c	Successful installation. Unstable strain response before/during overcoring.
1:10:4	131.74	130.01	Yes	Yes	No	c	Installation partly failed, strain gauges pressed too hard, indications of too high installation velocity.
1:11:1	132.57	130.83	No	No	No	c	Installation failed. The adapter did not release the *Borre* probe. However, the installation tool released the probe easily on surface. Something probably prevented the installation tool to properly reach the bottom of the hole.
1:12:1	132.60	130.86	Yes	Yes	No	c	Planing and pilot drilling to a depth 3 cm below test 1:11:1. Successful installation, but very unstable strain response during both overcoring and biaxial test.
1:13:3	135.80	134.02	Yes	Yes	Yes	b	Successful installation. Stable strain response during overcoring, but low strain recorded.
1:14:1	136.58	134.79	Yes	Yes	No	c	Successful installation, but unstable strain response during overcoring due to fracture intersecting the hollow core. This fracture was not visible on pilot core.
1:15:4	140.18	138.34	Yes	Yes	No	c	Successful installation, but large strain drift during overcoring and unstable response during biaxial test due to fracture intersecting the hollow core. This fracture was not visible on pilot core.

Test no. (pilot hole no. *)	Hole length [m]	Vertical depth [m] **)	Over-coring	Biaxial testing	Transient strain analysis	Rating	Comments
1:16:1	141.44	139.58	Yes	Yes	No	c	Successful installation, but a lot of drill cuttings. Somewhat drifting and unstable strain response during overcoring and biaxial test. Signs of debonding.
1:17:2	144.17	142.28	Yes	Yes	Yes	b	Successful installation, but a lot of drill cuttings. Somewhat drifting and unstable strain response during overcoring and biaxial test.
1:18:3	150.85	148.87	Yes	Yes	No	c	Successful installation, but a lot of drill cuttings. Somewhat drifting and unstable strain response during overcoring and biaxial test.
2:1:3	156.72	154.66	Yes	Yes	Yes	a	Successful installation. Stable strain response during overcoring but some strain drift after passing the position of the strain gauges.
2:2:1	159.67	157.57	Yes	Yes	No	c	Successful installation. Stable strain response during overcoring but some strain drift after passing the position of the strain gauges. Large amounts of small gravel on top of the core, around and on the gauges.
2:3:4	164.10	161.94	Yes	Yes	Yes	b	Successful installation. Stable strain response during overcoring but some strain drift after passing the position of the strain gauges.
2:4:1	165.66	163.48	Yes	Yes	No	c	Successful installation but unstable strain response during overcoring.
2:5:3	172.93	170.65	No	No	No	c	Strain gauges not properly installed, debonding.
2:6:2	178.03	175.68	Yes	Yes	Yes	b	Successful installation. Stable strain response during overcoring but some strain drift after passing the position of the strain gauges.
2:7:2	179.87	177.49	Yes	Yes	Yes	b	Successful installation. Stable strain response during overcoring but some strain drift after passing the position of the strain gauges.
2:8:1	180.90	178.51	Yes	Yes	No	c	Successful installation but unstable strain response during overcoring.
3:1:1	217.06	214.15	Yes	Yes	No	c	Installation partly successful but strain gauges suffer from debonding. Sign of gravel on the inside the pilot hole, probably causing debonding.
3:2:1	218.02	215.10	Yes	Yes	No	c	Installation successful but some strain gauges have clear signs of debonding although the strain gauges were well glued.
3:3:1	218.95	216.02	Yes	Yes	No	c	Installation successful but some strain gauges have clear signs of debonding although the strain gauges were very well glued.
3:4:2	220.79	217.83	Yes	Yes	No	c	Installation failed, strain gauges damaged and showed sign of debonding. Easy to dismantle from the rock.

Test no. (pilot hole no. *)	Hole length [m]	Vertical depth [m] **)	Over-coring	Biaxial testing	Transient strain analysis	Rating	Comments
3:5:2	227.97	224.91	Yes	Yes	No	c	Installation successful but some strain gauges showed clear signs of debonding. Strain rosettes nos. 1 and 2 were well glued, rosette no. 3 however not.
3:6:2	231.06	227.96	Yes	Yes	No	c	Installation partly failed, two rosettes were not well glued, and something had prevented a good installation. The gauges were covered with some drill cuttings.
3:7:1	232.31	229.19	Yes	Yes	No	c	Installation failed, all rosettes showed clear signs of debonding.
3:8:3	235.59	232.42	Yes	Yes	No	c	Installation successful but all rosettes showed clear signs of debonding and had a fine layer of dust on the surface.
3:9:2	238.11	234.91	Yes	Yes	No	c	Installation partly failed; all rosettes not well glued; something had prevented a good installation. The gauges had some drill cuttings on the surface.
3:10:1	239.28	236.06	Yes	Yes	No	c	Installation successful but all rosettes showed clear signs of debonding and had a fine layer of dust on the surface.
3:11:2	241.22	237.97	Yes	Yes	No	c	Installation partly failed; all rosettes not well glued; something had prevented a good installation. The gauges had some drill cuttings on the surface.
3:12:4	246.31	242.99	Yes	Yes	No	c	Installation successful but some strain gauges showed clear signs of debonding. Strain rosettes nos. 1 and 2 were well glued, rosette no. 3 however not.
3:13:1	247.43	244.10	Yes	No	No	c	Installation partly failed; all rosettes not well glued, something had prevented a good installation. The gauges had some drill cuttings on the surface. Steeply dipping fracture intersects the core.
3:14:1	248.41	245.06	Yes	Yes	No	c	Installation successful but all rosettes provided small responses and had a fine layer of dust on the surface, but were glued hard to the rock surface. Biaxial tests showed clear signs of debonding.
3:15:1	249.75	246.38	Yes	Yes	No	c	Installation successful but all rosettes gave small responses and had a fine layer of dust on the surface, but were glued hard to the rock surface. Biaxial tests showed clear signs of debonding.
3:16:1	250.88	247.50	Yes	Yes	No	c	Installation successful but all rosettes provided small and unstable responses. All gauges were clean on the surface, and were glued hard to the rock. Biaxial tests showed unrealistic response.

Test no. (pilot hole no. *)	Hole length [m]	Vertical depth [m] **)	Over-coring	Biaxial testing	Transient strain analysis	Rating	Comments
3:17:1	251.86	248.46	No	No	No	c	Installation failed, all rosettes not well glued, something had prevented a good installation. The strain rosettes had some drill cuttings on the gauges.
3:18:1	252.83	249.42	Yes	Yes	Yes	b	Installation successful, gauges were very well glued to the rock surface. Some unstable strain response and strain drift after the drill bit passed the position of strain gauges. Biaxial tests gave relatively stable strain response.
3:19:1	253.77	250.35	Yes	Yes	Yes	a	Installation successful, gauges were very well glued to the rock surface. Some strain drift after the drill bit passed the position of strain gauges. Biaxial tests resulted in relatively stable strain responses.
3:20:1	254.71	251.27	Yes	Yes	No	c	Installation successful, gauges very well glued to the rock surface. Some unstable strain response and strain drift after the drill bit passed the strain gauges. Biaxial tests gave unrealistic but relatively stable strain response. Signs of debonding.
3:21:1	256.13	252.67	Yes	Yes	Yes	a	Installation successful, gauges very well glued to the rock surface. Some strain drift after the drill bit passed the strain gauges. Biaxial tests gave relatively stable strain response.
4:1:1	300.07	295.99	Yes	Yes	No	c	Successful installation. Stable strain response during overcoring. Rosette no 2 was unstable (debonding) after overcoring.
4:2:1	301.22	297.12	Yes	Yes	No	c	Successful installation. Large strain drift after the drill bit passed the strain gauges.
4:3:1	302.33	298.22	Yes	Yes	Yes	a	Successful installation. Some strain drift after the drill bit passed the strain gauges.
4:4:1	303.30	299.17	Yes	Yes	No	c	Installation failed, the rosettes not well glued.
4.5:1	304.22	300.08	Yes	Yes	No	c	Installation failed, strain gauges not properly installed, debonding.
4:6:1	305.16	301.01	Yes	Yes	No	c	Successful installation. Unstable strain response during overcoring and large strain drift.
4:7:1	306.20	302.03	Yes	Yes	Yes	b	Successful installation. Some strain drift after the drill bit passed the strain gauges. Rosette no 1 was unstable after overcoring.
4:8:1	307.06	302.88	Yes	Yes	Yes	b	Successful installation but some strain drift during overcoring, one gauge indicated drift.

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*

**) vertical depth (below ground surface) interpolated from borehole orientation measurements (every three metres)

Borehole orientations for the measurement depths in question are shown in Table 5-2, as measured after completed drilling of the hole. Inclination, bearing and vertical depth at measuring points are calculated from given borehole orientation data measured with the "Flexit"-unit, data given to Vattenfall Power Consultant in March 2007. These orientation data were used in the stress calculations described below, together with the recorded orientations of the installed *Borre* probe.

5.2 Overcoring test data

Results from all tests with ratings *a* and *b* in Table 5-1 are presented in the following and in Appendices A through G. Key measurement data (recorded times for borehole activities) for these tests are presented in Appendix A. Furthermore, core logs and photos are presented in Appendices F and G. The core logs were conducted during the field campaign.

The strain response for each test is shown in Appendix B. Each test is presented with two plots displaying (i) the complete strain record (from activation of probe to core recovery), and (ii) the strain response from overcoring start to end of strain registration (core recovered from borehole). The latter was used to define strain differences for later input to stress calculation. The times for which the strain differences have been determined are shown in Appendix A (bottom of table for each test). The actual times for which the overcoring has been performed are shown together with recorded times for the drill bit passing the position of the strain gauges, and the core break in the Figures in Appendix B.

5.2.1 Measurement Level 1

A total of eighteen installations were attempted at the first measurement level in borehole KFM02B. During installation and overcoring of the tests, a number of installation problems occurred. Four tests completely failed (1:1:1, 1:2:1, 1:5:1 and 1:6:3) due to drill rig problems. One test failed (1:8:3) because the adapter did not release the *Borre* probe properly due to large amounts of sand and gravel at the bottom of the 76 mm hole and inside the pilot hole. Also test no. 1:11:1 failed due to some obstacle preventing the installation tool to properly release the *Borre* probe. One test (1:10:4) failed because the strain gauges were pressed too hard against the pilot hole, an indication of too high installation velocity. Four tests (1:4:1, 1:16:1, 1:17:2 and 1:18:3) had successful installations but with a larger amounts of drill cuttings in the pilot hole, preventing good bonding. Test no 1:17:2 suffered less from drill cuttings and showed the least influence of debonding of these four tests. Tests nos. 1:14:1 and 1:15:4 failed due to fractures intersecting the hollow core (which were not visible on the pilot core). Out of all eighteen installations, only three partially successful tests (1:7:1, 1:13:3 and 1:17:2) were obtained. The test level was completed (unsuccessfully) when the drilling reached the depth for the planned second measurements level. The decision to finish this level was made in agreement between the field crew and the Client. The measured temperature increased in the probe during overcoring by 2–3°C, but returned to pre-overcoring level after completed overcoring and flushing.

5.2.2 Measurement Level 2

In total, eight measurements were performed at this level. One successful test (2:1:3) and three partially successful tests (2:3:4, 2:6:2, and 2:7:2) were obtained. For the three latter tests, the main reason for not achieving *a*-rating is strain drift after the drill bit having passed the strain gauges, as well as somewhat scattered responses from the strain gauges during the biaxial testing. The unsuccessful tests (2:2:1, 2:4:1, 2:5:3, 2:8:1) suffered mainly from drill cuttings preventing good bonding and unstable strain response during overcoring. At this level the measured temperature increase in the probe during overcoring was between 3–4°C, but returned to 1–2°C above pre-overcoring temperature after completed overcoring and flushing.

Table 5-2. Borehole orientation for overcoring measurement points in borehole KFM02B. Orientations determined by linear interpolation between each measured section (at 3 m distances).

Level no.	Test no. (pilot hole no. *)	Hole length [m]	Borehole bearing [°] **)	Borehole dip [°] ***)
1	1:1:1	93.41	311.03	80.85
1	1:2:1	94.44	311.01	80.85
1	1:3:1	95.48	311.01	80.85
1	1:4:1	96.48	310.98	80.85
1	1:5:1	97.59	310.98	80.85
1	1:6:3	104.05	310.85	80.83
1	1:7:1	113.74	311.11	80.70
1	1:8:3	116.75	311.17	80.69
1	1:9:5	126.48	311.41	80.66
1	1:10:4	131.74	311.57	80.66
1	1:11:1	132.57	311.58	80.66
1	1:12:1	132.60	311.59	80.68
1	1:13:3	135.80	311.64	80.67
1	1:14:1	136.58	311.65	80.67
1	1:15:4	140.18	311.68	80.65
1	1:16:1	141.44	311.69	80.64
1	1:17:2	144.17	311.68	80.63
1	1:18:3	150.85	311.62	80.59
2	2:1:3	156.72	311.70	80.51
2	2:2:1	159.67	311.82	80.51
2	2:3:4	164.10	311.97	80.49
2	2:4:1	165.66	311.98	80.48
2	2.5:3	172.93	312.02	80.46
2	2:6:2	178.03	312.29	79.54
2	2:7:2	179.87	312.33	80.42
2	2:8:1	180.90	312.33	80.41
3	3:1:1	217.06	312.84	80.37
3	3:2:1	218.02	312.76	80.29
3	3:3:1	218.95	312.67	80.29
3	3:4:2	220.79	312.77	80.31
3	3:5:2	227.97	313.24	80.38
3	3:6:2	231.06	313.57	80.41
3	3:7:1	232.31	313.57	80.41
3	3:8:3	235.59	313.55	80.41
3	3:9:2	238.11	313.61	80.40
3	3:10:1	239.28	313.76	80.40
3	3:11:2	241.22	313.74	80.39
3	3:12:4	246.31	313.69	80.37
3	3:13:1	247.43	313.54	80.37
3	3:14:1	248.41	313.42	80.37
3	3:15:1	249.75	313.34	80.37
3	3:16:1	250.88	313.34	80.37
3	3:17:1	251.86	313.34	80.37
3	3:18:1	252.83	313.32	80.37
3	3:19:1	253.77	313.29	80.37

Level no.	Test no. (pilot hole no. *)	Hole length [m]	Borehole bearing [°] **)	Borehole dip [°] ***)
3	3:20:1	254.71	313.26	80.37
3	3:21:1	256.13	313.10	80.36
4	4:1:1	300.07	314.02	80.32
4	4:2:1	301.22	314.02	80.32
4	4:3:1	302.33	314.02	80.32
4	4:4:1	303.30	313.98	80.32
4	4.5:1	304.22	313.88	80.32
4	4:6:1	305.16	313.78	80.32
4	4:7:1	306.20	313.71	80.33
4	4:8:1	307.06	314.02	80.32

*) numbering scheme: (measurement level : test no. : pilot hole no.)

**) clockwise from geographic North

***) positive downwards from the horizontal

5.2.3 Measurement Level 3

Twenty-one measurements were attempted, and two tests (3:19:1 and 3:21:1) were judged successful and one partly successful (test no. 3:18:1). Both the successful and the partly successful tests displayed some strain drift after the drill bit having passed the position for the strain gauges and during the biaxial test. The main reason for the partly successful tests not obtaining an *a*-rating is strain drift after the drill bit passed the strain gauges. Test no. 3:18:1 indicated somewhat more unstable responses from some gauges compared to the two successful tests. The majority of the tests with successful installation but with *c*-ratings suffered from debonding due to gravel, drill cuttings or a fine dust, at the bottom of the 76 mm borehole or inside the pilot hole. Five tests (3.2:1, 3:3:1, 3:14:1, 3:15:1, and 3:16:1) were glued very firmly against the pilot hole wall but still showed clear signs of debonding. At this level, the measured temperature increased in the probe during overcoring by between 2–2.5°C, but returned to 1°C above pre-overcoring temperature after completed overcoring and flushing.

5.2.4 Measurement Level 4

At this level, eight measurements were performed, and one test (4:3:1) was judged successful and two partly successful (tests nos. 4:7:1 and 4:8:1). All other successfully installed tests (4:1:1, 4:2:1 and 4:6:1) showed signs of debonding and instability. Tests nos. 4:4:1 and 4:5:1 were not successful. All successful and partly successful tests displayed some strain drift after the drill bit having passed the position for the strain gauges. At this level, the measured temperature increased in the probe during overcoring by between 2–3°C but returned to 0.5–1°C above pre-overcoring temperature after completed overcoring and flushing.

5.3 Biaxial test data

All suitable overcore rock samples were tested in the biaxial cell to determine the elastic properties. For Level 1, only one test was successfully conducted, namely test no. 1:7:1, which had stable and linear strain response, whereas tests nos. 1:13:3 and 1:17:2 provided unstable and extremely high values of Young's modulus and Poisson's ratio. Some strain gauges at test 1:7:1 also gave unrealistically high values of both Young's modulus and Poisson's ratio, although all gauges showed stable responses. For that reason, rosettes nos. 2 and 3 were excluded when evaluating the elastic constants from test no 1:7:1.

Also at Level 2, only one test could be considered successful, namely test no. 2:1:3, which exhibited stable and linear strain response, while tests nos. 2:3:4, 2:6:2, and 2:7:2 yielded extremely high and unstable values of Young's modulus and Poisson's ratio. Some strain gauges at test 2:1:3 indicated unrealistically high values of both Young's modulus and Poisson's ratio, although all gauges displayed stable responses. Consequently, rosette no. 1 was excluded when evaluating the elastic constants from test no 2:1:3.

At Level 3, Test no. 3:18:1 showed stable and linear strain response, except for rosette no. 3, which was excluded when evaluating the elastic constants. Tests nos. 3:19:1, and 3:21:1 exhibited stable and linear strain response. However, some scatter of the strain response between the strain gauges was observed. When determining the elastic properties, rosettes nos. 2 and 3 were excluded from test no. 3:19:1 due to unrealistically high Poisson's ratio.

Finally, for Level 4, tests nos. 4:3:1 and 4:8:1 demonstrated stable and linear strain responses, while test no. 4:7:1 provided unstable and unrealistically high values of both Young's modulus and Poisson's ratio.

The results from biaxial testing on *a*- and *b* rated overcore samples from borehole KFM02B are summarised in Table 5-3.

5.4 In situ stress state

The in situ stress state was calculated using: (i) the measured strain response (difference between strain gauge readings after and prior to overcoring), (ii) recorded orientation of strain gauge rosettes in the borehole, and (iii) values on elastic constants determined from biaxial testing. Strain differences were determined from stable strain values before overcoring vs. stable values after completed overcoring. For tests with post-overcoring response with strain drift, the final strain values were taken at the end of the flushing period (just before core break) to minimize the possible influence of temperature on the strain readings (cf. Appendix A in which the times for which strain differences were calculated are given for each test).

The mean stresses were calculated from all successful (rating *a*) and partly successful (rating *b*) measurements at Levels 1, 2, 3, and 4.

For the majority of measurements there is a general strain drift in the post-overcoring response from the strain gauges. After completed overcoring and during the following flushing period, this general strain drift decreases to a stable value before the flushing period is over.

Due to what seems to be a temperature influence on the measurements, the strain values for determining the stresses for Level nos. 1 through 4 have been selected from an extended time interval. The start values for determining the stresses ("OC Start") have been chosen slightly before the start of overcoring but after start of flushing, and the stop values ("OC Stop") have been chosen after completed overcoring but slightly before the end of flushing. This was done in order to use start-stop values for determining the strain differences for constant physical conditions and with as small effect as possible from the temperature increase related to drilling.

The resulting stresses for each test, as well as the mean values for Levels 1, 2, 3 and 4, are shown in Appendix D, and in Table 5-4 through Table 5-6. All orientations are given relative to geographic North. Orientations of the principal stresses are also shown in Figure 5-1 to Figure 5-4 for Level 1 through 4. All original data are stored in the SKB database Sicada.

The calculated stresses for Level 1 showed a large scatter of the magnitude of the principal stresses between the measurements as well as for the orientations of the major principal stresses. Both tests nos. 1:7:1 and 1:13:3 also resulted in extremely low or negative values for the vertical stress. For test no. 1:17:2 the vertical stress is in agreement with the theoretical vertical stress determined from overburden weight. It must be considered that none of all tests at Level 1 was judged as an *a*-rated test.

Table 5-3. Results from biaxial testing on a- and b rated overcore samples from borehole KFM02B.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	Young's modulus, *E* [GPa]	Poisson's ratio, ν
1	1:7:1	113.74	78.0	0.33
1	1:13:3[1)]	135.80	N/A	N/A
1	1:17:2[1,2)]	144.17	N/A	N/A
2	2:1:3	156.72	89.7	0.40
2	2:3:4[1)]	164.10	N/A	N/A
2	2:6:2[1,2)]	178.03	N/A	N/A
2	2:7:2[1,2)]	179.87	N/A	N/A
3	3:18:1	252.83	95.8	0.38
3	3:19:1	253.77	78.5	0.34
3	3:21:1	256.13	77.2	0.34
4	4:3:1	302.33	95.7	0.40
4	4:7:1[1)]	306.20	N/A	N/A
4	4:8:1	307.06	67.2	0.24

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*

[1]**)** extremely high (and unrealistic) values of Young's modulus and Poisson's ratio

[2]**)** unstable strain response

The calculated mean principal stresses for Level 2 were moderate but with large scatter between the measurements. For tests no 2:1:3 the determined major horizontal stress is almost equal to the determined vertical stress. Tests nos. 2:3:4 and 2:6:2 provided low calculated horizontal and vertical stresses, whereas test no. 2:7:2 gave high calculated horizontal stresses and a vertical stress close to the theoretical value due to the overburden pressure. The measured bearing of the principal stresses was quite consistent for all tests, while the dip varied significantly between the tests.

The calculated stresses for Level 3 were moderate to moderately high and consistent. Only test 3:18:1 diverged somewhat in terms of magnitude of the major horizontal stress compared to tests nos. 3:19:1 and 3:21:1. Test no 3:18:1 showed a vertical stress close to the theoretical value due to the overburden pressure, whereas the remaining two tests indicated low vertical stress. The measured bearing was very consistent. The dip was considerably lower for two calculated principal stresses compared to Level 2, i.e. indicating a more horizontal vertical stress field.

The calculated principal stresses at Level 4 were very consistent and with small scatter in both magnitude and orientation. The calculated major and minor horizontal stresses were also very consistent. Tests 4:8:1, 4:3:1, and 4:7:1 indicated a low vertical stress compared to the theoretical vertical stress determined from the weight of the overburden.

Confidence intervals were calculated for the measurement results using the methodology proposed by /Walker et al. 1990/ and a newly developed computer code (described in /Lindfors et al. 2005/). Confidence intervals were determined for both magnitudes and orientations of the principal stresses at Level 1 to 4, as well as for the horizontal and vertical stress components. In this report, only the 90%-confidence intervals are presented, see Appendix H.

Observations of core disking can be used to estimate the virgin stress state. The methodology by /Hakala 1999ab/ can be utilized for this purpose. However, this methodology is developed for overcore samples with 62 mm outer diameter (i.e. normal overcoring diameter for stress measurements). The observed core disking in KFM02B was found for an overcoring diameter of 50 mm. Since a thin-walled cylinder is more susceptible to damage, stresses would be overestimated if normal overcoring diameter was assumed, and no stress estimation was thus conducted.

Table 5-4. Magnitudes of principal stress as determined by overcoring in borehole KFM02B.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	Vertical depth [m]	σ_1 [MPa]	σ_2 [MPa]	σ_3 [MPa]
1	1:7:1	113.74	112.25	10.8	4.8	–1.0
1	1:13:3	135.80	134.02	8.8	–0.4	–6.9
1	1:17:2	144.17	142.28	15.1	4.9	2.3
1	Mean	–	–	10.1	3.9	–1.2
2	2:1:3	156.72	154.66	13.7	11.9	3.4
2	2:3:4	164.10	161.94	8.3	5.1	–0.2
2	2:6:2	178.03	175.68	10.4	4.3	–3.3
2	2:7:2	179.87	177.49	20.0	9.5	4.9
2	Mean	–	–	12.7	5.2	4.2
3	3:18:1	252.83	249.42	21.3	11.8	5.4
3	3:19:1	253.77	250.35	15.9	11.7	1.1
3	3:21:1	256.13	252.67	16.6	8.7	1.0
3	Mean	–	–	17.9	10.7	2.6
4	4:3:1	302.33	298.22	16.3	8.1	3.8
4	4:7:1	306.20	302.03	14.3	5.8	3.3
4	4:8:1	307.06	302.88	14.4	7.6	0.7
4	Mean	–	–	14.2	6.7	3.9

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*

Table 5-5. Orientations of principal stress as determined by overcoring in borehole KFM02B.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	Vertical depth [m]	σ_1 Trend/Plunge [°]	σ_2 Trend/Plunge [°]	σ_3 Trend/Plunge [°]
1	1:7:1	113.74	112.25	114/06	021/26	216/63
1	1:13:3	135.80	134.02	167/20	073/13	312/66
1	1:17:2	144.17	142.28	126/15	219/11	343/72
1	Mean	–	–	134/15	043/04	299/75
2	2:1:3	156.72	154.66	138/59	358/25	260/17
2	2:3:4	164.10	161.94	132/26	226/09	333/62
2	2:6:2	178.03	175.68	155/14	263/50	054/36
2	2:7:2	179.87	177.49	153/12	247/19	033/67
2	Mean	–	–	155/19	262/42	046/42
3	3:18:1	252.83	249.42	128/05	220/30	030/59
3	3:19:1	253.77	250.35	139/10	232/14	015/72
3	3:21:1	256.13	252.67	130/10	224/18	012/69
3	Mean	–	–	131/08	224/20	020/68
4	4:3:1	302.33	298.22	296/02	205/43	028/47
4	4:7:1	306.20	302.03	324/07	094/79	233/09
4	4:8:1	307.06	302.88	281/03	190/05	039/84
4	Mean	–	–	303/03	212/17	041/73

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*

Table 5-6. Horizontal and vertical stress components calculated from measured principal stresses in borehole KFM02B.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	Vertical depth [m]	σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
1	1:7:1	113.74	112.25	10.7	3.7	0.2	115.6
1	1:13:3	135.80	134.02	7.1	–0.8	–4.8	171.0
1	1:17:2	144.17	142.28	14.2	4.8	3.2	125.1
1	Mean	–	–	9.4	3.8	–0.5	134.8
2	2:1:3	156.72	154.66	12.2	4.3	12.5	167.9
2	2:3:4	164.10	161.94	6.8	4.9	1.6	120.0
2	2:6:2	178.03	175.68	9.9	–0.6	2.0	149.9
2	2:7:2	179.87	177.49	19.5	9.0	6.0	151.3
2	Mean	–	–	11.8	4.7	5.5	153.4
3	3:18:1	252.83	249.42	21.2	10.1	7.1	126.5
3	3:19:1	253.77	250.35	15.5	11.0	2.2	133.3
3	3:21:1	256.13	252.67	16.2	7.9	2.3	127.1
3	Mean	–	–	17.6	9.7	3.9	128.0
4	4:3:1	302.33	298.22	16.3	6.1	5.8	116.4
4	4:7:1	306.20	302.03	14.2	3.3	5.9	143.9
4	4:8:1	307.06	302.88	14.4	7.5	0.8	101.0
4	Mean	–	–	14.1	6.5	4.2	123.1

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*

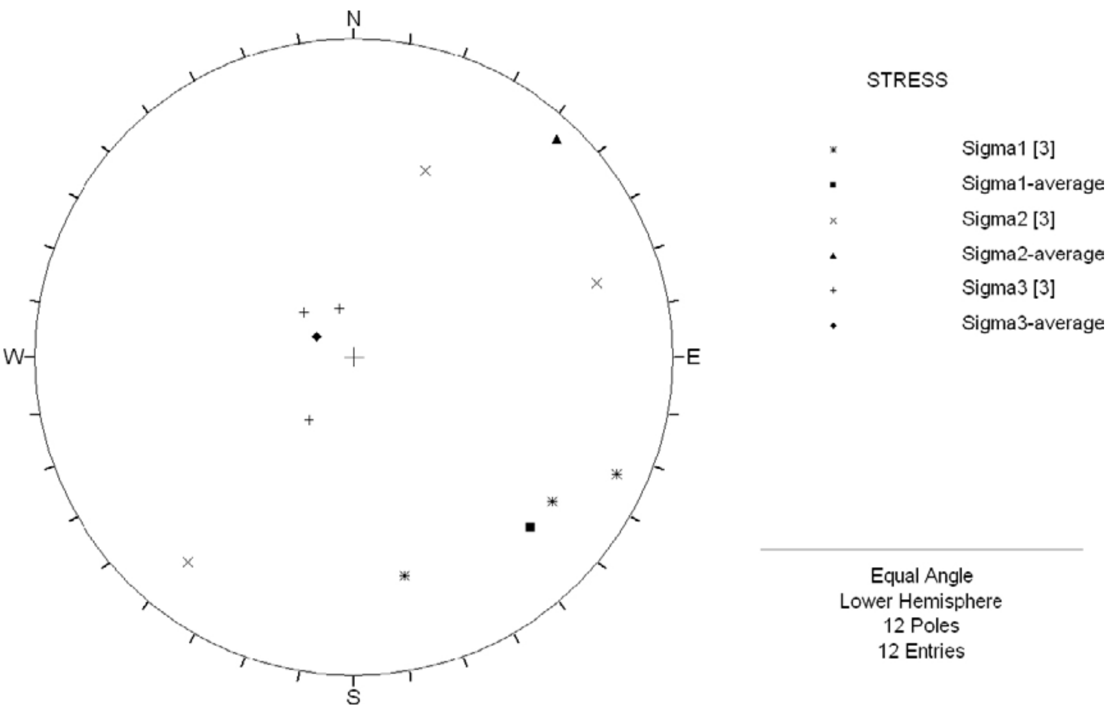


Figure 5-1. *Orientations of measured principal stresses in borehole KFM02B, Level 1, shown in a lower hemisphere projection (all measurements with ratings a and b; no measurements with rating a, cf. Table 5-1).*

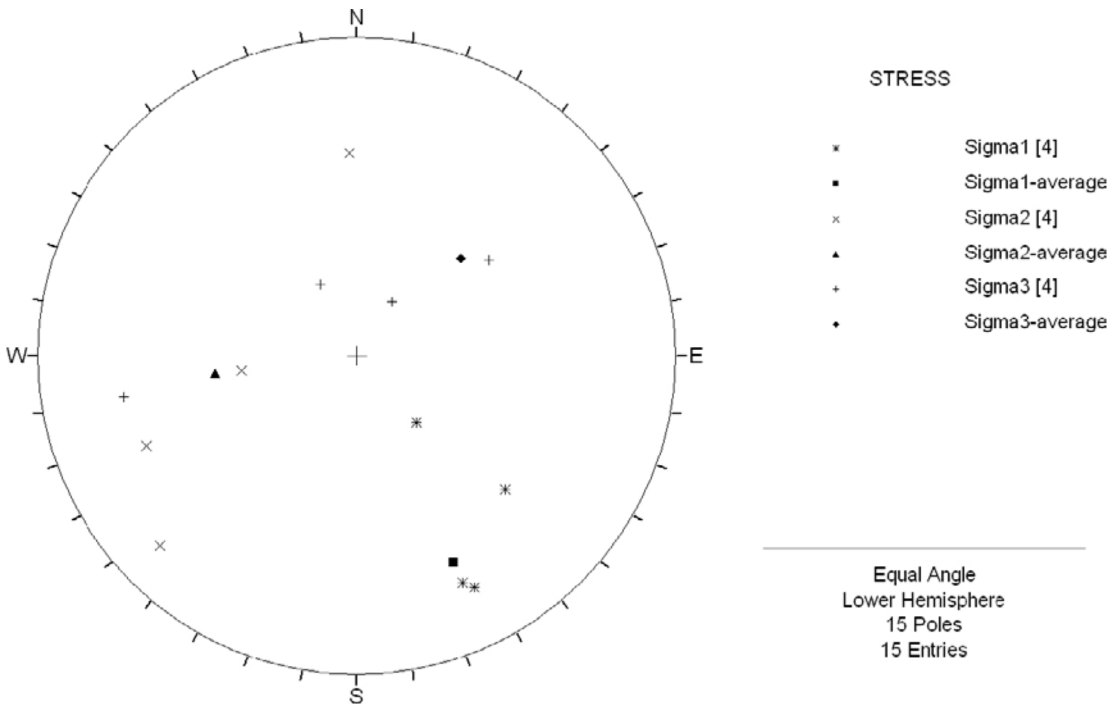


Figure 5-2. *Orientations of measured principal stresses in borehole KFM02B, Level 2, shown in a lower hemisphere projection (all measurements with ratings a and b; only one measurement with rating a, cf. Table 5-1).*

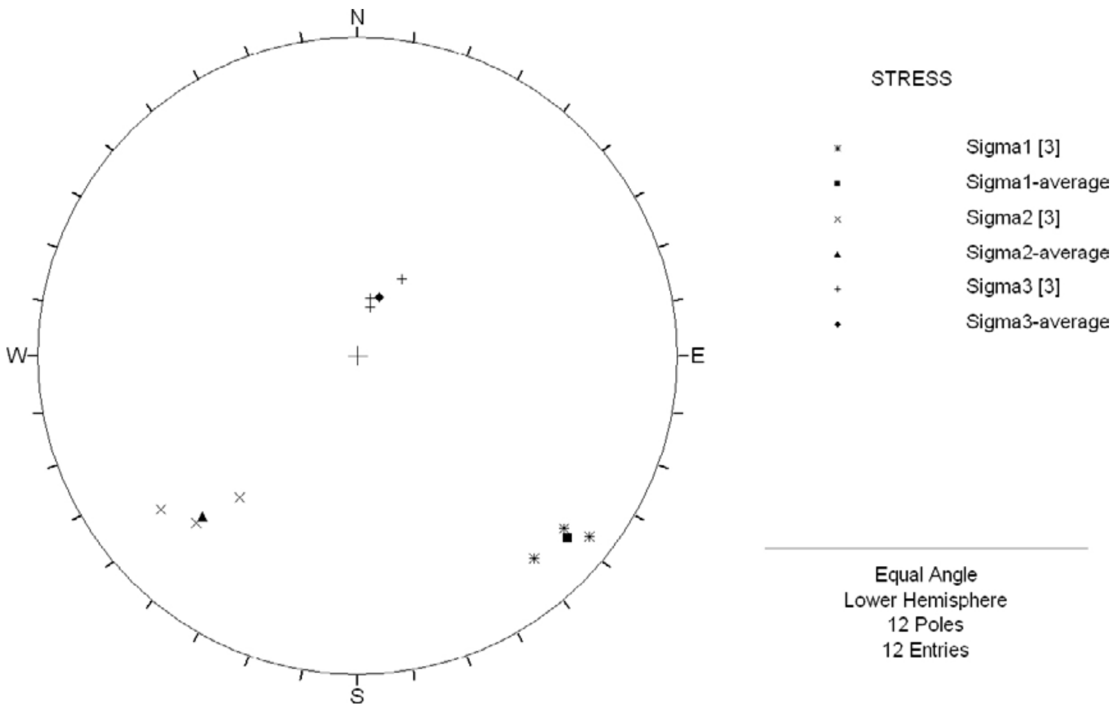


Figure 5-3. *Orientations of measured principal stresses in borehole KFM02B, Level 3, shown in a lower hemisphere projection (all measurements with ratings a and b; only two measurement with rating a, cf. Table 5-1).*

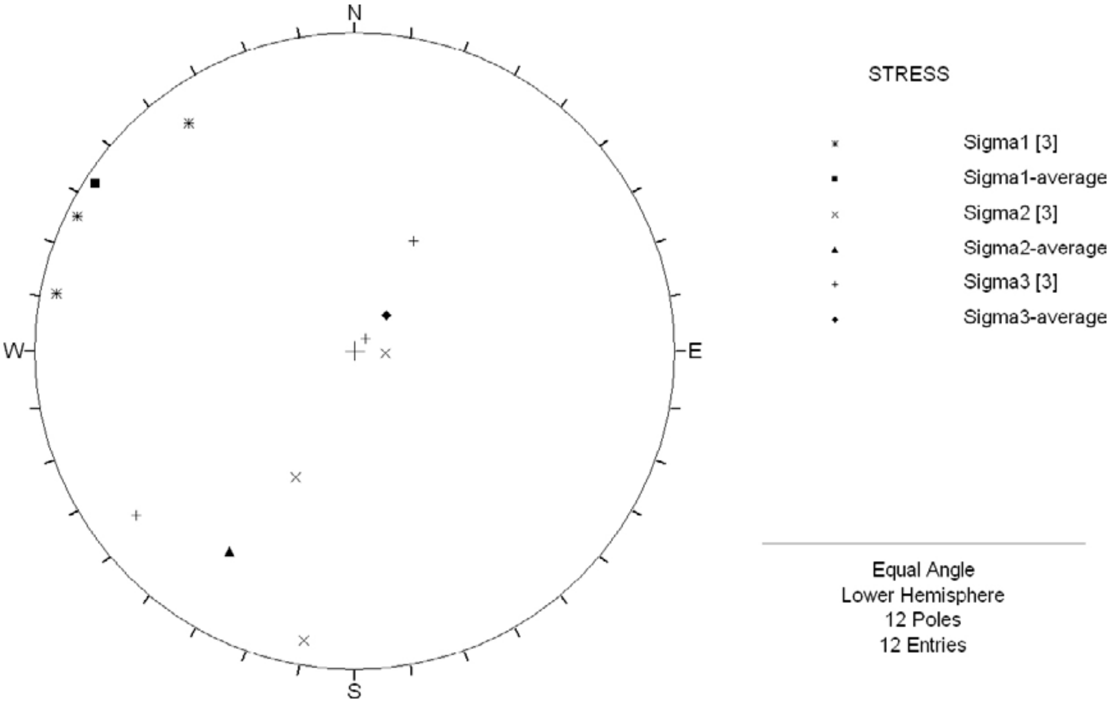


Figure 5-4. *Orientations of measured principal stresses in borehole KFM02B, Level 4, shown in a lower hemisphere projection (all measurements with ratings a and b; only one measurement with rating a, cf. Table 5-1).*

5.5 Transient strain analysis

5.5.1 Transient strain response

Transient strain analysis was conducted for all tests with ratings *a* and *b* from Levels 1, 2, 3 and 4 (see Table 5-1). The resulting calculated strain differences (compared to measured strains), amount of unexplained strain, and maximum tensile stress are shown in Appendix E.

For Level 1, a comparison between measured and theoretical strains shows a significant deviation (see Figure 5-5). The lowest amount of final unexplained strains at Level 1 was found for test no. 1:7:1 being 41%, which is very high. Test no. 1:7:1 was also the only test where the maximum tensile stress (12 MPa) was determined to be lower than the defined failure criterion, 14 MPa. The remaining successful tests at this level exceeded the defined failure criterion (for tensile strength).

For Level 2 the agreement between measured and theoretical strains is generally poor. Test no. 2:7:2, which had a fair agreement for the axial and tangential strains, see Figure 5-6, was also the test with the lowest amount of final unexplained strains at Level 2, 36%, which is still very high. The test also indicates a maximum tensile stress around 20 MPa to be compared with the tensile strength of 14 MPa.

For Level 3 measured and theoretical strains are still in disagreement, although not as much as for Levels nos. 1 and 2. Tests nos. 3:19:1 and 3:21:1 showed the lowest amount of final unexplained strains at Level 3, 24% and 22%, respectively, which are still high values. All tests also indicated a maximum tensile stress between 15 to 21 MPa, which is higher than the defined tensile strength.

