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Overcoring rock stress measurements in borehole KLX12A

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Summary

Overcoring stress measurements were conducted in borehole KLX12A at the Oskarshamn site. The equipment used for the measurements was the three-dimensional Borre probe. Measurements were conducted at three measurement levels in borehole KLX12A. Level 1 included measurements between 224 and 240 m borehole length. For Level 2, measurements were attempted between 350 and 368 m borehole length. Level 3 included measurements between 467 and 483 m borehole length. These relatively large depth intervals were required to obtain complete test series due to problems associated with the presence of fractures, varying geology, and rock fragments in the borehole (due to borehole instabilities), thus inhibiting correct installation of the measurement probe in several instances.

In conclusion, the stress state near borehole KLX12A is characterized by low to moderately high horizontal stresses at Level 1 (approximately 225 m depth) and ENE-WSW orientation of the major principal stress. The determined vertical stress is somewhat high compared to the theoretical value corresponding to overburden pressure. For Level 2 (about 345 m depth) slightly higher stresses were found, but with similar orientation as at Level 1. The determined mean vertical stress is in very good agreement with overburden load. The magnitude of the major principal stresses at Level 3 (approximately at 455 m depth) is moderately high to high. However, the vertical stress is significantly lower than the overburden pressure. For this level there is also a significant change in the dip angle and orientation for the principal stresses (compared to Level 1 and 2). However, the orientation of the horizontal stress components is only slightly different compared to the values for Levels 1 and 2. It should also be noted that the results from the transient strain analysis indicated that relatively high tensile stresses develop during overcoring for all tests, which may lead to tensile damage of the overcore samples.

Sammanfattning

Bergspänningsmätningar med överborrningsmetoden har genomförts i borrhål KLX12A i Oskarshamn. Vid mätningarna användes Borre-cellen, vilken är en tredimensionell mätmetod. Mätningarna utfördes på tre mätnivåer i borrhålet. Den första nivån omfattade mätförsök på mellan 224 och 240 m borrhålslängd. Mätningar på den andra nivån utfördes mellan 350 och 368 m hållängd. Nivå 3 omfattade mätningar mellan 467 och 483 m hållängd. Dessa delvis långa mätsträckor krävdes för att erhålla kompletta mätserier, beroende på problem med sprickor, varierande geologi samt närvaron av bergfragment (på grund av borrhålsinstabiliteter), vilket omöjliggjorde korrekt installation av mätsonden.

Sammanfattningsvis kan spänningstillståndet runt borrhål KLX12A beskrivas av låga till medel-höga horisontalspänningar för mätnivå 1 (cirka 225 m djup) med största spänningen orienterad ENE-WSW. Den vertikala spänningen för nivån är dock något hög jämfört med teoretiskt beräknad vertikalspänning utifrån tyngden av ovanliggande berg. Spänningsnivån för nivå 2 (cirka 345 m djup) är medelhög och med samma orientering som för nivå 1. Medelvärdet på de uppmätta vertikalspänningarna överrensstämmer mycket väl belastningen från ovanliggande berg. På mätnivå 3 (cirka 455 m djup) är spänningar måttligt höga till höga, men medelvärdet på de uppmätta vertikalspänningarna är betydligt lägre än den teoretiskt beräknade spänningen utifrån tyngden av ovanliggande berg. På mätnivå 3 sker även en vridning av uppmätta horisontalspänningar i förhållande till mätnivåerna 1 och 2. Riktningen på de horisontella spänningskomponenterna uppvisar dock relativt liten skillnad jämfört med motsvarande värden på nivå 1 och 2. Utförda transientanalyser visade också att för alla tester utförda i KLX12A uppkommer relativt höga dragspänningar under överborrningsfasen vilket kan orsaka skador på överborrad kärna.

Contents

1 Introduction

This document reports the data gained from three-dimensional overcoring rock stress measurements in borehole KLX12A, which is one of the activities within the site investigation at Oskarshamn. The borehole is located in the Laxemar candidate area as shown in Figure 1-1.

The borehole was drilled subvertically (at approximately 75° dip) from the ground surface and is of “telescope” type with the upper 100 metres of larger diameter (165 mm), which subsequently is cased. The rest of the borehole is drilled with 76 mm diameter down to a depth of 600 metres. Overcoring rock stress measurements were planned to be conducted at approximately 200–250, 350–400 and 475–565 metres depth, during drilling of the hole, according to the Activity Plan AP PS 400-05-070 (SKB internal controlling document). All results are stored in the SKB database SICADA.

Figure 1-1. *Location of core hole KLX12A within the Laxemar area, as of April, 2006.*

2 Objective and scope

The objective of the overcoring rock stress measurements was to determine the complete in situ stress field in the undisturbed rock mass at three measurement levels: 250, 400, and 500 m borehole length (corresponding to slightly less vertical depth since the borehole is inclined). This was to be achieved by 3–4 successful test results from each level.

All measurements were conducted using the three-dimensional Borre probe for overcoring (developed and used by SwedPower AB). The method is described in detail in Chapter 3 of this report. Field measurements were done in three periods during 2005 and 2006 The first period started November 18 and was completed December 4. The second field period commenced December 14 and was completed January 15 (2006). Finally, the third period started January 23 and was completed February 17.

Execution of field measurements and data analysis is presented in Chapter 4 of this report. In addition to conventional analysis of overcoring data, transient strain analysis was conducted, following the methodology developed by /Hakala et al. 2003/. The objective of this analysis was to aid in: (i) quality control of the overcoring data, (ii) judgment of reliability of single measurements, and (iii) possibly establishing bounds on the measured stresses. Transient strain analysis was conducted for all successful measurements from the three measurement levels. 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 hole 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.

3 Equipment

3.1 The overcoring method

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 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/.

3.2 Description of field equipment

The Borre probe /Sjöberg and Klasson 2003/ is owned and used by SwedPower 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, and
- portable computer.

A new pilot hole wireline drilling equipment was recently 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 these systems produce a 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 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 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).

Figure 3-1. *The Borre probe.*

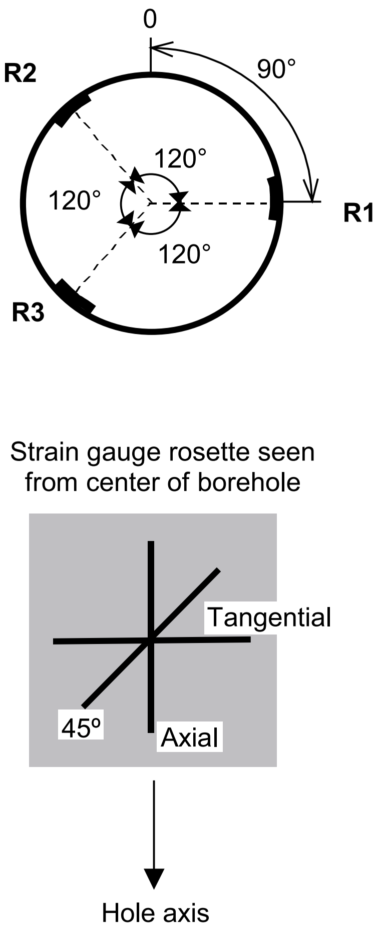

__Figure 3-2.__ Strain gauge configuration of the Borre probe. Axial strain gauges are denoted L1, L2, and L3 (gauge nos. 1, 4, 7), tangential gauges are denoted T1, T2, and T3 (gauge nos. 2, 5, 8), and inclined gauges are denoted 45-1, 45-2, and 45-3 (gauge nos. 3, 6, 9).

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 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, and
- functional checks of drilling and installation equipment.

4.3 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.

4.3.1 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: Continuous core, mechanical fractures accepted. No healed fracture that (length) 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 (core discing, 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.

4.3.2 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, and
- 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.

4.3.3 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). 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 for completed overcoring (normally 100 cm length).

The borehole is left with no on-going activity for approximately 15 minutes after completed overcoring but 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.

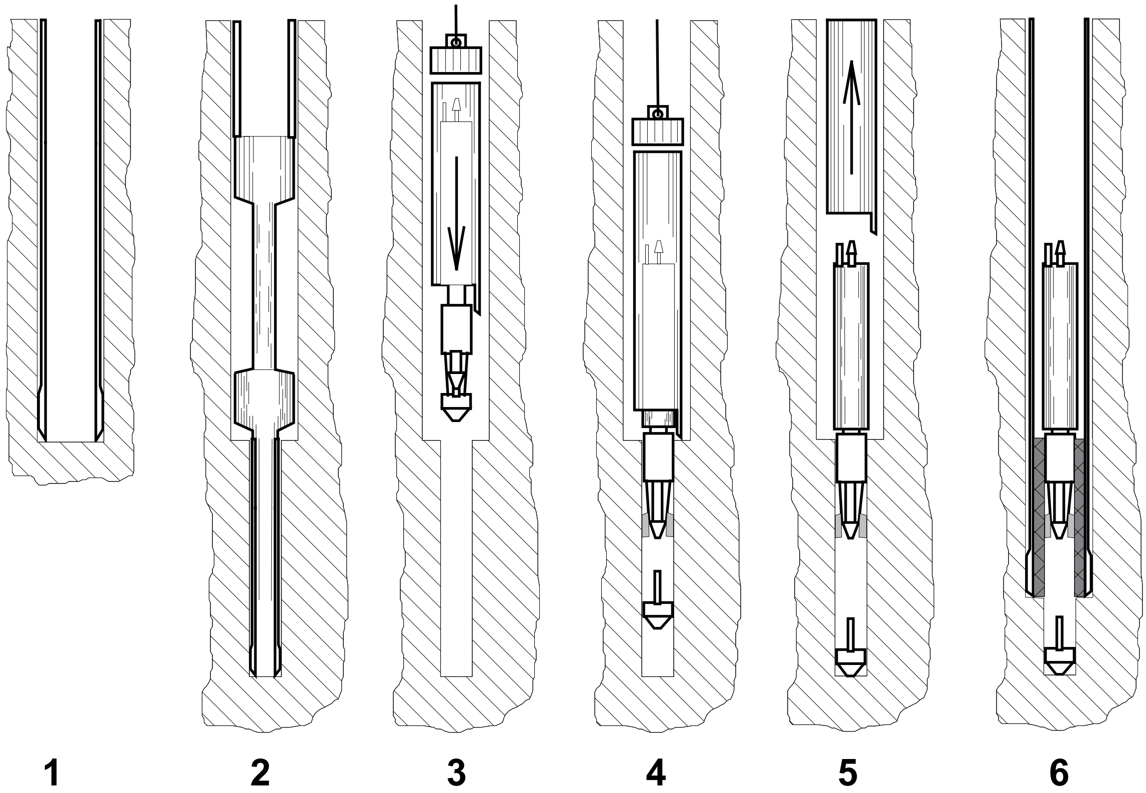

Figure 4-1. *Installation and measurement procedure with the Borre probe:*

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.*

4.3.4 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, is also measured.