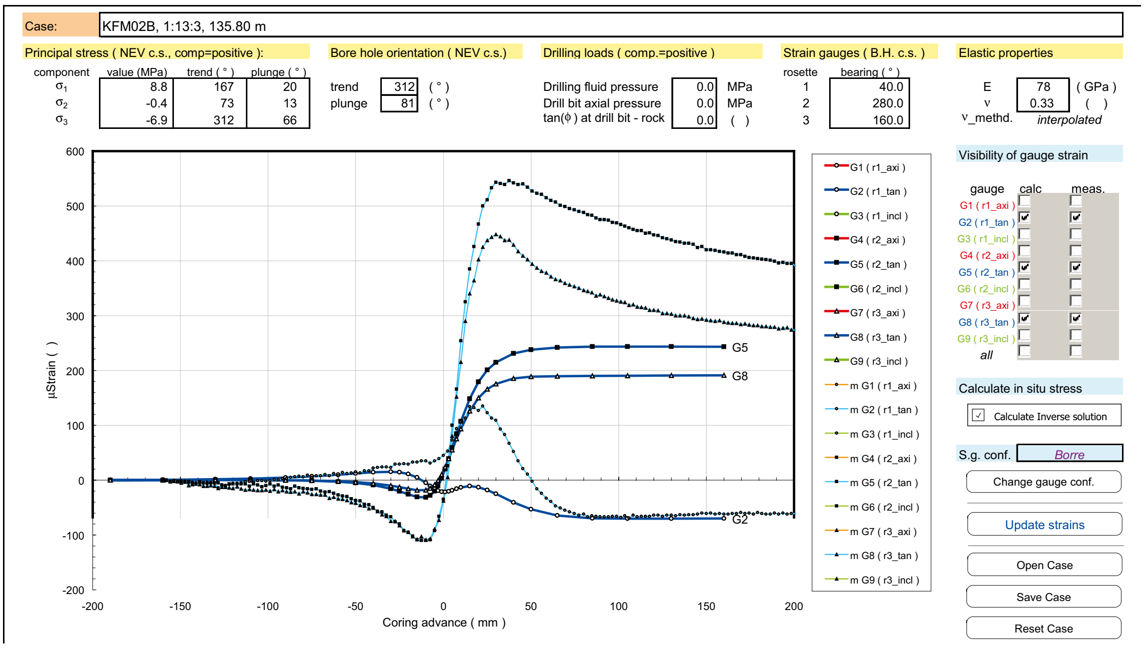


Figure 5-5. *Calculated vs. measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no. 1:13:3 and all tangential gauges.*

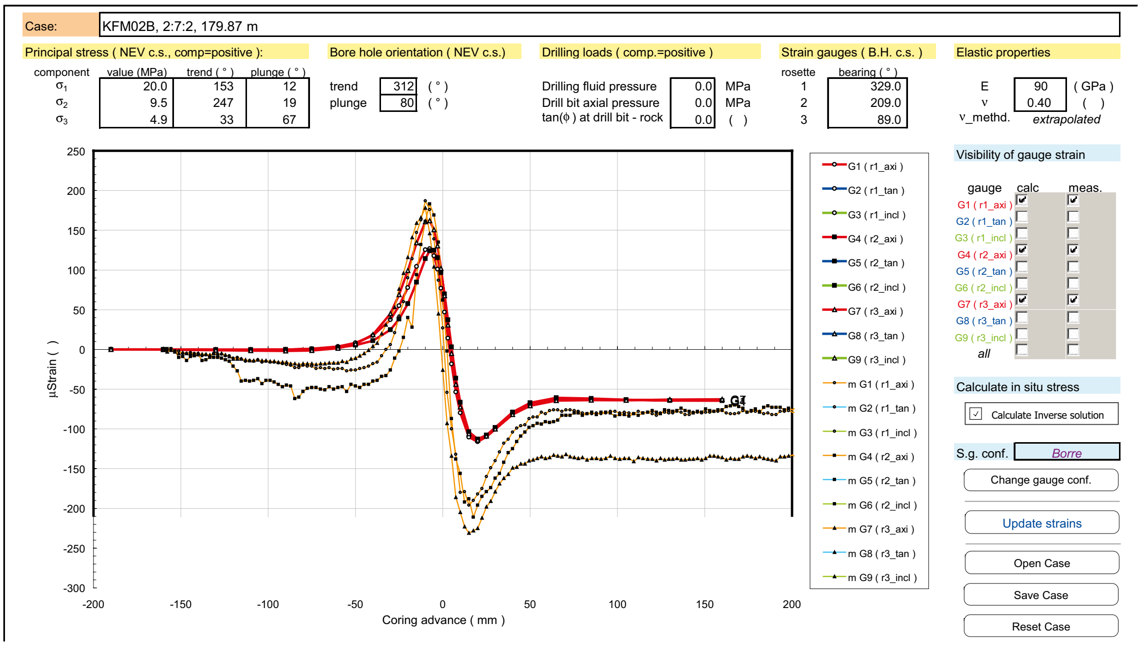


Figure 5-6. *Calculated vs. measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no. 2:7:2 and all axial gauges.*

For Level 4 the agreement between measured and theoretical strains was poor for test no 4:7:1 (60%). Tests nos. 4:3:1 and 4:8:1 exhibited a fair agreement for the axial and tangential strains, and were also the tests with the lowest amount of final unexplained strains at Level 4, being 25% and 23%, respectively, which is still high. Also at this level all tests indicated a maximum tensile stress equal to or higher than the defined tensile strength.

5.5.2 Inverse solution stress estimate

The inverse solution was used to complement the stress determination from classical analysis. The inverse solution is a tool to theoretically determine the stresses, and is normally used if difficulties to determine the stresses from measurements occur, e.g. malfunctioning gauges, extensive core damage and/or core disking, etc.

For the present campaign, the measurements have not suffered from any severe problems of the above-mentioned nature. Nevertheless, the inverse solution was attempted using the early (transient) strain response from overcoring to assess whether this would provide improved reliability in the estimation of the stress state. Generally, the stresses calculated with the inverse solution vary significantly with coring advance. To obtain a reliable stress estimate, the calculated stresses must be relatively constant over some distance during the early overcoring phase. This requires that the overcoring response during the first few minutes (before passing the strain gauges at 16 cm position) is stable and that the coring advance is accurate. Unfortunately, these two conditions are seldom satisfied simultaneously.

For Level 1 through 4 the stresses calculated from the early strain response were clearly unrealistic with e.g. negative values for the minor horizontal and/or vertical stresses. This is primarily attributed to the difficulties in finding a stable pre-overcoring response (see Figure 5-7), as well as the (occasionally) low strain values. Consequently, the stress state could not be determined unambiguously for Level 1 through Level 4.

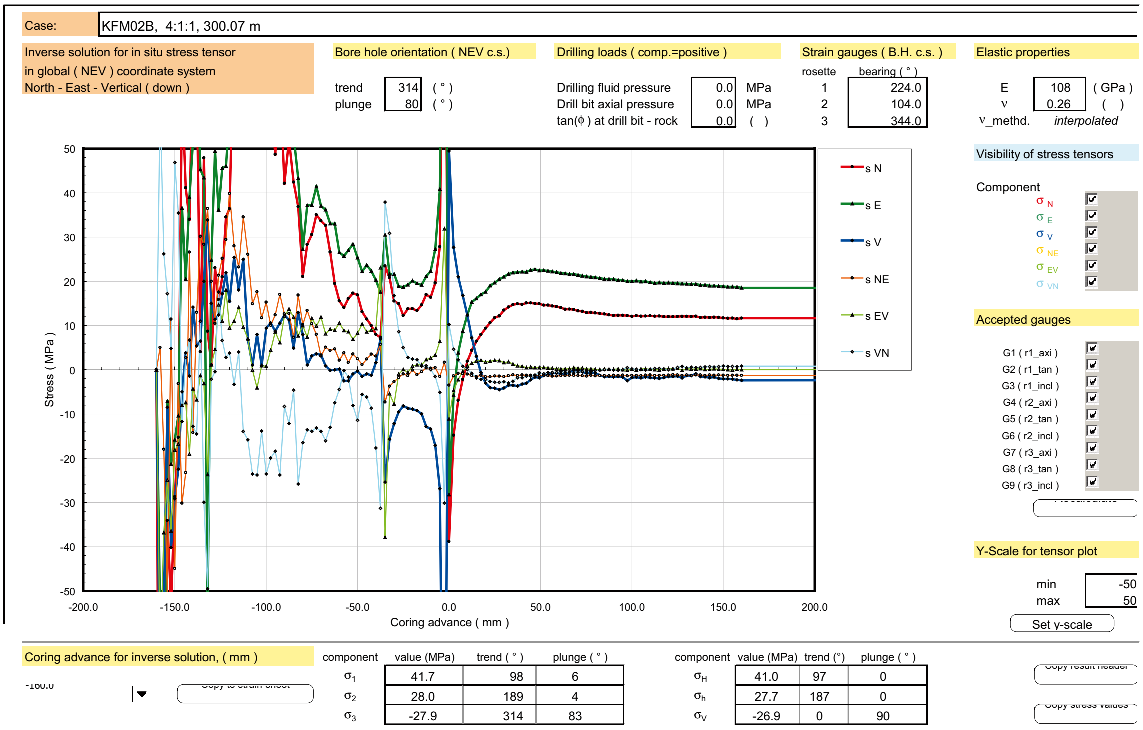


__Figure 5-7.__ Example of inverse stress solution for test no. 4:1:1 (no stable pre-overcoring values found).

5.6 Summary results and discussion

The overcoring measurements in borehole KFM02B can be considered only partly successful, because during the measuring campaign a number of the installations were not optimal. Some of the non-optimal or partly optimal installations had obvious causes for the failure, but in other cases it was more difficult to determine the exact nature of the problem. The reasons for unsuccessful installations were also to some degree varying during the course of the test campaign and at different test levels. At Level 1 a number of problems with impact on the installations, which were not observed elsewhere in the borehole, occurred. These were:

- Malfunctioning wireline system of the drill rig.
- Fractures that were not visible on the pilot core but inflicted on the overcored core. These fractures were semi-parallel to the borehole axis, see example in Figure 5-8. With other orientations of the borehole or of the fracture set, these fractures would probably have been discovered on the pilot cores and new, better installation positions chosen.

Hence, the causes for unsuccessful installations were of both technical and geological nature.

However, some other causes for problematic installations were more frequently observed at all levels (Level 1 to Level 4). These are:

- Contamination of the pilot hole by drill cuttings (example shown in Figure 5-9).
- Debonding.
- Unstable strain response.

The problem with the presence of drill cuttings in the pilot hole while gluing strain gauges against the borehole wall is a well-known phenomenon. It is difficult to achieve a completely "clean" borehole, especially at large depths. Therefore is the fact that some failures were due to presence of drill cuttings in the pilot hole not surprising. Many efforts and improvements have been done during measurements in connection with the site investigations to avoid or decrease this problem, but in some situations sedimentation of drill cuttings may still occur after cleaning of the borehole by water or gas flushing, before the strain gauges are installed.

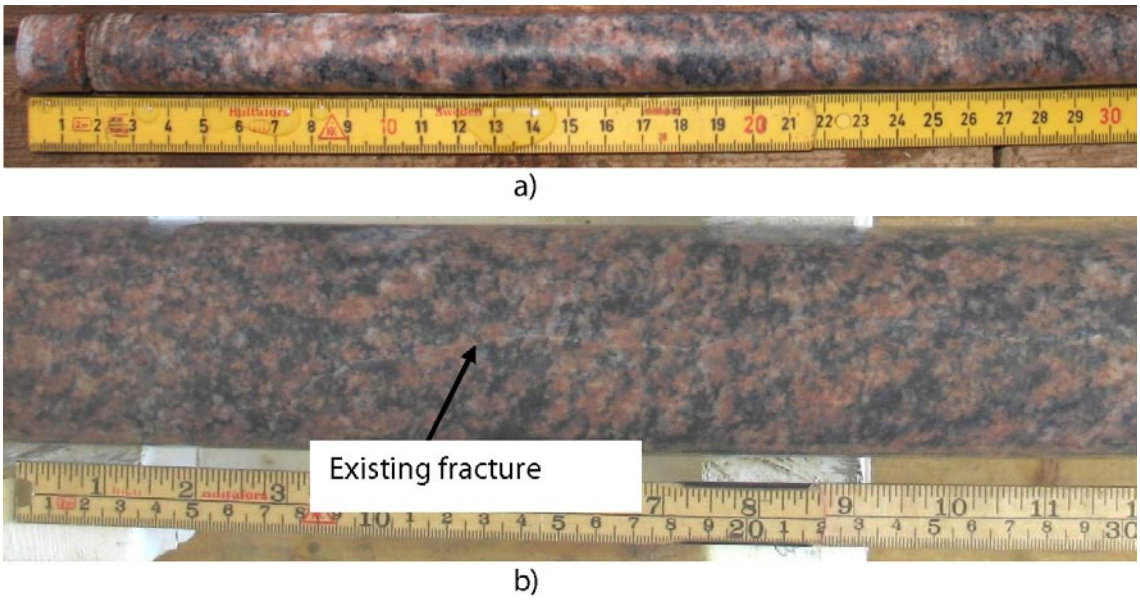
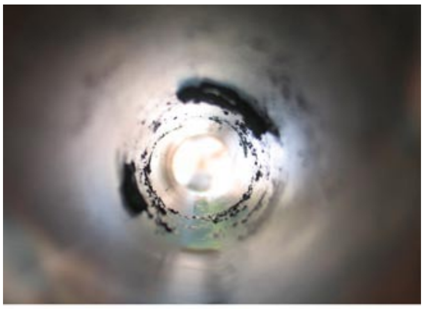


__Figure 5-8.__ Example of a) fracture free pilot core b) but with existing fracture intersecting the overcored, hollow core, see thin white line at the centre of the core from test 1:14:1.



a)

b)

Figure 5-9. *Example of a) drill cuttings in the pilot hole and b) drill cuttings covering strain gauges (test 2:2:1).*

Installation failure due to debonding was in some cases caused by weakly glued strain gauges, but occurred also when the strain gauges were glued very firmly against the wall of the pilot hole. At the majority of failed installations due to debonding by weakly glued strain gauges, a fine “dust” or remainders of the drill cuttings were covering the surface of the strain gauges.

At a number of occasions the biaxial tests indicated debonding of the strain gauges, although the gauges were attached very firmly to the overcored core and at very good rock conditions. An example is shown in Figure 5-10. Here again, at least at some of the tests, a fine “dust” could be observed on the surface of gauges. It seems reasonable to believe that this very fine-grained material is inhibiting the strain gauges from correctly recording the strain changes during overcoring. If this is a flushing problem or not, is difficult to determine. The unsuccessful installations due to debonding occurred regardless of the quality of the rock mass.

Installation failure due to unstable strain response is somewhat more difficult to link to a specific technical or geological problem. However, it is acknowledged that heating of the surrounding rock during overcoring may affect the behaviour of the glue for the strain gauges. Another cause may be micro-fracturing of the rock sample while overcoring. These two phenomena might be the reason for unstable strain response during and after overcoring. Unstable strain response occurred regardless of the quality of the rock mass.

For Level 1 most tests can be considered unsuccessful. The obtained stress state from the measurements at Level 1 (approximately 113–143 m vertical depth) is characterised by stress magnitudes with a mean value equal to 10.1 MPa for the major principal stresses, and by a sub-horizontal orientation. The magnitude of the mean calculated major horizontal stress is 9.4 MPa with a NW-SE orientation, and the magnitude of the minor horizontal mean stress is 3.8 MPa. The mean vertical stress component is –0.5 MPa, which is very low compared to the theoretical value of the overburden weight. Only test 1:17:2 provided what can be considered a reliable result regarding the vertical stress. Variations between the individual measurements are quite large with respect to both orientation and magnitude, as manifested by the calculated confidence intervals (Appendix H). It must be noticed that at this level, none of the tests were judged to have an *a*-rating (problems with fractures sub-parallel with the borehole axis).

a)

b)

Figure 5-10. *Example of a) pilot core and b) overcored core from tests 3:15:1 where the strain gauges show debonding in spite of efficient gluing.*

The results from the measured stresses at Level 2 (approximately 154–178 m vertical depth) gave similar magnitudes for the major principal stress as for Level 1, and the major stress was also sub-horizontally oriented. The magnitude of the mean calculated major horizontal stress is equal to 11.8 MPa. The orientation is, however, NNW-SSE with relatively low scatter, see also Appendix H. The minor horizontal stress is determined to 4.7 MPa and the mean vertical stress to 5.5 MPa, which is in fair agreement with the theoretical value corresponding to the overburden pressure, although the scatter between individual measurements is large.

For Level 3 (approximately 250–253 m vertical depth), the magnitude of the mean major horizontal stress is 17.6 MPa with a NW-SE orientation. The magnitude of the mean minor horizontal stress is 9.7 MPa, whereas the mean vertical stress determined from the tests is 3.9 MPa, which is somewhat low compared to the magnitude of the overburden stress. This level shows the best consistency both regarding magnitudes and orientation of the measured stresses.

For Level 4 (approximately 298–303 m vertical depth), the mean magnitude of the principal stresses was lower compared to Level 3. The scatter in the magnitudes among the individual measurements is quite low, giving a mean value for the magnitude of the major horizontal stress equal to 14.1 MPa and 6.5 MPa for the minor. The mean orientation was determined to be NW-SE at this level. The scatter of the measured orientation was larger than for Level 3. The mean vertical stress is 4.2 MPa, which is only about 50% of the theoretically determined vertical stress.

Transient strain analysis was conducted for all tests with ratings *a* and *b* at all levels. For the large majority of tests, the amount of unexplained stress was considered high (>20%). Levels nos. 1 and 2 showed very high amounts of unexplained strains, between 36 and 58%. Level 3 demonstrated somewhat better results with 22–29% of unexplained strains. At Level 4, two tests (4:3:1 and 4:8:1) indicated unexplained strains comparable to Level 3 (23–25%), whereas test no. 4:7:1 gave extremely high values (60%).

In general, high maximum tensile stresses were obtained from the calculations. All tests showed tensile stresses higher than or very close to 14 MPa. These values are high enough to cause tensile damages in overcore samples from the dominating rock types at the site.

Stress determination using the inverse solution was attempted on all tests subjected to transient strain analysis. However, it was not possible to obtain stable stress values during the pre-overcoring phase. Therefore, stresses could not be determined with any reliability and the stress state could not be unambiguously determined for any of the measurements levels using the inverse solution.

It appears that there is a temperature effect on the strain gauges from the drilling. The effect is clearly visible during varying time periods of the post-peak strain behaviour. The phenomenon is visible, though in various degrees, at all measuring levels in KFM02B. The temperature effects appear to be more prominent than in previous overcoring measurements at the site (see e.g. /Sjöberg 2004/). It is not possible to solve this issue within the present work, only to minimize and avoid any effects on the determination of the stress field. This is done by carefully selecting strain input data for stress calculations. A more detailed investigation is presently on-going to quantify possible temperature effects in overcoring.

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Appendix A

Key measurement data

Table A1. Key measurement data for test no. 1:7:1, 113.74 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-08-29	14:30:00
Mixing of glue	2006-08-29	14:43:00
Application of glue to gauges	2006-08-29	14:48:00
Probe installation in pilot hole	2006-08-29	14:54:00
Start time for dense sampling (5 s interval)	2006-08-30	06:30:00
Adapter retrieved	2006-08-30	07:38:55
Adapter on surface	2006-08-30	07:42:15
Drill string fed down the hole	2006-08-30	07:49:30
Drill string in place	2006-08-30	08:06:15
Flushing start	2006-08-30	08:06:20
Rotation start	2006-08-30	08:26:10
Overcoring start	2006-08-30	08:26:40
Overcoring 4 cm	2006-08-30	08:28:05
Overcoring 8 cm	2006-08-30	08:29:35
Overcoring 12 cm	2006-08-30	08:08:31
Overcoring 16 cm	2006-08-30	08:32:25
Overcoring 20 cm	2006-08-30	08:33:45
Overcoring 24 cm	2006-08-30	08:35:05
Overcoring 28 cm	2006-08-30	08:36:20
Overcoring 32 cm	2006-08-30	08:37:45
Overcoring stop (90 cm)	2006-08-30	08:57:20
Flushing off	2006-08-30	09:12:30
Core break	2006-08-30	09:28:30
Core retrieval start	2006-08-30	09:43:45
Core and probe on surface	2006-08-30	10:01:00
End of strain registration	2006-08-30	10:24:10
Calculation of strain difference: OC Start	2006-08-30	08:15:40
Calculation of strain difference: OC Stop	2006-08-30	09:10:20

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.8
16 – 32 cm	3.0
32 cm – overcoring stop	3.0

Table A2. Key measurement data for test no. 1:13:3, 135.80 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-09-10	17:45:00
Mixing of glue	2006-09-10	18:18:00
Application of glue to gauges	2006-09-10	18:22:00
Probe installation in pilot hole	2006-09-10	18:27:00
Start time for dense sampling (5 s interval)	2006-09-11	06:30:00
Adapter retrieved	2006-09-11	07:37:10
Adapter on surface	2006-09-11	07:39:55
Drill string fed down the hole	2006-09-11	07:48:10
Drill string in place	2006-09-11	08:07:40
Flushing start	2006-09-11	08:08:10
Rotation start	2006-09-11	08:49:05
Overcoring start	2006-09-11	08:49:20
Overcoring 4 cm	2006-09-11	08:50:55
Overcoring 8 cm	2006-09-11	08:52:20
Overcoring 12 cm	2006-09-11	08:53:40
Overcoring 16 cm	2006-09-11	08:55:00
Overcoring 20 cm	2006-09-11	08.56:20
Overcoring 24 cm	2006-09-11	08:57:35
Overcoring 28 cm	2006-09-11	08:59:00
Overcoring 32 cm	2006-09-11	09:00:20
Overcoring stop (70 cm)	2006-09-11	09:13:30
Flushing off	2006-09-11	09:29:10
Core break	2006-09-11	09:46:30
Core retrieval start	2006-09-11	10:05:25
Core and probe on surface	2006-09-11	10:28:00
End of strain registration	2006-09-11	10:45:30
Calculation of strain difference: OC Start	2006-09-11	08:36:20
Calculation of strain difference: OC Stop	2006-09-11	09:27:30

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.8
16 – 32 cm	3.0
32 cm – overcoring stop	2.9

Table A3. Key measurement data for test no. 1:17:2, 144.17 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-09-15	18:45:00
Mixing of glue	2006-09-15	18:59:00
Application of glue to gauges	2006-09-15	19:03:00
Probe installation in pilot hole	2006-09-15	19:10:05
Start time for dense sampling (5 s interval)	2006-09-16	07:00:00
Adapter retrieved	2006-09-16	07:44:30
Adapter on surface	2006-09-16	07:48:10
Drill string fed down the hole	2006-09-16	08:13:50
Drill string in place	2006-09-16	08:35:50
Flushing start	2006-09-16	08:36:00
Rotation start	2006-09-16	08:54:35
Overcoring start	2006-09-16	08:54:55
Overcoring 4 cm	2006-09-16	08:55:55
Overcoring 8 cm	2006-09-16	08:57:20
Overcoring 12 cm	2006-09-16	08:58:20
Overcoring 16 cm	2006-09-16	09:01:00
Overcoring 20 cm	2006-09-16	09:01:20
Overcoring 24 cm	2006-09-16	09:02:40
Overcoring 28 cm	2006-09-16	09:04:00
Overcoring 32 cm	2006-09-16	09:05:20
Overcoring stop (95 cm)	2006-09-16	09:28:15
Flushing off	2006-09-16	09:43:10
Core break	2006-09-16	10:04:20
Core retrieval start	2006-09-16	10:22:45
Core and probe on surface	2006-09-16	10:50:00
End of strain registration	2006-09-16	11:03:00
Calculation of strain difference: OC Start	2006-09-16	08:50:55
Calculation of strain difference: OC Stop	2006-09-16	09:42:15

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	3.1
16 – 32 cm	3.0
32 cm – overcoring stop	2.9

Table A4. Key measurement data for test no. 2:1:3, 156.72 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-09-19	12:45:00
Mixing of glue	2006-09-19	14:22:00
Application of glue to gauges	2006-09-19	14:24:00
Probe installation in pilot hole	2006-09-19	14:32:00
Start time for dense sampling (5 s interval)	2006-09-20	06:30:00
Adapter retrieved	2006-09-20	07:30:50
Adapter on surface	2006-09-20	07:33:40
Drill string fed down the hole	2006-09-20	07:45:15
Drill string in place	2006-09-20	08:08:15
Flushing start	2006-09-20	08:08:20
Rotation start	2006-09-20	08:28:20
Overcoring start	2006-09-20	08:29:05
Overcoring 4 cm	2006-09-20	08:30:30
Overcoring 8 cm	2006-09-20	08:31:50
Overcoring 12 cm	2006-09-20	08:33:10
Overcoring 16 cm	2006-09-20	08:34:55
Overcoring 20 cm	2006-09-20	08:35:55
Overcoring 24 cm	2006-09-20	08:37:15
Overcoring 28 cm	2006-09-20	08:38:35
Overcoring 32 cm	2006-09-20	08:40:00
Overcoring stop (100 cm)	2006-09-20	09:02:55
Flushing off	2006-09-20	09:18:40
Core break	2006-09-20	09:34:30
Core retrieval start	2006-09-20	09:51:35
Core and probe on surface	2006-09-20	10:17:30
End of strain registration	2006-09-20	10:36:55
Calculation of strain difference: OC Start	2006-09-20	08:21:05
Calculation of strain difference: OC Stop	2006-09-20	09:17:55

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.7
16 – 32 cm	3.1
32 cm – overcoring stop	3.0

Table A5. Key measurement data for test no. 2:3:4, 164.10 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-09-23	14:00:00
Mixing of glue	2006-09-23	15:51:00
Application of glue to gauges	2006-09-23	15:52:00
Probe installation in pilot hole	2006-09-23	16:02:00
Start time for dense sampling (5 s interval)	2006-09-24	06:30:00
Adapter retrieved	2006-09-24	07:44:50
Adapter on surface	2006-09-24	07:50:00
Drill string fed down the hole	2006-09-24	07:59:25
Drill string in place	2006-09-24	08:22:35
Flushing start	2006-09-24	08:22:45
Rotation start	2006-09-24	08:44:10
Overcoring start	2006-09-24	08:44:25
Overcoring 4 cm	2006-09-24	08:45:25
Overcoring 8 cm	2006-09-24	08:46:50
Overcoring 12 cm	2006-09-24	08:48:10
Overcoring 16 cm	2006-09-24	08:49:30
Overcoring 20 cm	2006-09-24	08:50:50
Overcoring 24 cm	2006-09-24	08:52:10
Overcoring 28 cm	2006-09-24	08:53:30
Overcoring 32 cm	2006-09-24	08:54:50
Overcoring stop (90 cm)	2006-09-24	09:14:45
Flushing off	2006-09-24	09:30:50
Core break	2006-09-24	09:52:30
Core retrieval start	2006-09-24	10:11:40
Core and probe on surface	2006-09-24	10:35:20
End of strain registration	2006-09-24	10:53:15
Calculation of strain difference: OC Start	2006-09-24	08:40:50
Calculation of strain difference: OC Stop	2006-09-24	09:29:40

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	3.1
16 – 32 cm	3.0
32 cm – overcoring stop	2.9

Table A6. Key measurement data for test no. 2:6:2, 178.03 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-09-28	14:00:00
Mixing of glue	2006-09-28	14:36:00
Application of glue to gauges	2006-09-28	14:41:00
Probe installation in pilot hole	2006-09-28	14:47:00
Start time for dense sampling (5 s interval)	2006-09-29	06:30:00
Adapter retrieved	2006-09-29	07:20:10
Adapter on surface	2006-09-29	07:23:20
Drill string fed down the hole	2006-09-29	07:32:50
Drill string in place	2006-09-29	08:01:05
Flushing start	2006-09-29	08:01:10
Rotation start	2006-09-29	08:19:35
Overcoring start	2006-09-29	08:20:20
Overcoring 4 cm	2006-09-29	08:21:40
Overcoring 8 cm	2006-09-29	08:23:05
Overcoring 12 cm	2006-09-29	08:24:30
Overcoring 16 cm	2006-09-29	08:25:50
Overcoring 20 cm	2006-09-29	08:27:10
Overcoring 24 cm	2006-09-29	08:28:30
Overcoring 28 cm	2006-09-29	08:29:55
Overcoring 32 cm	2006-09-29	08:31:15
Overcoring stop (86 cm)	2006-09-29	08:49:30
Flushing off	2006-09-29	09:05:15
Core break	2006-09-29	09:21:10
Core retrieval start	2006-09-29	09:41:15
Core and probe on surface	2006-09-29	10:13:00
End of strain registration	2006-09-29	10:30:15
Calculation of strain difference: OC Start	2006-09-29	08:20:20
Calculation of strain difference: OC Stop	2006-09-29	09:04:20

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.9
16 – 32 cm	3.0
32 cm – overcoring stop	3.0

Table A7. Key measurement data for test no. 2:7:2, 179.87 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-09-30	12:00:00
Mixing of glue	2006-09-30	12:39:00
Application of glue to gauges	2006-09-30	12:44:00
Probe installation in pilot hole	2006-09-30	12:50:00
Start time for dense sampling (5 s interval)	2006-10-01	06:30:00
Adapter retrieved	2006-10-01	07:40:10
Adapter on surface	2006-10-01	07:43:30
Drill string fed down the hole	2006-10-01	08:15:30
Drill string in place	2006-10-01	08:50:45
Flushing start	2006-10-01	08:50:50
Rotation start	2006-10-01	09:08:00
Overcoring start	2006-10-01	09:08:50
Overcoring 4 cm	2006-10-01	09:10:20
Overcoring 8 cm	2006-10-01	09:11:45
Overcoring 12 cm	2006-10-01	09:13:05
Overcoring 16 cm	2006-10-01	09:14:25
Overcoring 20 cm	2006-10-01	09:15:45
Overcoring 24 cm	2006-10-01	09:17:10
Overcoring 28 cm	2006-10-01	09:18:25
Overcoring 32 cm	2006-10-01	09:19:50
Overcoring stop (101 cm)	2006-10-01	09:44:00
Flushing off	2006-10-01	10:00:20
Core break	2006-10-01	10:16:10
Core retrieval start	2006-10-01	10:30:40
Core and probe on surface	2006-10-01	11:10:20
End of strain registration	2006-10-01	11:28:05
Calculation of strain difference: OC Start	2006-10-01	09:00:50
Calculation of strain difference: OC Stop	2006-10-01	09:59:30

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.9
16 – 32 cm	3.0
32 cm – overcoring stop	2.9

Table A8. Key measurement data for test no. 3:18:1, 252.83 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-11-15	14:00:00
Mixing of glue	2006-11-15	15:05:00
Application of glue to gauges	2006-11-15	15:08:00
Probe installation in pilot hole	2006-11-15	03:36:00
Start time for dense sampling (5 s interval)	2006-11-16	06:30:00
Adapter retrieved	2006-11-16	09:19:55
Adapter on surface	2006-11-16	09:23:40
Drill string fed down the hole	2006-11-16	09:30:50
Drill string in place	2006-11-16	10:06:50
Flushing start	2006-11-16	10:07:00
Rotation start	2006-11-16	10:24:45
Overcoring start	2006-11-16	10:25:15
Overcoring 4 cm	2006-11-16	10:26:20
Overcoring 8 cm	2006-11-16	10:27:40
Overcoring 12 cm	2006-11-16	10:29:00
Overcoring 16 cm	2006-11-16	10:30:25
Overcoring 20 cm	2006-11-16	10:31:45
Overcoring 24 cm	2006-11-16	10:33:10
Overcoring 28 cm	2006-11-16	10:34:30
Overcoring 32 cm	2006-11-16	10:35:50
Overcoring stop (93 cm)	2006-11-16	10:55:55
Flushing off	2006-11-16	11:11:50
Core break	2006-11-16	11:28:20
Core retrieval start	2006-11-16	11:43:20
Core and probe on surface	2006-11-16	12:17:30
End of strain registration	2006-11-16	12:34:15
Calculation of strain difference: OC Start	2006-11-16	10:21:15
Calculation of strain difference: OC Stop	2006-11-16	11:10:55

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	3.1
16 – 32 cm	3.0
32 cm – overcoring stop	3.0

Table A9. Key measurement data for test no. 3:19:1, 253.77 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-11-17	13:15:00
Mixing of glue	2006-11-17	13:59:00
Application of glue to gauges	2006-11-17	14:03:00
Probe installation in pilot hole	2006-11-17	14:11:00
Start time for dense sampling (5 s interval)	2006-11-18	06:30:00
Adapter retrieved	2006-11-18	07:32:45
Adapter on surface	2006-11-18	07:37:10
Drill string fed down the hole	2006-11-18	07:44:30
Drill string in place	2006-11-18	08:17:00
Flushing start	2006-11-18	08:17:15
Rotation start	2006-11-18	08:36:40
Overcoring start	2006-11-18	08:36:50
Overcoring 4 cm	2006-11-18	08:38:25
Overcoring 8 cm	2006-11-18	08:39:50
Overcoring 12 cm	2006-11-18	08:41:10
Overcoring 16 cm	2006-11-18	08:42:30
Overcoring 20 cm	2006-11-18	08:43:55
Overcoring 24 cm	2006-11-18	08:45:15
Overcoring 28 cm	2006-11-18	08:46:40
Overcoring 32 cm	2006-11-18	08:48:00
Overcoring stop (91 cm)	2006-11-18	09:08:40
Flushing off	2006-11-18	09:24:40
Core break	2006-11-18	09:40:05
Core retrieval start	2006-11-18	09:56:15
Core and probe on surface	2006-11-18	10:27:40
End of strain registration	2006-11-18	10:44:10
Calculation of strain difference: OC Start	2006-11-18	08:33:50
Calculation of strain difference: OC Stop	2006-11-18	09:22:40

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.8
16 – 32 cm	2.9
32 cm – overcoring stop	2.9

Table A10. Key measurement data for test no. 3:21:1, 256.13 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-11-21	13:15:00
Mixing of glue	2006-11-21	13:35:00
Application of glue to gauges	2006-11-21	13:39:00
Probe installation in pilot hole	2006-11-21	13:46:00
Start time for dense sampling (5 s interval)	2006-11-22	06:30:00
Adapter retrieved	2006-11-22	07:19:25
Adapter on surface	2006-11-22	07:23:50
Drill string fed down the hole	2006-11-22	07:31:00
Drill string in place	2006-11-22	08:09:35
Flushing start	2006-11-22	08:09:40
Rotation start	2006-11-22	08:37:35
Overcoring start	2006-11-22	08:37:50
Overcoring 4 cm	2006-11-22	08:39:20
Overcoring 8 cm	2006-11-22	08:40:46
Overcoring 12 cm	2006-11-22	08:42:10
Overcoring 16 cm	2006-11-22	08:43:30
Overcoring 20 cm	2006-11-22	08:44:50
Overcoring 24 cm	2006-11-22	08:46:10
Overcoring 28 cm	2006-11-22	08:47:30
Overcoring 32 cm	2006-11-22	08:47:50
Overcoring stop (92 cm)	2006-11-22	09:25:20
Flushing off	2006-11-22	09:25:05
Core break	2006-11-22	09:40:55
Core retrieval start	2006-11-22	10:06:10
Core and probe on surface	2006-11-22	10:37:30
End of strain registration	2006-11-22	10:53:50
Calculation of strain difference: OC Start	2006-11-22	08:34:50
Calculation of strain difference: OC Stop	2006-11-22	09:23:05

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.8
16 – 32 cm	3.7
32 cm – overcoring stop	2.8

Table A11. Key measurement data for test no. 4:3:1, 302.33 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-11-30	13:15:00
Mixing of glue	2006-11-30	14:03:00
Application of glue to gauges	2006-11-30	14:07:00
Probe installation in pilot hole	2006-11-30	14:15:00
Start time for dense sampling (5 s interval)	2006-12-01	06:30:00
Adapter retrieved	2006-12-01	07:41:40
Adapter on surface	2006-12-01	07:46:05
Drill string fed down the hole	2006-12-01	07:52:40
Drill string in place	2006-12-01	08:29:35
Flushing start	2006-12-01	08:29:40
Rotation start	2006-12-01	08:48:15
Overcoring start	2006-12-01	08:48:25
Overcoring 4 cm	2006-12-01	08:49:45
Overcoring 8 cm	2006-12-01	08:51:15
Overcoring 12 cm	2006-12-01	08:52:40
Overcoring 16 cm	2006-12-01	08:54:00
Overcoring 20 cm	2006-12-01	08:55:20
Overcoring 24 cm	2006-12-01	08:56:40
Overcoring 28 cm	2006-12-01	08:58:00
Overcoring 32 cm	2006-12-01	08:59:25
Overcoring stop (95 cm)	2006-12-01	09:20:35
Flushing off	2006-12-01	09:37:20
Core break	2006-12-01	09:52:40
Core retrieval start	2006-12-01	10:18:50
Core and probe on surface	2006-12-01	10:57:50
End of strain registration	2006-12-01	11:15:25
Calculation of strain difference: OC Start	2006-12-01	08:44:25
Calculation of strain difference: OC Stop	2006-12-01	09:35:35

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.9
16 – 32 cm	3.0
32 cm – overcoring stop	3.0

Table A12. Key measurement data for test no. 4:7:1, 306.20 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-12-10	13:30:00
Mixing of glue	2006-12-10	13:50:00
Application of glue to gauges	2006-12-10	13:55:00
Probe installation in pilot hole	2006-12-10	14:04:00
Start time for dense sampling (5 s interval)	2006-12-11	06:30:00
Adapter retrieved	2006-12-11	07:13:00
Adapter on surface	2006-12-11	07:17:00
Drill string fed down the hole	2006-12-11	07:41:10
Drill string in place	2006-12-11	08:24:50
Flushing start	2006-12-11	08:25:00
Rotation start	2006-12-11	08:44:25
Overcoring start	2006-12-11	08:45:05
Overcoring 4 cm	2006-12-11	08:46:40
Overcoring 8 cm	2006-12-11	08:48:00
Overcoring 12 cm	2006-12-11	08:49:25
Overcoring 16 cm	2006-12-11	08:50:45
Overcoring 20 cm	2006-12-11	08:52:10
Overcoring 24 cm	2006-12-11	08:53:30
Overcoring 28 cm	2006-12-11	08:54:50
Overcoring 32 cm	2006-12-11	08:56:10
Overcoring stop (96 cm)	2006-12-11	09:14:15
Flushing off	2006-12-11	09:31:05
Core break	2006-12-11	09:47:35
Core retrieval start	2006-12-11	10:03:50
Core and probe on surface	2006-12-11	10:53:00
End of strain registration	2006-12-11	11:09:50
Calculation of strain difference: OC Start	2006-11-27	08:38:05
Calculation of strain difference: OC Stop	2006-11-27	09:30:15

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.8
16 – 32 cm	3.0
32 cm – overcoring stop	2.8

Table A13. Key measurement data for test no. 4:8:1, 307.06 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	2006-12-12	14:30:00
Mixing of glue	2006-12-12	15:00:00
Application of glue to gauges	2006-12-12	15:05:00
Probe installation in pilot hole	2006-12-12	15:14:00
Start time for dense sampling (5 s interval)	2006-12-13	06:30:00
Adapter retrieved	2006-12-13	07:17:25
Adapter on surface	2006-12-13	07:23:45
Drill string fed down the hole	2006-12-13	07:57:10
Drill string in place	2006-12-13	08:41:05
Flushing start	2006-12-13	08:41:10
Rotation start	2006-12-13	08:59:10
Overcoring start	2006-12-13	08:59:55
Overcoring 4 cm	2006-12-13	09:01:25
Overcoring 8 cm	2006-12-13	09:02:50
Overcoring 12 cm	2006-12-13	09:04:10
Overcoring 16 cm	2006-12-13	09:05:35
Overcoring 20 cm	2006-12-13	09:06:55
Overcoring 24 cm	2006-12-13	09:08:15
Overcoring 28 cm	2006-12-13	09:09:35
Overcoring 32 cm	2006-12-13	09:10:55
Overcoring stop (91 cm)	2006-12-13	09:31:25
Flushing off	2006-12-13	09:48:20
Core break	2006-12-13	10:08:05
Core retrieval start	2006-12-13	10:25:10
Core and probe on surface	2006-12-13	11:17:00
End of strain registration	2006-12-13	11:33:25
Calculation of strain difference: OC Start	2006-12-13	08:59:55
Calculation of strain difference: OC Stop	2006-12-13	09:31:25