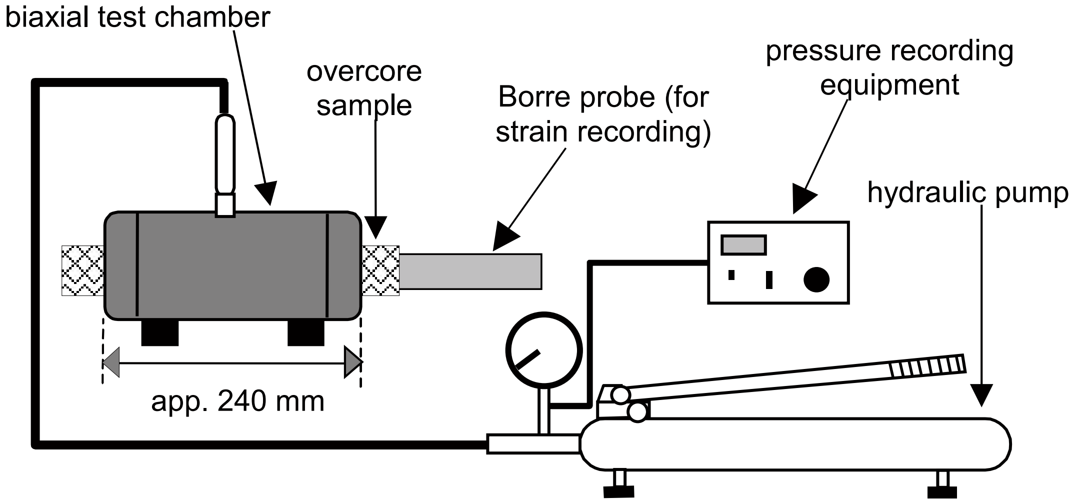

Figure 4-2. Schematic drawing of the biaxial load cell with pressure generator and recording equipment.

4.4 Data handling

The raw data include overcoring strain data files, biaxial strain data files, and completed checklists 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. All original data are stored in the SKB database SICADA, where they are traceable by the Activity Plan number.

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 average stresses for each level.

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, and
- values on elastic constants from biaxial testing.

4.5 Data analyses

4.5.1 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). 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 v (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 average 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 average values, the average principal stresses, as well as the average horizontal and vertical stresses, are determined. All calculated data are stored in SICADA, traceable by the Activity Plan number.

4.5.2 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/

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

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, strength values are not known for this site. For illustrative purposes, a uniaxial compressive strength of 200 MPa and a uniaxial tensile strength of 20 MPa were assumed to define a failure criterion. 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 can, obviously, not be studied with this computer program.

Finally, the developed code has the capability to solve for 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 KLX12A, 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 KLX12A, as described in the following.

5 Results

5.1 Overview

Measurements were conducted at three measurement levels in borehole KLX12A. Level 1 included measurements between 224 and 240 m borehole length. For Level 2, measurements were attempted between 350 and 368 m borehole length. Level 3 included measurements between 467 and 483 m borehole length. These relatively large depth intervals were required to obtain complete test series due to problems associated with the presence of fractures, varying geology, and rock fragments in the borehole (due to borehole instabilities), thus inhibiting correct installation of the measurement probe in several instances. Extended periods of flushing as well as blowing the hole with nitrogen gas helped improving borehole conditions.

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 3:6:2 denotes measurement Level 3, test (or measurement) no. 6 at that level, and pilot hole no. 2 (to reach an acceptable mea surement 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 μstrain 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 μstrain) accepted. • Stress calculation possible with classical analysis (Section 4.4.1). 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 4.4.1) but results judged uncertain and/or less reliable. • Additional stress determination may be conducted using inverse solution of transient strain analysis (Section 4.4.2).
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 KLX12A, Oskarshamn.

Test no. (pilot hole no. *)	Hole length [m]	Vertical depth [m] **)	Over-coring	Biaxial testing	Transient strain analysis	Rating	Comments
1:1:1	224.22	214.82	No	No	No	*c*	Successful installation, but overcoring failed. See "Avvikelserapport 051124".
1:2:2	226.98	217.45	No	No	No	*c*	Installation failed; rock piece prevented gauge holder from entering the pilot hole.
1:3:1	227.97	218.39	No	No	No	*c*	Installation failed; rock piece prevented gauge holder from entering the pilot hole.
1:4:3	231.36	221.61	Yes	No	Yes	*b*	Successful installation and overcoring. Stable strain response during overcoring. Biaxial testing not done due to oil leakage.
1:5:1	232.40	222.60	Yes	Yes	Yes	*b*	Successful installation and overcoring. Stable strain response during overcoring. Fair biaxial test results; rosette 1 and 3 excluded when evaluating elastic constants.
1:6:2	236.26	226.28	Yes	Yes	Yes	*a*	Successful installation and overcoring. Stable strain response during overcoring. Stable strain response in biaxial testing, pressure up to 8 MPa.
1:7:1	237.33	227.30	Yes	Yes	Yes	*b*	Successful installation and overcoring. Unstable strain response during over-coring. Biaxial testing yielded unstable response and unrealistic values.
1:8:1	239.37	229.24	Yes	Yes	Yes	*b*	Successful installation and overcoring. Stable strain response during overcoring. Biaxial testing yielded unstable response and unrealistic values.
2:1:4	350.10	335.20	Yes	Yes	Yes	*b*	Successful installation and overcoring. Stable strain response during overcoring. Fair biaxial test results; rosette 1 and 3 excluded when evaluating elastic constants.
2:2:1	351.28	336.34	Yes	Yes	Yes	*b*	Successful installation and overcoring. Stable strain response during overcoring. Larger strain drift in biaxial testing. Elastic constants from 2:1:4 used in stress calculation.
2:3:3	355.23	340.16	Yes	Yes	No	*c*	Installation successful, but overcoring response some-what unstable. Biaxial test with large hystereses.
2:4:2	357.39	342.25	Yes	Yes	No	*c*	Installation successful and fair overcoring response. Biaxial testing yielded unstable response and unrealistic values.
2:5:2	359.58	344.36	Yes	Yes	Yes	*a*	Successful installation and overcoring. Stable strain response during overcoring. Fair biaxial test response; rosette 1 and 2 excluded when evaluating elastic constants.
2:6:4	365.33	349.92	No	No	No	*c*	Installation failed for unknown reasons. Damages on protective cone.
2:7:1	365.38	349.97	No	No	No	*c*	Installation failed; metal object (flattened nail?) prevented gauge holder from entering pilot hole.

Test no. (pilot hole no. *)	Hole length [m]	Vertical depth [m] **)	Over-coring	Biaxial testing	Transient strain analysis	Rating	Comments
2:8:1	366.38	350.94	Yes	Yes	Yes	*a*	Successful installation and overcoring. Very stable strain response during overcoring and biaxial testing.
2:9:1	367.40	351.92	Yes	Yes	Yes	*a*	Successful installation and overcoring. Very stable strain response during overcoring and biaxial testing. Rosette 1 excluded when evaluating elastic constants.
3:1:1	467.39	448.61	Yes	Yes	No	*c*	Installation partly failed due to stub in the borehole, overcoring response unstable. Biaxial test with large hystereses.
3:2:1	468.48	449.66	Yes	Yes	Yes	*a*	Successful installation and overcoring. Stable strain response during overcoring. Some strain drift in biaxial testing.
3:3:2	470.79	451.90	Yes	Yes	Yes	*a*	Successful installation and overcoring. Stable strain response during overcoring. Some strain drift in biaxial testing, rosette 1 and 3 excluded when evaluating elastic constants.
3:4:1	471.92	452.99	Yes	Yes	Yes	*b*	Installation successful and fair over-coring response. Biaxial test with large hystereses, rosette 1 and 3 excluded when evaluating elastic constants.
3:5:1	473.29	454.32	Yes	Yes	No	*c*	Installation successful, but overcoring response indicating very low strains. Biaxial test with large hystereses.
3:6:2	475.41	456.37	Yes	Yes	Yes	*a*	Successful installation and overcoring. Stable strain response during overcoring. Some strain drift in biaxial testing, rosette 2 and 3 excluded when evaluating elastic constants.
3:7:3	479.33	460.16	No	No	No	*c*	Installation partly failed, unknown reason and overcoring response indicating very low strains. Biaxial test with large hystereses.
3:8:1	481.81	462.56	Yes	Yes	No	*c*	Installation failed; unknown reasons, damages on protective cone.
3:9:1	481.88	462.63	Yes	Yes	No	*c*	Installation successful, but overcoring response unstable. Biaxial test with large hystereses.
3:10:1	482.98	463.69	Yes	Yes	No	*c*	Installation successful, but overcoring response unstable. Biaxial test with large hystereses.

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

**) Vertical depth (below ground surface) interpolated from borehole orientation measurements (every three metre).

Borehole orientations for the measurement depths in question are shown in Table 5-2, as measured after completed drilling of the hole. These orientation data were used in the stress calculations described below, together with the recorded orientations of the installed Borre probe.