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.8
16 – 32 cm	3.0
32 cm – overcoring stop	2.9

Overcoring strain data and graphs

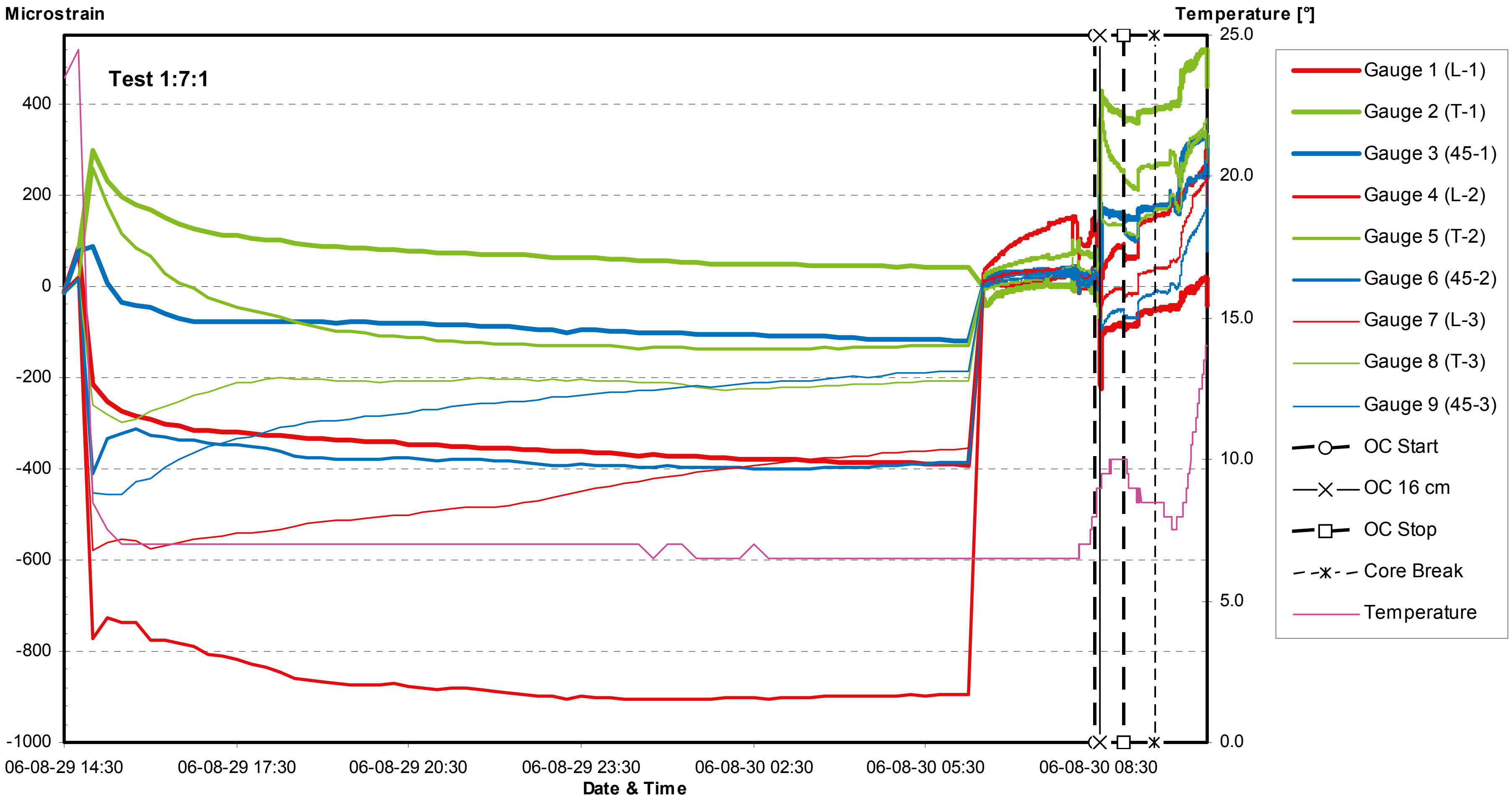


Figure B1. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:7:1, 113.74 m borehole length.*

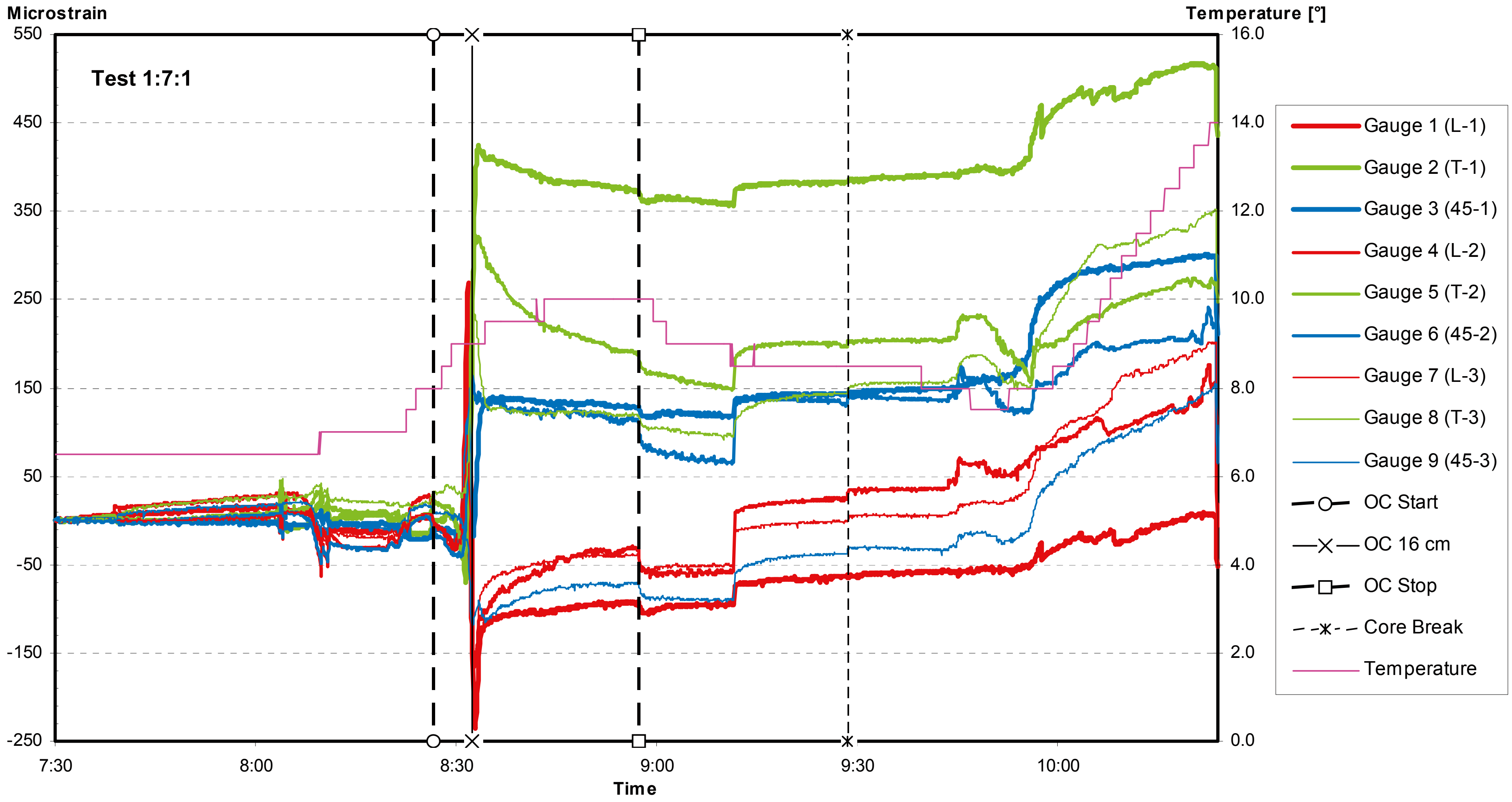


Figure B2. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:7:1, 113.74 m borehole length. Strain values reset to zero at 07:30.*

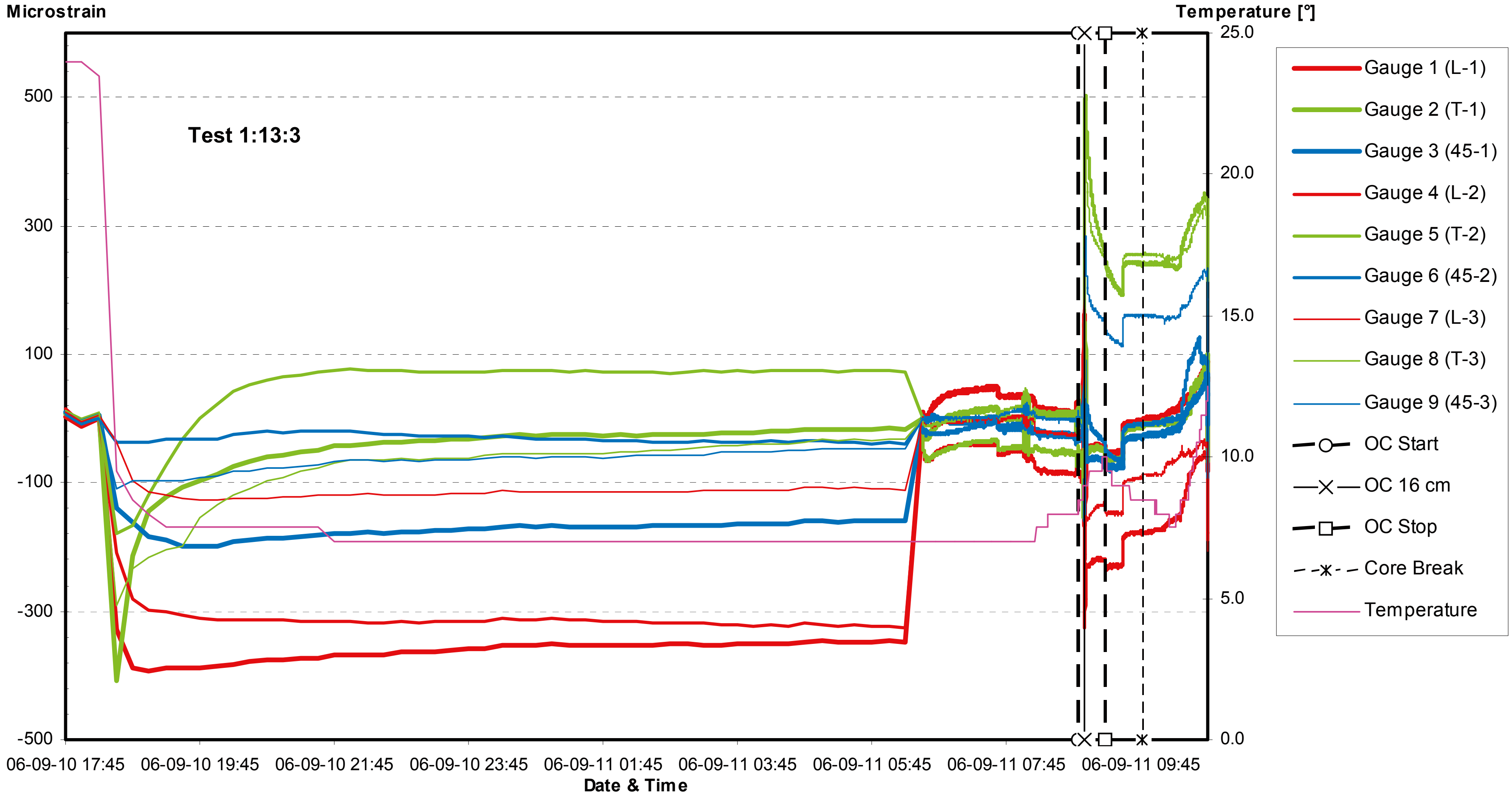


Figure B3. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:13:3, 135.80 m borehole length.*

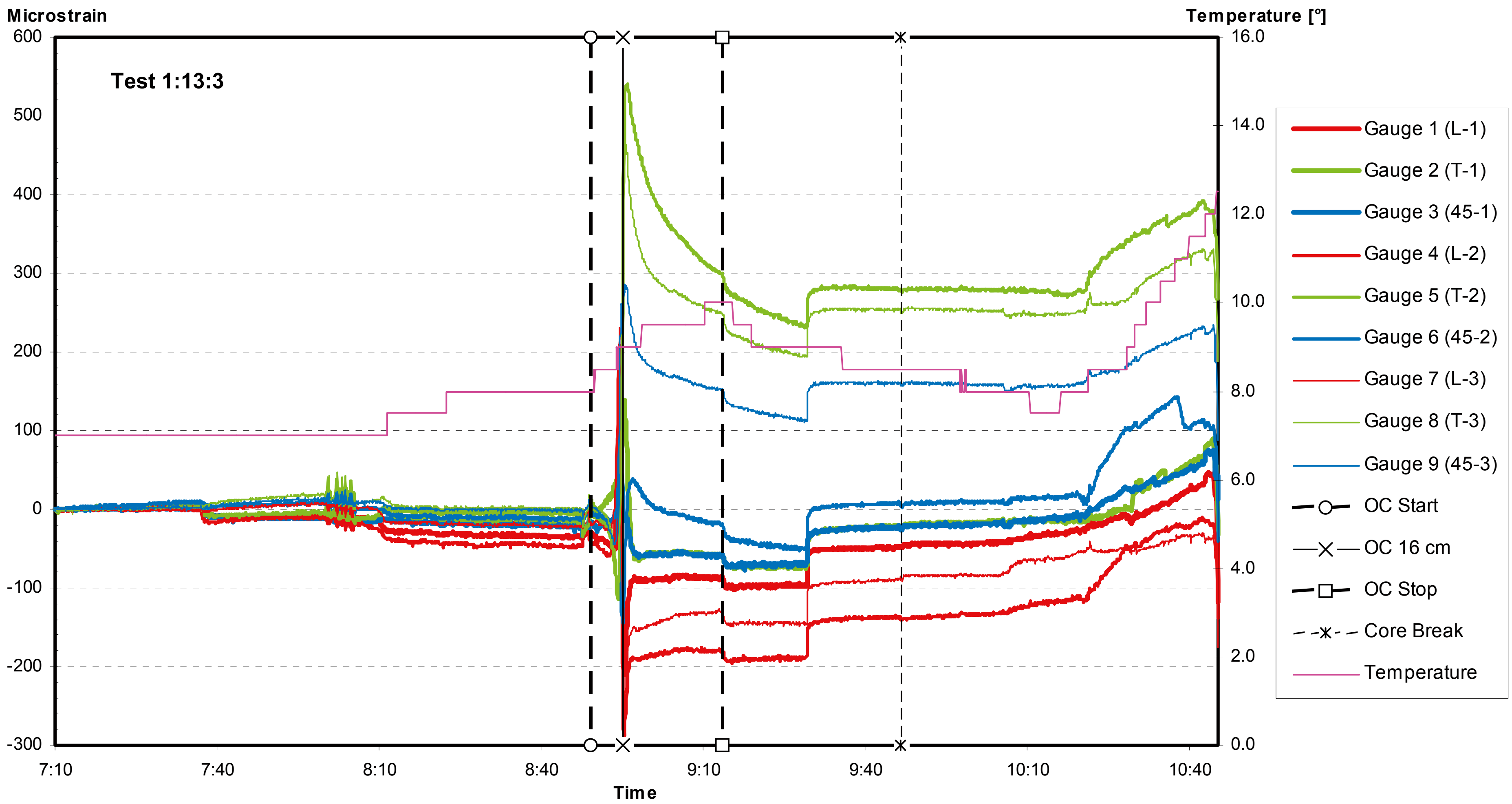


Figure B4. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:13:3, 135.80 m borehole length. Strain values reset to zero at 7:10.*

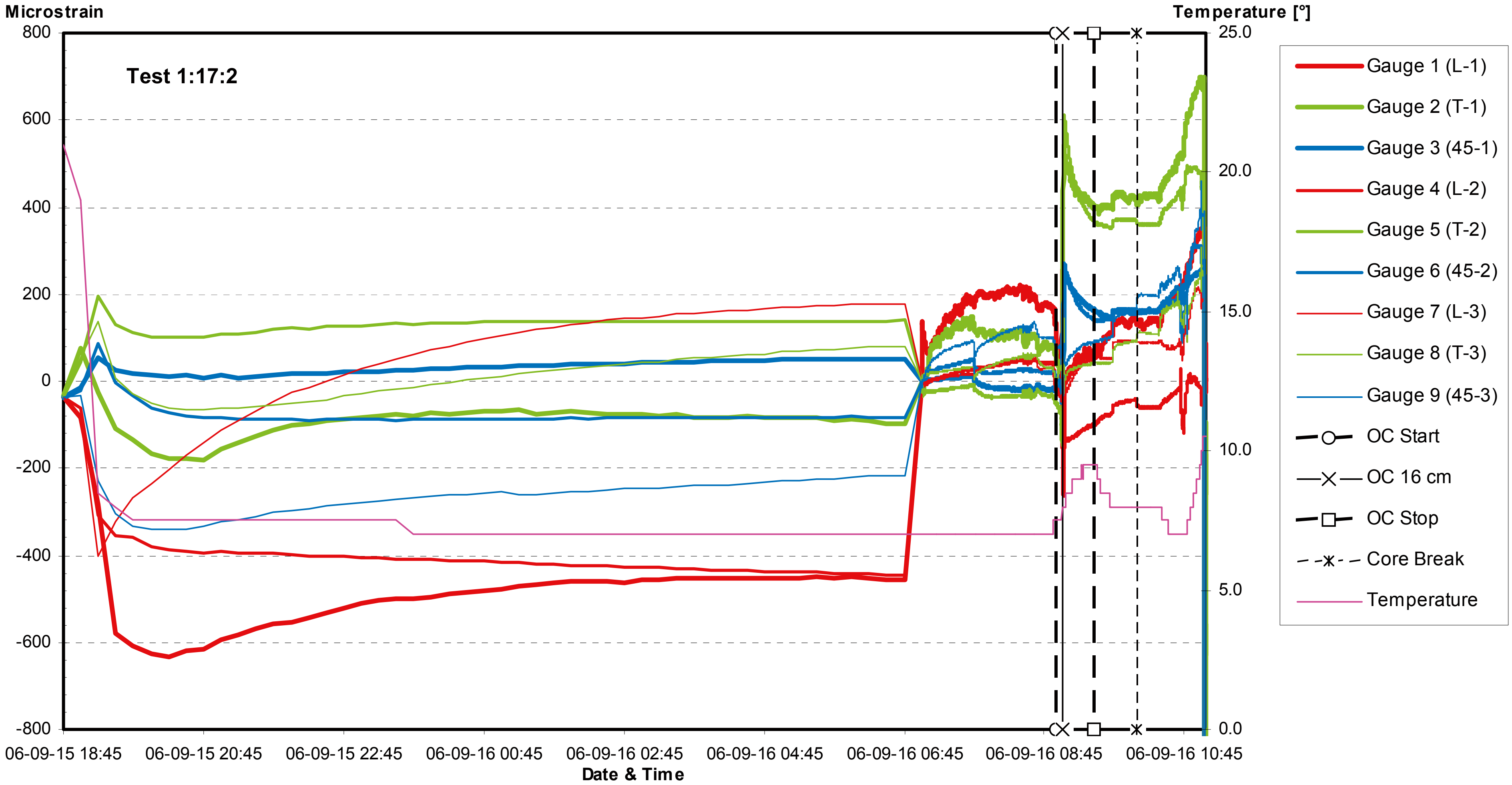


Figure B5. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:17:2, 144.17 m borehole length.*

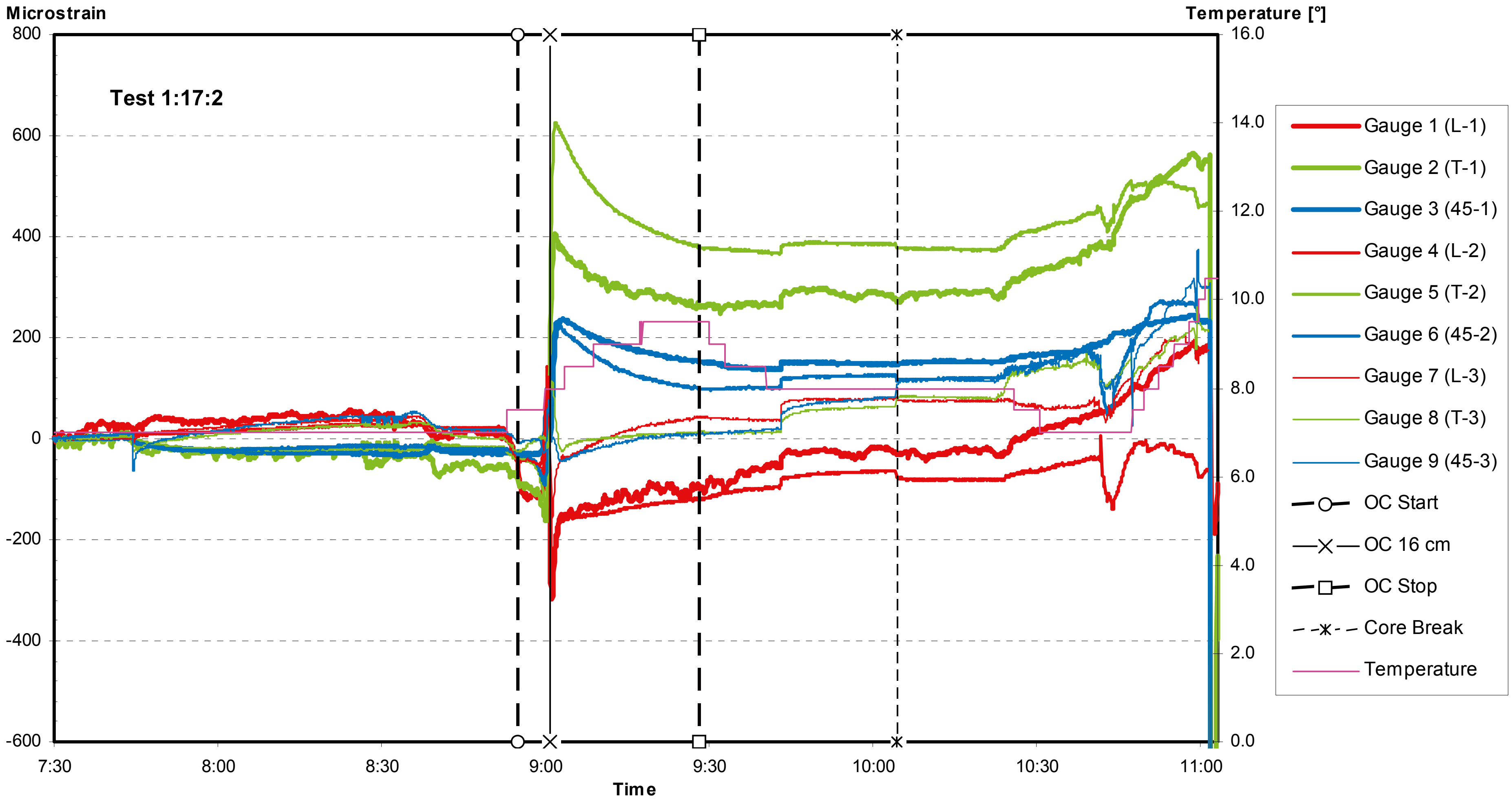


Figure B6. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:17:2, 144.17 m borehole length. Strain values reset to zero at 07:30.*

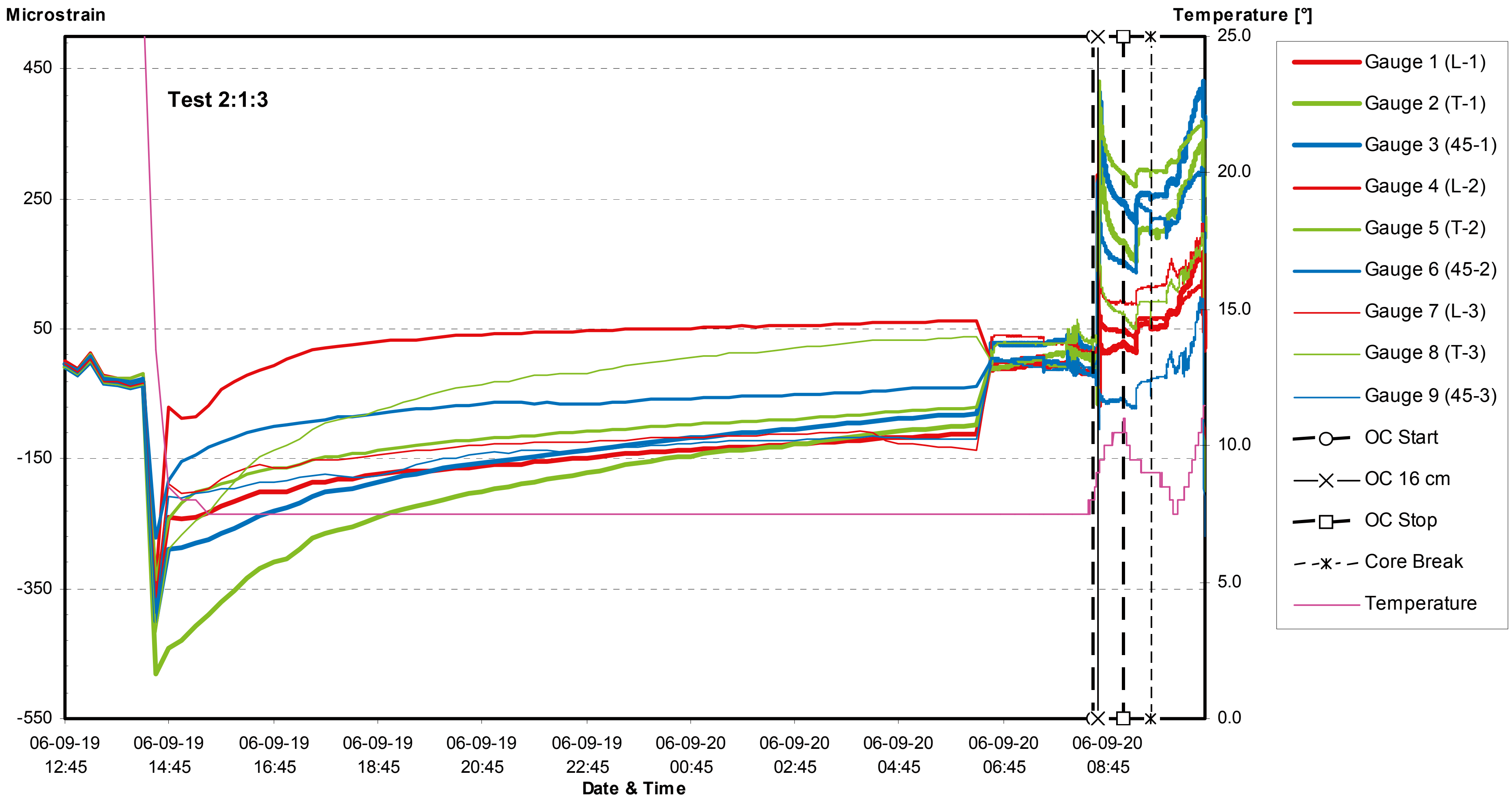


Figure B7. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:1:3, 156.72 m borehole length.*

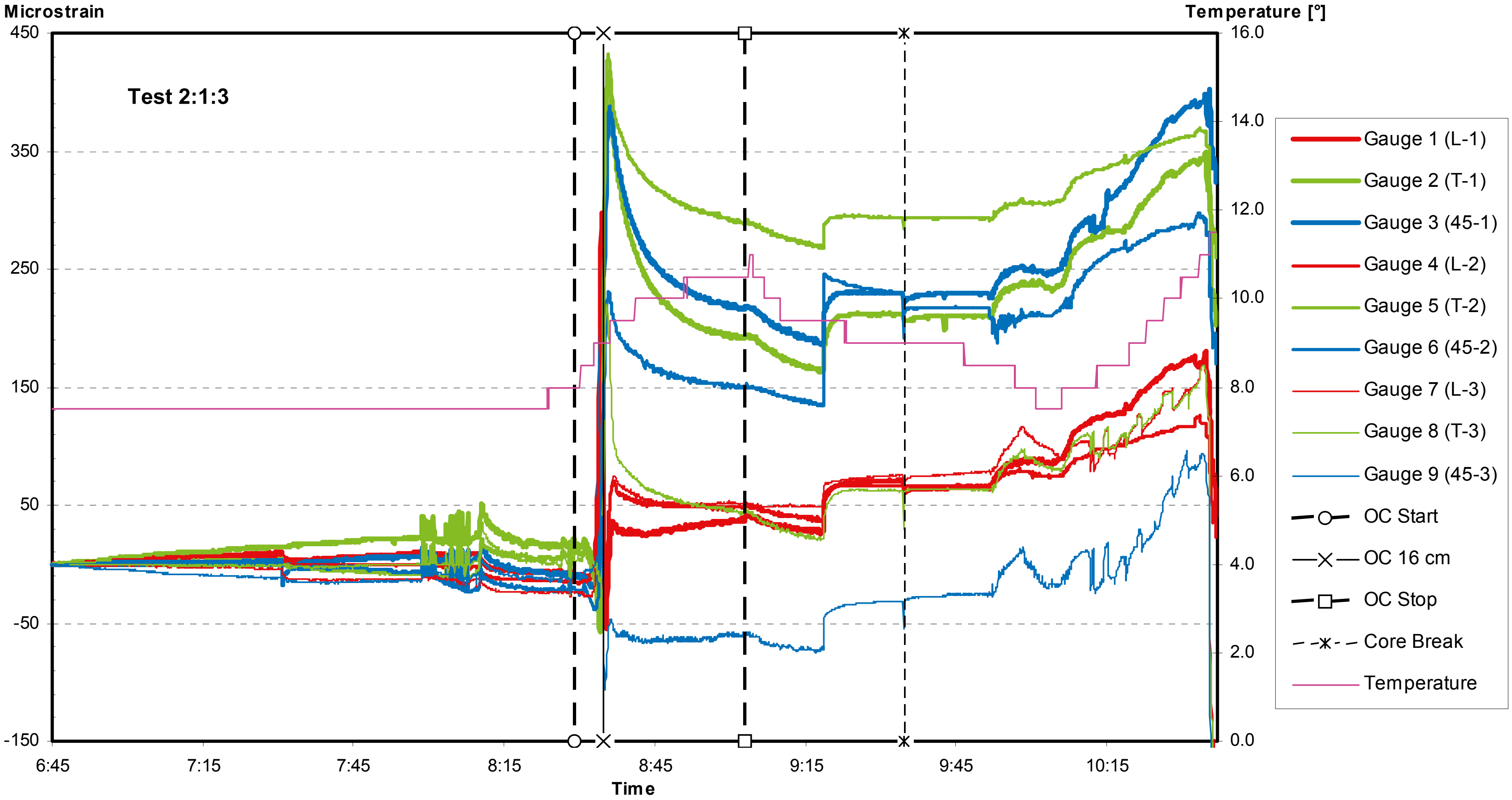


Figure B8. Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:1:3, 156.72 m borehole length. Strain values reset to zero at 06:45.

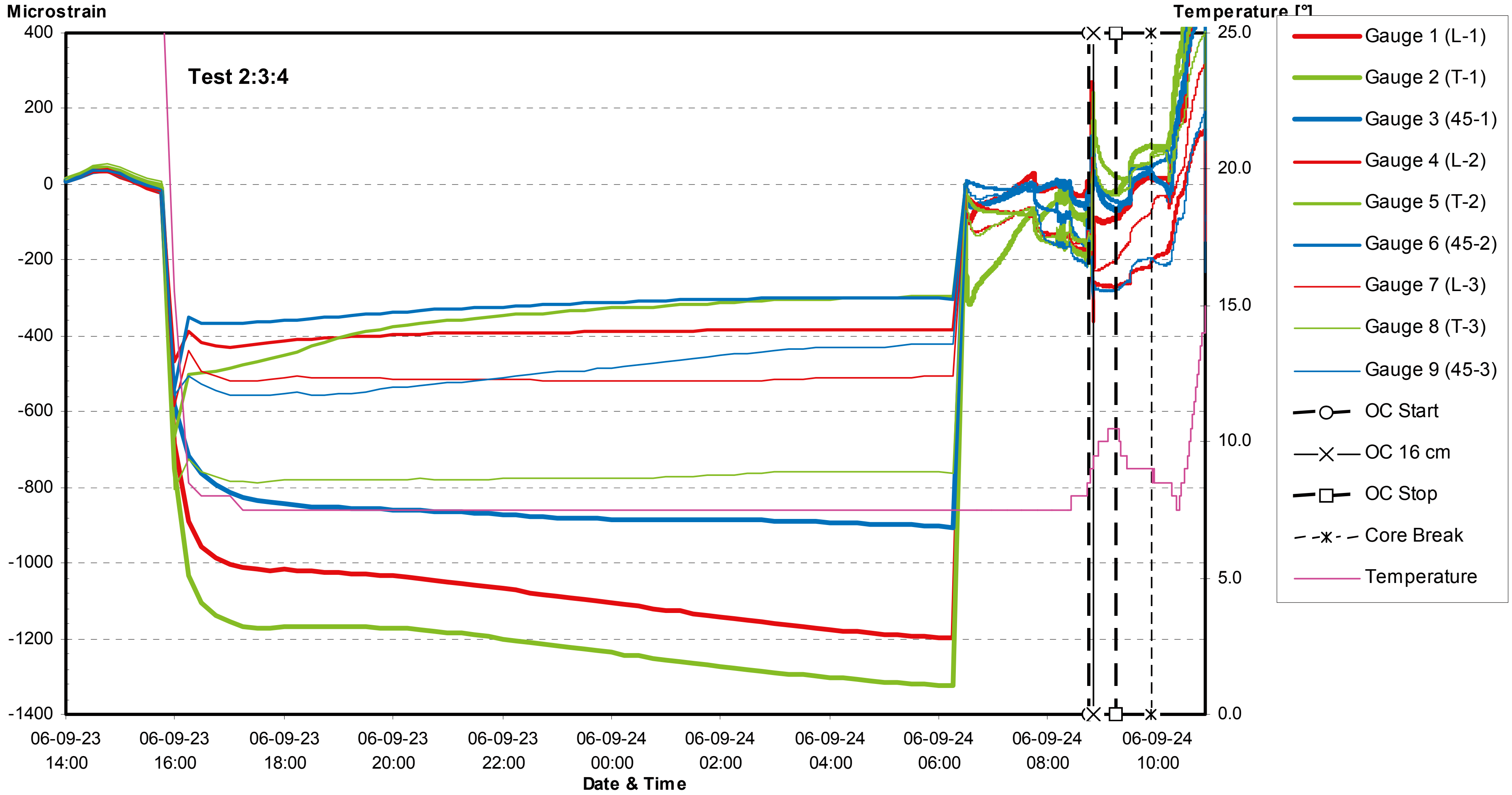


Figure B9. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:3:4, 164.10 m borehole length.*

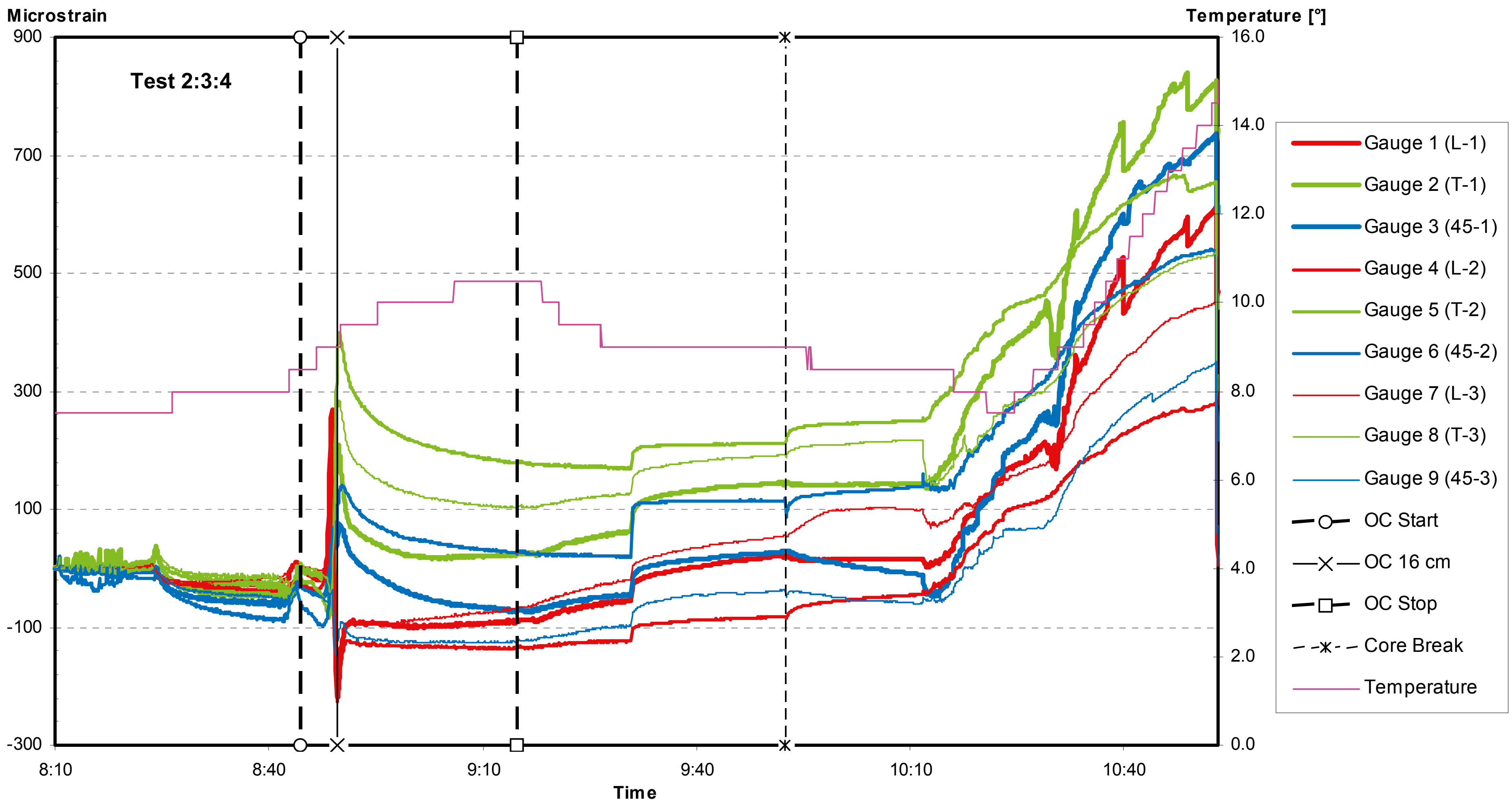


Figure B10. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:3:4, 164.10 m borehole length. Strain values reset to zero at 08:10.*

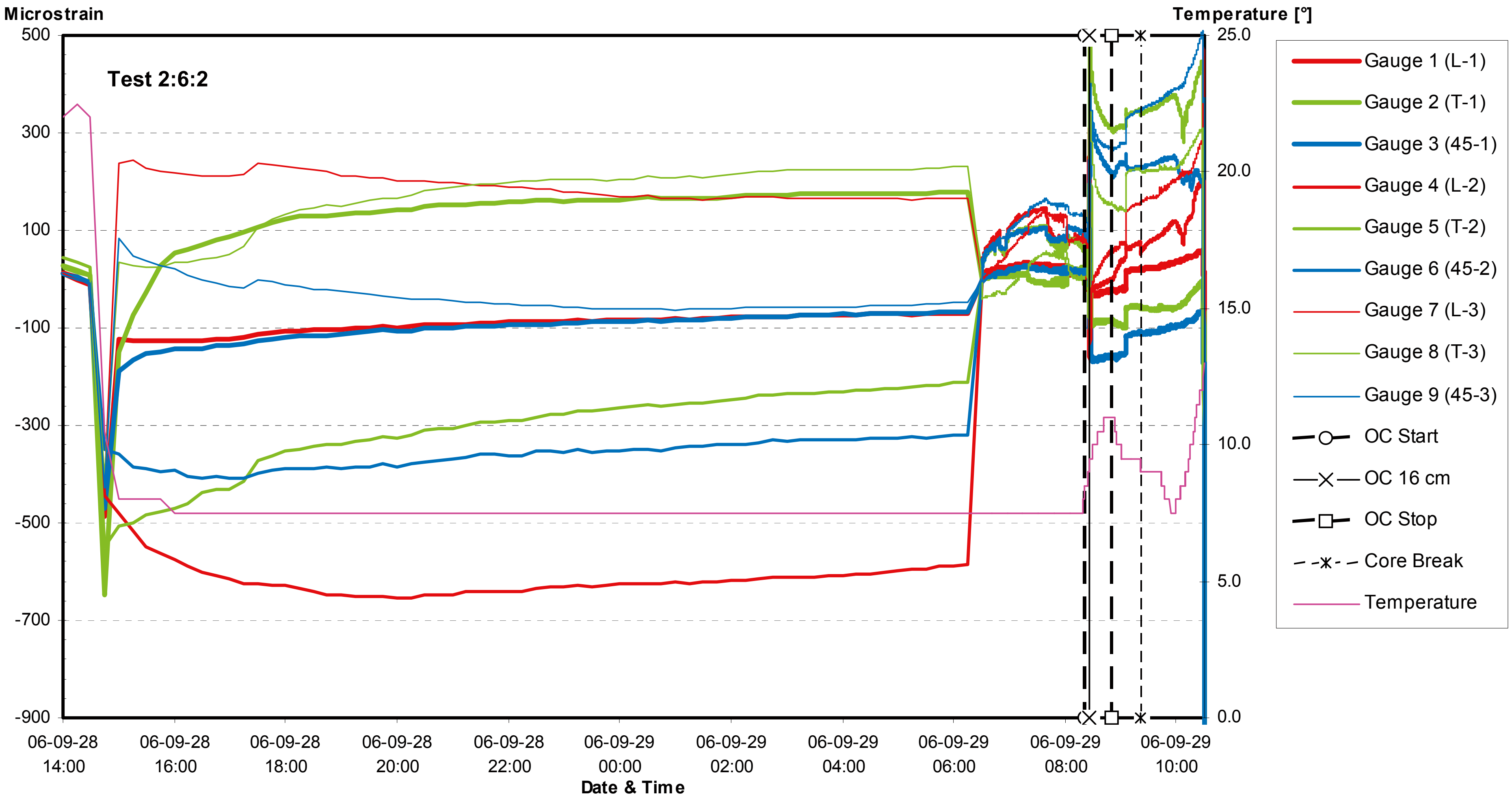


Figure B11. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:6:2, 178.03 m borehole length.*

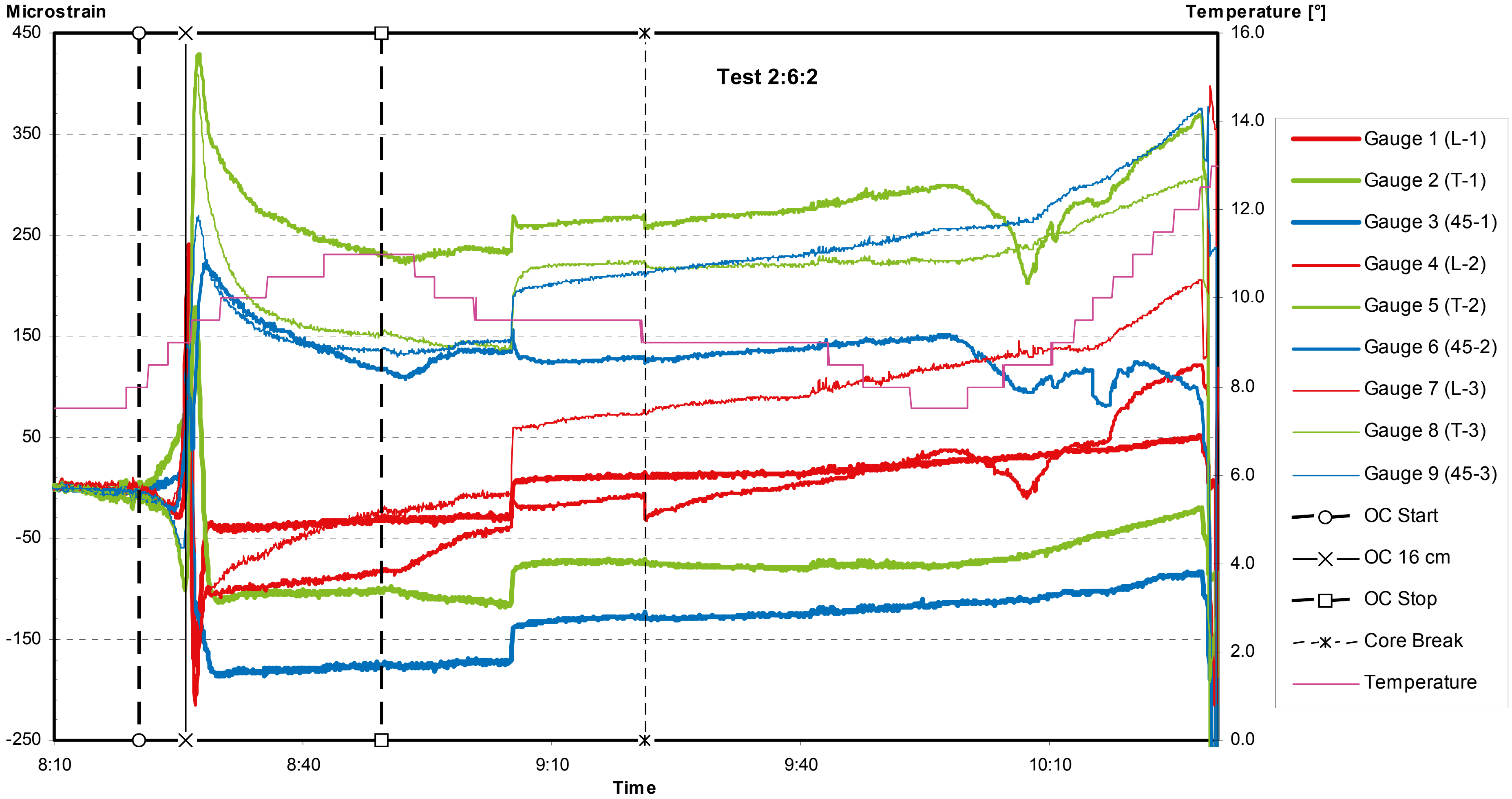


Figure B12. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:6:2, 178.03 m borehole length. Strain values reset to zero at 08:10.*

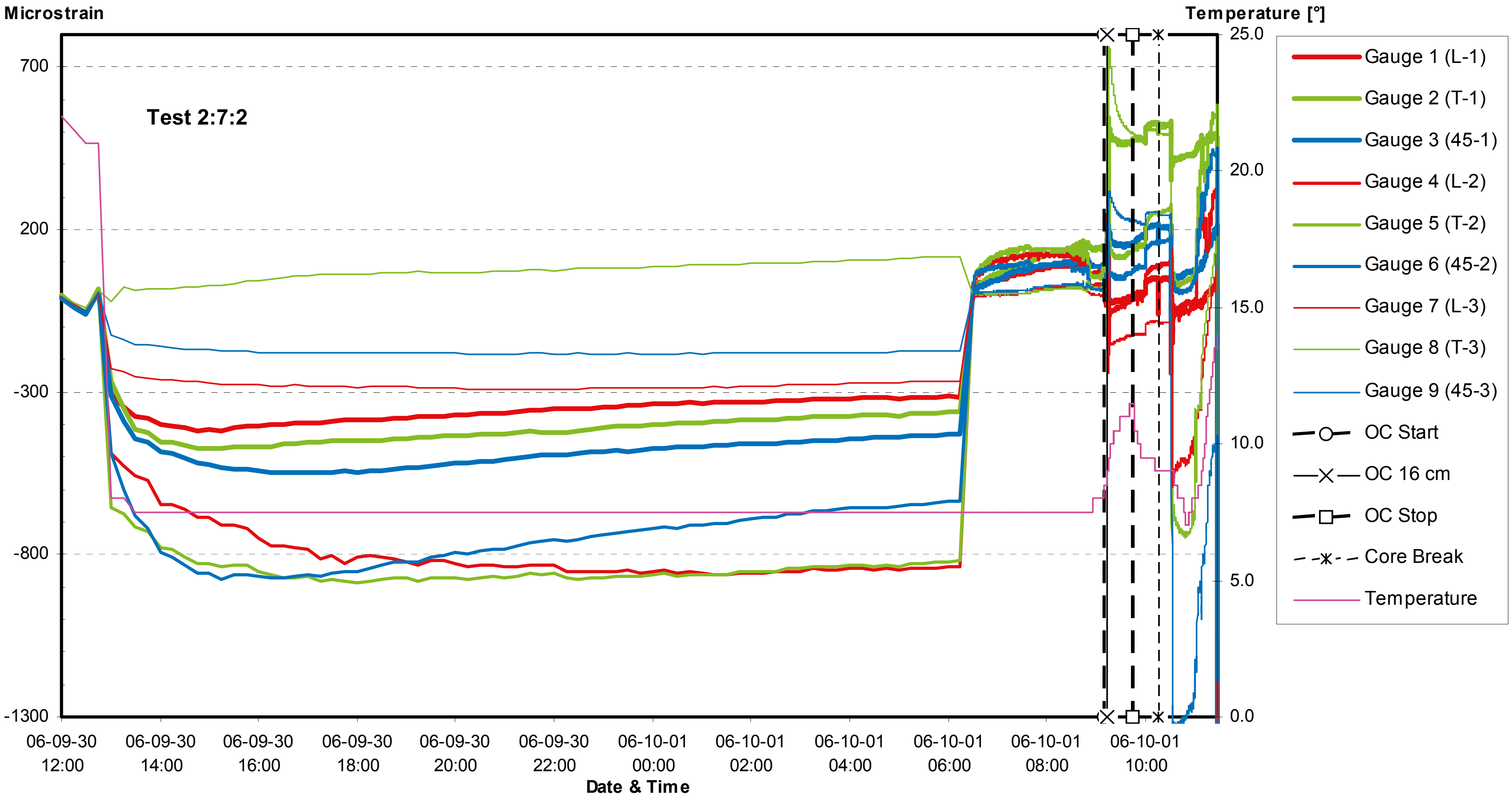


Figure B13. All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:7:2, 179.87 m borehole length.

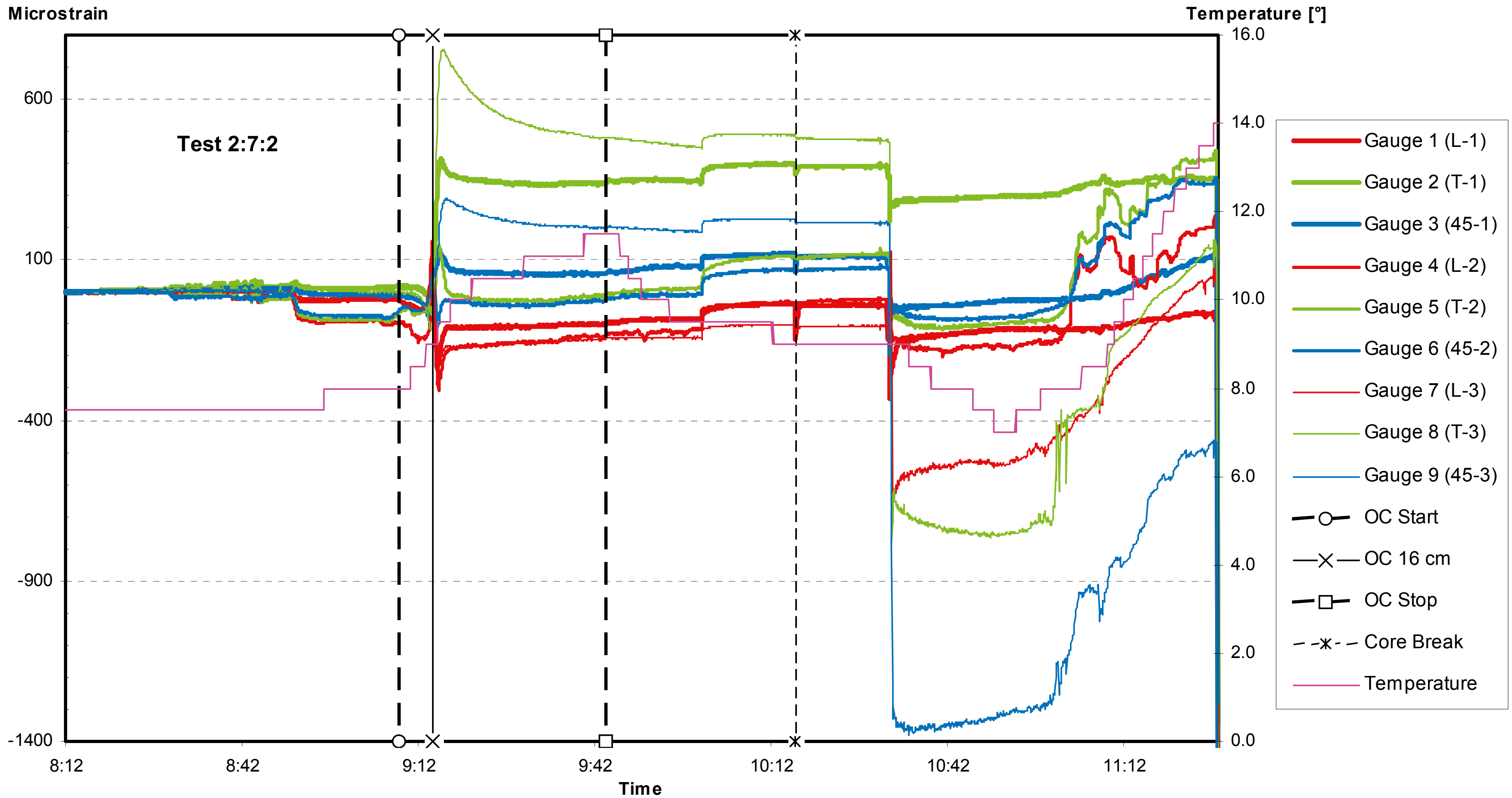


Figure B14. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:7:2, 179.87 m borehole length. Strain values reset to zero at 08:12.*

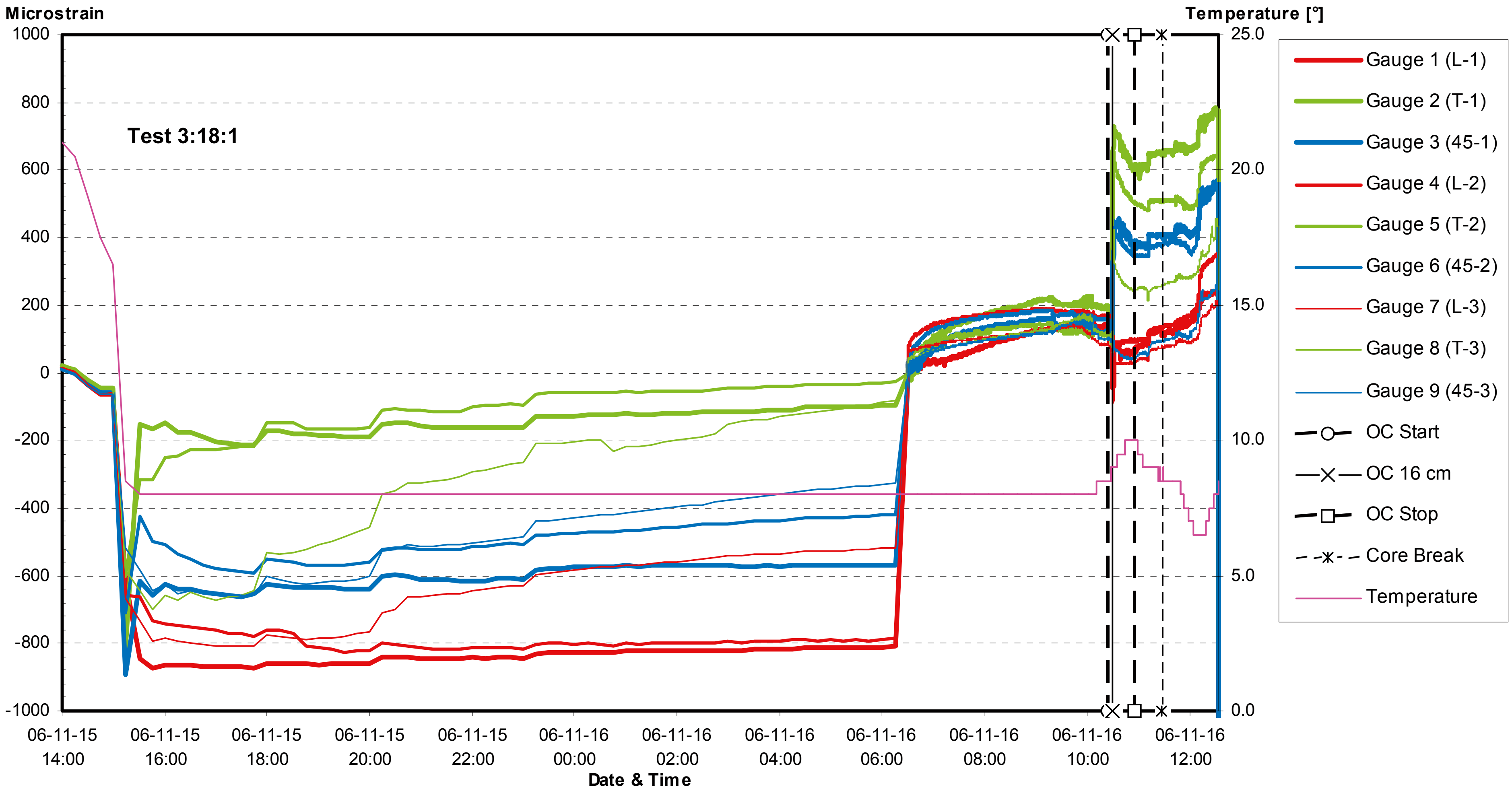


Figure B15. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:18:1, 252.83 m borehole length.*

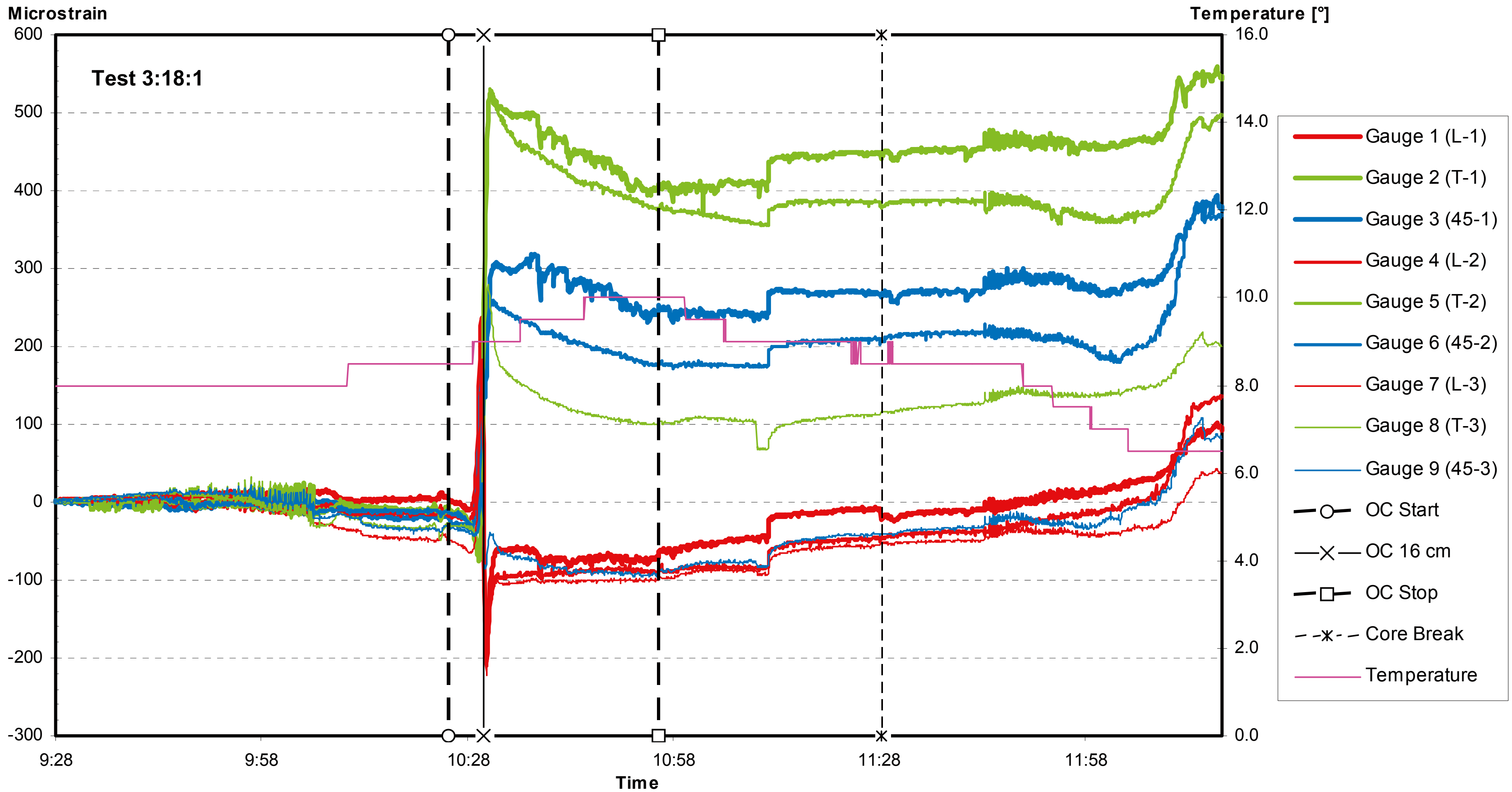


Figure B16. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 3:18:1, 252.83 m borehole length. Strain values reset to zero at 09:28.*

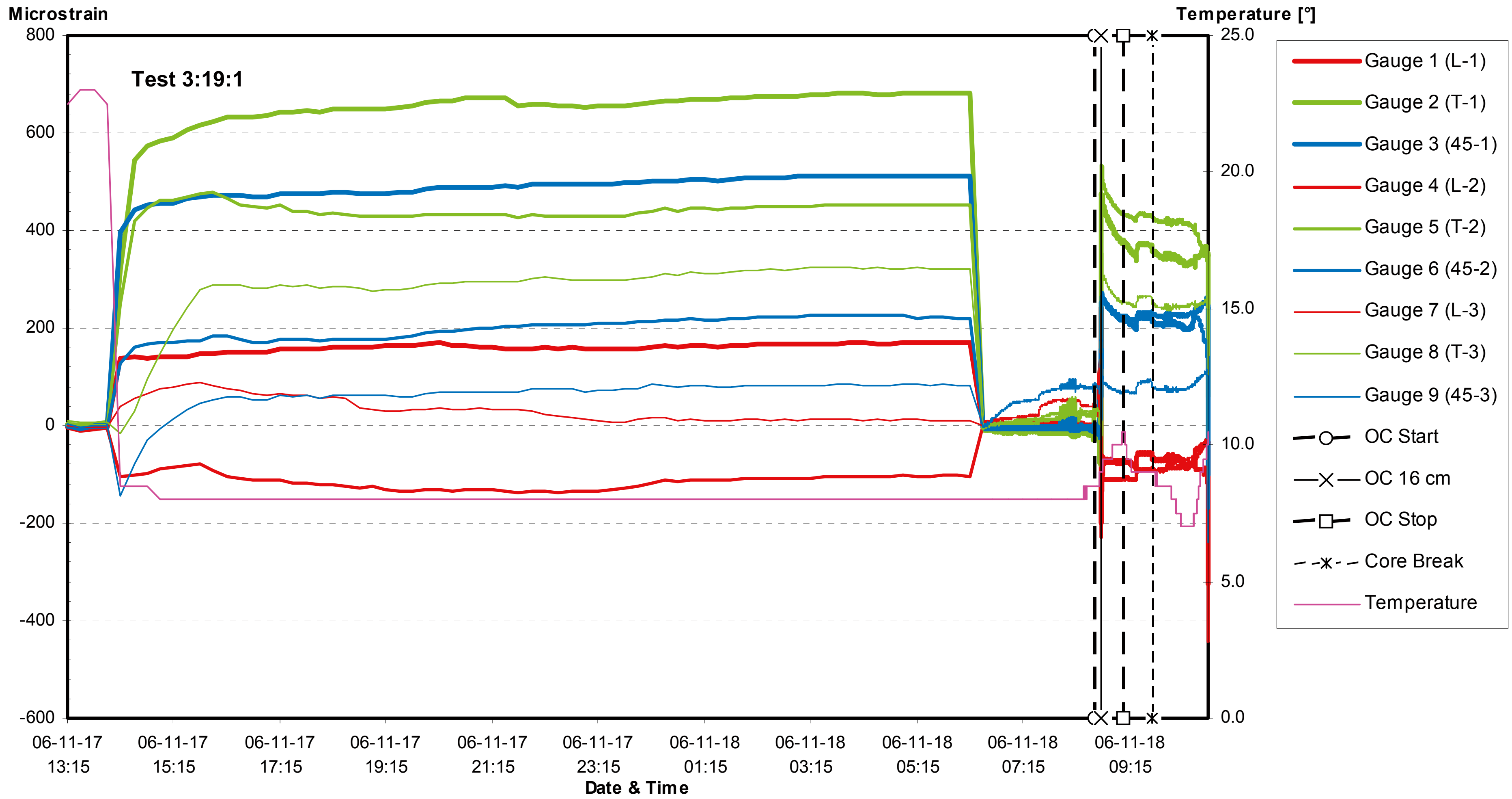


Figure B17. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:19:1, 253.77 m borehole length.*

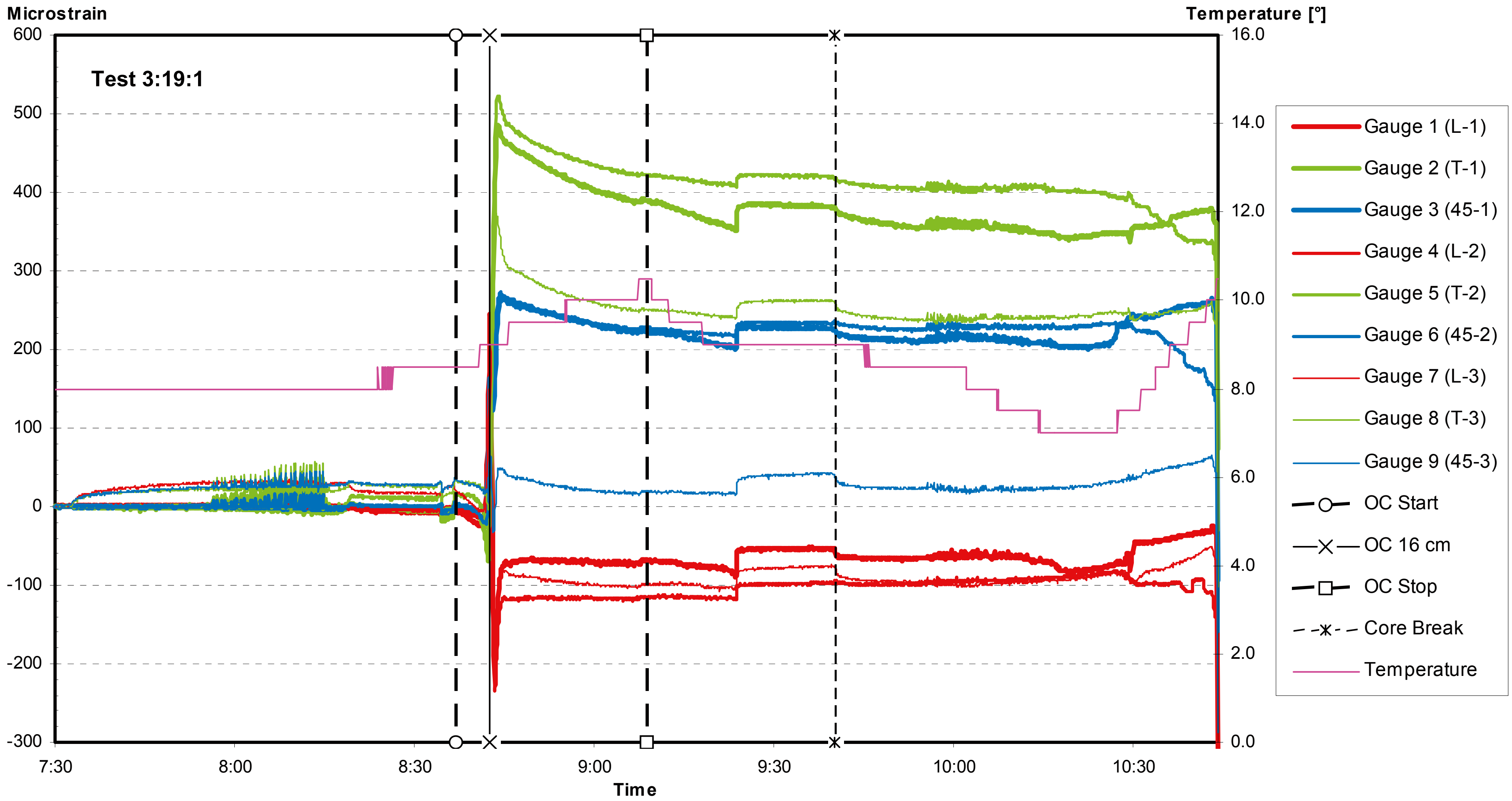


Figure B18. *Recorded strain data and temperature during overcoring (from start to stop) for test no 3:19:1, 253.77 borehole length. Strain values reset to zero at 07:30.*

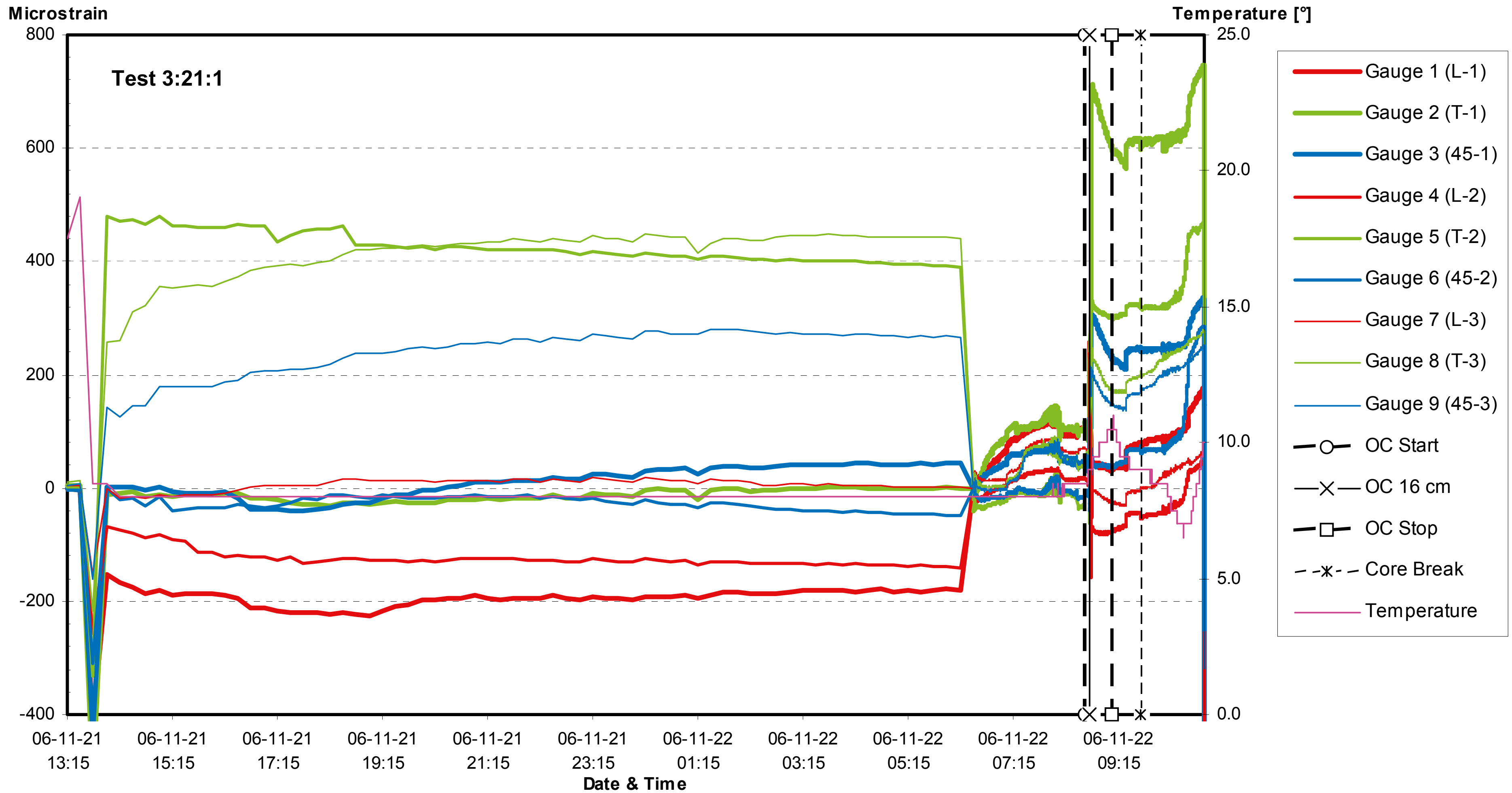


Figure B19. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:21:1, 256.13 m borehole length.*

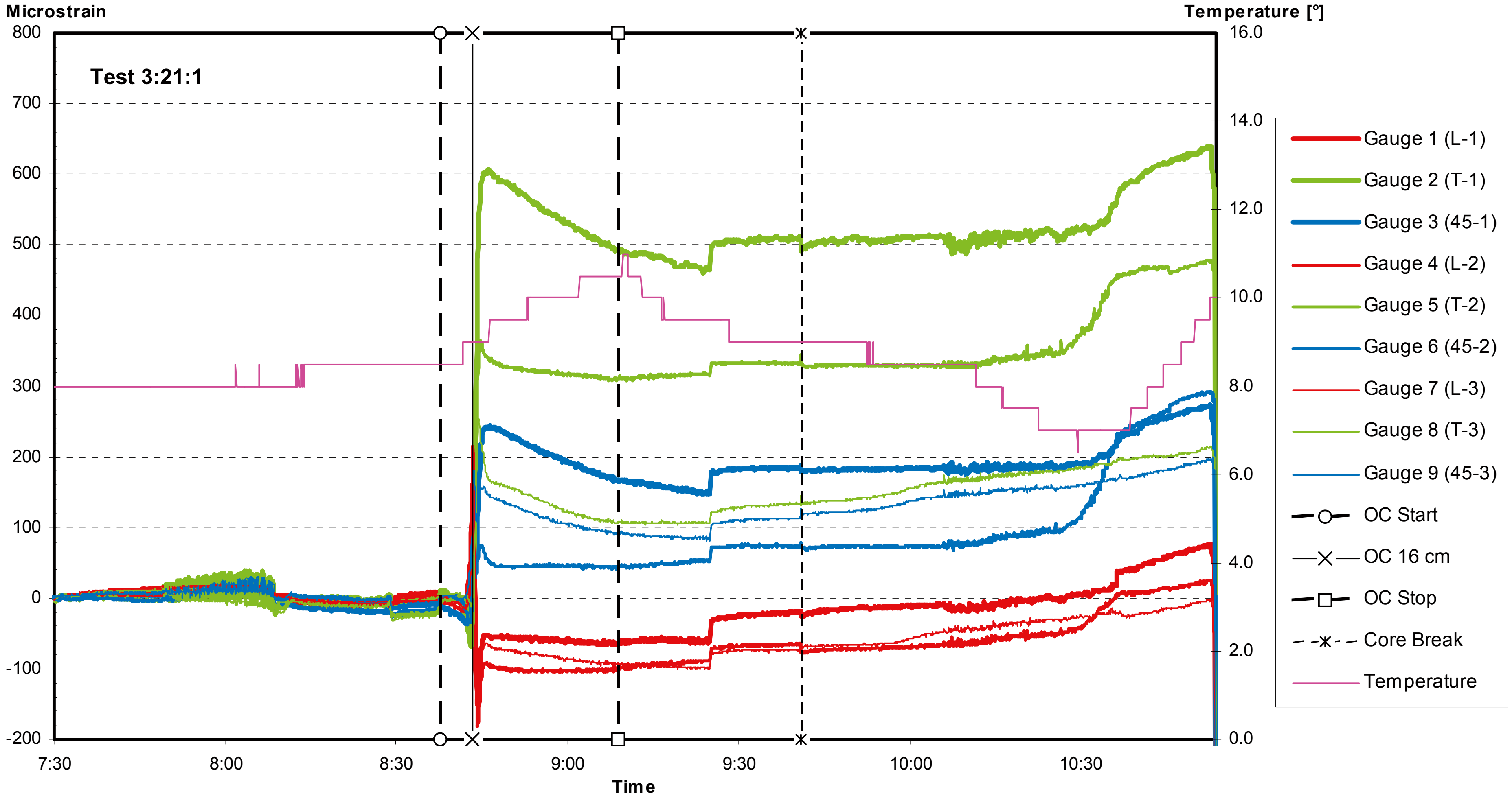


Figure B20. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 3:21:1, 256.13 m borehole length. Strain values reset to zero at 07:30.*

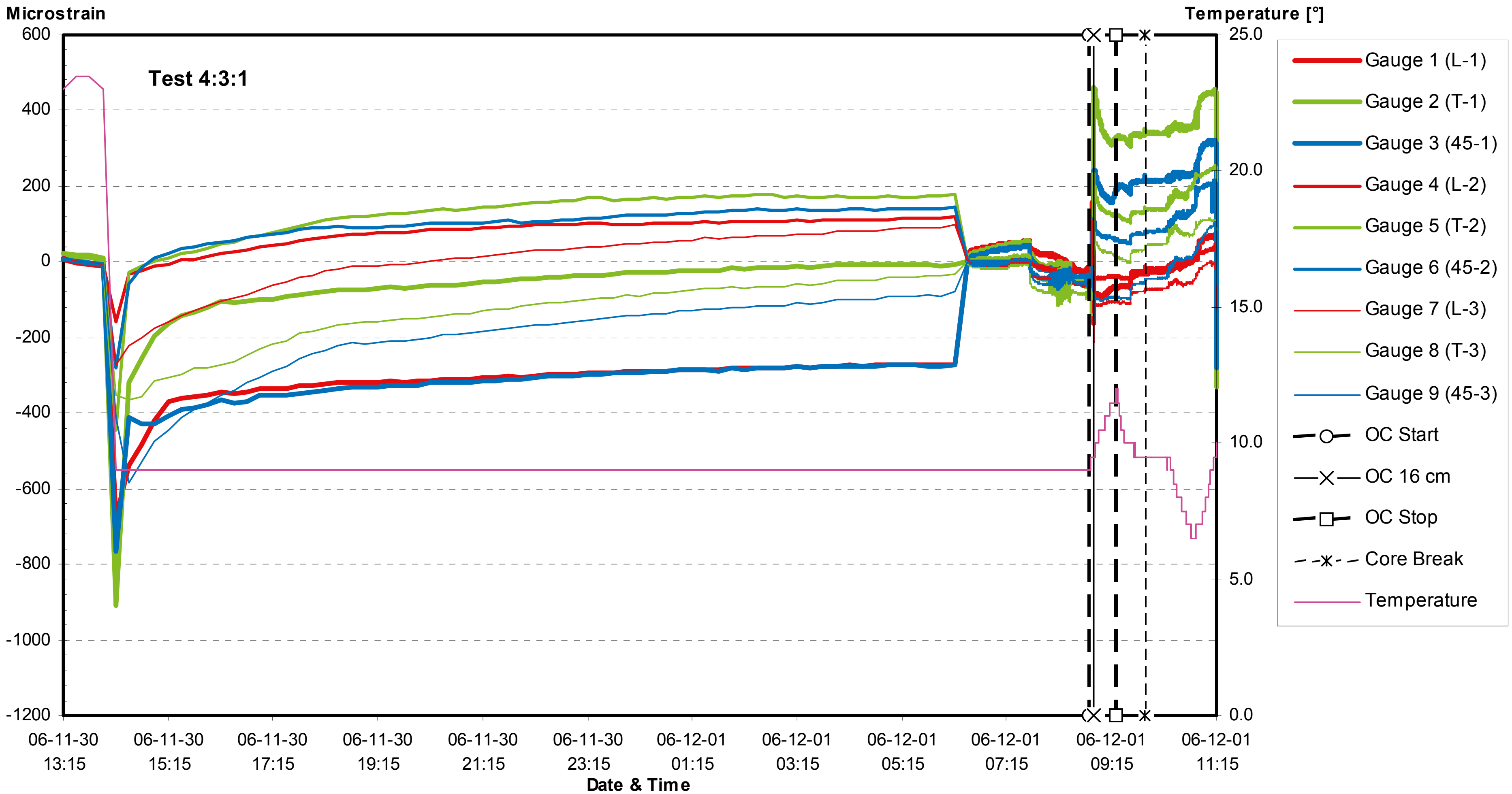


Figure B21. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 4:3:1, 302.33 m borehole length.*