Table 5-2. Borehole orientation for overcoring measurement points in borehole KLX12A. Orientations determined by linear interpolation between each measured section (at 3 metre distances).

Level no.	Test no. (pilot hole no. *)	Hole length [m]	Borehole bearing [°] **)	Borehole dip [°] ***)
1	1:1:1	224.22	313.20	72.26
1	1:2:2	226.98	313.77	72.25
1	1:3:1	227.97	314.05	72.25
1	1:4:3	231.36	314.04	72.25
1	1:5:1	232.40	313.89	72.25
1	1:6:2	236.26	312.74	72.25
1	1:7:1	237.33	312.36	72.25
1	1:8:1	239.37	311.79	72.23
2	2:1:4	350.10	307.77	75.19
2	2:2:1	351.28	307.87	75.19
2	2:3:3	355.23	307.74	75.18
2	2:4:2	357.39	307.47	75.19
2	2:5:2	359.58	306.96	75.17
2	2:6:4	365.33	307.09	75.16
2	2:7:1	365.38	307.10	75.16
2	2:8:1	366.38	307.20	75.16
2	2:9:1	367.40	307.30	75.16
3	3:1:1	467.39	307.79	75.30
3	3:2:1	468.48	307.79	75.30
3	3:3:2	470.79	307.76	75.29
3	3:4:1	471.92	307.75	75.29
3	3:5:1	473.29	307.74	75.28
3	3:6:2	475.41	307.73	75.28
3	3:7:3	479.33	307.35	75.30
3	3:8:1	481.81	307.33	75.31
3	3:9:1	481.88	307.34	75.31
3	3:10:1	482.98	307.39	75.31

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

**) Clockwise from geographic north.

***) Positive downward from the horizontal.

5.2 Overcoring test data

Results from all tests with rating *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) are presented in Appendix A. Furthermore, core logs and photos are presented in Appendices F and G.

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 overcoring stop. The latter was used to define strain differences for later input to stress calculation. In the Figures, the given times reflect the events recorded during overcoring. The times for which the strain differences have been determined ("OC Start" and "OC Stop") are shown in Appendix A.

In the following, a short description is presented for each of the measurement attempts at the two levels.

5.2.1 Measurement Level 1

A total of eight installations were attempted at the first measurement level in borehole KLX12A. Out of these, 1 successful tests with rating *a* (1:6:2) and four partially successful tests (1:4:3, 1:5:1, 1:7:1, and 1:8:1) were obtained. Installation failed for three other tests. For test no. 1:1:1, the reason is unknown. For test nos. 1:2:2 and 1:3:1 rock pieces prevented the gauge holder from entering the pilot hole. For test no. 1:4:3 the installation was successful with stable strain response from overcoring – only gauges nos. 2 and 3 showed some minor drift after completed coring and flushing. Unfortunately no biaxial test could be performed for this test (due to oil leakage, see Section 5.3). Stable strain response was observed for test no. 1:5:1 with minimal strain drift after the core break and during core retrieval. Test no. 1:6:2 resulted in very stable strain response right up to the point of dismantling the gauges from the overcore sample. Both test nos. 1.7:1 and 1:8:1 were successfully overcored but the biaxial tests gave unstable response and hystereses (see also Section 5.3). During overcoring of all successful installations the temperature increase was between 2.5° and 3°C, which is considered as a moderate increase.

5.2.2 Measurement Level 2

In total, nine measurements were attempted at this level, with three measurements judged experimentally successful (test nos. 2:5:2, 2:8:1, and 2:9:1) and two partially successful tests (2:1:4 and 2:2:1) were obtained. Some of the unsuccessful tests (2:3:3 and 2:4:2) were installed correctly but resulted in unstable strain response during overcoring as well as biaxial tests with large hystereses. These tests were therefore judged as not acceptable. For test no. 2:6:4, installation failed with damages on the equipment (protective cone) indicating that something prevented the nose cone to enter the pilot hole correctly. Installation of test no. 2:7:1 failed due to a metal object (retrieved piece similar to a flattened nail) preventing the nose cone to enter the pilot hole correctly. The overcoring strain response was stable to very stable for the successful tests with only minor strain drift after overcoring and during core retrieval. However, for some biaxial tests (2:1:4, 2:2:1 and 2:5:2) strain drift occurred. The other tests at this level gave very stable strain response during biaxial testing. During overcoring of successful test, the general temperature increase was between 2.5° and 3.5°C.

5.2.3 Measurement Level 3

In total, nine measurements were attempted at this level, with three measurements judged experimentally successful (test nos. 3:2:1, 3:3:2 and 3:6:2) and one partially successful test (3:4:1). All these test showed stable strain response, with only minor strain drift after overcoring and until core retrieval started. In general, the gauges showed some drifts during retrieval of the rock core as the temperature sunk from 16°C down to 7–9°C in a short period. Installation of test no. 3:1:1 partly failed due to stub in the borehole, which gave unstable response for both overcoring and biaxial test. Test no. 3:5:1 was successfully installed but gave unreasonably low strains during overcoring, as well as large hystereses during biaxial testing. The same behaviour occurred for test 3:7:3 due to debonding of the gauges. For test no. 3:8:1 installation failed for unknown reason, with damages observed on the protective cone. It is not clear if the protective cone has fallen off during transportation down the hole and therefore prevented the nose cone to properly enter the pilot hole. Another scenario is that the protective cone was stuck at the collar of the pilot hole, thus preventing the cell to be installed properly. Test nos. 3:9:1 and 3:10:1 were installed correctly but the overcoring response from both tests was unstable. For both these tests, biaxial data revealed large hystereses. After test no. 3:10:1, SKB decided to terminate the measurement campaign. During overcoring of successful installations the temperature, in general, increased with 2° to 2.5°C.

5.3 Biaxial test data

All suitable overcore rock samples were tested in the biaxial cell to determine the elastic properties, except for test no. 1:4:3 where oil leakage occurred. Several attempts to complete the biaxial test, including changing the membrane, were made without success. For Level 1, one successful biaxial test was conducted, namely test no. 1:6:2, which had a stable and linear strain response. This biaxial test was conducted with a maximum applied pressure of 8 MPa due to presence of a pre-existing fracture at the top of the rock core. Test no. 1:5:1 gave somewhat unstable response and was therefore excluded even though the values of the elastic properties were similar to those of test no. 1:6:2. For test nos. 1.7:1 and 1:8:1, unstable strain response with large hystereses was found – these tests were therefore excluded.

Biaxial tests on successful overcored samples from Level 2 showed very good linearity and isotropic behaviour for test nos. 2:8:1 and 2:9:1 although rosette 1 were excluded when evaluating elastic constants for the latter one. For test 2:1:4, strain rosette nos. 1 and 3 had to be excluded due to signs of debonding. Large strain drifts occurred during biaxial testing of sample no. 2:2:1 (despite the good strain response during overcoring). Hence, the elastic properties from test no. 2:1:4 were used for stress calculation. Fair response was observed for test no. 2:5:2, but rosettes nos. 1 and 2 were excluded when evaluating the elastic constants.

At Level 3 the successful overcoring tests gave fair results from their biaxial tests with some strain drifts. For test no. 3:3:2 and 3:4:1, rosettes nos. 1 and 3 were excluded in the evaluation of elastic constants. Similarly for test 3:6:2, rosettes nos. 2 and 3 were excluded from the evaluation. The results from the successful biaxial tests are presented in Table 5-3. The gauge response-curves from these tests are shown in Appendix C. All original data are stored in the SKB database SICADA.

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 very stable post-overcoring response, 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).

Table 5-3. Results from biaxial testing on overcore samples from borehole KLX12A.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	Young's modulus, *E* [GPa]	Poisson's ratio, *v*
1	1:5:1[1)]	232.40	N/A	N/A
1	1:6:2	236.26	78.2	0.30
2	2:1:4	350.10	79.0	0.33
2	2:5:2	359.58	73.2	0.35
2	2:8:1**)	366.38	91.6	0.44
2	2:9:1**)	367.40	102.0	0.47
3	3:2:1	468.48	101.4	0.42
3	3:3:2	470.79	92.4	0.31
3	3:4:1	471.92	97.9	0.32
3	3:6:2	475.41	81.8	0.29

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

**) Linear fit mean, others using secant value mean.

1) Values not usable.

Mean stresses were calculated from all successful (both *a* and *b* rating) measurements. For Level 1, all measurements were included in the calculation of the mean stress state (although the individual scatter between single measurements is relatively large).

At Level 2, test nos. 2:1:4 and 2.2:1 gave unrealistically low values for the minor principal stresses. The calculated magnitude and orientation of the maximum horizontal stress for test nos. 2:1:4 and 2.2:1 is similar to the other tests at this measurement level; however, large differences were found for the minor horizontal and vertical stresses. The transient strain analysis (Section 5.5 below) further confirmed that these two tests were suspicious due to large amount of unexplained strains in the solution. Thus, these tests were excluded from the averaging calculations for Level 2.

For Level 3, two distinct groups of stress states can be inferred based on magnitudes and orientations of the resulting stresses. However, these two groups are not separate in terms of geology, depth, or observed strain response from overcoring or biaxial testing.

The first group comprises measurements 3:2:1 and 3:4:1, and the second group consists of measurements 3:3:2 and 3:6:2. The mean stress magnitudes and orientations determined for the first group (3:2:1 and 3:4:1) are similar to mean stresses for Level 1. The vertical stress determined from these two tests is also much lower than the theoretical value due to overburden (1.9 vs. 12 MPa). The average stresses determined from measurements 3:3:2 and 3:6:2 (the second group) indicate a sub-horizontal major principal stress trending nearly N-S, and with a magnitude of 25.5 MPa. The vertical stress determined from these two tests is 8 MPa, which is somewhat lower than the theoretical value due to the overburden pressure.

If an average value is determined from all successful measurements at Level 3 (both groups), the preliminary major principal stress is trending NWN-SES with a magnitude of 19 MPa. Using all successful measurements, an average vertical stress of 4.9 MPa is obtained.