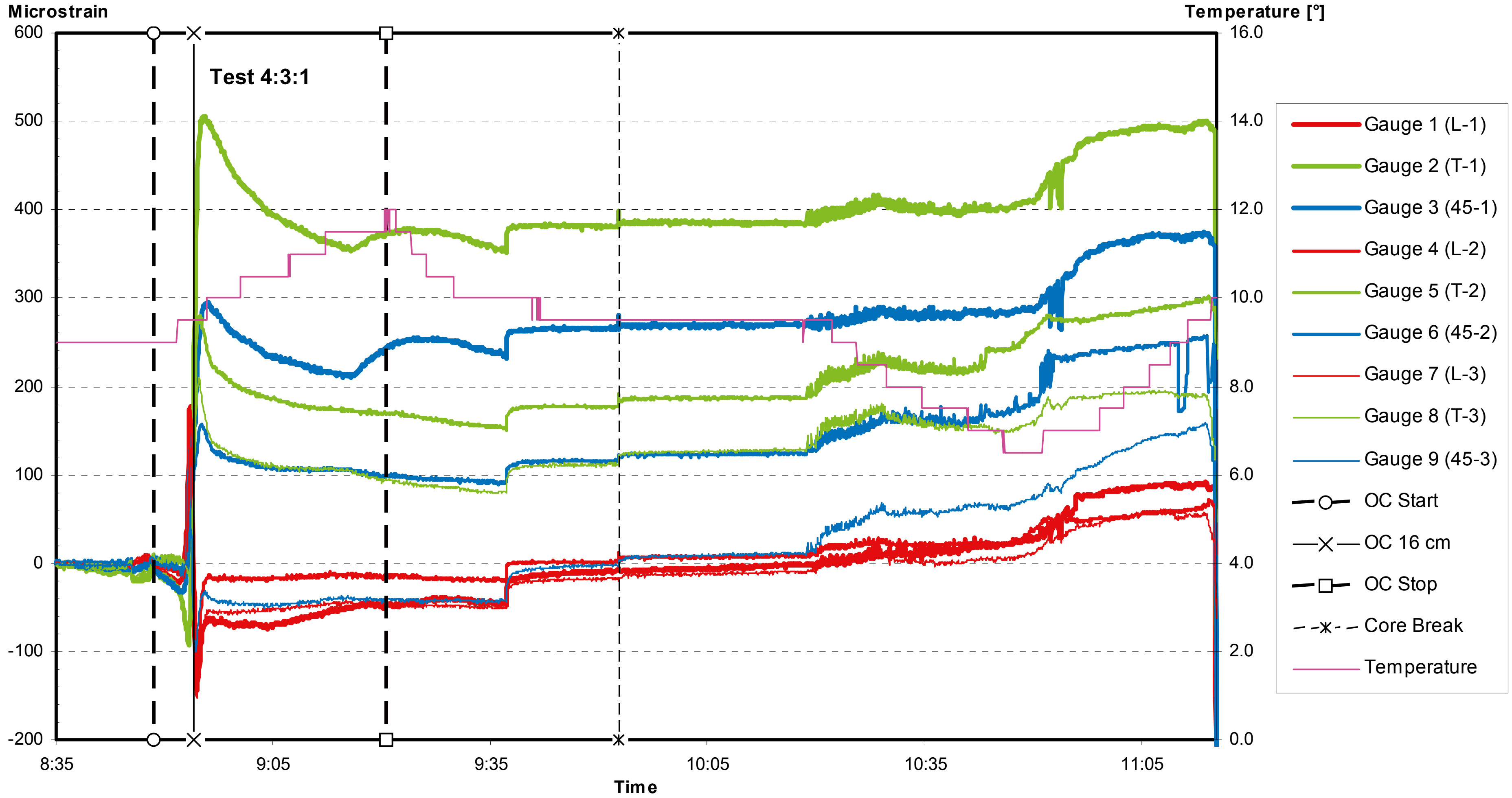


Figure B22. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 4:3:1, 302.33 borehole length. Strain values reset to zero at 08:35.*

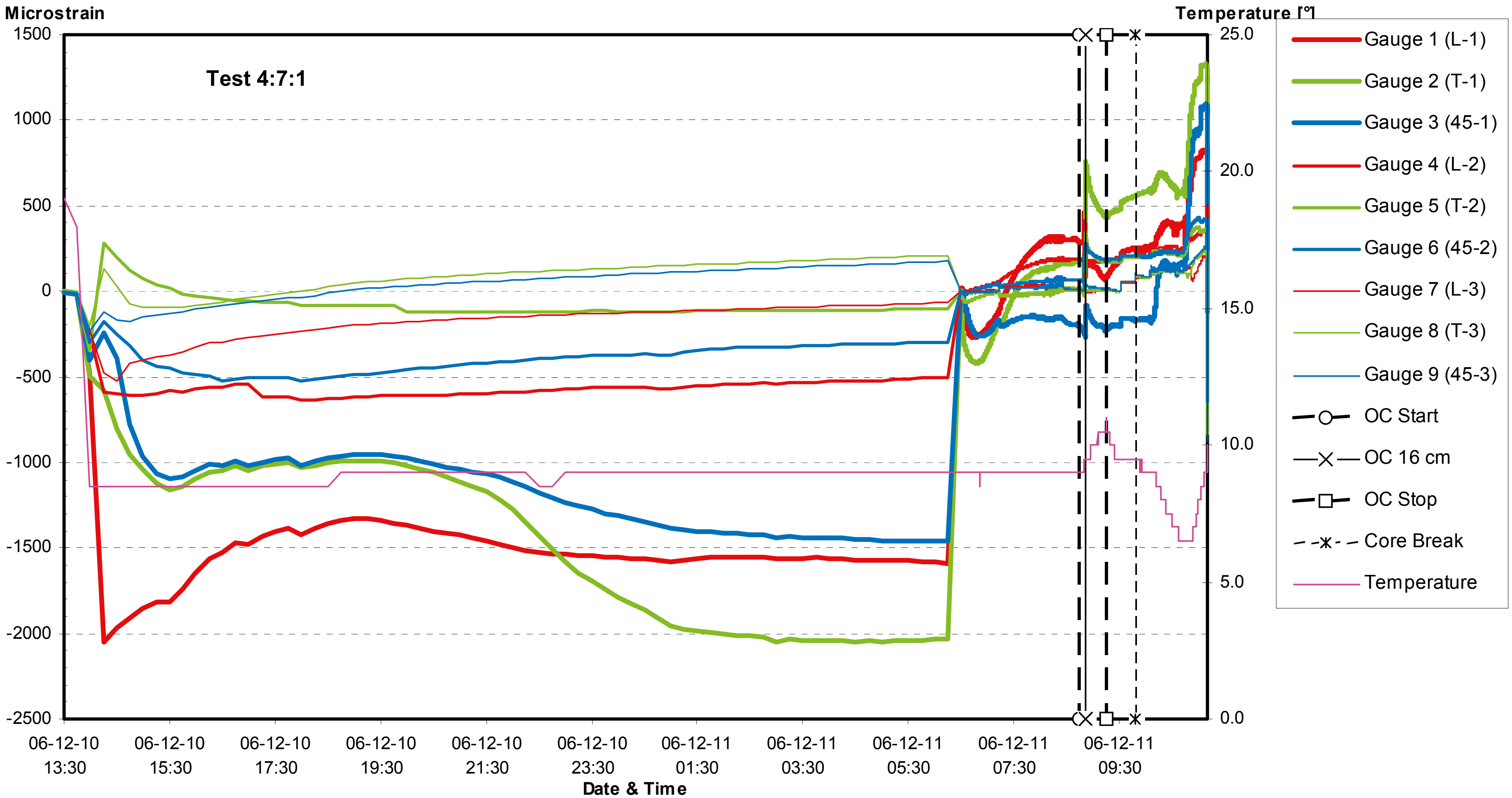


Figure B23. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 4:7:1, 306.20m borehole length.*

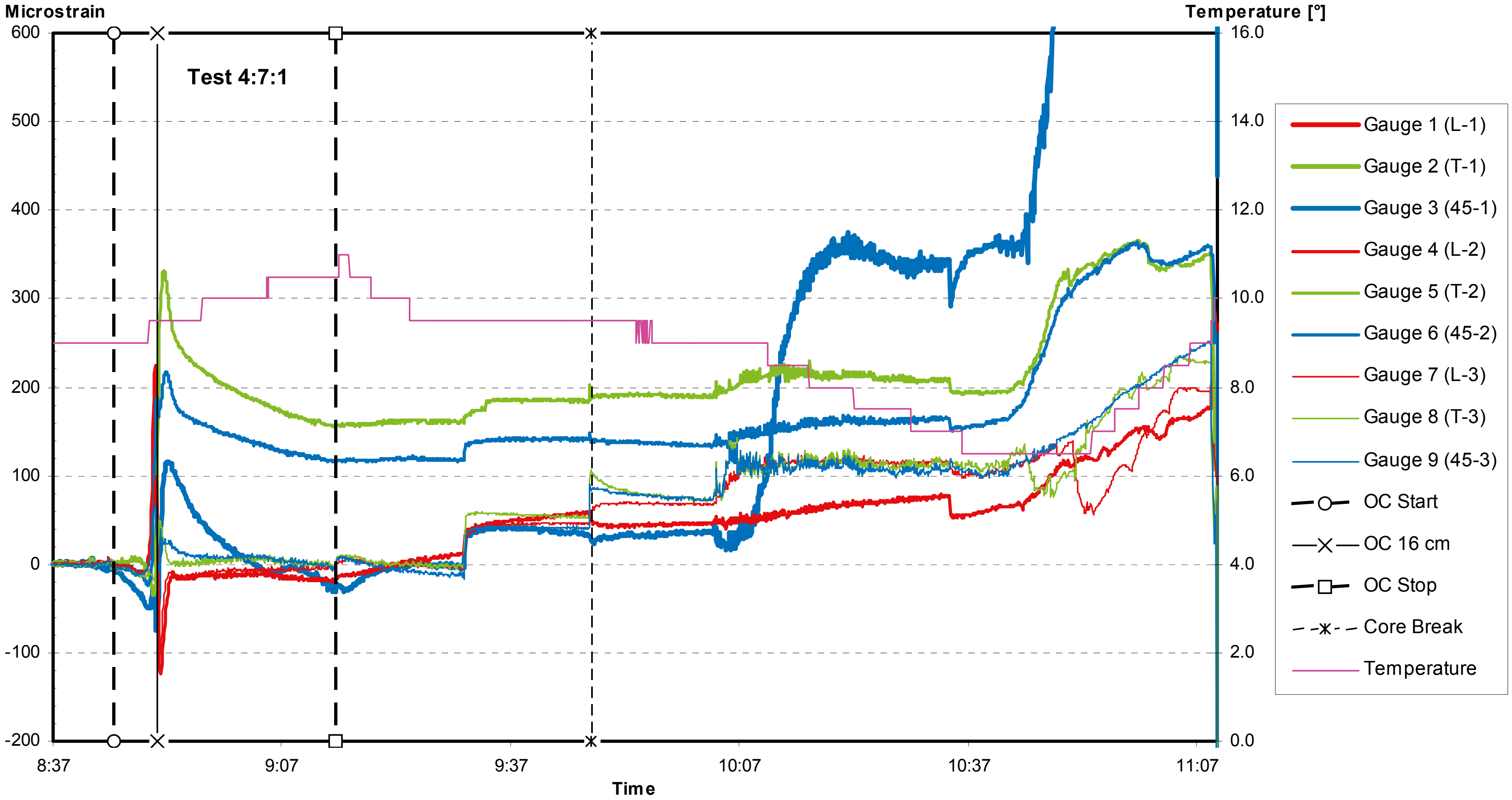


Figure B24. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 4:7:1, 306.20 borehole length. Strain values reset to zero at 08:37.*

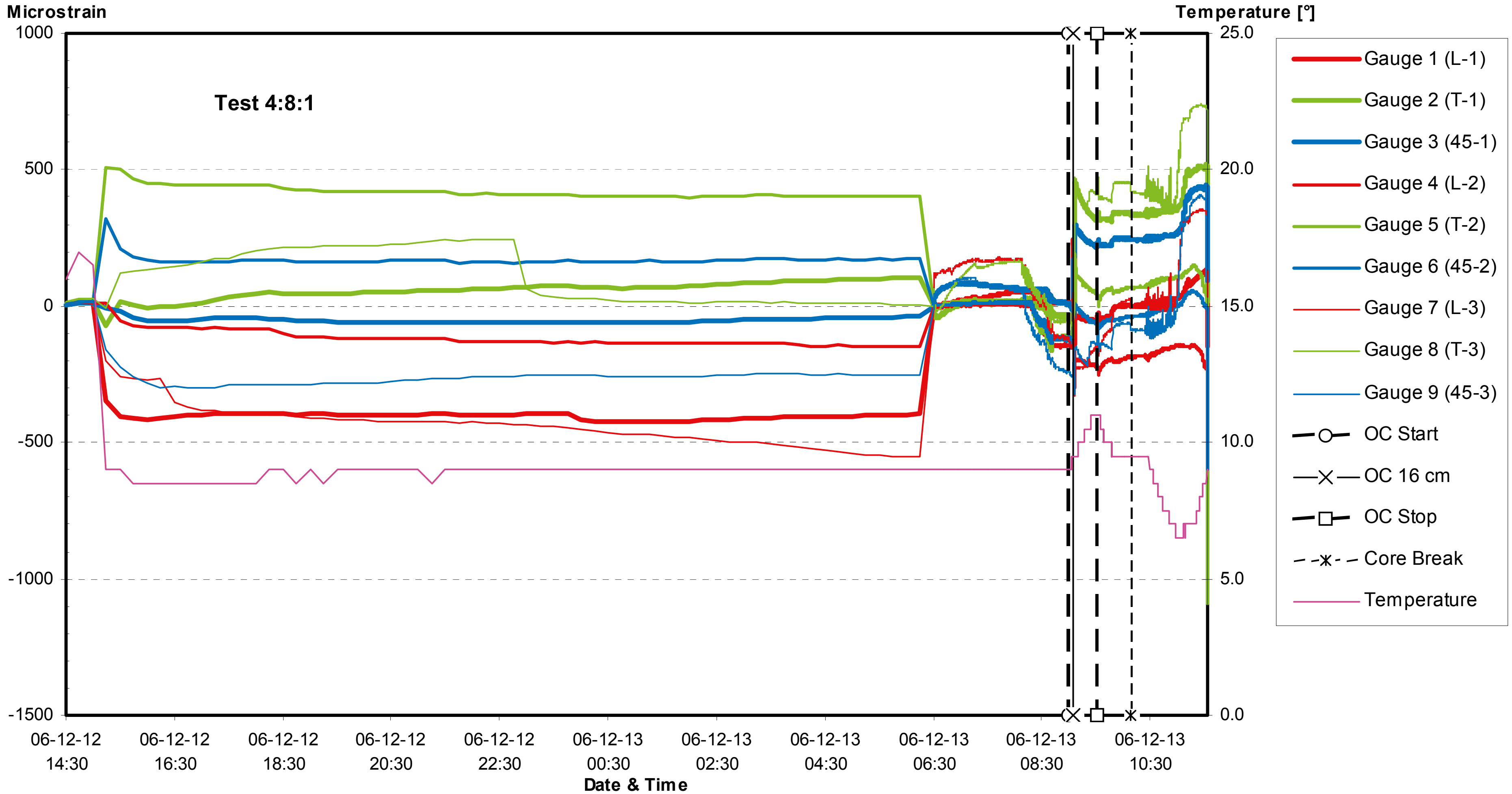


Figure B25. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 4:8:1, 307.06 m borehole length.*

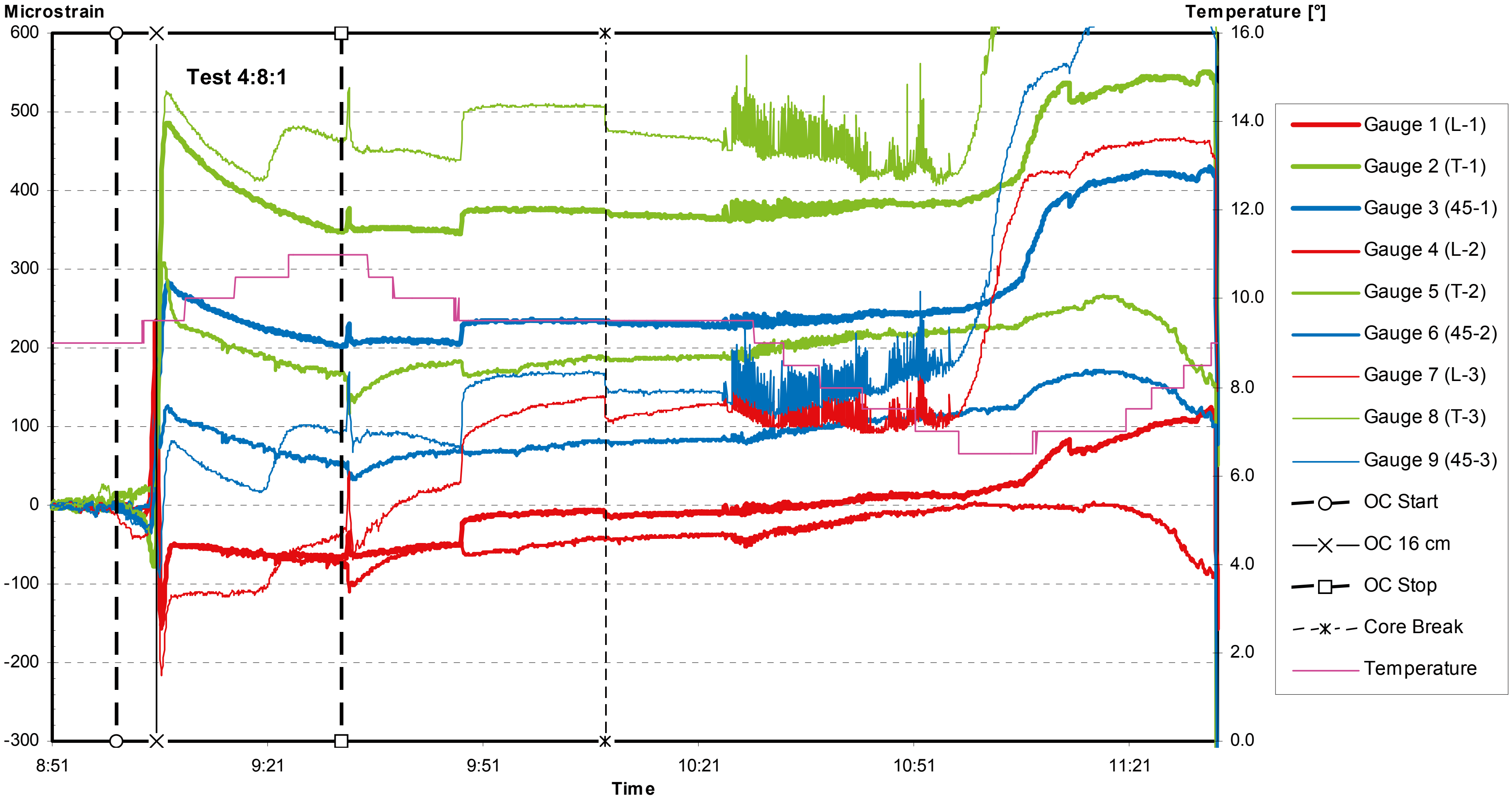


Figure B26. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 4:8:1, 307.06 borehole length. Strain values reset to zero at 08:51.*

Appendix C

Biaxial test data

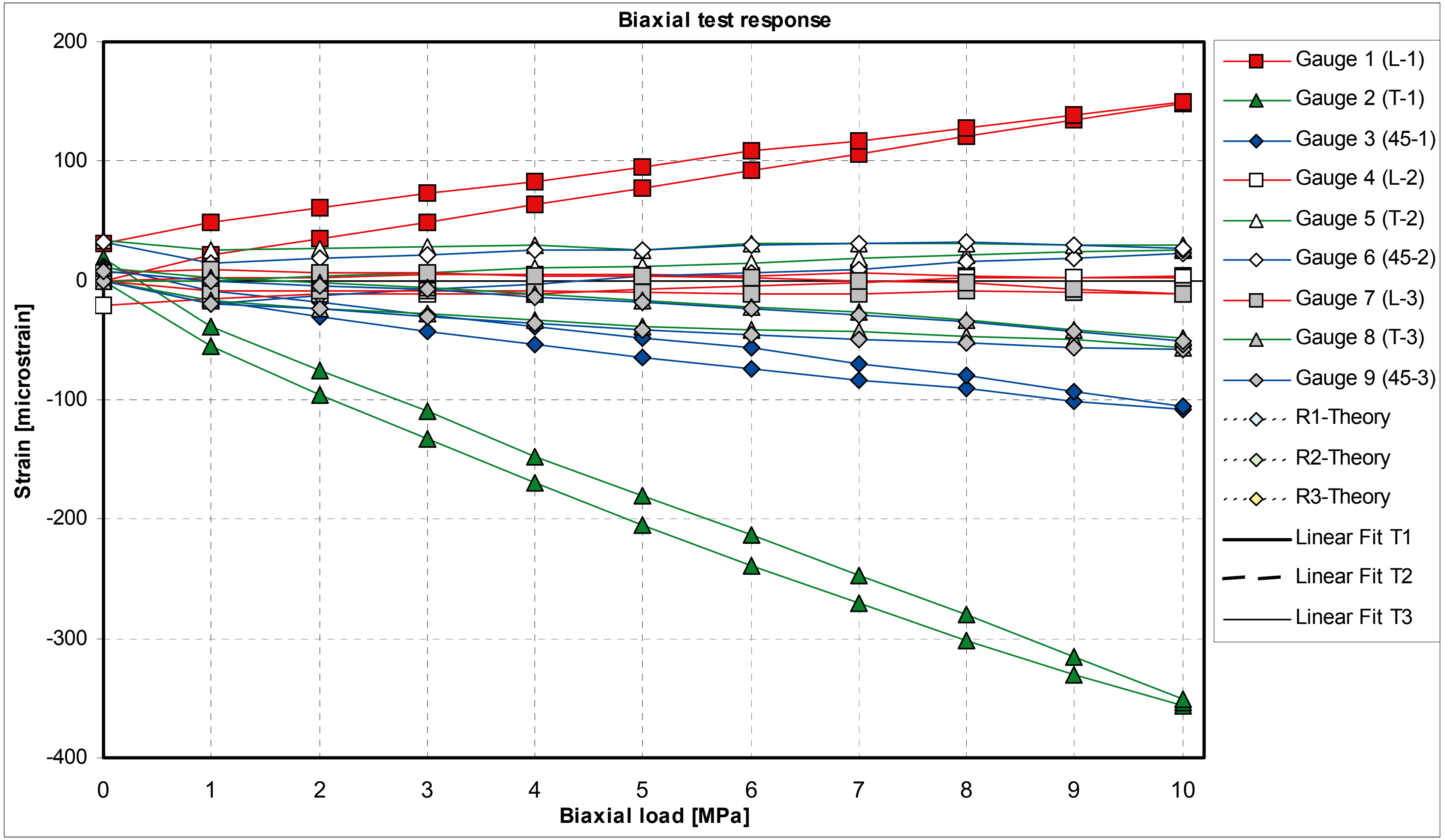


Figure C1. Results from biaxial testing of test no. 1:7:1, 113.74 m borehole length (rosettes nos. 2 and 3 were excluded when determining elastic constants).

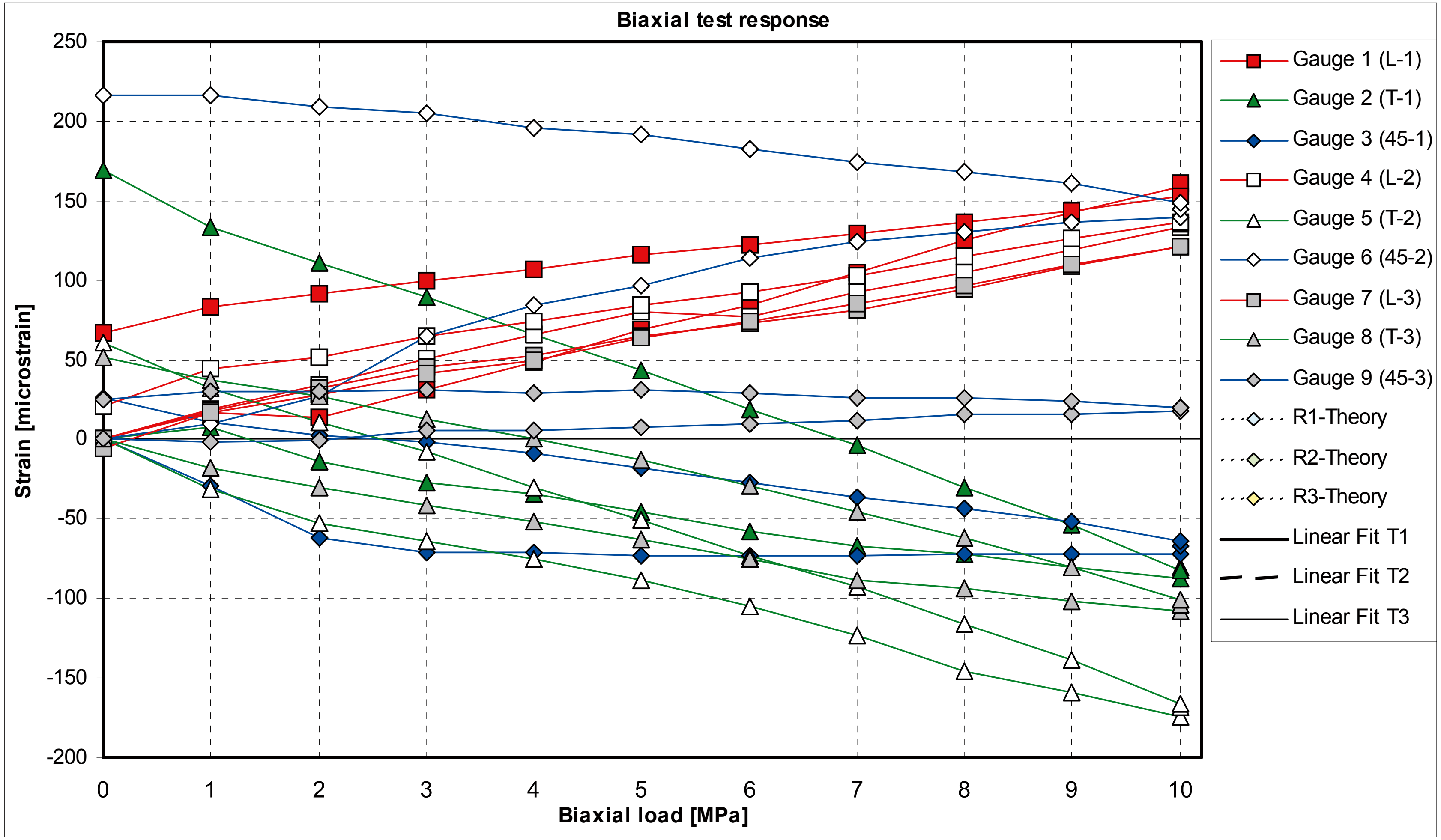


Figure C2. *Results from biaxial testing of test no. 1:13:3, 135.80 m borehole length.*

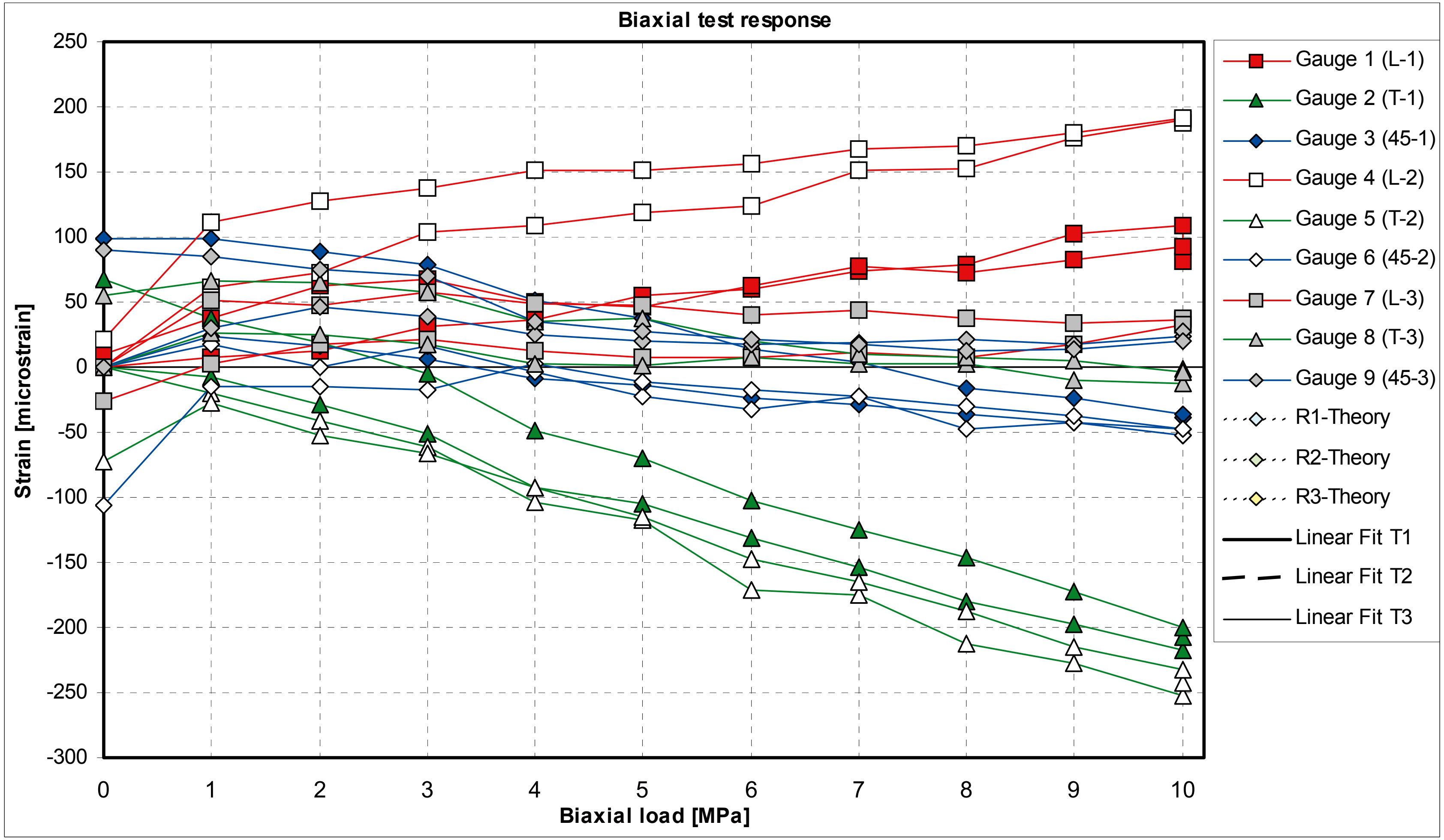


Figure C3. *Results from biaxial testing of test no. 1:17:2, 144.17 m borehole length.*

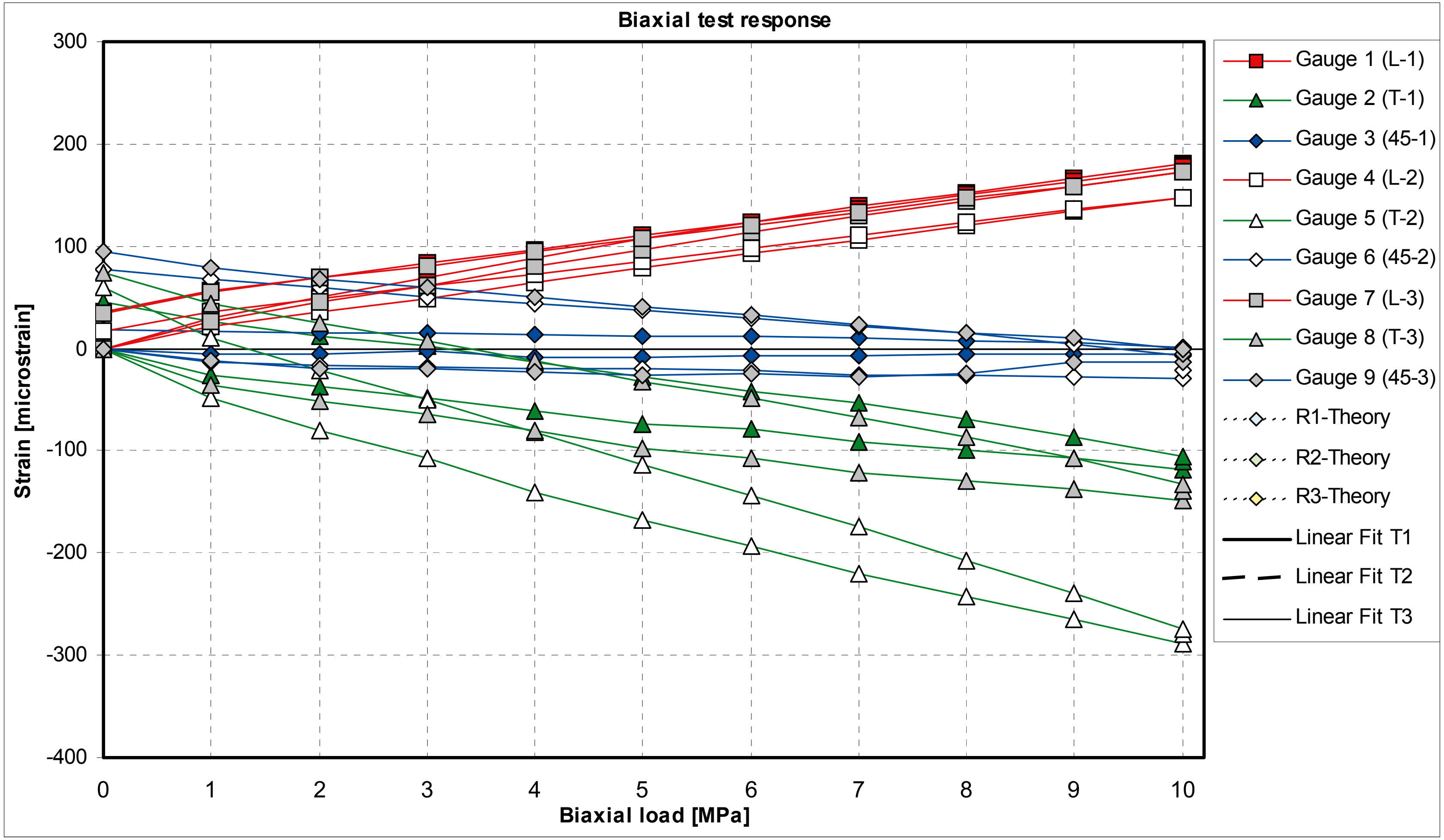


Figure C4. *Results from biaxial testing of test no. 2:1:3, 156.72 m borehole length (rosette no. 1 was excluded when determining elastic constants).*

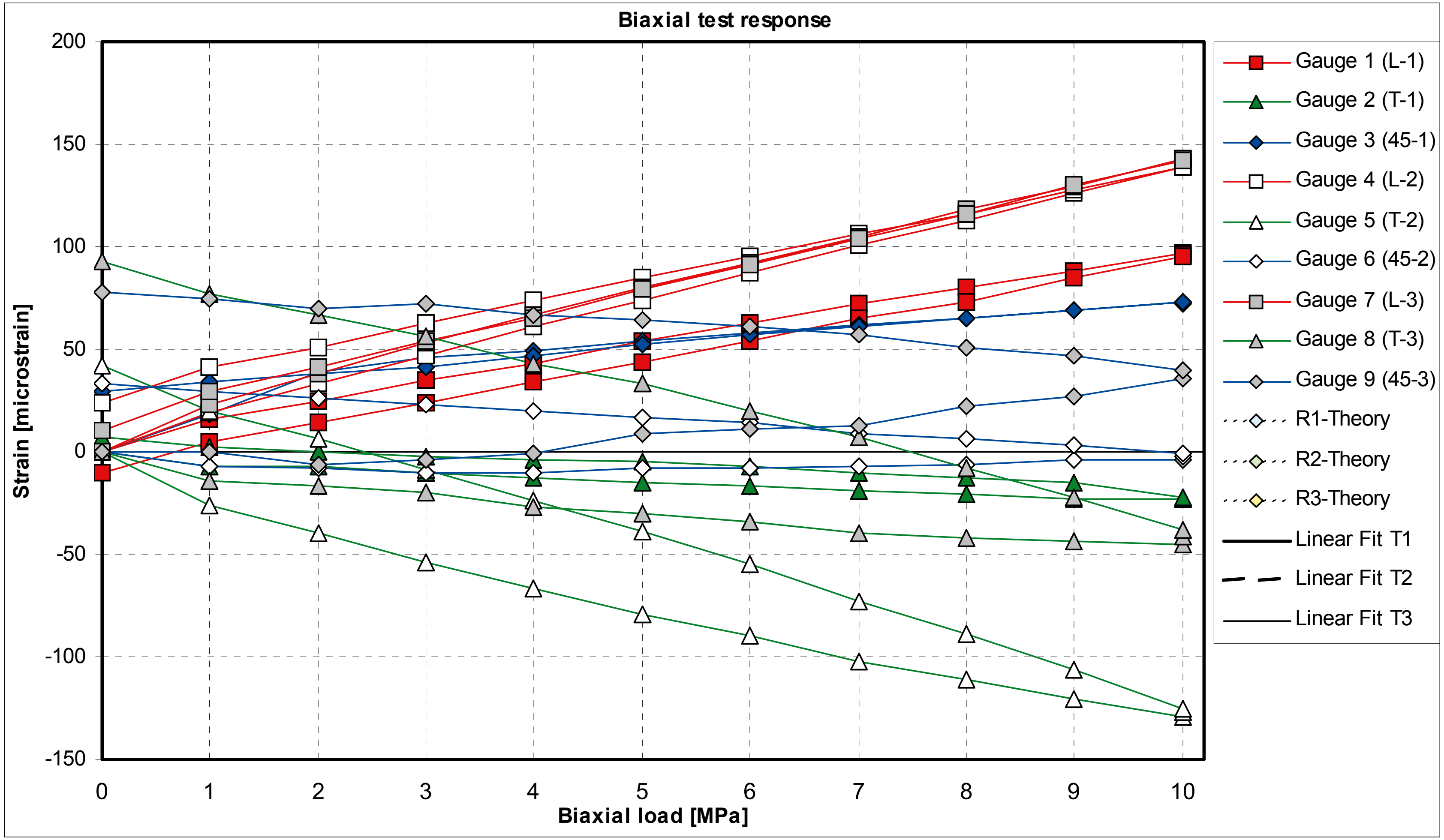


Figure C5. *Results from biaxial testing of test no. 2:3:4, 164.10 m borehole length.*