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

Table 5-4. Magnitudes of principal stress as determined by overcoring in borehole KLX12A.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	σ_1 [MPa]	σ_2 [MPa]	σ_3 [MPa]
1	1:4:3	231.36	18.2	5.6	4.2
1	1:5:1	232.40	19.2	13.9	4.6
1	1:6:2	236.26	17.5	3.9	–0.1
1	1:7:1	237.33	11.8	2.8	–0.1
1	1:8:1	239.37	10.4	2.9	0.7
1	Average	–	14.0	6.4	2.7
2	2:1:4 **)	350.10	16.9	0.8	–3.5
2	2:2:1 **)	351.28	12.4	2.5	–1.9
2	2:5:2	359.58	16.6	5.1	2.2
2	2:8:1	366.38	20.1	9.2	4.7
2	2:9:1	367.40	17.8	7.1	4.0
2	Average	–	17.4	7.1	4.4
3	3:2:1	468.48	15.3	7.5	2.9
3	3:3:2	470.79	28.2	12.2	5.2
3	3:4:1	471.92	16.0	7.7	–2.0
3	3:6:2	475.41	24.3	12.0	8.4
3	Average	–	19.4	11.0	4.0

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

**) Not included in calculation of average stress for Level 2.

Table 5-5. Orientations of principal stress as determined by overcoring in borehole KLX12A.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	σ_1 Trend/plunge [°]	σ_2 Trend/plunge [°]	σ_3 Trend/plunge [°]
1	1:4:3	231.36	170/43	068/13	326/45
1	1:5:1	232.40	130/34	249/35	010/36
1	1:6:2	236.26	130/40	291/48	032/10
1	1:7:1	237.33	119/24	235/45	010/36
1	1:8:1	239.37	188/38	327/44	080/22
1	Average	–	145/41	260/26	012/38
2	2:1:4 **)	350.10	147/24	300/64	053/11
2	2:2:1 **)	351.28	177/19	300/58	078/25
2	2:5:2	359.58	151/31	046/23	286/49
2	2:8:1	366.38	146/07	024/77	237/11
2	2:9:1	367.40	156/41	350/48	252/07
2	Average	–	150/27	359/60	247/13
3	3:2:1	468.48	139/20	230/01	322/70
3	3:3:2	470.79	003/05	093/06	234/82
3	3:4:1	471.92	139/13	046/12	274/72
3	3:6:2	475.41	168/16	068/31	281/54
3	Average	–	163/09	071/17	280/71

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

**) Not included in calculation of average stress for Level 2.

Table 5-6. Horizontal and vertical stress components calculated from measured principal stresses in borehole KLX12A.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
1	1:4:3	231.36	11.8	5.5	10.7	173
1	1:5:1	232.40	16.9	8.5	12.3	111
1	1:6:2	236.26	11.8	0.1	9.5	127
1	1:7:1	237.33	10.2	1.0	3.3	115
1	1:8:1	239.37	7.4	1.1	5.5	003
1	Average	–	9.9	4.9	8.2	132
2	2:1:4 **)	350.10	14.3	–3.3	3.2	146
2	2:2:1 **)	351.28	11.3	–1.0	2.8	175
2	2:5:2	359.58	12.9	4.5	6.5	155
2	2:8:1	366.38	19.9	4.8	9.2	146
2	2:9:1	367.40	13.2	4.1	11.7	158
2	Average	–	15.2	4.6	9.1	152
3	3:2:1	468.48	13.8	7.5	4.4	139
3	3:3:2	470.79	28.1	12.1	5.4	002
3	3:4:1	471.92	15.2	7.2	–0.7	142
3	3:6:2	475.41	23.2	10.9	10.5	170
3	Average	–	19.1	10.4	4.9	165

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

**) Not included in calculation of average stress for Level 2.

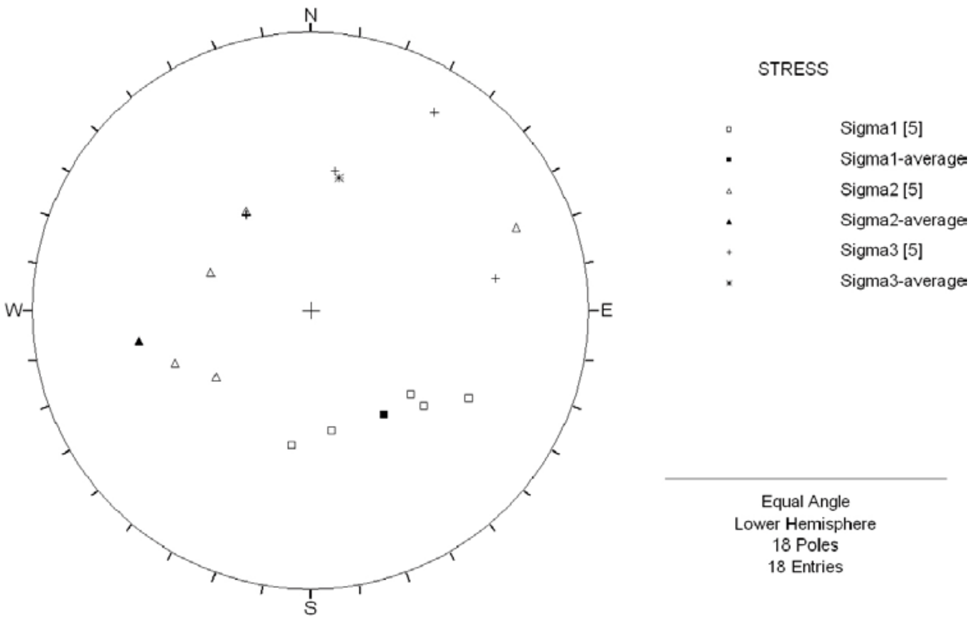

Figure 5-1. *Orientations of measured principal stresses in borehole KLX12A, Level 1, shown in a lower hemisphere projection (test nos. 1:4:3, 1:5:1, 1:6:2, 1:7:1, and 1:8:1).*

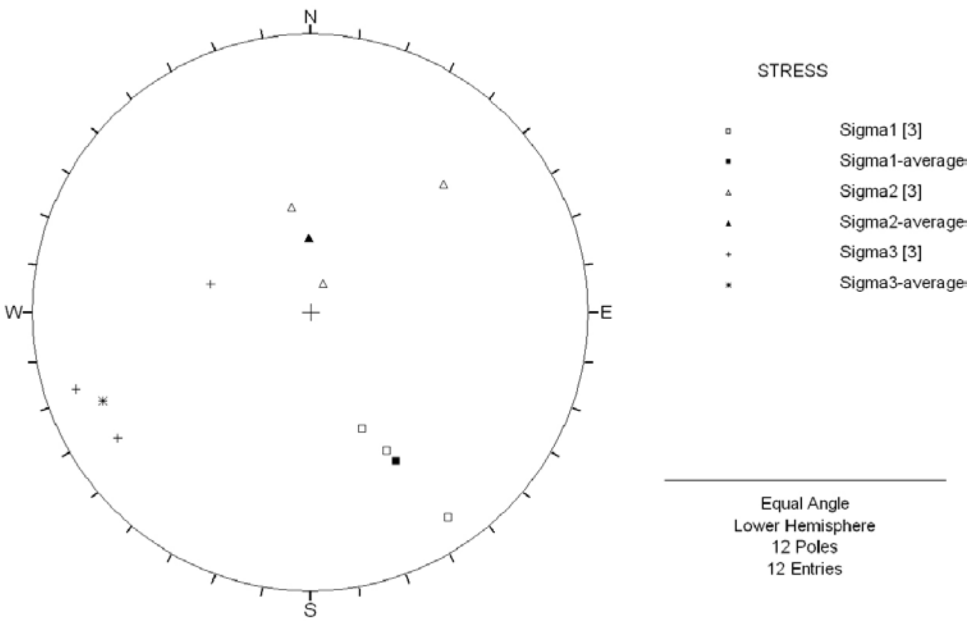

Figure 5-2. *Orientations of measured principal stresses in borehole KLX12A, Level 2, shown in a lower hemisphere projection (test nos. 2:5:2, 2:8:1, and 2:9:1).*

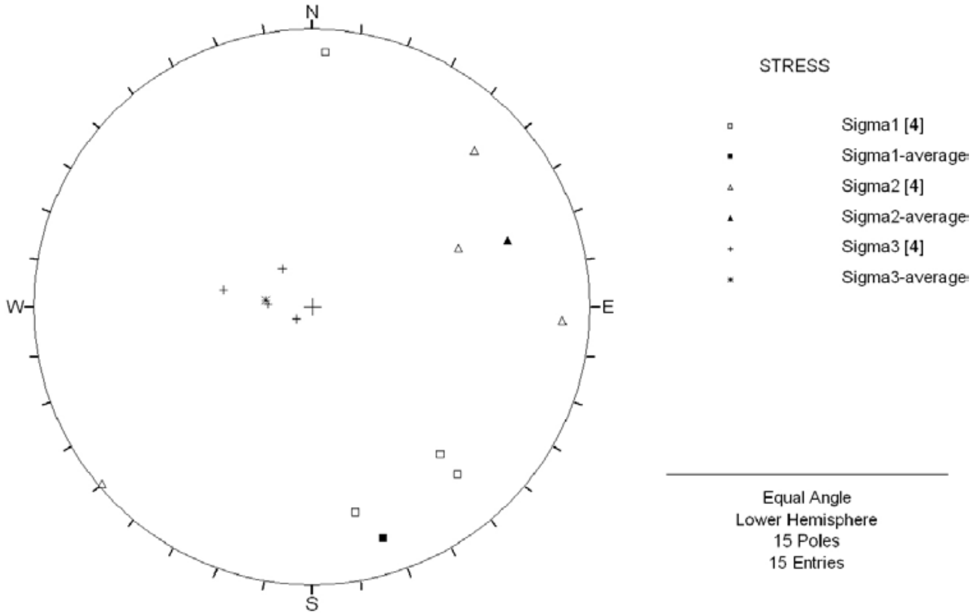

Figure 5-3. *Orientations of measured principal stresses in borehole KLX12A, Level 3, shown in a lower hemisphere projection (test nos. 3:2:1, 3:3:2, 3:4:1, and 3:6:2).*

5.5 Transient strain analysis

5.5.1 Transient strain response

Transient strain analysis was conducted for all tests with rating *a* and *b* from Levels 1, 2 and 3 (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, the agreement between measured and theoretical strains is in general fair (see Figure 5-4), but test nos. 1:5:1 and 1:8:1 shows larger deviation, see Figure 5-5. The deviation between measured and calculated strains for Level 1 can partly be attributed to the low strains recorded at the majority of the gauges during overcoring of all tests, especially for test no. 1:8:1 (generally with strain response between of 50–150 μstrain). Overall, the measured tangential strains show the best agreement with calculated strains, whereas axial and inclined strains show larger deviation.