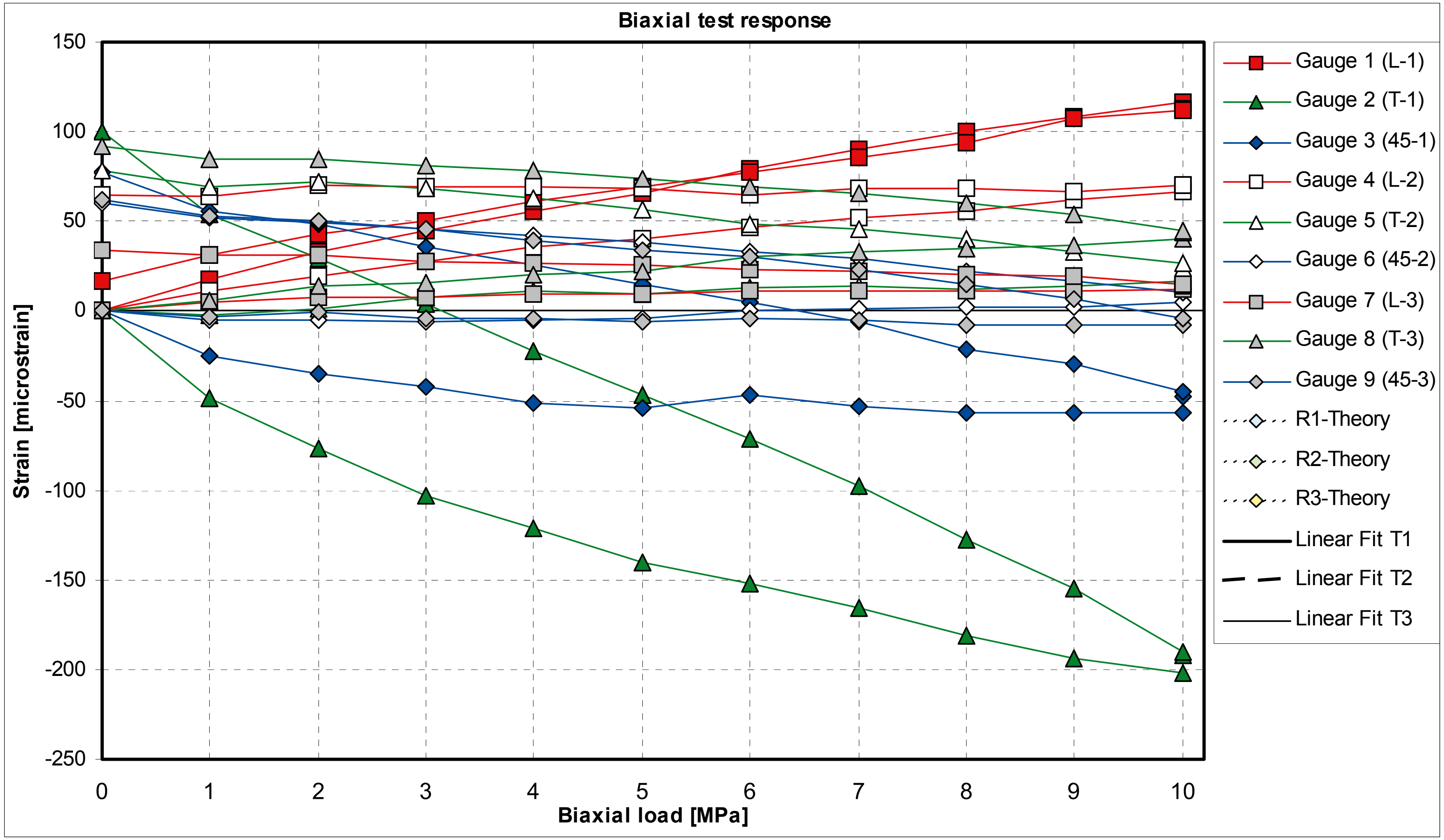


Figure C6. *Results from biaxial testing of test no. 2:6:2, 178.03 m borehole length.*

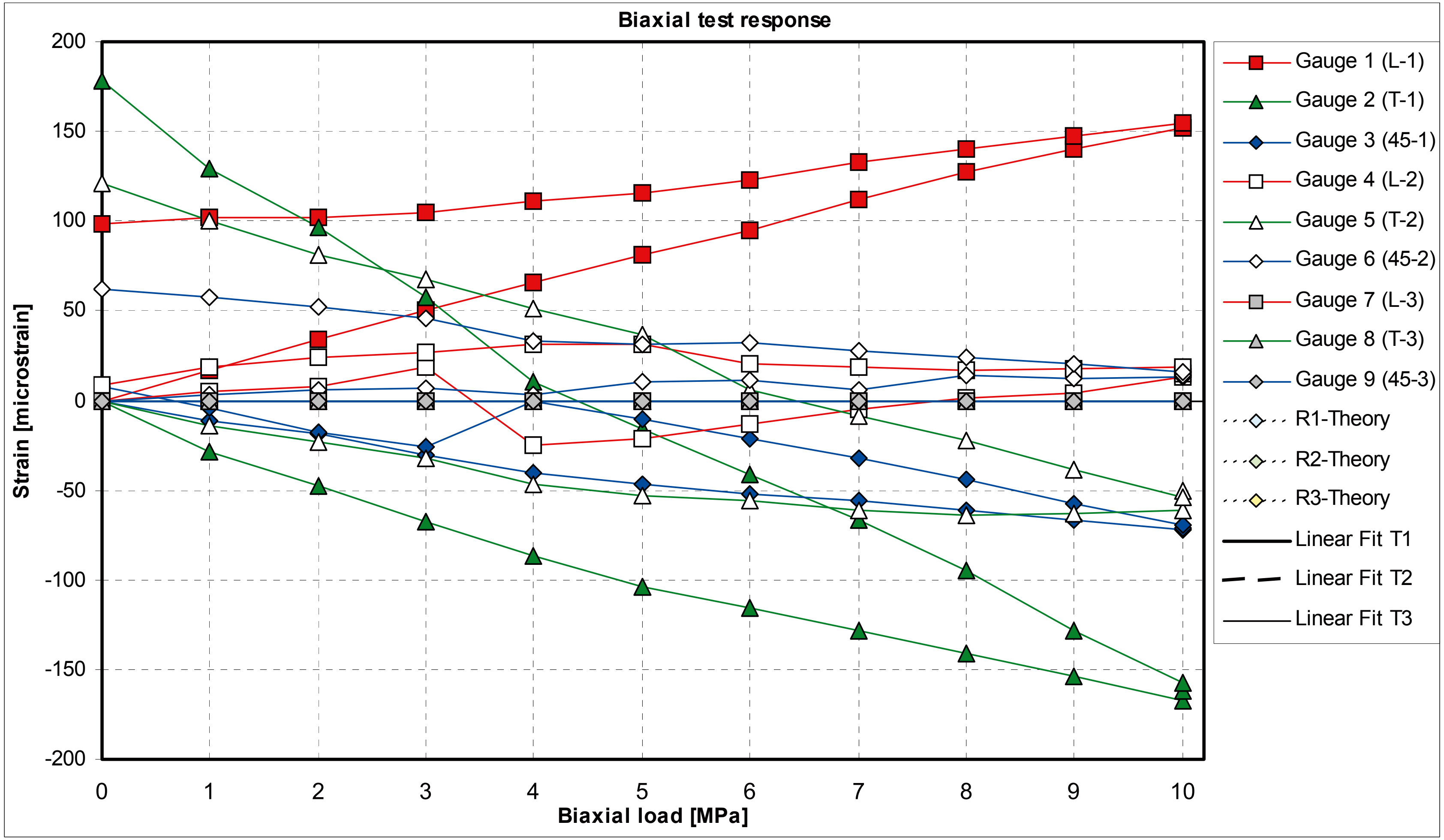


Figure C7. *Results from biaxial testing of test no. 2:7:2, 179.87 m borehole length.*

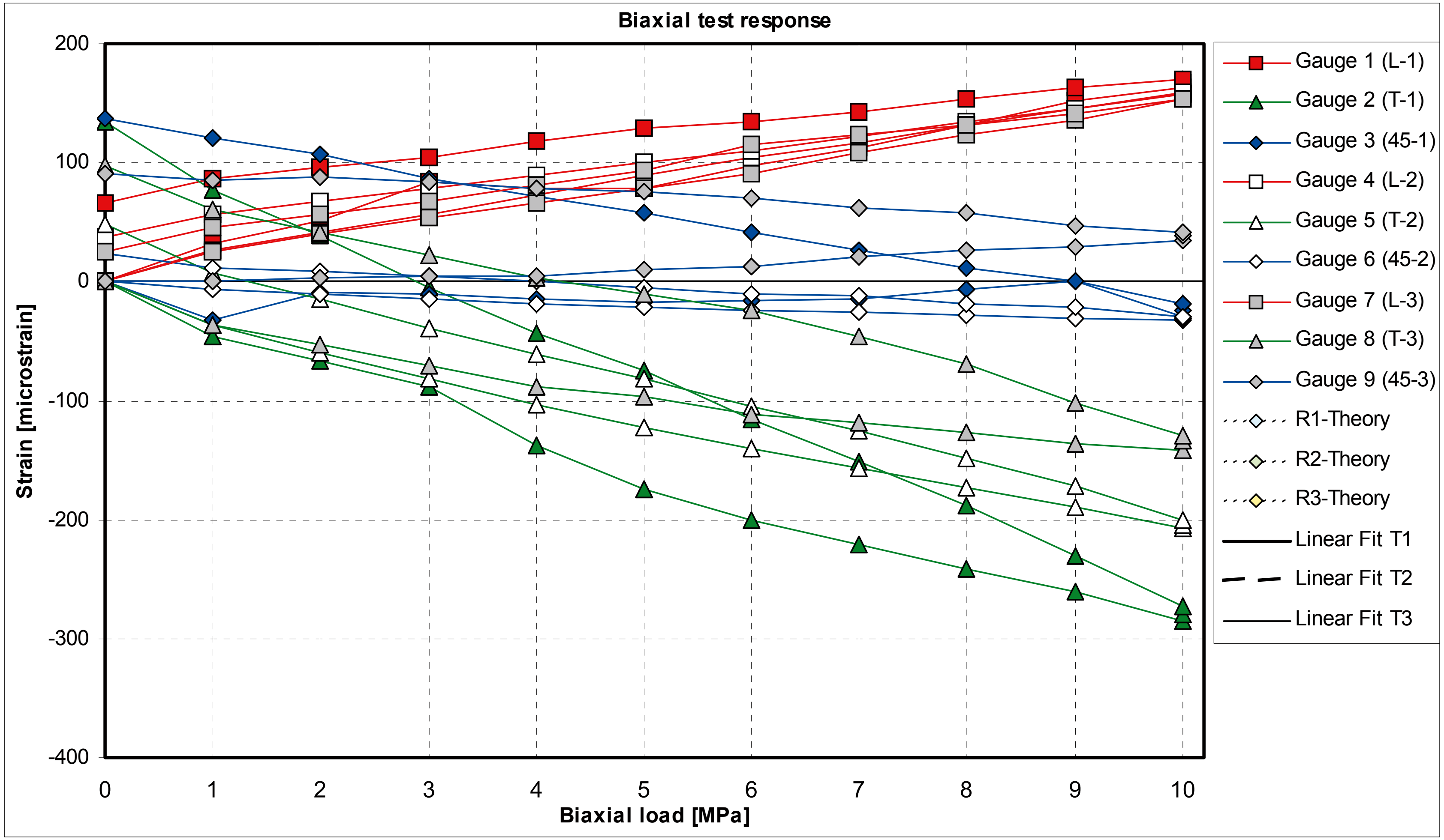


Figure C8. *Results from biaxial testing of test no. 3:18:1, 252.83 m borehole length (rosette no. 3 was excluded when determining elastic constants).*

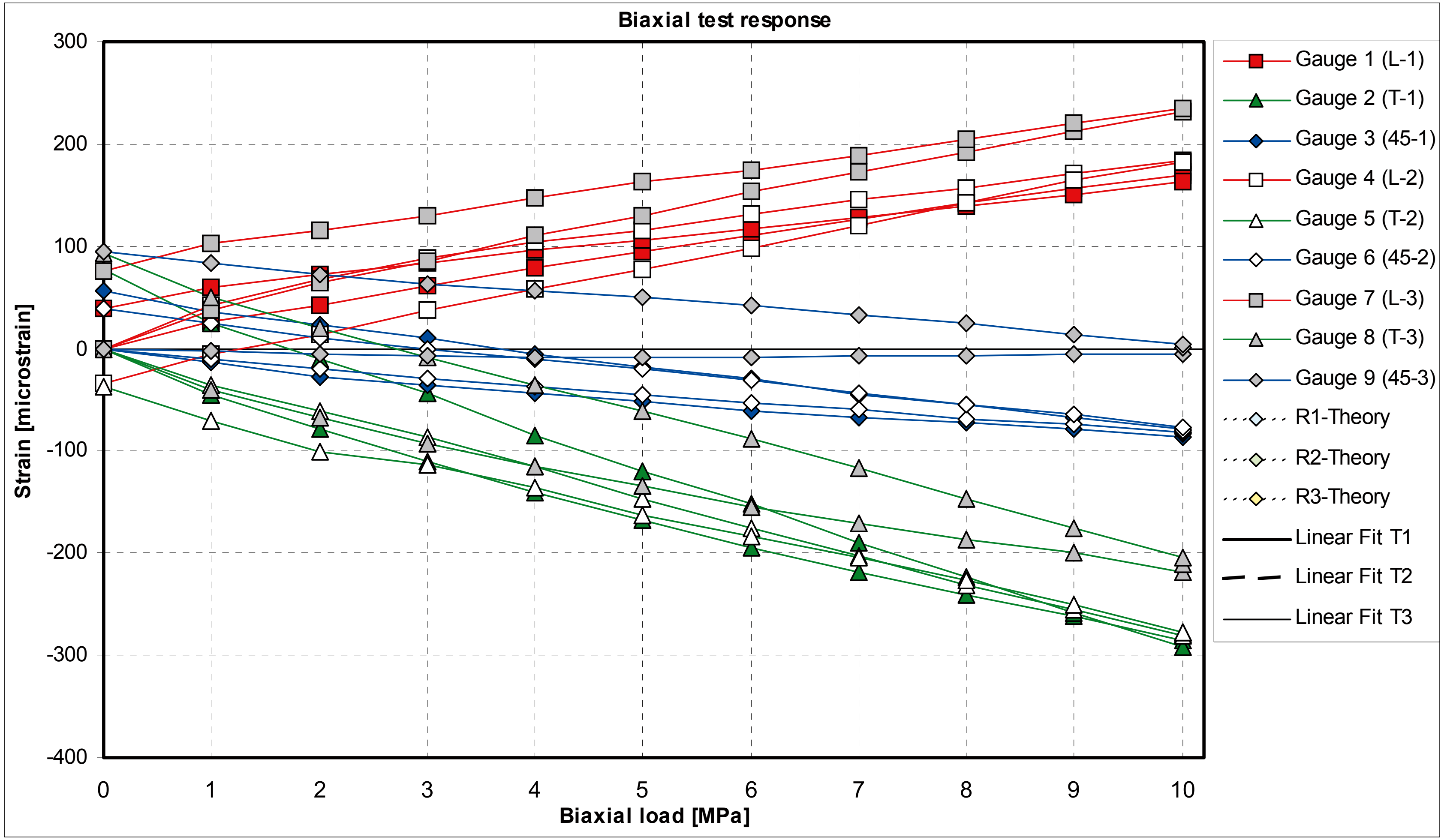


Figure C9. *Results from biaxial testing of test no. 3:19:1, 253.77 m borehole length (rosettes nos. 2 and 3 were excluded when determining elastic constants).*

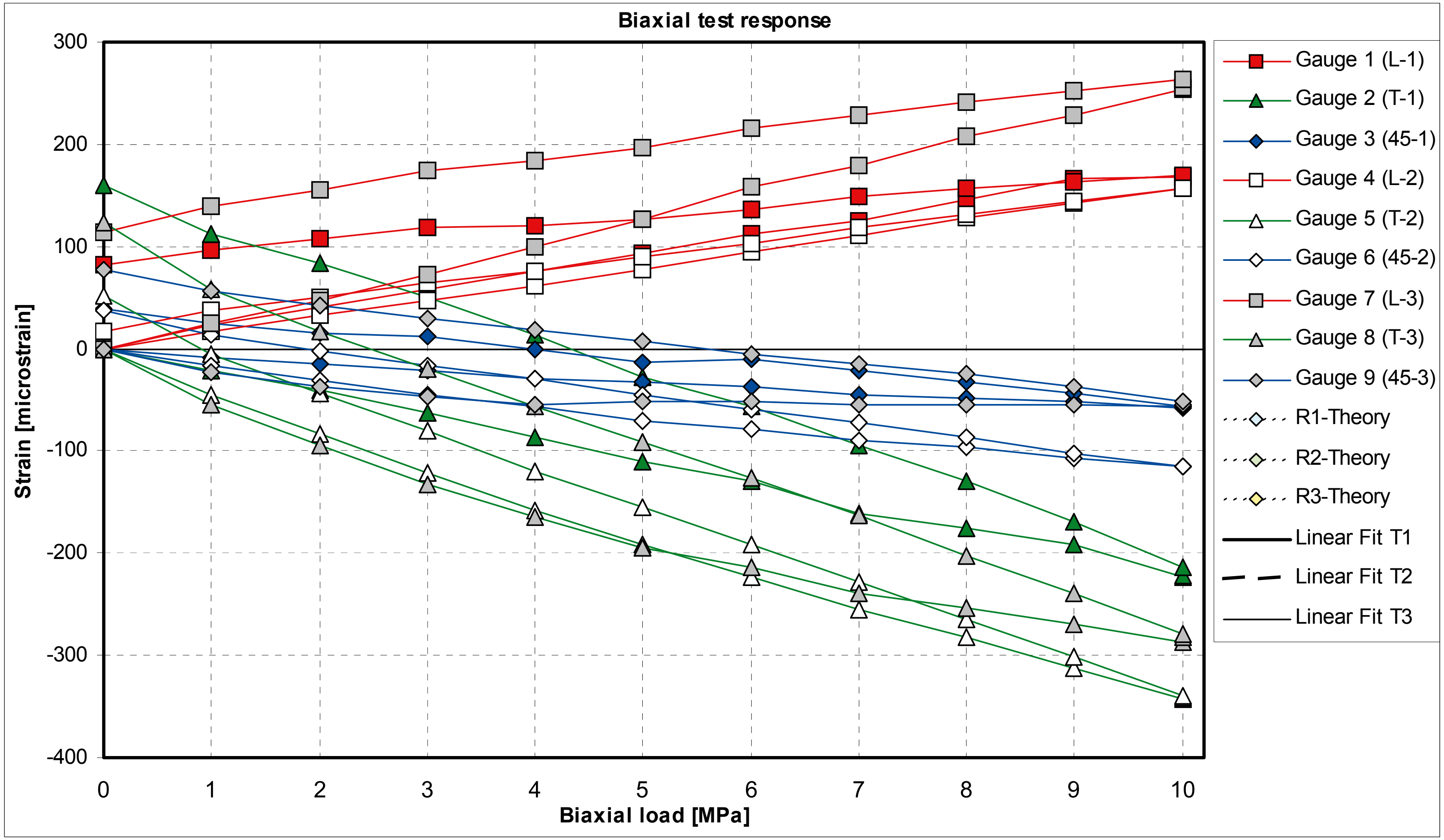


Figure C10. *Results from biaxial testing of test no. 3:21:1, 256.13 m borehole length.*

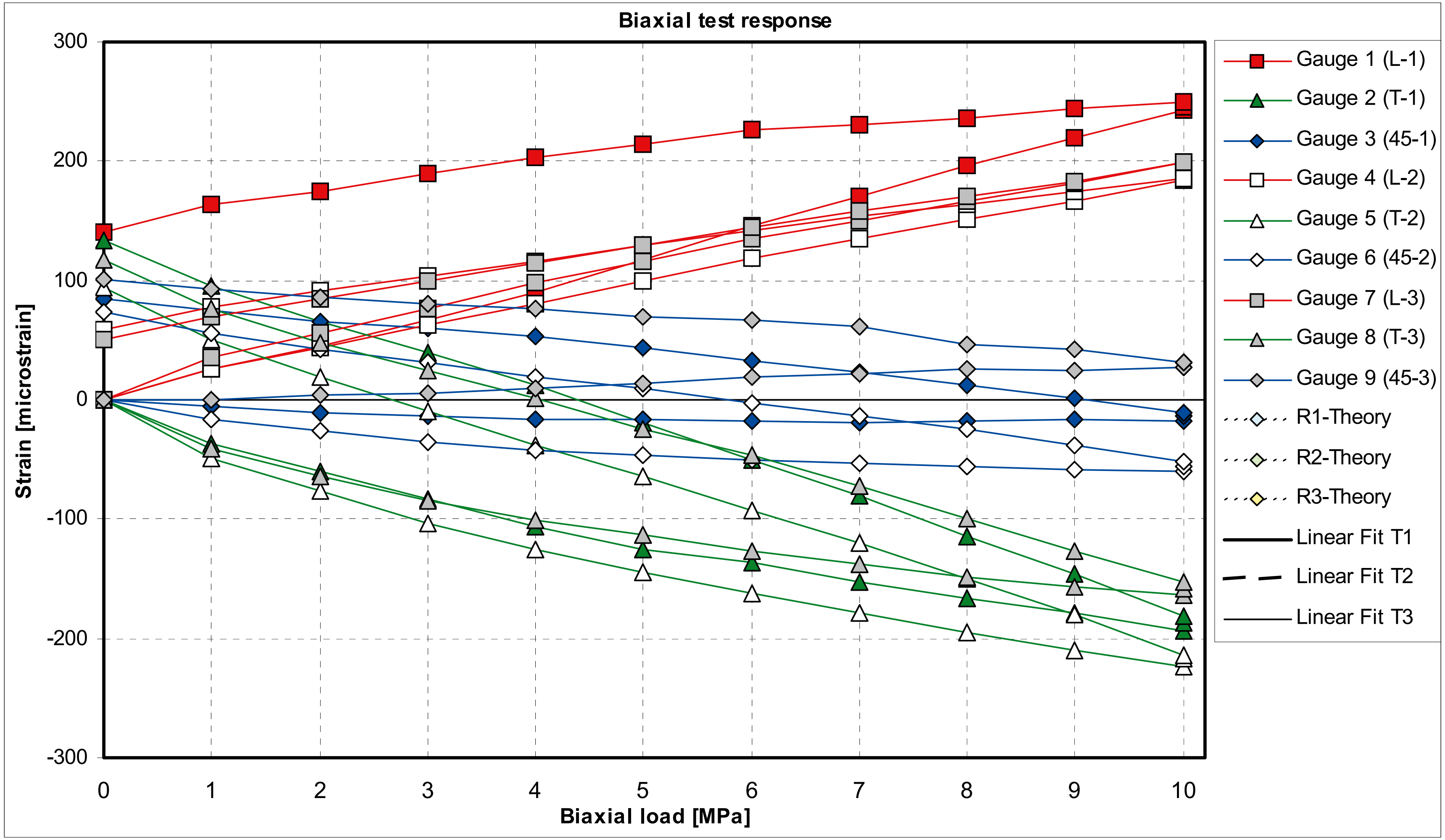


Figure C11. *Results from biaxial testing of test no. 4:3:1, 302.33 m borehole length.*

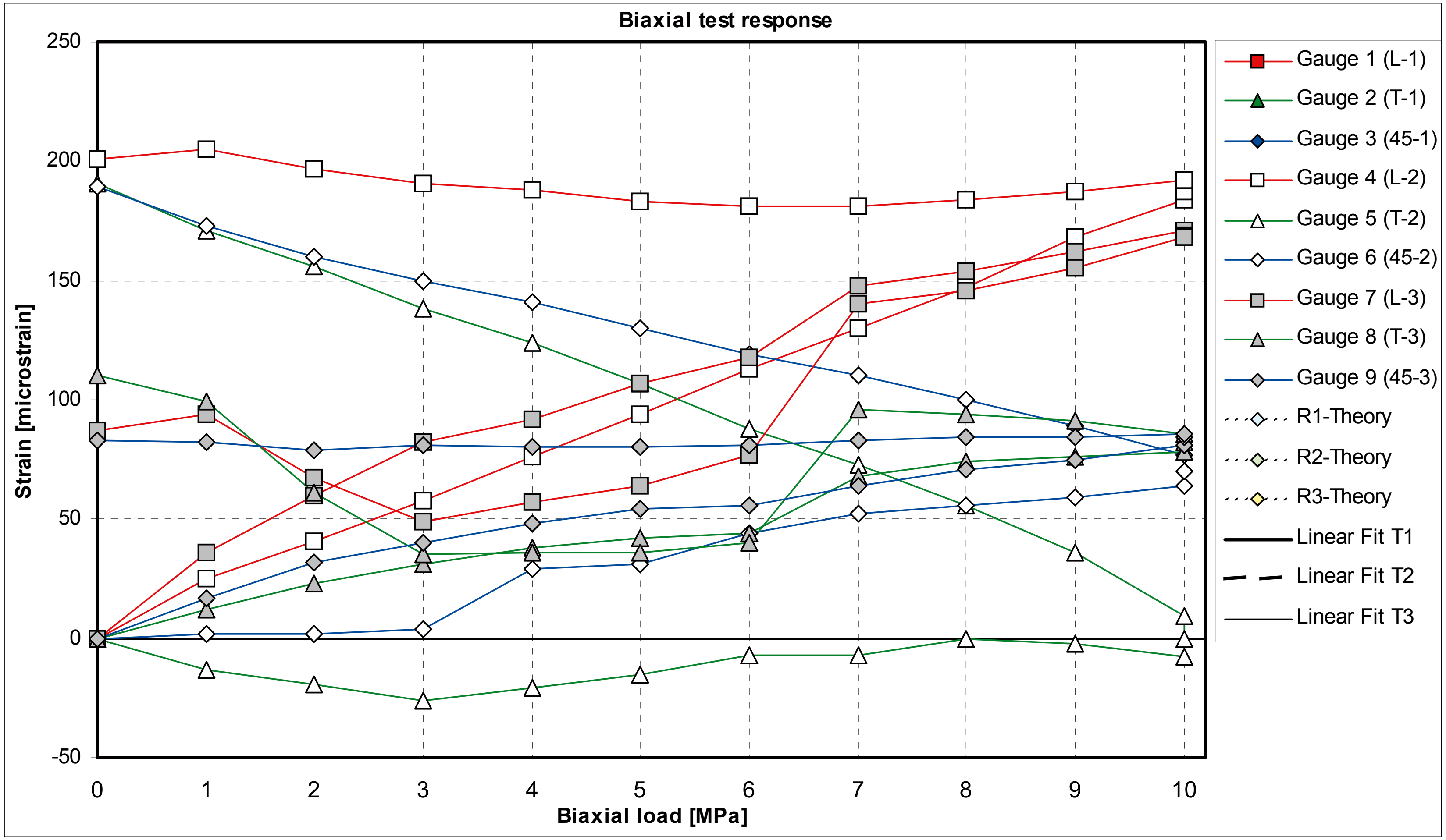


Figure C12. *Results from biaxial testing of test no. 4:7:1, 306.20 m borehole length, excluding strain rosette no. 1.*

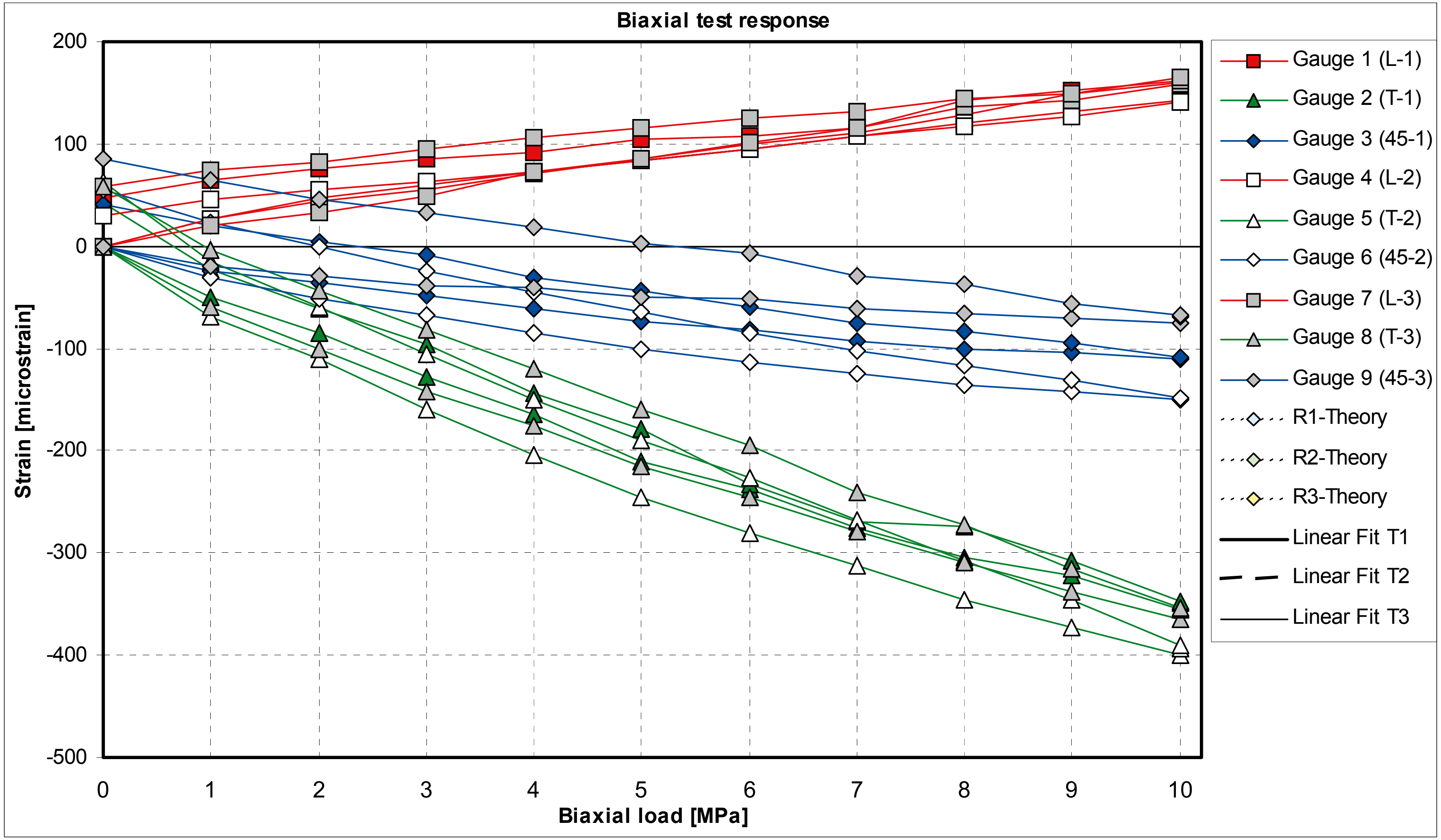


Figure C13. *Results from biaxial testing of test no. 4:8:1, 307.06 m borehole length.*

Appendix D

Stress calculation input data and results

Table D1. Measured and average in situ stresses for borehole KFM02B, Level 1, tests nos. 1:7:1, 1:13:3, and 1:17:2.

VATTENFALL

OVERCORING STRESS MEASUREMENTS

Project Description : Forsmark KFM02B
Measurement Level : Level 1
Date : 2007-04-23

(values for gauge and resistance factor are always 2 and 1, respectively)

Input Data

Depth [m]	Hole dip [º]	Hole bearing [º]	Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	Needle bearing [º]	Overcoring Time [hh:mm:ss]	[hh:mm:ss]
113.74	80.70	311.11	335	78.0	0.33	-	Start=08:15:40	Stop=09:10:20
135.80	80.67	311.64	310	78.0	0.33	-	Start=08:36:20	Stop=09:27:30
144.17	80.63	311.68	320	78.0	0.33	-	Start=08:50:55	Stop=09:42:15

Strains

Depth [m]	ε_{L1} (gauge no. 1) [µstrain]	ε_{T1} (gauge no. 2) [µstrain]	ε_{45_1} (gauge no. 3) [µstrain]	ε_{L2} (gauge no. 4) [µstrain]	ε_{T2} (gauge no. 5) [µstrain]	ε_{45_2} (gauge no. 6) [µstrain]	ε_{L3} (gauge no. 7) [µstrain]	ε_{T3} (gauge no. 8) [µstrain]	ε_{45_3} (gauge no. 9) [µstrain]
113.74	-82	354	123	-29	141	99	-30	74	-82
135.80	-66	-74	-49	-146	248	-38	-124	194	115
144.17	-59	329	166	-117	386	125	22	13	1

Calculated Principal Stresses

Depth [m]	σ_1 [MPa]	σ_1 - Dip [º]	σ_1 - Bearing [º]	σ_2 [MPa]	σ_2 - Dip [º]	σ_2 - Bearing [º]	σ_3 [MPa]	σ_3 - Dip [º]	σ_3 - Bearing [º]
113.74	10.8	6.2	113.6	4.8	25.8	20.6	-1.0	63.4	216.0
135.80	8.8	19.6	167.4	-0.4	12.6	72.9	-6.9	66.4	312.0
144.17	15.1	14.8	125.8	4.9	10.7	218.7	2.3	71.6	343.2
Mean	*10.1*	*14.6*	*134.0*	*3.9*	*3.7*	*43.0*	*-1.2*	*75.0*	*299.0*

Calculated Horizontal and Vertical Stresses

Depth [m]	Major stress σ_A [MPa]	σ_A - Bearing [º]	Minor stress σ_B [MPa]	σ_B - Bearing [º]	Vertical stress σ_z [MPa]	Error (sum of squares)	Strains re-calculated?
113.74	10.7	115.6	3.7	25.6	0.2	3054.9	No
135.80	7.1	171.0	-0.8	81.0	-4.8	3448.0	No
144.17	14.2	125.1	4.8	35.1	3.2	9754.2	No
Mean	*9.4*	*134.8*	*3.8*	*44.8*	*-0.5*		

Table D2. Measured and average in situ stresses for borehole KFM02B, Level 2, tests nos. 2:1:3, 2:3:4, 2:6:2, 2:7:2

VATTENFALL

OVERCORING STRESS MEASUREMENTS

Project Description : Forsmark KFM02B
Measurement Level : Level 2
Date : 2007-04-16

(values for gauge and resistance factor are always 2 and 1, respectively)

Input Data

Depth	Hole dip	Hole bearing	Bearing (ball) - X	Young's modulus	Poisson's ratio	Needle bearing	Overcoring Time	
[m]	[º]	[º]	[º]	[GPa]		[º]	[hh:mm:ss]	[hh:mm:ss]
156.72	80.51	311.70	348	89.7	0.40	-	Start=08:21:05	Stop=09:17:55
164.10	80.49	311.97	102	89.7	0.40	-	Start=08:40:50	Stop=09:29:40
178.03	79.54	312.29	298	89.7	0.40	-	Start=08:20:20	Stop=09:04:20
179.87	80.42	312.33	239	89.7	0.40	-	Start=09:00:50	Stop=09:59:30

Strains

	ε_{L1}	ε_{T1}	ε_{45_1}	ε_{L2}	ε_{T2}	ε_{45_2}	ε_{L3}	ε_{T3}	ε_{45_3}
Depth	(gauge no. 1)	(gauge no. 2)	(gauge no. 3)	(gauge no. 4)	(gauge no. 5)	(gauge no. 6)	(gauge no. 7)	(gauge no. 8)	(gauge no. 9)
[m]	[µstrain]	[µstrain]	[µstrain]	[µstrain]	[µstrain]	[µstrain]	[µstrain]	[µstrain]	[µstrain]
156.72	33	145	194	52	264	158	74	18	-62
164.10	-28	105	14	-86	194	107	-2	143	-48
178.03	-24	-112	-168	-35	244	142	-3	149	151
179.87	-59	337	90	-25	96	68	-118	452	198

Calculated Principal Stresses

Depth	σ_1	σ_1 - Dip	σ_1 - Bearing	σ_2	σ_2 - Dip	σ_2 - Bearing	σ_3	σ_3 - Dip	σ_3 - Bearing
[m]	[MPa]	[º]	[º]	[MPa]	[º]	[º]	[MPa]	[º]	[º]
156.72	13.7	58.9	138.4	11.9	25.0	357.8	3.4	17.3	259.5
164.10	8.3	26.0	131.8	5.1	8.8	226.1	-0.2	62.3	333.3
178.03	10.4	14.3	154.9	4.3	50.1	262.7	-3.3	36.3	54.1
179.87	20.0	11.7	152.9	9.5	19.3	247.1	4.9	67.2	33.4
Mean	*12.7*	*18.9*	*154.7*	*5.2*	*41.5*	*262.4*	*4.2*	*42.4*	*46.4*

Calculated Horizontal and Vertical Stresses

	Major stress		Minor stress		Vertical stress		
Depth	σ_A	σ_A - Bearing	σ_B	σ_B - Bearing	σ_z	Error	Strains re-
[m]	[MPa]	[º]	[MPa]	[º]	[MPa]	(sum of squares)	calculated?
156.72	12.2	167.9	4.3	77.9	12.5	844.0	No
164.10	6.8	120.0	4.9	30.0	1.6	5498.7	No
178.03	9.9	149.9	-0.6	59.9	2.0	582.1	No
179.87	19.5	151.3	9.0	61.3	6.0	4475.4	No
Mean	*11.8*	*153.4*	*4.7*	*63.4*	*5.5*		

Table D3. Measured and average in situ stresses for borehole KFM02B, Level 3, tests nos. 3:18:1, 3:19:1, 3:21:1.

VATTENFALL

OVERCORING STRESS MEASUREMENTS

Project Description : Forsmark KFM02B
Measurement Level : Level 3
Date : 2007-04-23

(values for gauge and resistance factor are always 2 and 1, respectively)

Input Data

Depth [m]	Hole dip [º]	Hole bearing [º]	Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	Needle bearing [º]	Overcoring Time [hh:mm:ss]	[hh:mm:ss]
252.83	80.37	313.32	150	95.8	0.38	-	Start=10:21:15	Stop=11:10:55
253.77	80.37	313.29	150	78.5	0.34	-	Start=08:33:50	Stop=09:22:40
256.13	80.36	313.10	338	77.2	0.34	-	Start=08:34:50	Stop=09:23:05

Strains

Depth [m]	ε_{L1} (gauge no. 1) [µstrain]	ε_{T1} (gauge no. 2) [µstrain]	ε_{45_1} (gauge no. 3) [µstrain]	ε_{L2} (gauge no. 4) [µstrain]	ε_{T2} (gauge no. 5) [µstrain]	ε_{45_2} (gauge no. 6) [µstrain]	ε_{L3} (gauge no. 7) [µstrain]	ε_{T3} (gauge no. 8) [µstrain]	ε_{45_3} (gauge no. 9) [µstrain]
252.83	-49	420	259	-71	367	185	-47	102	-46
253.77	-74	363	207	-109	399	218	-120	215	-10
256.13	-65	471	167	-85	340	64	-100	131	92

Calculated Principal Stresses

Depth [m]	σ_1 [MPa]	σ_1 - Dip [º]	σ_1 - Bearing [º]	σ_2 [MPa]	σ_2 - Dip [º]	σ_2 - Bearing [º]	σ_3 [MPa]	σ_3 - Dip [º]	σ_3 - Bearing [º]
252.83	21.3	4.7	127.6	11.8	30.2	220.4	5.4	59.4	29.7
253.77	15.9	10.2	139.0	11.7	14.3	231.7	1.1	72.3	14.7
256.13	16.6	10.4	130.0	8.7	18.2	223.5	1.0	68.9	11.7
Mean	*17.9*	*8.2*	*130.7*	*10.7*	*20.1*	*223.7*	*2.6*	*68.2*	*19.7*

Calculated Horizontal and Vertical Stresses

Depth [m]	Major stress σ_A [MPa]	σ_A - Bearing [º]	Minor stress σ_B [MPa]	σ_B - Bearing [º]	Vertical stress σ_z [MPa]	Error (sum of squares)	Strains re-calculated?
252.83	21.2	126.5	10.1	36.5	7.1	658.9	No
253.77	15.5	133.3	11.0	43.3	2.2	2506.0	No
256.13	16.2	127.1	7.9	37.1	2.3	734.2	No
Mean	*17.6*	*128.0*	*9.7*	*38.0*	*3.9*		

Table D4. Measured and average in situ stresses for borehole KFM02B, Level 4, tests nos., 4:3:1, 4:7:1, 4:8:1.

VATTENFALL

OVERCORING STRESS MEASUREMENTS

Project Description : Forsmark KFM02B
Measurement Level : Level 4
Date : 2007-04-18

(values for gauge and resistance factor are always 2 and 1, respectively)

Input Data

Depth [m]	Hole dip [º]	Hole bearing [º]	Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	Needle bearing [º]	Overcoring Time [hh:mm:ss]	[hh:mm:ss]
302.33	80.32	314.02	157	95.7	0.40	-	Start=08:44:25	Stop=09:35:35
306.20	80.33	313.71	355	95.7	0.40	-	Start=08:38:05	Stop=09:30:15
307.06	80.32	314.02	186	67.2	0.24	-	Start=08:59:55	Stop=09:31:25

Strains

Depth [m]	ε_{L1} (gauge no. 1) [μstrain]	ε_{T1} (gauge no. 2) [μstrain]	ε_{45_1} (gauge no. 3) [μstrain]	ε_{L2} (gauge no. 4) [μstrain]	ε_{T2} (gauge no. 5) [μstrain]	ε_{45_2} (gauge no. 6) [μstrain]	ε_{L3} (gauge no. 7) [μstrain]	ε_{T3} (gauge no. 8) [μstrain]	ε_{45_3} (gauge no. 9) [μstrain]
302.33	-39	368	243	-20	156	92	-48	84	-41
306.20	4	313	73	9	158	118	-2	2	-14
307.06	-62	352	207	-77	154	52	-26	457	98

Calculated Principal Stresses

Depth [m]	σ_1 [MPa]	σ_1 - Dip [º]	σ_1 - Bearing [º]	σ_2 [MPa]	σ_2 - Dip [º]	σ_2 - Bearing [º]	σ_3 [MPa]	σ_3 - Dip [º]	σ_3 - Bearing [º]
302.33	16.3	1.5	296.1	8.1	43.3	204.6	3.8	46.7	27.7
306.20	14.3	7.3	324.1	5.8	78.6	93.9	3.3	8.6	233.0
307.06	14.4	2.9	280.7	7.6	5.4	190.4	0.7	83.9	38.6
Mean	*14.2*	*2.5*	*302.9*	*6.7*	*16.5*	*212.1*	*3.9*	*73.3*	*41.1*

Calculated Horizontal and Vertical Stresses

Depth [m]	Major stress σ_A [MPa]	σ_A - Bearing [º]	Minor stress σ_B [MPa]	σ_B - Bearing [º]	Vertical stress σ_z [MPa]	Error (sum of squares)	Strains re-calculated?
302.33	16.3	116.4	6.1	26.4	5.8	829.2	Yes
306.20	14.2	143.9	3.3	53.9	5.9	999.6	No
307.06	14.4	101.0	7.5	11.0	0.8	1766.0	No
Mean	*14.1*	*123.1*	*6.5*	*33.1*	*4.2*		

Appendix E

Transient strain analysis results

Table E1. Results from transient strain analysis of selected overcoring measurements in borehole KFM02B, Level 1

Test no.	Hole length [m]		G1 ε_{L1}	G2 ε_{T1}	G3 ε_{45_1}	G4 ε_{L2}	G5 ε_{T2}	G6 ε_{45_2}	G7 ε_{L3}	G8 ε_{T3}	G9 ε_{45_3}	Unexplained strain [%]	Max tensile stress [MPa]	Comments
1:7:1	113.74	Max strain am-plitude [µstrain]	130	380	153	164	165	123	168	111	69	41	12	The measurement has b-rating but showed large deviations between measured and calculated strains. High amount of unexplained strains, but low tensile stress.
		Max strain difference [%]	213	29	76	68	103	73	59	102	140			
1:13:3	135.80	Max strain am-plitude [µstrain]	172	86	93	131	275	79	133	210	123	49	16	The measurement has b-rating but showed large deviations between measured and calculated strains. High amount of unexplained strains and relative low tensile stress.
		Max strain difference [%]	62	176	78	199	119	153	216	130	193			
1:17:2	144.17	Max strain am-plitude [µstrain]	210	372	190	200	435	140	179	92	67	55	15	The measurement has b-rating but showed large deviations between measured and calculated strains. High amount of unexplained strains and relative low tensile stress.
		Max strain difference [%]	62	48	52	81	69	123	77	51	73			

Table E2. Results from transient strain analysis of selected overcoring measurements in borehole KFM02B, Level 2.

Test no.	Hole length [m]		G1 ε_{L1}	G2 ε_{T1}	G3 ε_{45_1}	G4 ε_{L2}	G5 ε_{T2}	G6 ε_{45_2}	G7 ε_{L3}	G8 ε_{T3}	G9 ε_{45_3}	Unexplained strain [%]	Max tensile stress [MPa]	Comments
2:1:3	156.72	Max strain am-plitude [µstrain]	103	174	210	169	311	163	98	86	99	47	12	The measurement has a-rating and in general fair agreement between calculated and measured strains. High amount of unexplained strains, but relative low tensile stress.
		Max strain difference [%]	196	144	92	67	69	74	228	179	64			
2:3:4	164.10	Max strain am-plitude [µstrain]	95	118	42	141	212	137	133	158	61	58	10	The measurement has b-rating but showed large deviations between measured and calculated strains, for axial and tangential strains. High amount of unexplained strains, but relative low tensile stress.
		Max strain difference [%]	250	104	309	102	127	50	112	114	91			
2:6:2	178.03	Max strain am-plitude [µstrain]	93	121	181	70	274	157	109	176	156	38	19	The measurement has b-rating but showed large deviations between measured and calculated strains. High amount of unexplained strains and tensile stress.
		Max strain difference [%]	196	173	65	322	88	101	159	170	108			
2:7:2	179.87	Max strain am-plitude [µstrain]	243	388	111	238	171	114	276	518	208	36	20	The measurement has b-rating and in general fair agreement between calculated and measured strains. High amount of unexplained strains and tensile stress.
		Max strain difference [%]	41	22	109	45	45	127	52	64	54			

Table E3. Results from transient strain analysis of selected overcoring measurements in borehole KFM02B, Level 3.

Test no.	Hole length [m]		G1 ε_{L1}	G2 ε_{T1}	G3 ε_{45_1}	G4 ε_{L2}	G5 ε_{T2}	G6 ε_{45_2}	G7 ε_{L3}	G8 ε_{T3}	G9 ε_{45_3}	Unexplained strain [%]	Max tensile stress [MPa]	Comments
3:18:1	252.83	Max strain am-plitude [µstrain]	234	479	269	279	430	187	234	182	89	29	21	The measurement has b-rating and in general fair agreement between calculated and measured strains. High amount of unexplained strains and tensile stress.
		Max strain difference [%]	45	30	35	46	44	72	44	77	41			
3:19:1	253.77	Max strain am-plitude [µstrain]	250	416	209	307	462	213	272	282	75	24	15	The measurement has a-rating and in general fair agreement between calculated and measured strains. Relatively low amount of unexplained strains and tensile stress.
		Max strain difference [%]	61	35	49	45	38	49	35	38	70			
3:21:1	256.13	Max strain am-plitude [µstrain]	290	532	194	241	381	111	249	196	132	22	16	The measurement has a-rating and in general fair agreement between calculated and measured strains. Relatively low amount of unex-plained strains and tensile stress.
		Max strain difference [%]	39	25	42	84	36	83	79	43	44			

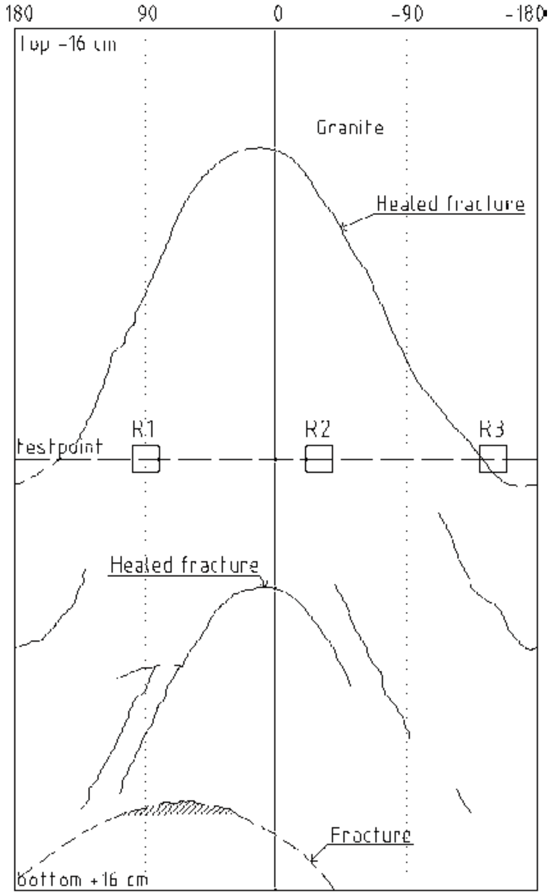
Table E4. Results from transient strain analysis of selected overcoring measurements in borehole KFM02B, Level 4.

Test no.	Hole length [m]		G1 ε_{L1}	G2 ε_{T1}	G3 ε_{45_1}	G4 ε_{L2}	G5 ε_{T2}	G6 ε_{45_2}	G7 ε_{L3}	G8 ε_{T3}	G9 ε_{45_3}	Unexplained strain [%]	Max tensile stress [MPa]	Comments
4:3:1	302.33	Max strain am-plitude [µstrain]	164	421	245	200	205	89	159	139	62	25	18	The measurement has a-rating and in general fair agreement between calculated and measured strains. Relatively low amount of unexplained strains and tensile stress.
		Max strain difference [%]	56	39	30	32	54	102	64	54	133			
4:7:1	306.20	Max strain am-plitude [µstrain]	120	349	93	107	175	136	142	57	69	60	16	The measurement has a-rating but showed large deviations between measured and calculated strains. High amount of unexplained strains, but relative low tensile stress.
		Max strain difference [%]	177	97	122	141	103	87	89	48	90			
4:8:1	307.06	Max strain am-plitude [µstrain]	213	400	238	268	213	101	221	486	123	23	14	The measurement has a-rating but showed large deviations between measured and calculated strains. Relatively low amount of unex-plained strains and tensile stress.
		Max strain difference [%]	81	32	31	20	49	52	45	19	91			

Overcore logging sheets

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KFM02B, Test no. 1:7:1, 113.74 m depth**



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

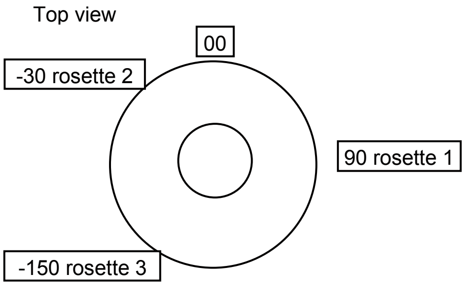
GEOLOGY

Granite

STRUCTURES (JOINTS)

Thin pegmatite band.

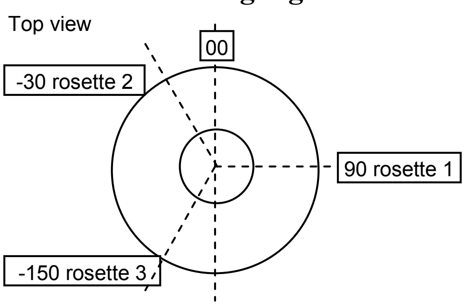
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

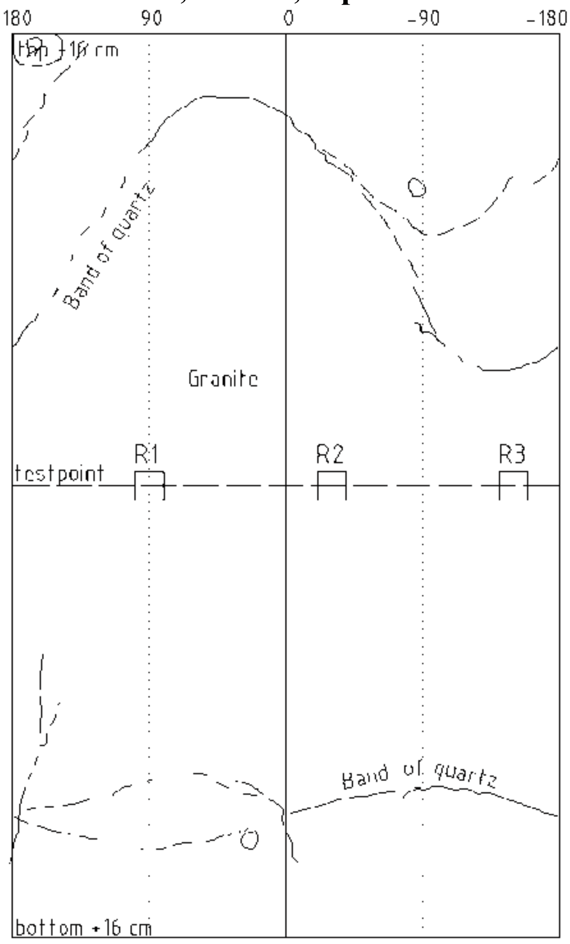
Control of strain gauge orientation



Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KFM02B, Test no. 1:13:3, 135.80 m depth**



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

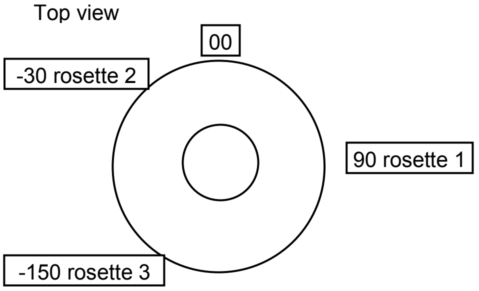
GEOLOGY

Granite, band of quartz.

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

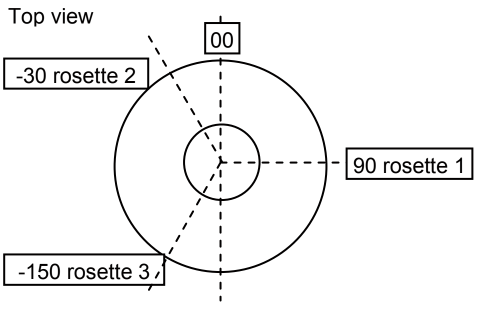
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

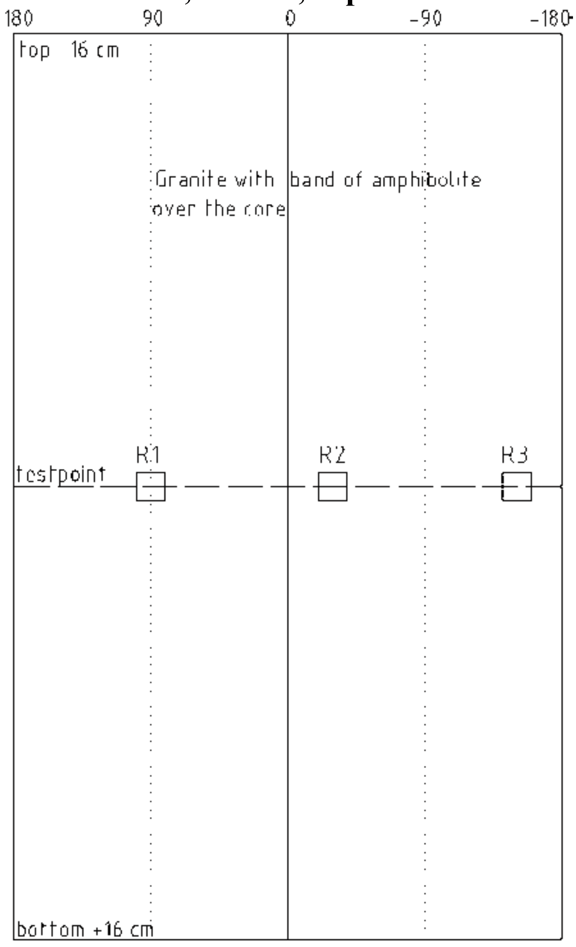
Control of strain gauge orientation



Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KFM02B, Test no. 1:17:2, 144.17 m depth**



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

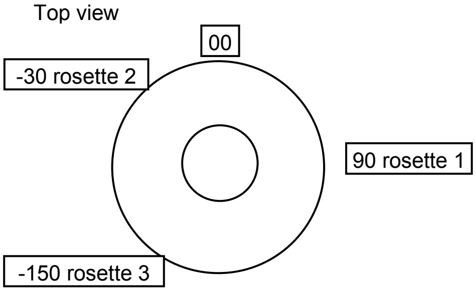
GEOLOGY

Granite with band of amphibolite over the core.

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

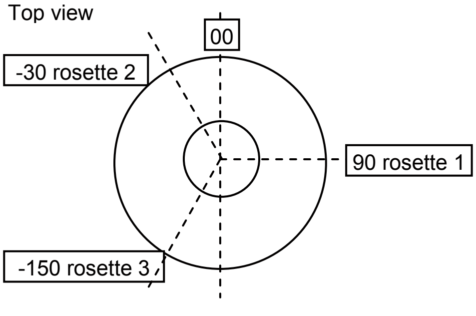
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

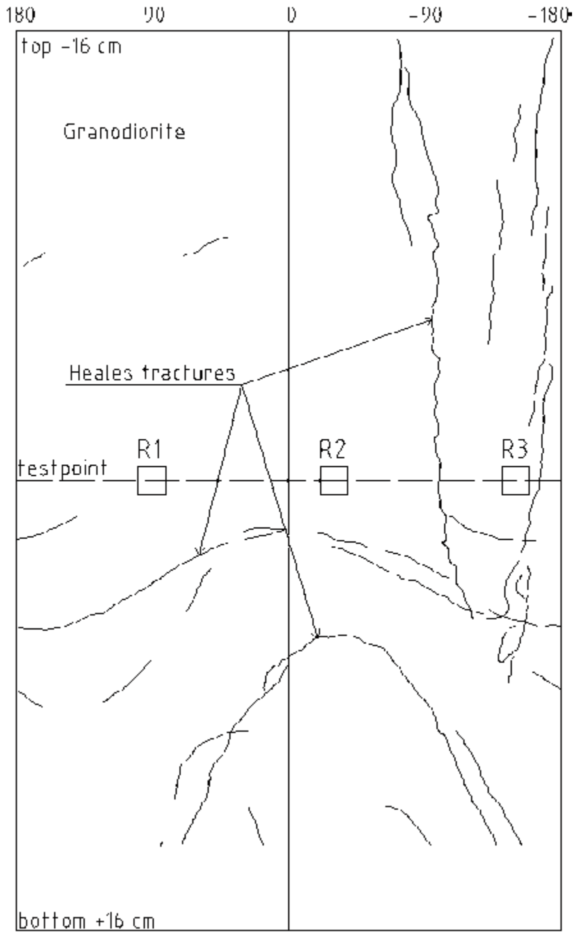
Control of strain gauge orientation



Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KFM02B, Test no. 2:1:3, 156.72 m depth**



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

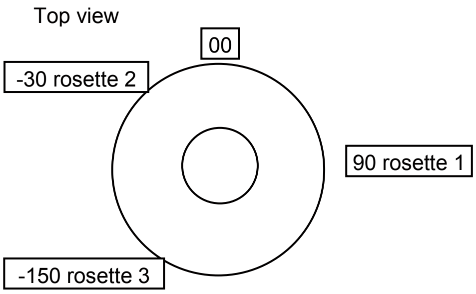
GEOLOGY

Granodiorite

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

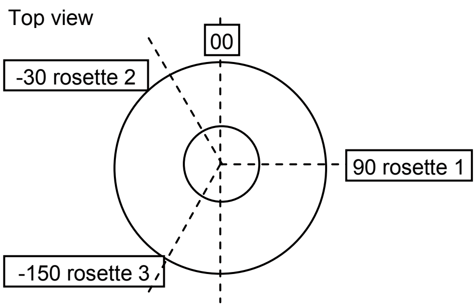
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

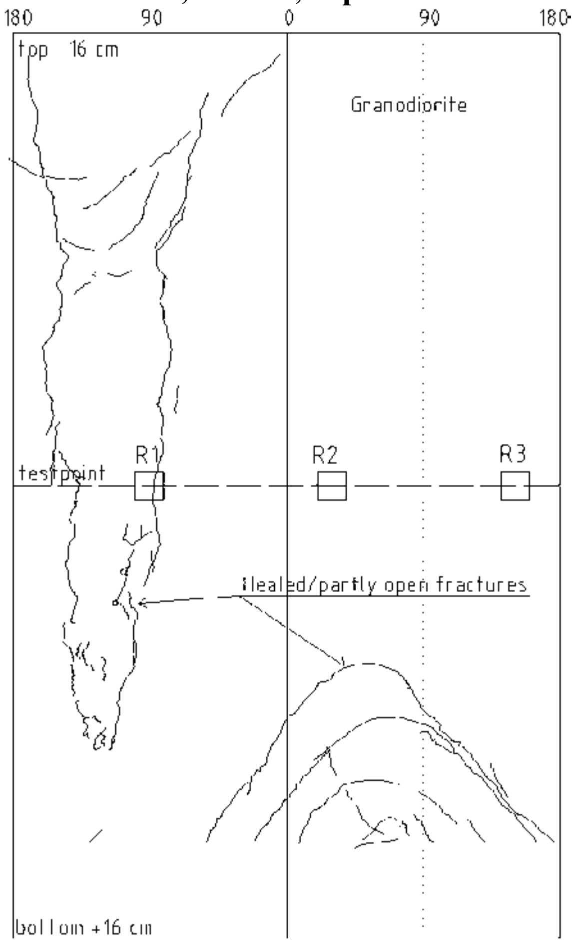
Control of strain gauge orientation



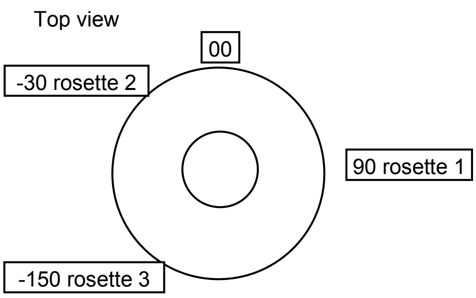
Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

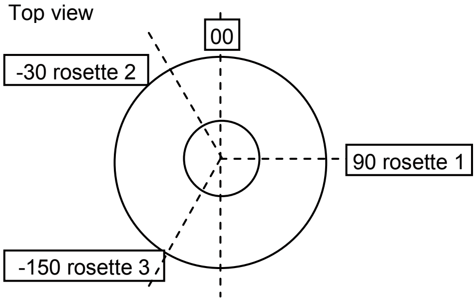
Borehole no., test no., depth : **KFM02B, Test no. 2:3:4, 164.10 m depth**



Mark any observed fractures



Control of strain gauge orientation



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

Granodiorite

STRUCTURES (JOINTS)

Healed/partly open fractures

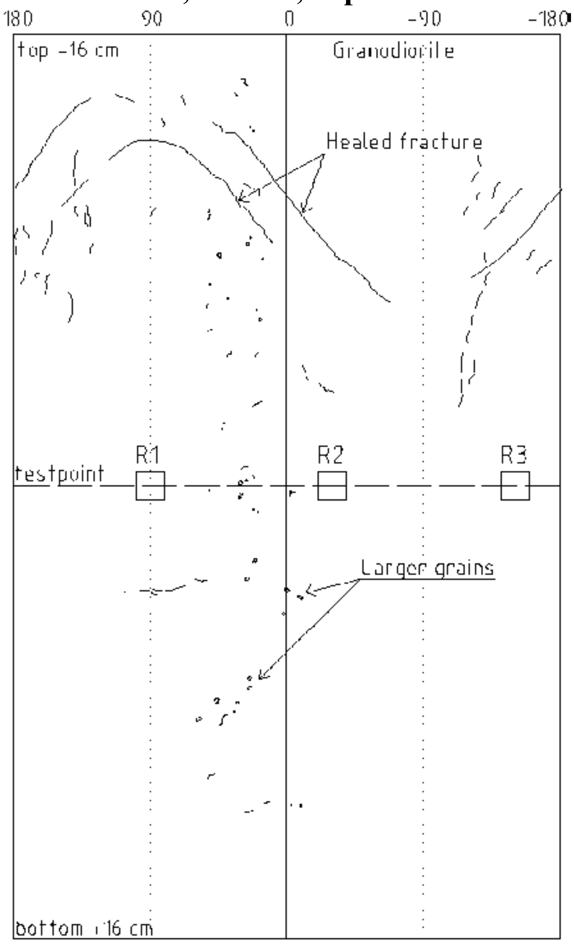
COMMENTS

Strain gauge orientation OK.

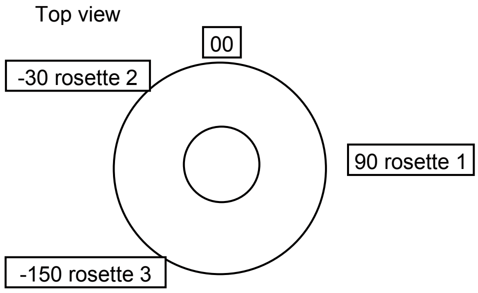
Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KFM02B, Test no. 2:6:2, 178.03 m depth



Mark any observed fractures



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

Granodiorite

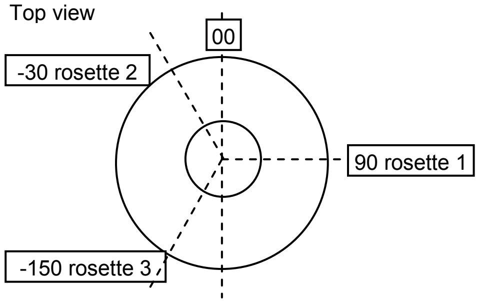
STRUCTURES (JOINTS)

Healed fracture

COMMENTS

Strain gauge orientation OK.

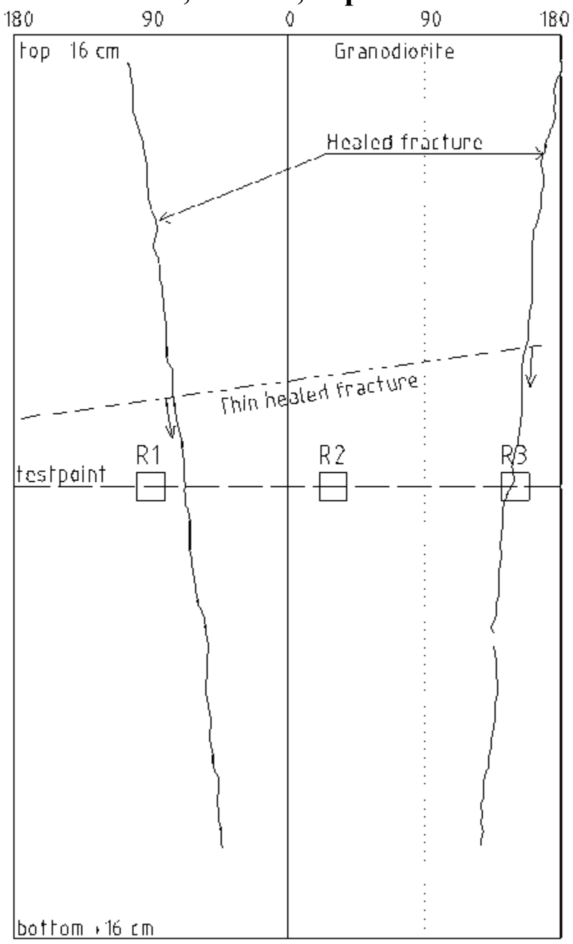
Control of strain gauge orientation



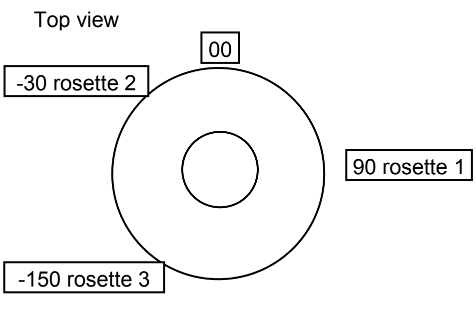
Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

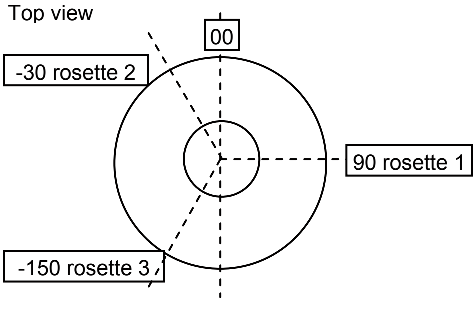
Borehole no., test no., depth : KFM02B, Test no. 2:7:2, 179.87 m depth



Mark any observed fractures



Control of strain gauge orientation



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

Granodiorite

STRUCTURES (JOINTS)

Healed fractures

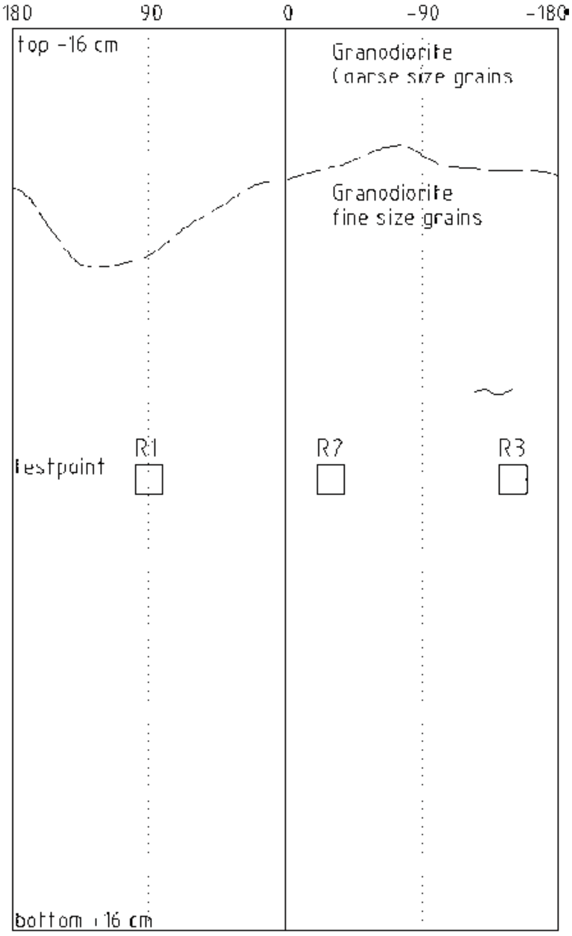
COMMENTS

Strain gauge orientation OK.

Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KFM02B, Test no. 3:18:1, 252.83 m depth**



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

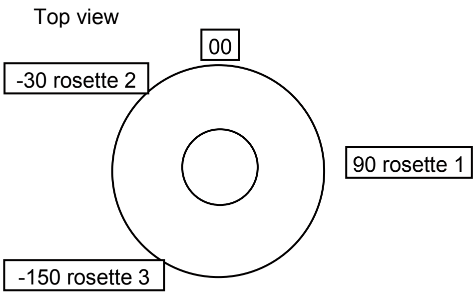
GEOLOGY

Granodiorite

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

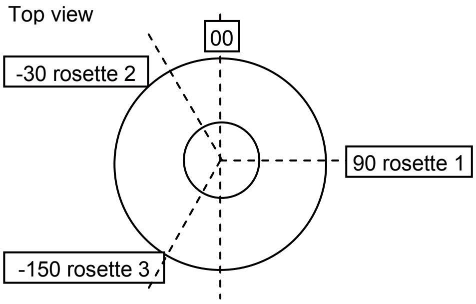
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

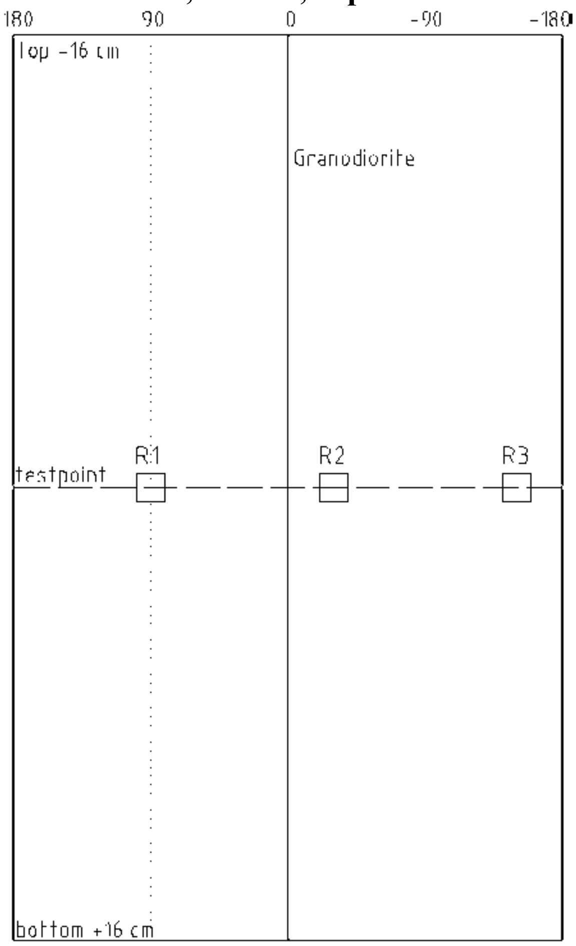
Control of strain gauge orientation



Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KFM02B, Test no. 3:19:1, 253.77 m depth**



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

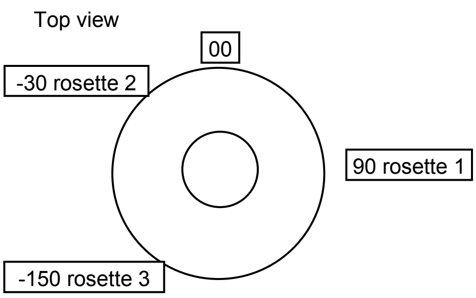
GEOLOGY

Granodiorite

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

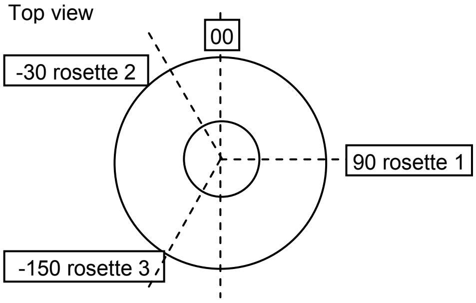
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

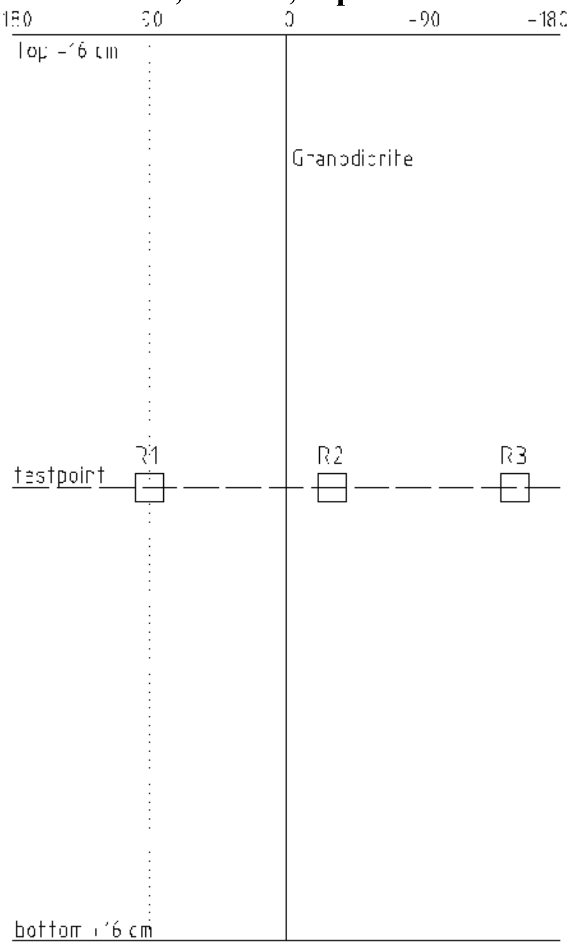
Control of strain gauge orientation



Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KFM02B, Test no 3:21:1, 256.13 m depth**



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

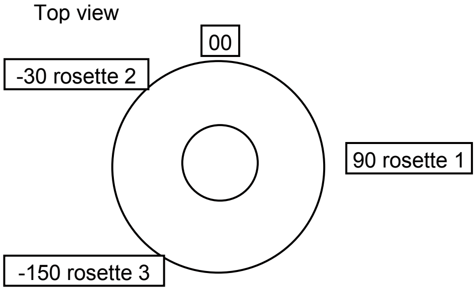
Granodiorite

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

Mark any observed fractures

Top view

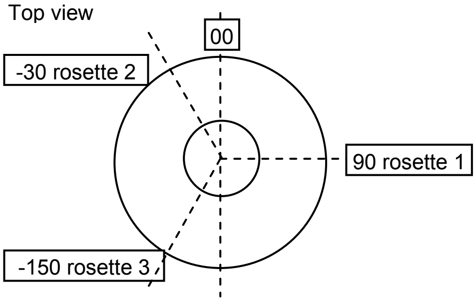


COMMENTS

Strain gauge orientation OK.