The lowest amount of final unexplained strains at Level 1 was found for test nos. 1:4:3, 1:6:2, and 1:7:1, being between 13% and 24%. This is still judged to be relatively high. For test 1:5:1 and 1:8:1, the amount of unexplained strains is as high as 32% and 47%. For the test no 1:7:1 the lowest amount (< 10%) of unexplained stress is found for coring advances between 70 and 170 mm, but increases afterwards. The calculated value on the maximum tensile stress is moderate to relative high for tests at Level 1 (11 to 21 MPa). For test nos. 1:4:3, 1:5:1 and 1:6:2, the calculated maximal stress is between 18 to 21 MPa, which is judged to be high enough to cause tensile damage in overcore samples in the dominating rock types at the site.

The agreement between measured and calculated strains is good for tests at Level 2, as exemplified in Figure 5-6 and Figure 5-7. The amount of unexplained strain for final strain values is large for test nos. 2:1:4 and 2:2:1 (36% and 26%), and the maximum tensile stress was also high for these tests (31 and 21 MPa, respectively). These two tests were also excluded from the determination of the average stress at Level 2 (Section 5.4). For the rest of the tests at Level 2, the amount of final unexplained strains varies between 9% and 15%, which is considered low to moderate. However, the calculated value on the maximum tensile stresses for these test are high (19 to 23 MPa). For all tests at Level 2, the calculated tensile stress for each measurement is high enough to cause tensile damage in overcore samples in the dominating rock types.

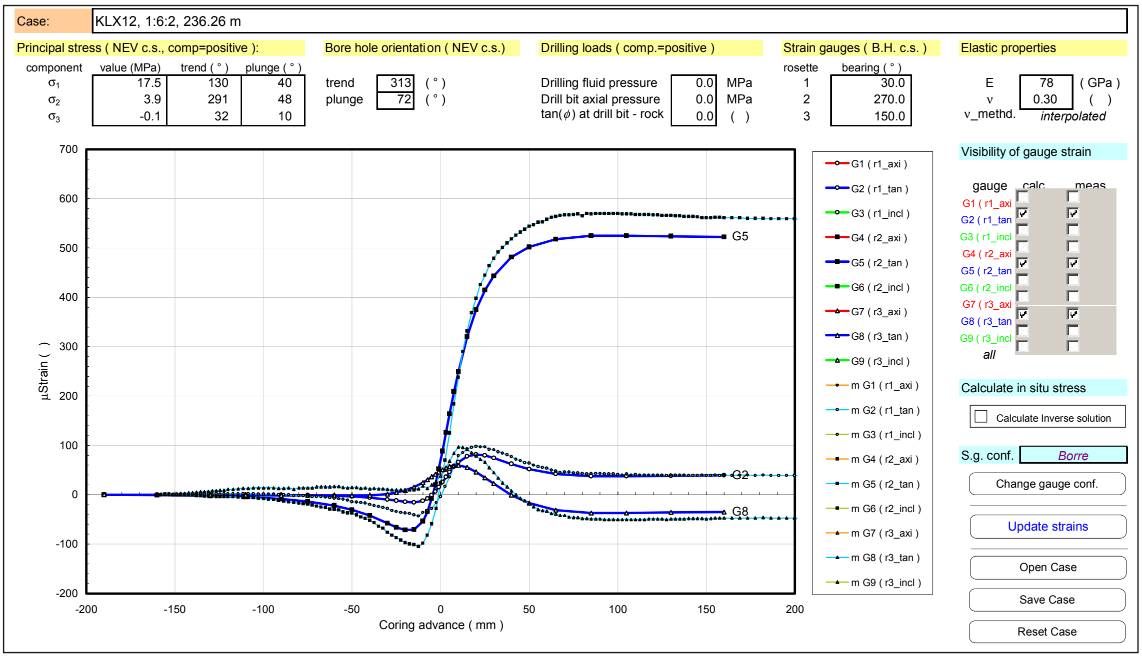

__Figure 5-4.__ Calculated vs. measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no. 1:6:2 and all tangential gauges.

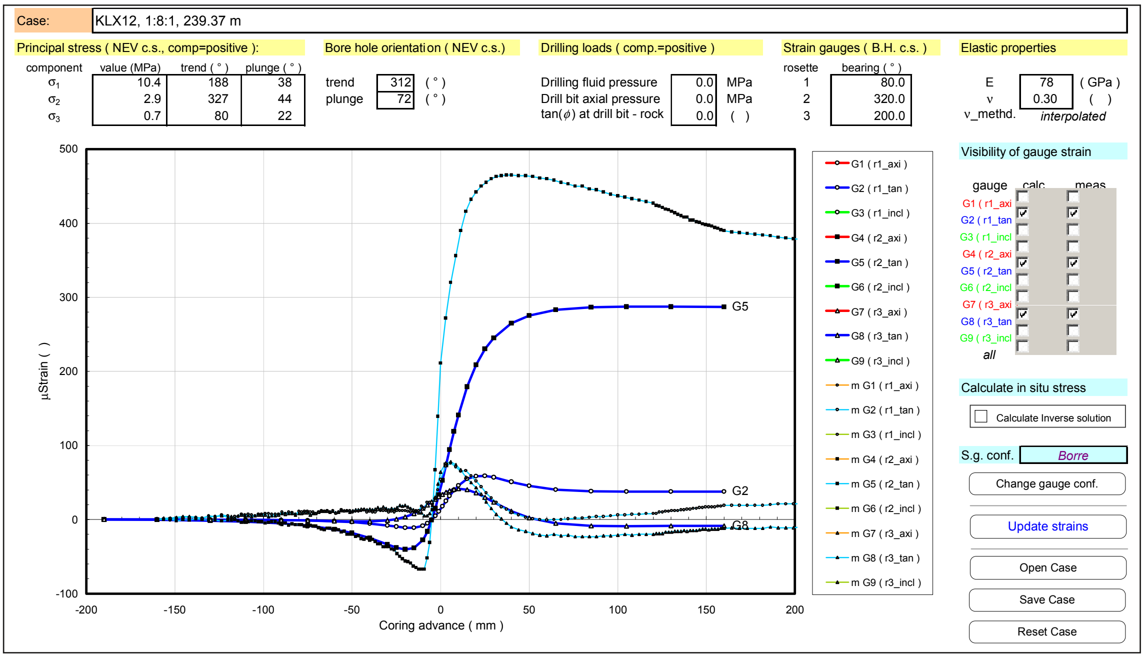

__Figure 5-5.__ Calculated vs. measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no. 1:8:1 and all tangential gauges.

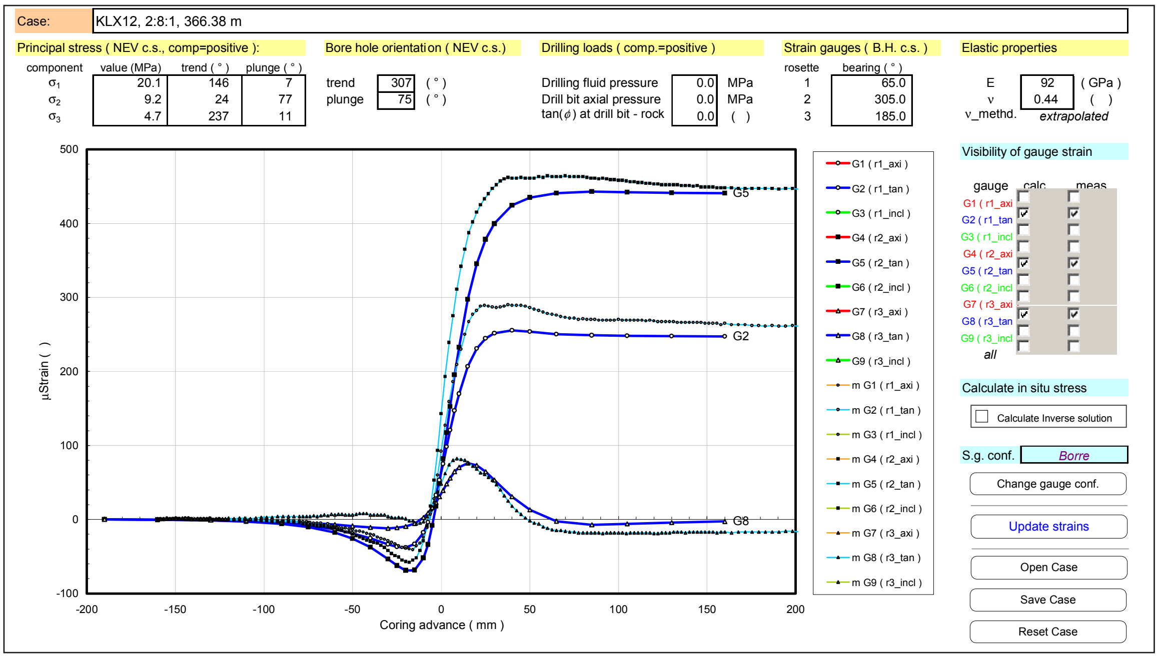

Figure 5-6. *Calculated vs. measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no. 2:8:1 and all tangential gauges.*