Control of strain gauge orientation

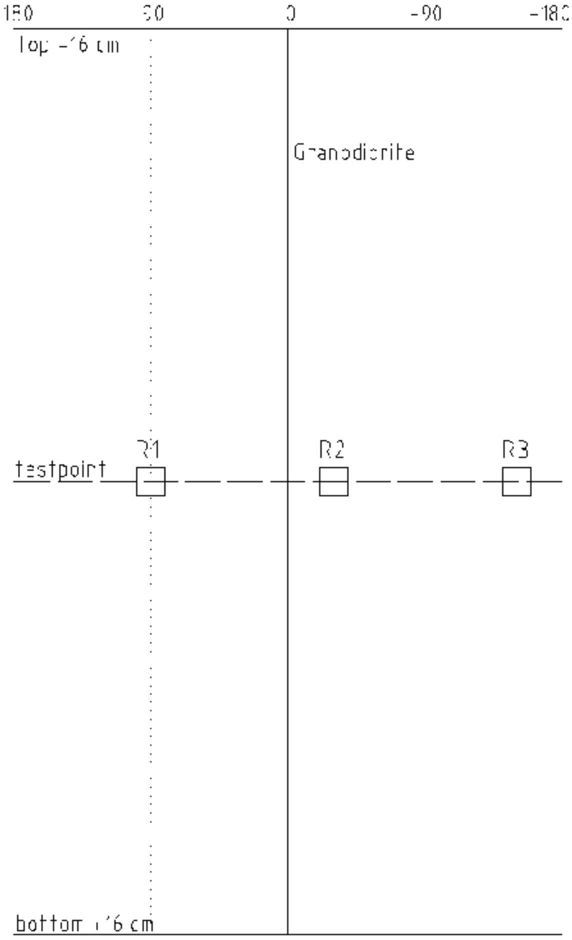
Top view



Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KFM02B, Test no 4:3:1. 302.33 m depth



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

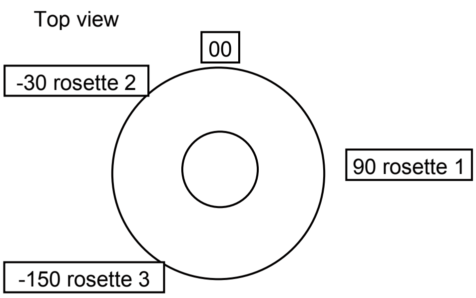
GEOLOGY

Granodiorite

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

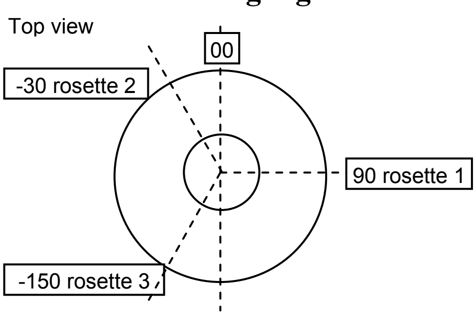
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

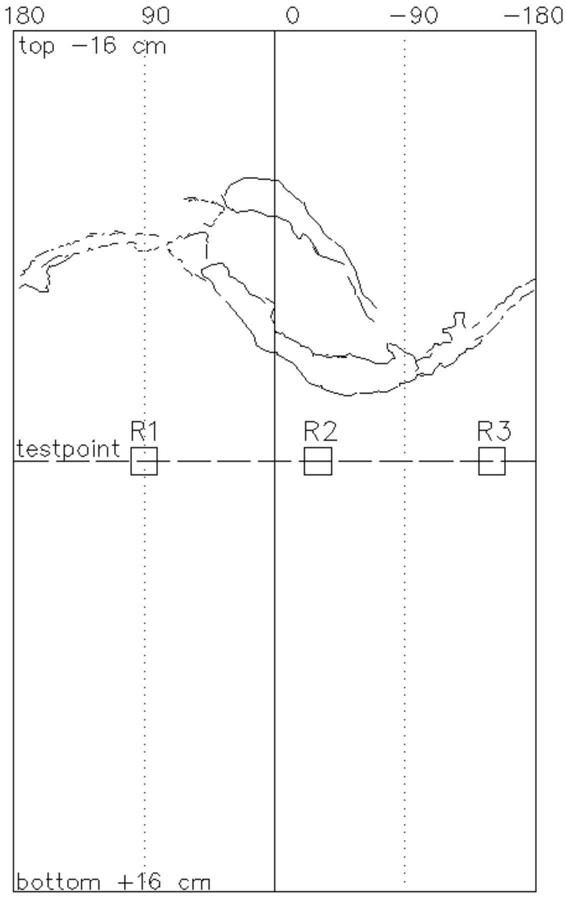
Control of strain gauge orientation



Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

Borehole no., test no., depth : **KFM02B, Test no 4:7:1, 306.20 m depth**



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

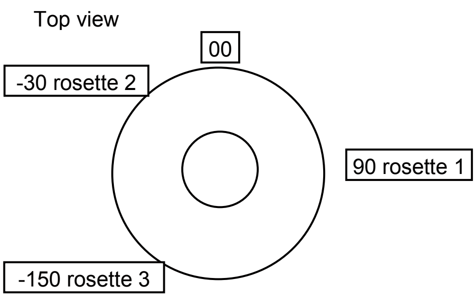
GEOLOGY

Thin pegmatite band.

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

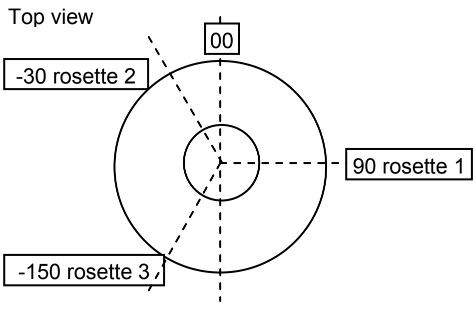
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

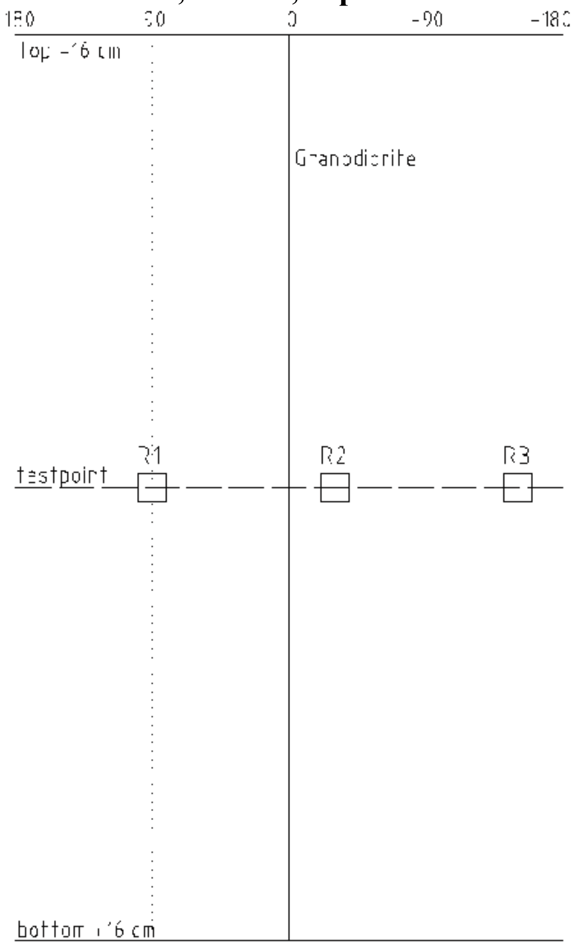
Control of strain gauge orientation



Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KFM02B, Test no 4:8:1, 307.06 m depth



Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

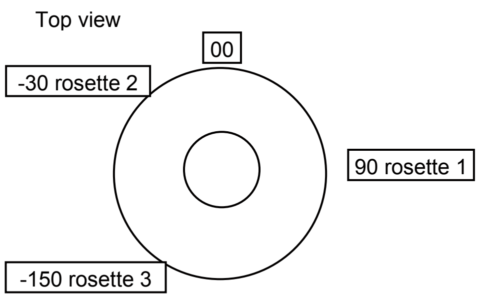
GEOLOGY

Granodiorite

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

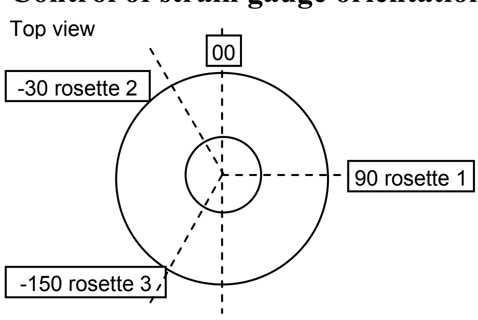
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

Control of strain gauge orientation



Use special tool to check that strain gauges are 120 degrees apart. Mark any deviations in the figure.

Photos of core samples

1:7:1, 113.74 m — pilot core

1:7:1, 113.74 m — overcore sample

1:13:3, 135.80 m — pilot core

1:13:3, 135.80 m — overcore sample

1:17:2, 144.17 m — pilot core

1:17:2, 144.17 m — overcore sample

Figure G1. *Photos of pilot core and overcore sample for borehole KFM02B, Level 1.*

2:1:3, 156.72 m — pilot core

2:1:3, 156.72 m — overcore sample

2:3:4, 164.10 m — pilot core

2:3:4, 164.10 m — overcore sample

2:6:2, 178.03 m — pilot core

2:6:2, 178.03 m — overcore sample

Figure G2. *Photos of pilot core and overcore sample for borehole KFM02B, Level 2.*

2:7:2, 179.87 m — pilot core

2:7:2, 179.87 m — overcore sample

Figure G2. *(Concluded.)*

3:18:1, 252.83 m — pilot core

3:18:1, 252.83 m — overcore sample

3:19:1, 253.77 m — pilot core

3:19:1, 253.77 m — overcore sample

3:21:1, 256.13 m — pilot core

3:21:1, 256.13 m — overcore sample

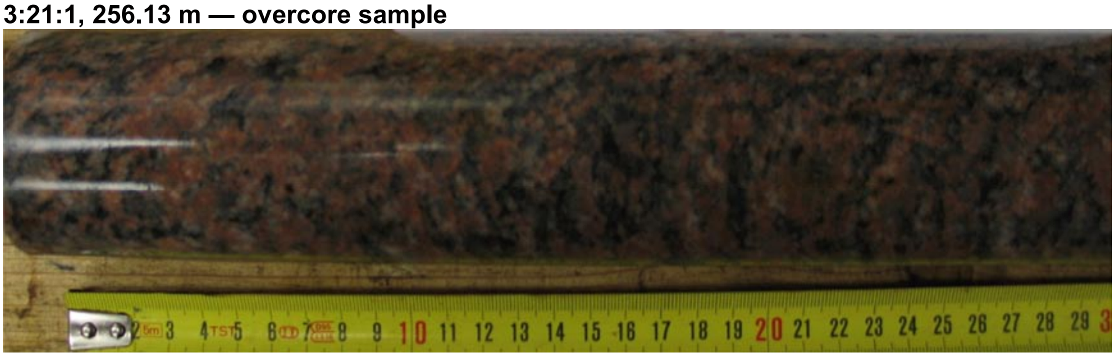


Figure G3. *Photos of pilot core and overcore sample for borehole KFM02B, Level 3*

4:3:1, 302.33 m — pilot core

4:3:1, 302.33 m — overcore sample

4:7:1, 306.20 m — pilot core

4:7:1, 306.20 m — overcore sample

4:8:1, 307.06 m — pilot core

4:8:1, 307.06 m — overcore sample

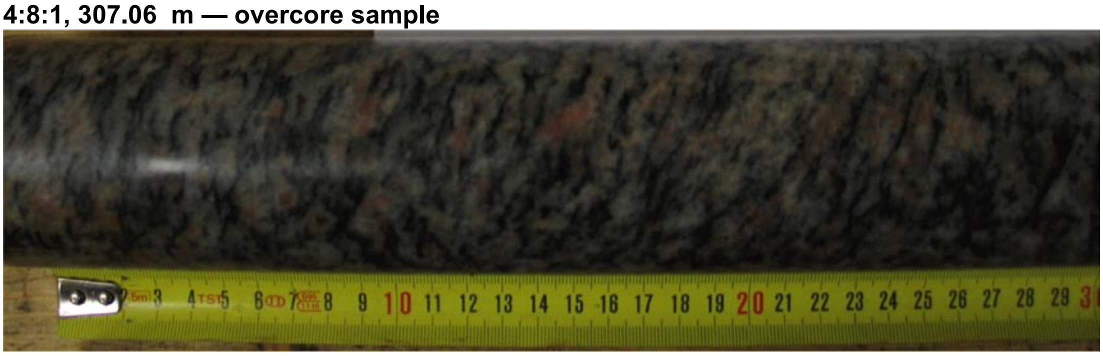


Figure G4. *Photos of pilot core and overcore sample for borehole KFM02B, Level 4.*

Appendix H

Confidence intervals for measured stresses

Table H1. 90%-confidence intervals for the principal stresses as determined from overcoring measurements in borehole KFM02B.

Level		Magnitude and Trend/Plunge of principal stresses					
		σ_1		σ_2		σ_3	
		[MPa]	[°]	[MPa]	[°]	[MPa]	[°]
Level 1	Average	101	134/15	3.9	043/04	–1.2	299/75
	90% lower	5.2	*)	–1.2	*)	–10.8	*)
	90% upper	20.3		7.8		3.4	
Level 2	Average	12.7	155/19	5.2	262/42	4.2	046/42
	90% lower	6.4	*)	1.6	*)	–8.2	*)
	90% upper	23.1		13.9		7.0	
Level 3	Average	17.9	131/08	10.7	224/20	2.6	020/68
	90% lower	12.6	*)	7.4	*)	–2.6	*)
	90% upper	23.6		14.0		7.3	
Level 4	Average	14.2	303/03	6.7	212/17	3.9	041/73
	90% lower	11.6	*)	3.2	*)	–1.9	*)
	90% upper	19.2		10.7		6.5	

*) all orientation data presented in Figures H1, H2, H3 and H4.

Table H2. 90%-confidence intervals for the horizontal and vertical stress components as determined from overcoring measurements in borehole KFM02B.

Level		σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
Level 1	Average	9.4	3.8	–0.5	135
	90% lower	4.2	–2.9	–9.2	*)
	90% upper	19.0	6.0	8.4	
Level 2	Average	11.8	4.7	5.5	153
	90% lower	4.7	–4.0	–2.2	*)
	90% upper	21.3	11.2	13.2	
Level 3	Average	17.6	9.7	3.9	128
	90% lower	12.3	6.4	–0.7	*)
	90% upper	21.3	12.8	8.4	
Level 4	Average	14.1	6.5	4.2	123
	90% lower	11.4	1.3	–0.9	*)
	90% upper	18.9	9.7	9.2	

*) all orientation data presented in Figures H6, H7, H8 and H9.

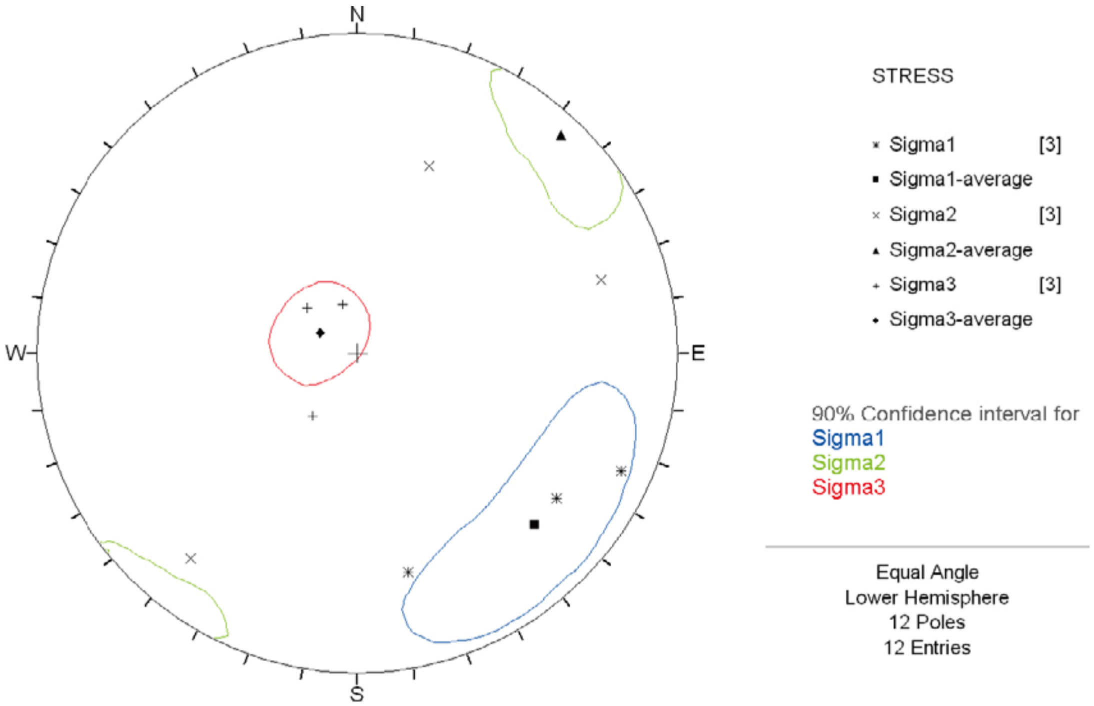


Figure H1. *90%-confidence interval for the orientation of the principal stresses in borehole KFM02B, Level 1, shown in a lower hemisphere projection.*

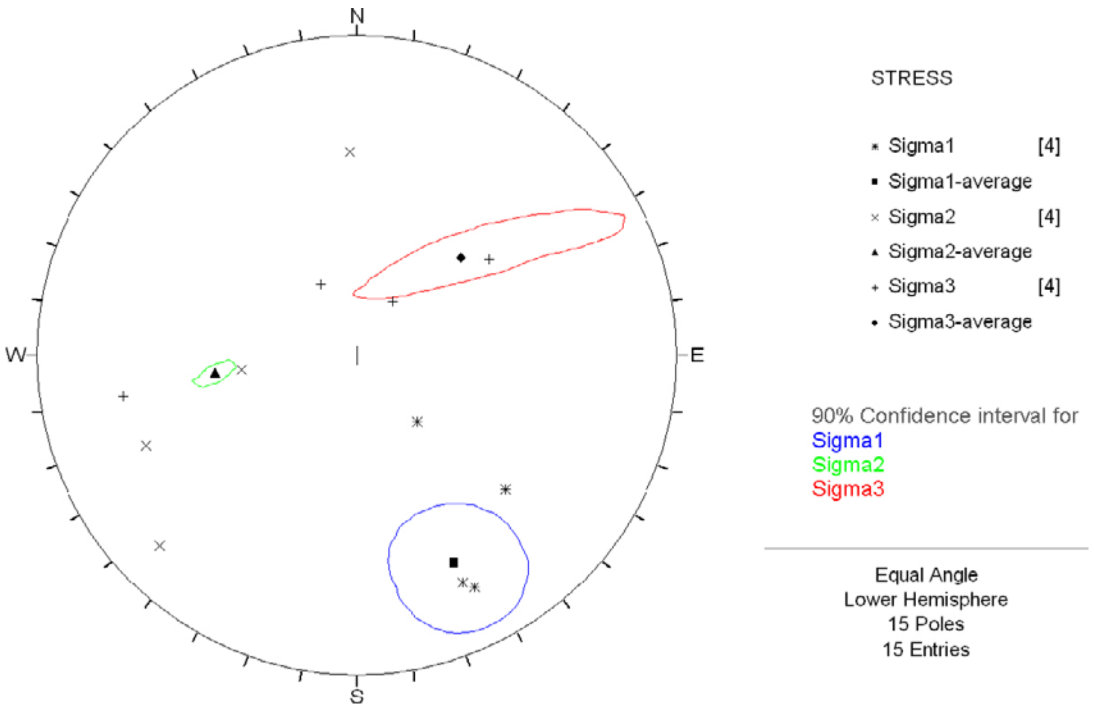


Figure H2. *90%-confidence interval for the orientation of the principal stresses in borehole KFM02B, Level 2, shown in a lower hemisphere projection.*

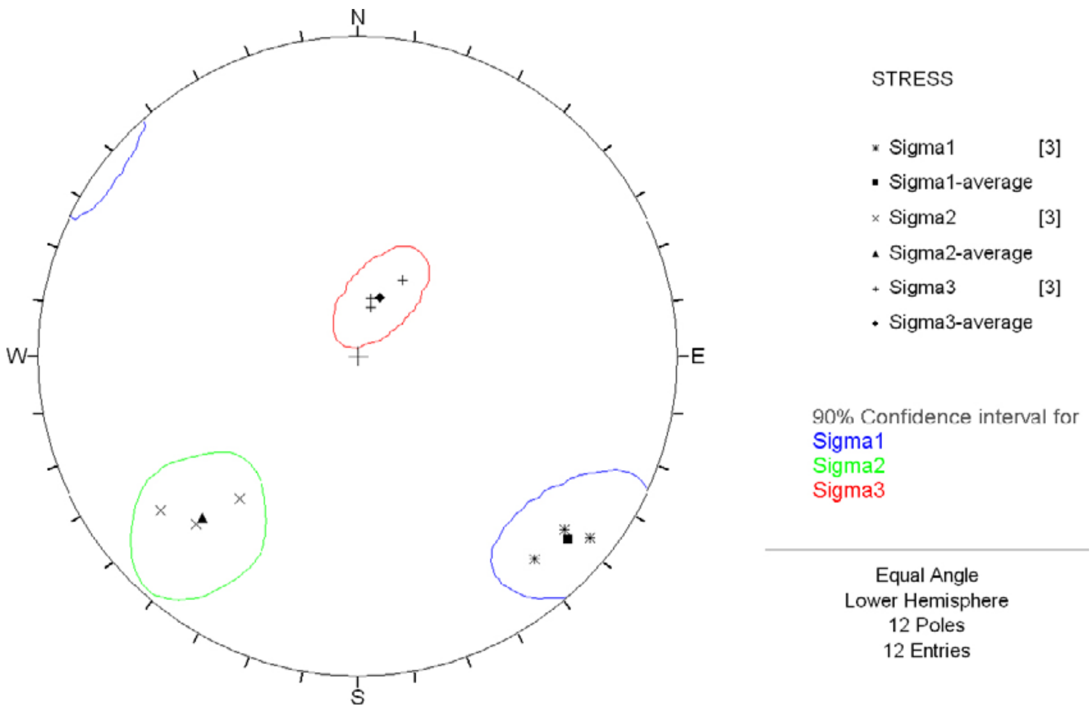


Figure H3. *90%-confidence interval for the orientation of the principal stresses in borehole KFM02B, Level 3, shown in a lower hemisphere projection.*

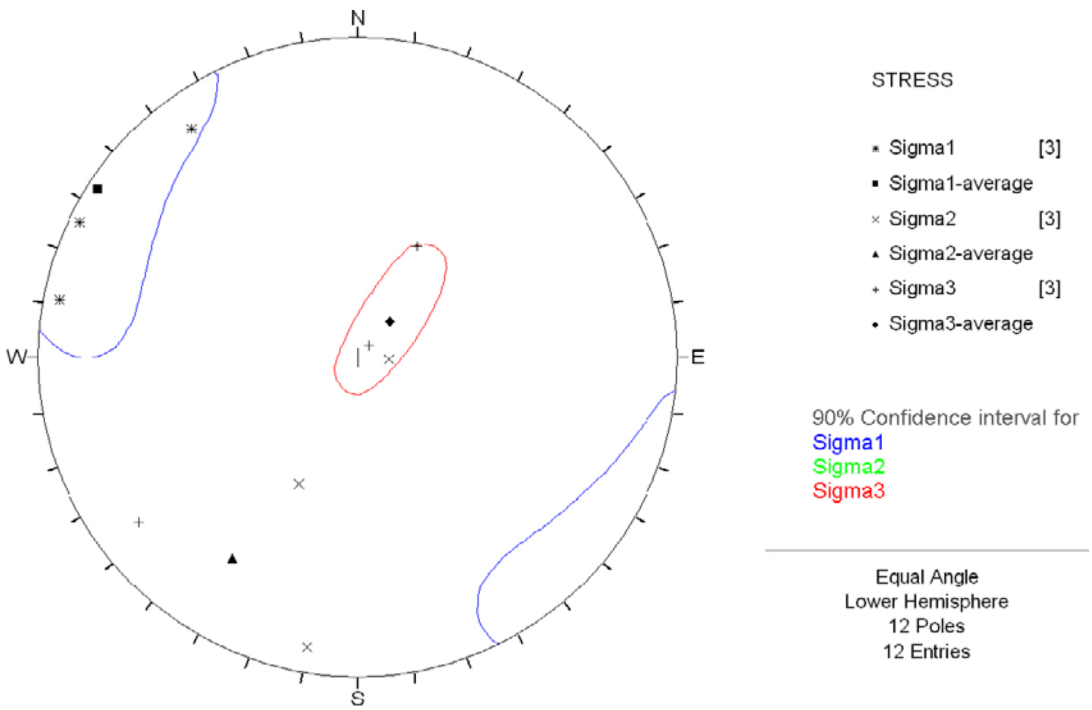


Figure H4. *90%-confidence interval for the orientation of the principal stresses in borehole KFM02B, Level 4, shown in a lower hemisphere projection.*

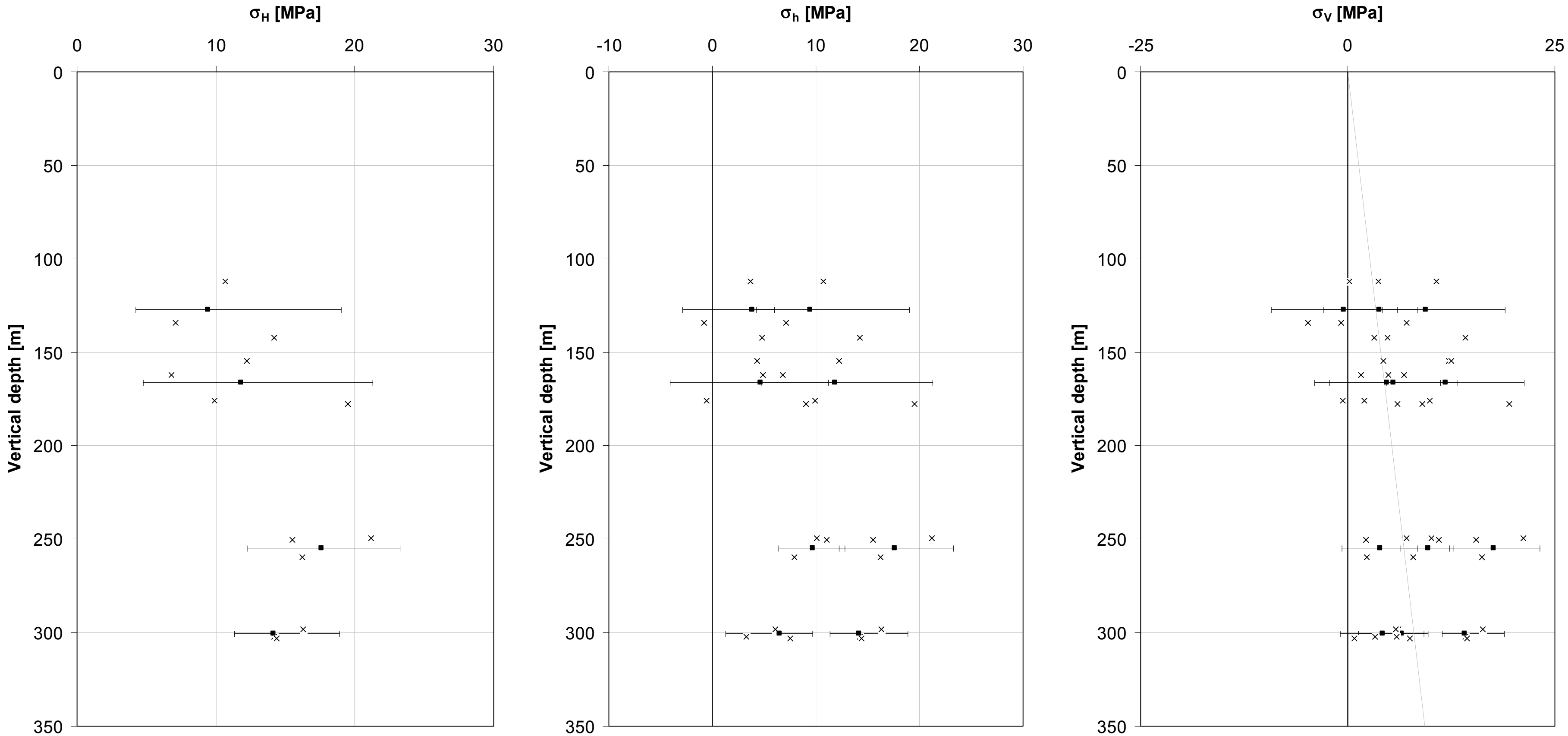


Figure H5. *Average values (■-markers) and 90%-confidence intervals (├──┤) for the horizontal and vertical stress components, shown together with measured values for each measurement level (x-markers) in borehole KFM02B.*

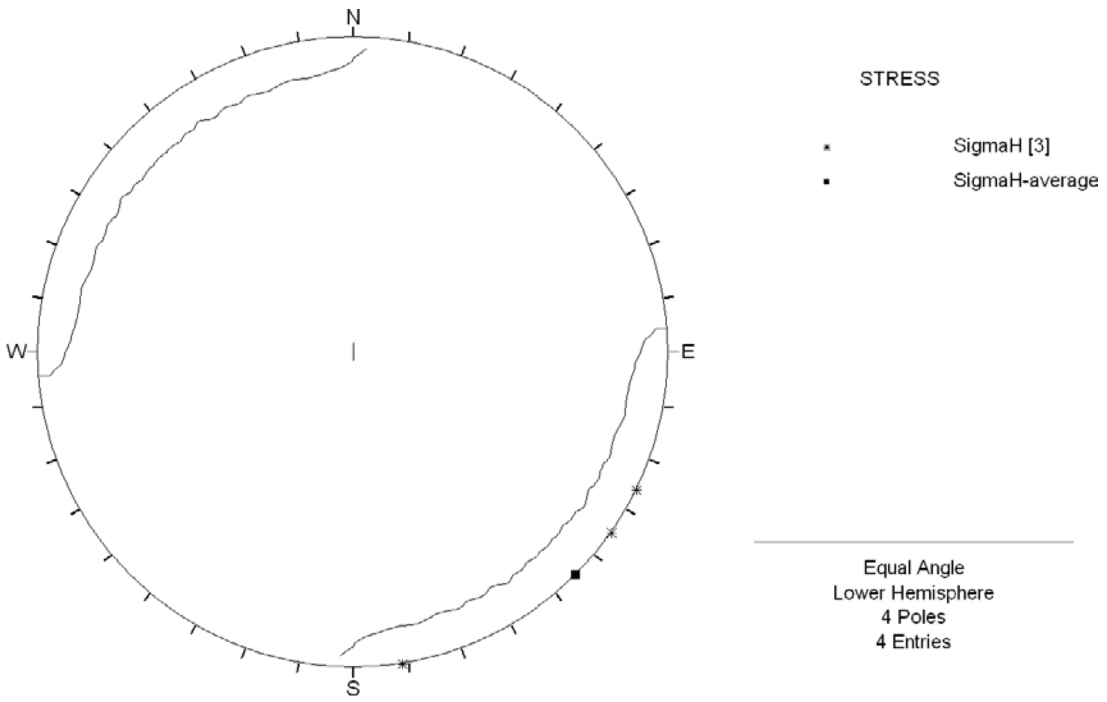


Figure H6. *90%-confidence interval for the orientation of the maximum horizontal stress for Level 1 in borehole KFM02B, shown in a lower hemisphere projection.*

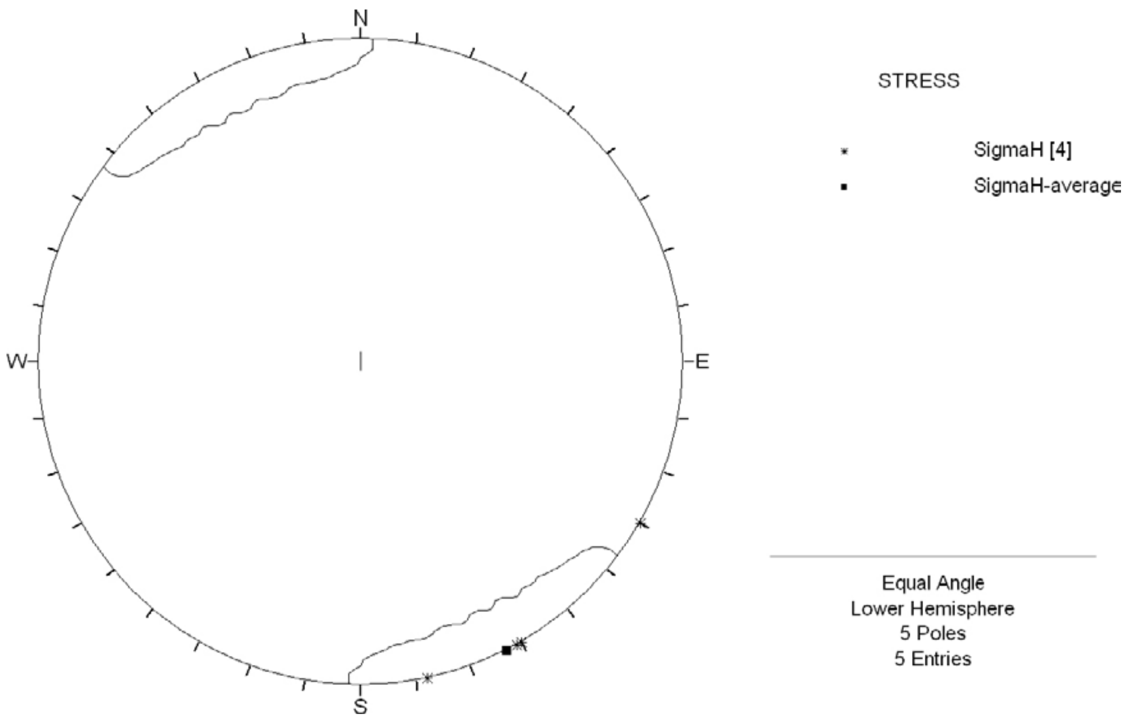


Figure H7. *90%-confidence interval for the orientation of the maximum horizontal stress for Level 2 in borehole KFM02B, shown in a lower hemisphere projection.*

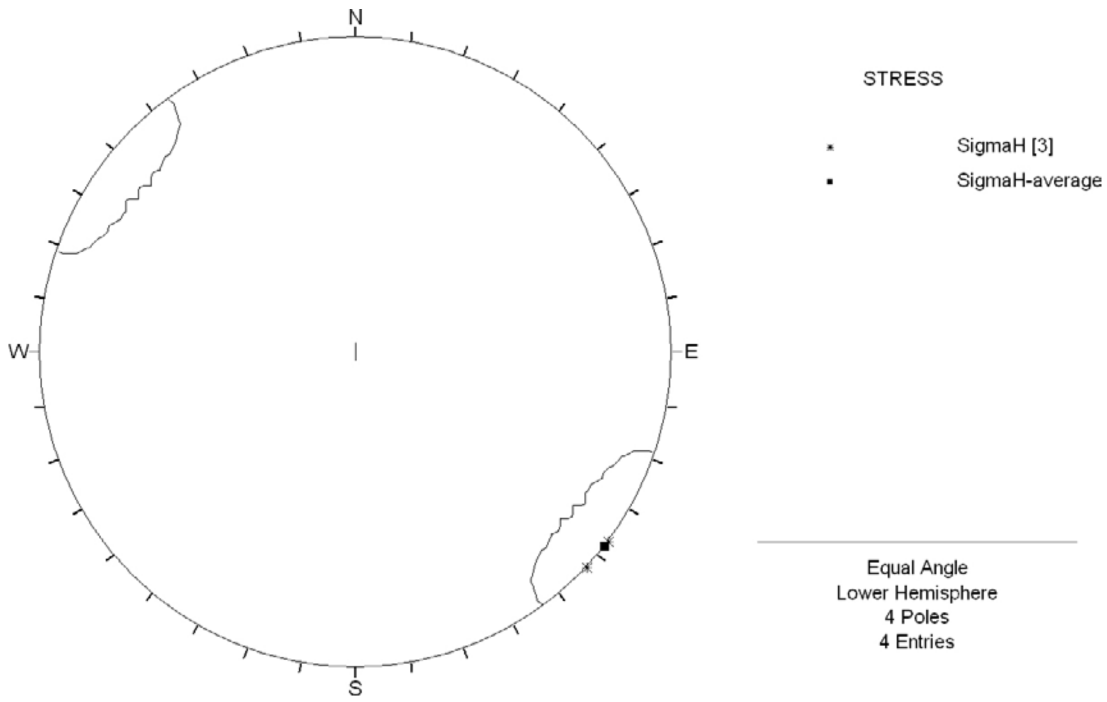


Figure H8. *90%-confidence interval for the orientation of the maximum horizontal stress for Level 3 in borehole KFM02B, shown in a lower hemisphere projection.*

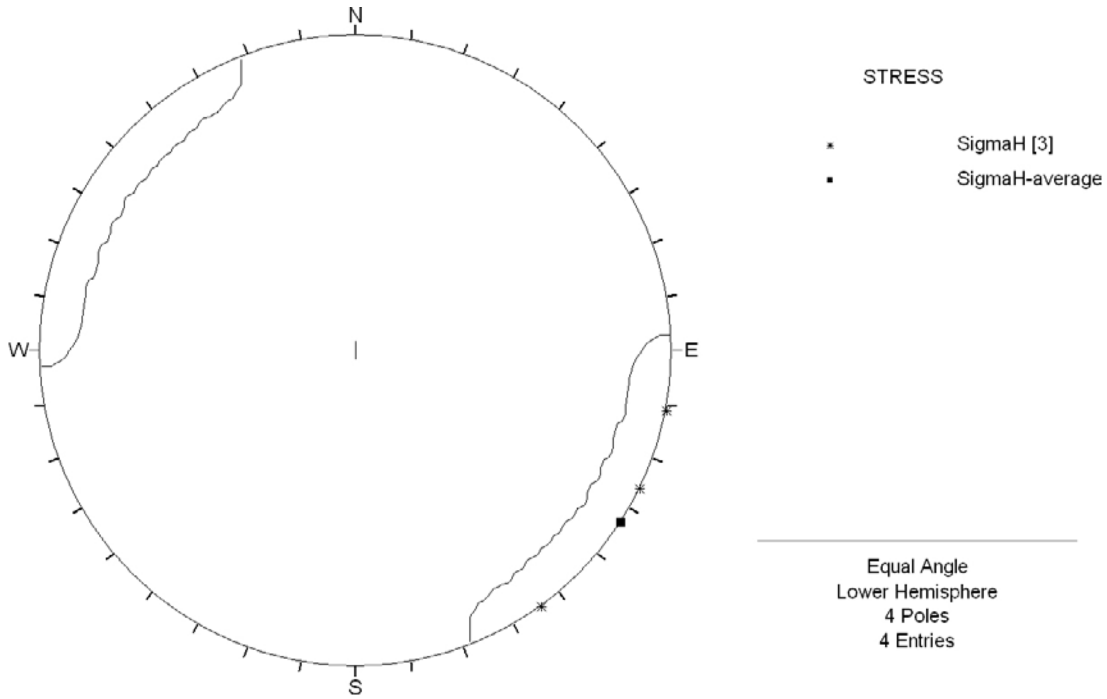


Figure H9. *90%-confidence interval for the orientation of the maximum horizontal stress for Level 4 in borehole KFM02B, shown in a lower hemisphere projection.*

Appendix I

Quality operating procedures for overcoring measurements

The following quality operating procedures are adhered to when conducting overcoring rock stress measurements using the *Borre* probe. A complete description of each procedure with adjoining checklists, can be obtained (on request) from the measurement contractor.

Pre-mobilization equipment assembly and checking

- Strain gauges assembly
  - Visual check of geometry
  - Check of glued parts
  - Visual check of wires and resistance measurement
- Glue test on new batches
- Computer and software
- Packing and transport
  - Equipment
  - Consumable supplies

Mobilization

- Mobilization on site
- Drilling contractor contacts, instructions for operation, etc
- Function test of the *Borre* probe
- Function test of biaxial load cell and pump
- Function test of installation tool (adapter)
- Function test of computer and computer programs
- Glue test (if required by the client)
- Function test and control of drilling equipment

Overcoring stress measurement procedure

- Pilot hole drilling and examination
  - Planing and drilling of pilot hole
  - Examination of pilot core and decision on installation (or not)
  - Flushing and checking the pilot hole with dummy probe
- Preparation of the Borre-cell
  - Attaching strain gauges, including resistance check and geometry check
  - Function test of *Borre* probe with attached gauges
- Installation of Borre probe
  - Function test of installation tool (adapter)
  - Glue application including thickness and application check
- Overcoring
  - Check glue hardening time
  - Check that no activity is on-going in the borehole
  - Retrieval of adapter
  - Drill string in place and marked every 4 cm (0–32 cm)
  - Flushing and overcoring activities according to specification list
  - Retrieval of drill string and *Borre* probe

- Recovery of the *Borre* probe
  - Orientation of probe installation recorded
  - Data collection (transfer to computer from logger)
- Logging and photography of overcore sample
- Biaxial testing of the overcore sample
  - Test setup and programming of logger (*Borre* probe)
  - Biaxial testing
  - Data collection (transfer to computer from logger)
  - Logging of overcore sample after biaxial testing

Evaluation and analysis

- Plotting of overcoring and biaxial test data on computer
- Data assessment (reliability, sources of error, rating)
- Stress calculation for successful measurements; average stresses calculated for each measurement level
- Continuous reporting to client

Demobilization

- Packing and transport

Final reporting

- Complementary data assessment and rating of tests
- Final stress calculation
- Transient strain analysis on selected tests
- Calculation of final stress averages
- Final reporting to client