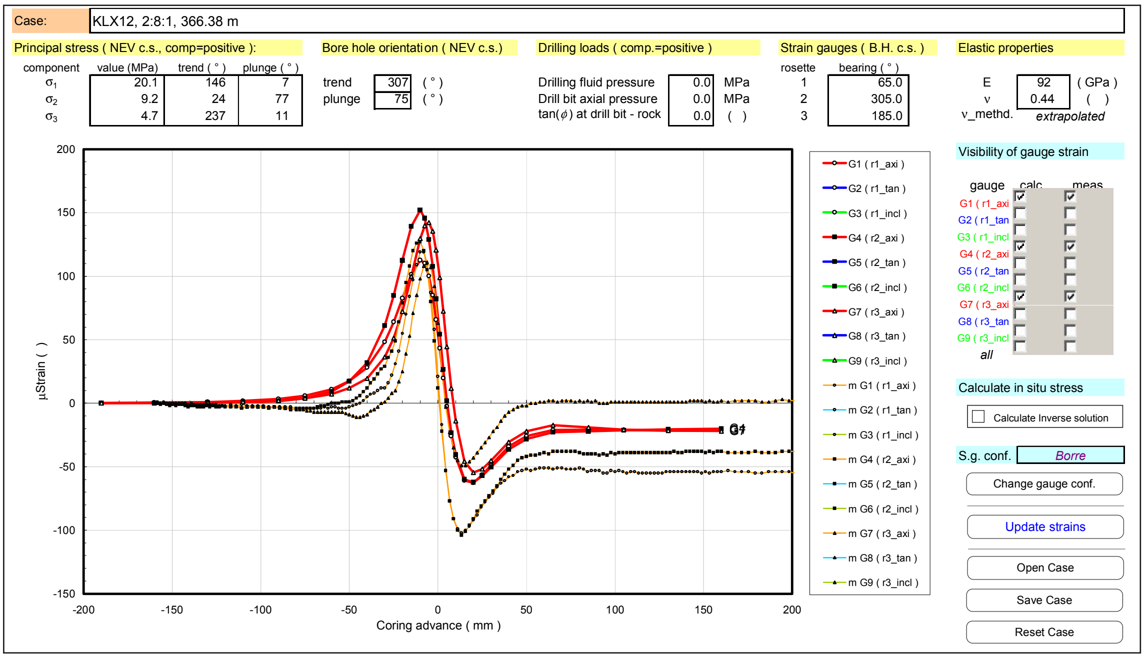

Figure 5-7. *Calculated vs. measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no. 2:8:1 and all axial gauges.*

For Level 3, the calculated transient strain response is, in general, in fair to good agreement with the measured strain response, see Figure 5-8 and Figure 5-9. The agreement is particularly good for tangential strains whereas axial and inclined strains, occasionally, shows large deviation. The amount of final unexplained strains calculated for test nos. 3:3:2 and 3:4:1 is low (11%) but test nos. 3:2:1 and 3:6:2 the amount is as high as 34% and 31%, respectively. The calculated value on the maximum tensile stress is relatively high for all tests at Level 3, ranging from 17 to 29 MPa. For at least test nos. 3:4:1 and 3:6:2, the calculated tensile stress is high enough to cause tensile damage to the rock types during overcoring.

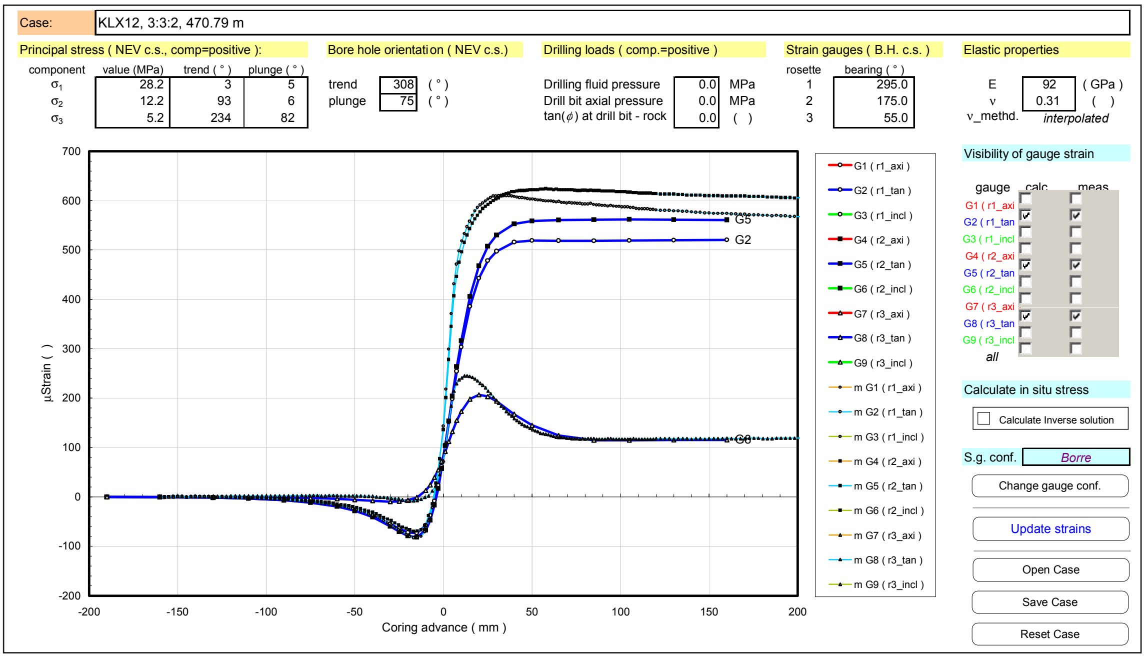

Figure 5-8. *Calculated vs. measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no. 3:3:2 and all tangential gauges.*

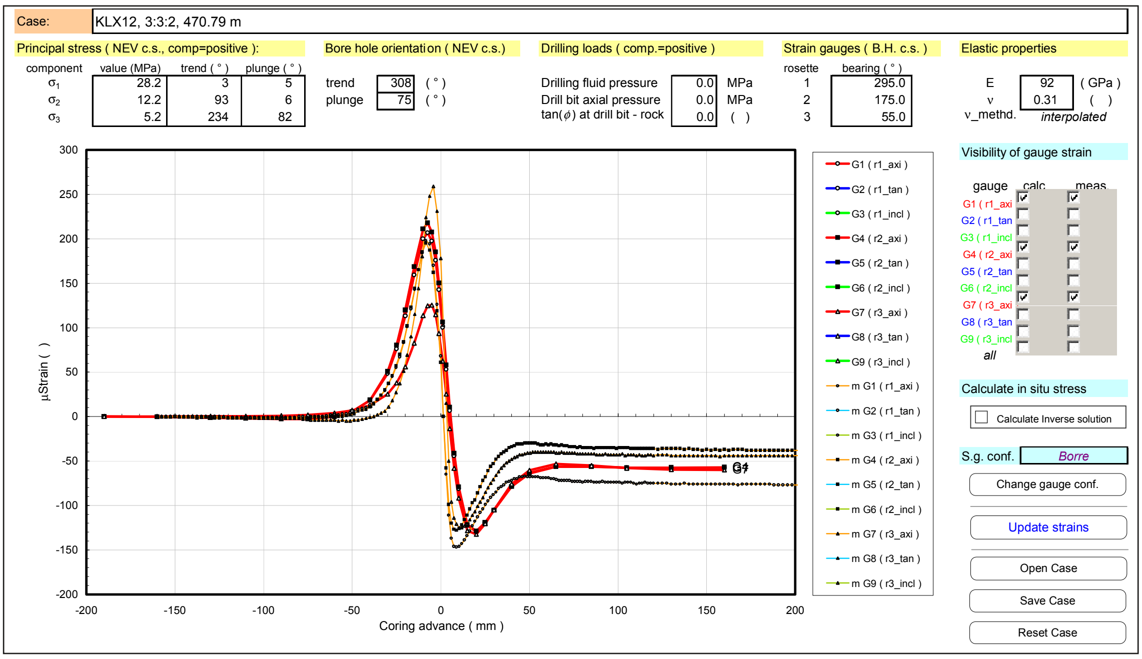

Figure 5-9. *Calculated vs. measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no. 3:3:2 and all axial gauges.*

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 measurement 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. Calculations rendering unrealistic values, for example negative stresses, have been rejected. The result from the inverse solution is further used in comparison with stresses determined using classical analysis, to indicate possible effects of microcracking or other problems during overcoring. Water pressure was not included in the analysis.

For Level 1 and 2 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 5-10 and Figure 5-11), as well as the (occasionally) low strain values. Consequently, the stress state could not be determined unambiguously for Level 1 and Level 2.

For Level 3, the above described requirements for using early strain response is, at least, partly fulfilled for one test (no. 3.3:2) for a short interval – between –50 and –60 mm coring advance (Figure 5-12). The other tests at this level resulted in tensile stresses for least one stress component using the inverse solution, except for test no. 3:2:1 which gave slightly high major horizontal stresses, and less stable values compared to test no. 3:3:2.

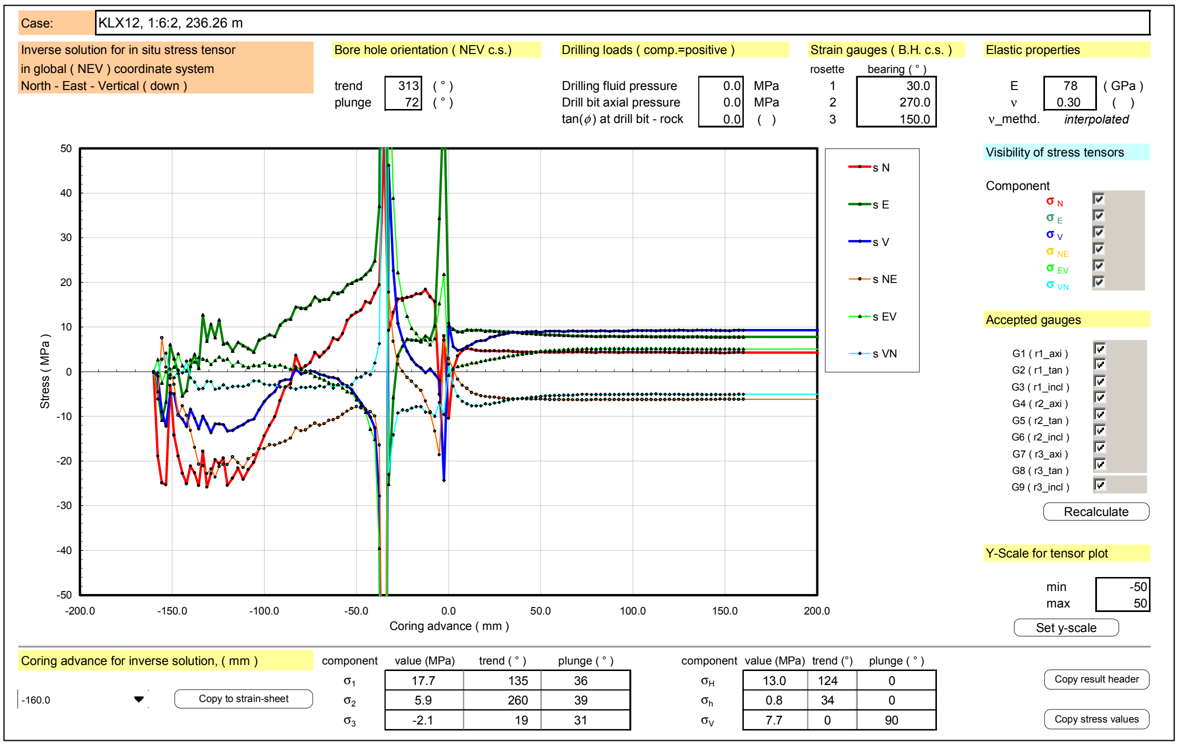

__Figure 5-10.__ Example of inverse stress solution for test no. 1:6:2 (no stable pre-overcoring values found).

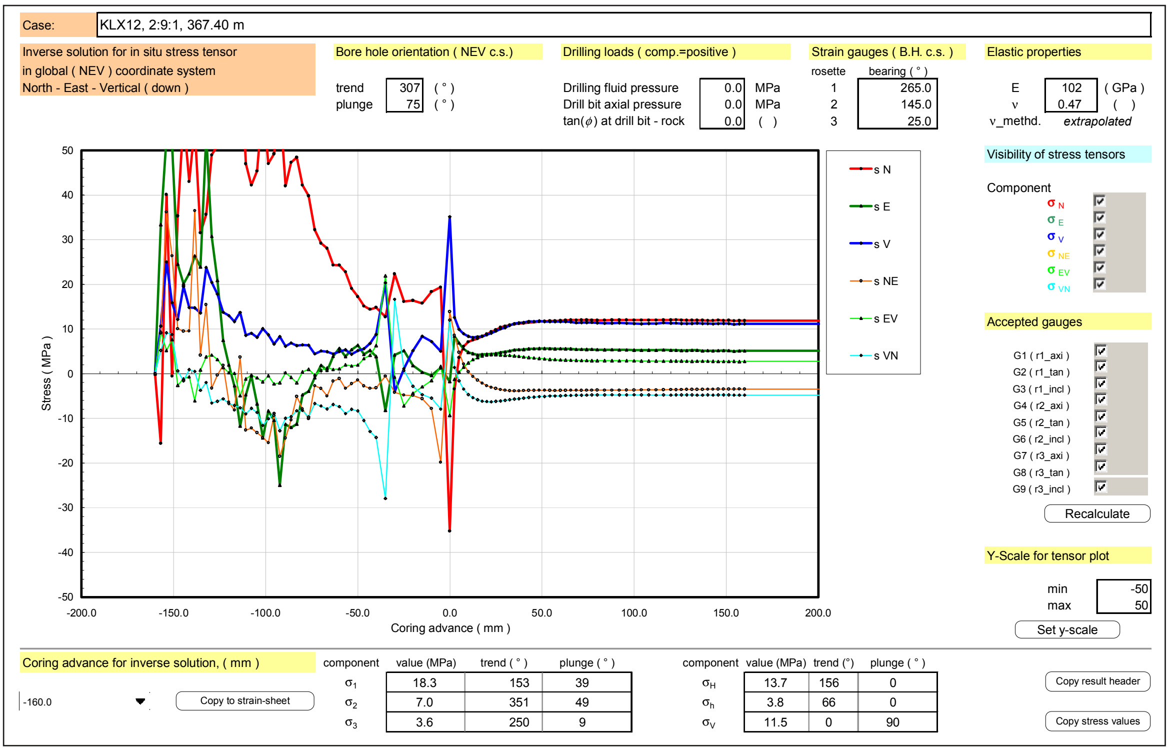

***Figure 5-11.** Example of inverse stress solution for test no. 2:9:1 (no stable pre-overcoring values found).*

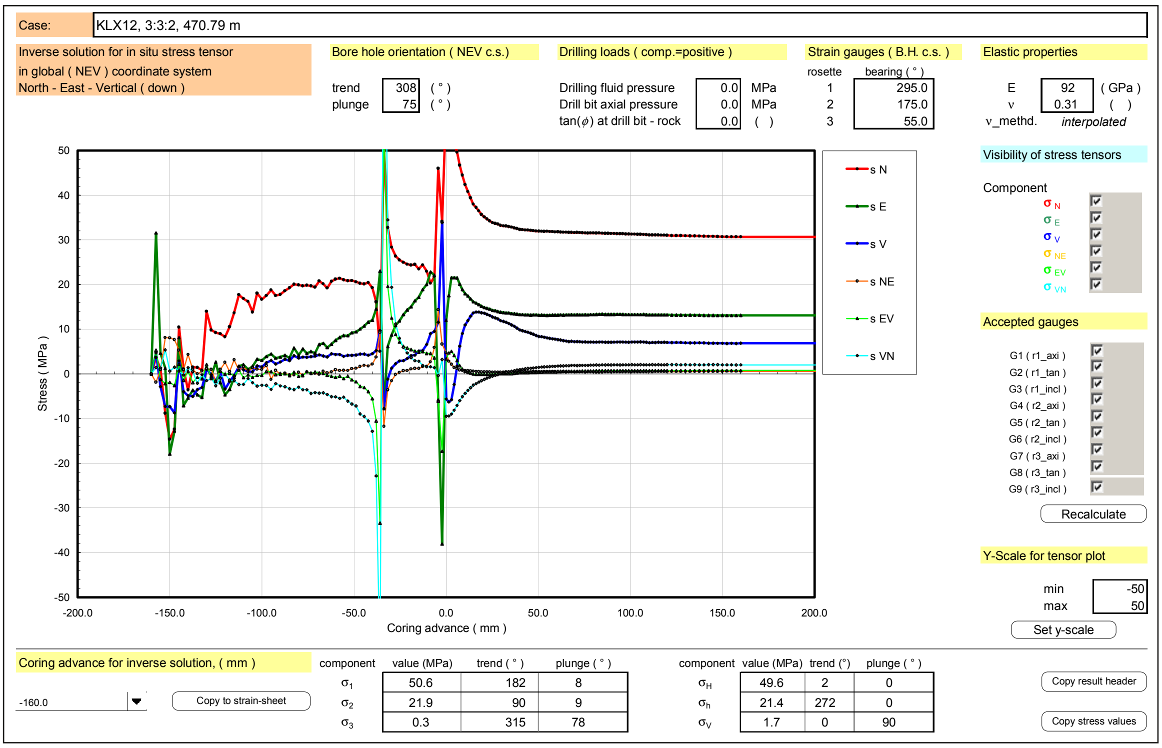

***Figure 5-12.** Example of inverse stress solution for test no. 3:3:2 (semi-stable pre-overcoring values found).*

The results from the inverse solution for test no. 3:3:2 are shown in Table 5-7 through Table 5-9 together with the results from the classical analysis. A comparison between these two stress determinations showed that the stress components determined using the inverse solution for early, pre-overcoring, strains, were somewhat lower, 67–80%, the stresses obtained from classical analysis and post-overcoring strains. The source for the deviation between measured and early-determined stresses may be due to microcracking, but this cannot be substantiated at this point. Since only one set of reliable data was obtained from the inverse solution and because these data point at similar stress state as those from the classical analysis, the inverse solution data were not included in the determination of mean stresses for Level 3.

Table 5-7. Magnitudes of principal stress as determined from transient strain analysis (inverse solution). Results from classical analysis shown for comparison.

Measurement no. (pilot hole no. *)	Coring advance [mm]	σ_1 [MPa]	σ_2 [MPa]	σ_3 [MPa]
3:3:2 (inverse)	–57.8	23.1	8.1	2.7
3:3:2 (classical)		28.2	12.2	5.2

Table 5-8. Orientations of principal stress as determined from transient strain analysis (inverse solution). Results from classical analysis shown for comparison.

Measurement no. (pilot hole no. *)	Coring advance [mm]	σ_1 Trend/plunge [°]	σ_2 Trend/plunge [°]	σ_3 Trend/plunge [°]
3:3:2 (inverse)	–57.8	184/16	274/02	011/74
3:3:2 (classical)		003/05	093/06	234/82

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

Table 5-9. Horizontal and vertical stress components as determined from transient strain analysis (inverse solution). Results from classical analysis shown for comparison.

Measurement no. (pilot hole no. *)	Coring advance [mm]	σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
3:3:2 (inverse)	–57.8	21.4	8.1	4.3	003
3:3:2 (classical)		28.1	12.1	5.4	002

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

5.6 Summary results and discussion

Confidence intervals were calculated for the measurements 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 the magnitudes and the orientations of the principal stresses at each measurement level, as well as for the horizontal and vertical stress components. In this report, only the 90%-confidence intervals are presented (Appendix H). The calculated confidence intervals were based solely on the stresses obtained from classical analysis, as presented in Table 5-4 through Table 5-6.

The stress state for Level 1 is characterised by low to moderately low stresses. The mean major principal stress is dipping 41°, oriented ESE-WNW, and with a magnitude of 14.1 MPa. The mean maximum horizontal stress component has a magnitude of 10 MPa, orientated ESE-WNW, and the vertical stress component is, on average, 8.3 MPa, which is slightly higher than the theoretical value corresponding to the overburden pressure. Since the principal stress components are relatively similar in magnitudes, the determination of reliable mean values of the principal stresses is difficult. The transient strain analysis indicated a relatively high potential for tensile stress damages for these tests. The variations between the individual measurements are quite large, with respect to both orientation and magnitude, as manifested by the calculated confidence intervals, which are large (Appendix H).

For Level 2, moderately high stresses are inferred from the measurements. The mean major principal stress has a dip of around 27°, is orientated ESE-WNW, and has a magnitude of 17.4 MPa. The mean maximum horizontal stress for Level 2 is around 15 MPa, whereas the minimum horizontal stress is only 6 MPa. The mean vertical stress (9.2 MPa) is in good agreement with the overburden pressure at these depths. The calculated confidence intervals for all three tests are fairly large in terms of magnitude and orientation but comparatively less than for the other measurement levels. This stands also for the orientation of the horizontal stress components (see Appendix H). similar to Level 1, the transient strain analysis indicated a relatively high potential for tensile stress damages for all tests. The inverse solution of transient strain analysis did not provide any additional reliable stress determinations for either Level 1 or Level 2.

Measured stresses at Level 3 were moderately high, with a sub-horizontally oriented mean major principal stress, trending SSE-NNW, and with a magnitude of 19.4 MPa. The determined vertical stress component is low (4.9 MPa) both compared to earlier measured levels and when compared with the overburden pressure at these depths. One reliable result could be obtained from the inverse solution, which showed good agreement with the classical analysis result. The transient strain analysis indicated a high potential for tensile damages of the cores during overcoring. At Level 3, the calculated confidence intervals for all five tests were larger than for the other levels in terms of magnitude variation, but similar compared to the other levels in terms of the orientation of the horizontal stress components (see Appendix H).

In conclusion, the stress state near borehole KLX12A is characterized by low to moderately high stresses at Level 1 (approximately 225 m depth) and ENE-WSW orientation of the major principal stress. This is followed by a moderate increase of the major horizontal stress component for both Level 2 (around 345 m depth) and Level 3 (at around 455 m depth). The orientation of major principal stress is the same for Level 2 as for Level 1. The vertical stress determined at the first two levels is in close agreement with the theoretical value corresponding to the overburden pressure. At Level 3 a sudden change of the measured vertical stress compared to overburden pressure was found, with markedly lower vertical stresses. At this level there is also a significant change in the dip angle and orientation of the principal stresses (compared to Level 1 and 2). However, the orientation of the horizontal stress components is only slightly different compared to the values for Levels 1 and 2.

6 References

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Appendix A

Key measurement data

Table A-1. Key measurement data for test no. 1:4:3, 231.16 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	05-11-25	15:30:00
Mixing of glue	05-11-25	16:02:00
Application of glue to gauges	05-11-25	16:08:00
Probe installation in pilot hole	05-11-25	16:13:00
Start time for dense sampling (5 s interval)	05-11-26	07:00:00
Adapter retrieved	05-11-26	07:40:00
Adapter on surface	05-11-26	07:44:00
Drill string fed down the hole	05-11-26	07:54:00
Drill string in place	05-11-26	08:34:00
Flushing start	05-11-26	08:37:00
Rotation start	05-11-26	09:03:40
Overcoring start	05-11-26	09:05:00
Overcoring 4 cm	05-11-26	09:06:30
Overcoring 8 cm	05-11-26	09:07:50
Overcoring 12 cm	05-11-26	09:09:10
Overcoring 16 cm	05-11-26	09:10:30
Overcoring 20 cm	05-11-26	09:11:50
Overcoring 24 cm	05-11-26	09:13:10
Overcoring 28 cm	05-11-26	09:14:30
Overcoring 32 cm	05-11-26	09:15:00
Overcoring stop (100 cm)	05-11-26	09:28:20
Flushing off	05-11-26	10:03:00
Core break	05-11-26	10:20:45
Core retrieval start	05-11-26	10:35:30
Core and probe on surface	05-11-26	11:08:00
End of strain registration	05-11-26	12:27:00
Calculation of strain difference: OC Start	05-11-26	09:05:00
Calculation of strain difference: OC Stop	05-11-26	09:28:20
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	2.9	
16–32 cm	3.6	
32 cm–overcoring stop	5.4	

Table A-2. Key measurement data for test no. 1:5:1, 232.40 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	05-11-26	12:00:00
Mixing of glue	05-11-26	12:35:00
Application of glue to gauges	05-11-26	12:43:00
Probe installation in pilot hole	05-11-26	12:56:00
Start time for dense sampling (5 s interval)	05-11-27	07:00:00
Adapter retrieved	05-11-27	07:37:30
Adapter on surface	05-11-27	07:42:00
Drill string fed down the hole	05-11-27	08:06:00
Drill string in place	05-11-27	08:45:00
Flushing start	05-11-27	09:39:40
Rotation start	05-11-27	10:03:35
Overcoring start	05-11-27	10:04:40
Overcoring 4 cm	05-11-27	10:06:20
Overcoring 8 cm	05-11-27	10:07:40
Overcoring 12 cm	05-11-27	10:09:05
Overcoring 16 cm	05-11-27	10:10:25
Overcoring 20 cm	05-11-27	10:11:45
Overcoring 24 cm	05-11-27	10:13:10
Overcoring 28 cm	05-11-27	10:14:25
Overcoring 32 cm	05-11-27	10:15:50
Overcoring stop (100 cm)	05-11-27	10:27:50
Flushing off	05-11-27	10:52:00
Core break	05-11-27	11:08:20
Core retrieval start	05-11-27	12:09:55
Core and probe on surface	05-11-27	12:42:00
End of strain registration	05-11-27	13:11:40
Calculation of strain difference: OC Start	05-11-27	10:04:40
Calculation of strain difference: OC Stop	05-11-27	10:50:50
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	2.8	
16–32 cm	2.9	
32 cm–overcoring stop	5.7	

Table A-3. Key measurement data for test no. 1:6:2, 236.26 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	05-11-28	13:00:00
Mixing of glue	05-11-28	13:31:00
Application of glue to gauges	05-11-28	13:34:00
Probe installation in pilot hole	05-11-28	13:46:00
Start time for dense sampling (5 s interval)	05-11-29	05:30:00
Adapter retrieved	05-11-29	06:13:00
Adapter on surface	05-11-29	06:15:00
Drill string fed down the hole	05-11-29	06:30:00
Drill string in place	05-11-29	07:22:00
Flushing start	05-11-29	07:25:00
Rotation start	05-11-29	07:42:00
Overcoring start	05-11-29	07:44:30
Overcoring 4 cm	05-11-29	07:46:00
Overcoring 8 cm	05-11-29	07:47:10
Overcoring 12 cm	05-11-29	07:48:30
Overcoring 16 cm	05-11-29	07:49:50
Overcoring 20 cm	05-11-29	07:51:10
Overcoring 24 cm	05-11-29	07:52:30
Overcoring 28 cm	05-11-29	07:53:55
Overcoring 32 cm	05-11-29	07:55:15
Overcoring stop (100 cm)	05-11-29	08:08:00
Flushing off	05-11-29	08:27:25
Core break	05-11-29	08:47:00
Core retrieval start	05-11-29	09:02:30
Core and probe on surface	05-11-29	09:42:00
End of strain registration	05-11-29	11:06:20
Calculation of strain difference: OC Start	05-11-29	07:39:30
Calculation of strain difference: OC Stop	05-11-29	08:26:15
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	3.0	
16–35cm	2.8	
35 cm–overcoring stop	5.7	

Table A-4. Key measurement data for test no. 1:7:1, 237.33 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	05-11-30	15:45:00
Mixing of glue	05-11-30	16:16:00
Application of glue to gauges	05-11-30	16:19:00
Probe installation in pilot hole	05-11-30	16:32:00
Start time for dense sampling (5 s interval)	05-12-01	06:30:00
Adapter retrieved	05-12-01	08:15:00
Adapter on surface	05-12-01	08:22:10
Drill string fed down the hole	05-12-01	08:38:30
Drill string in place	05-12-01	09:30:00
Flushing start	05-12-01	09:32:00
Rotation start	05-12-01	10:25:00
Overcoring start	05-12-01	10:30:00
Overcoring 4 cm	05-12-01	10:31:25
Overcoring 8 cm	05-12-01	10:32:45
Overcoring 12 cm	05-12-01	10:33:50
Overcoring 16 cm	05-12-01	10:34:45
Overcoring 20 cm	05-12-01	10:35:40
Overcoring 24 cm	05-12-01	10:36:45
Overcoring 28 cm	05-12-01	10:37:45
Overcoring 32 cm	05-12-01	10:38:50
Overcoring stop (98 cm)	05-12-01	10:52:30
Flushing off	05-12-01	11:08:00
Core break	05-12-01	11:23:00
Core retrieval start	05-12-01	13:07:00
Core and probe on surface	05-12-01	13:50:00
End of strain registration	05-12-01	15:04:20
Calculation of strain difference: OC Start	05-12-01	10:30:00
Calculation of strain difference: OC Stop	05-12-01	10:36:30

Overcoring advance	Overcoring rate [cm/min]
0–16 cm	3.4
16–32 cm	4.0
32 cm–overcoring stop	5.0

Table A-5. Key measurement data for test no. 1:8:1, 239.37 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	05-12-02	16:30:00
Mixing of glue	05-12-02	16:44:00
Application of glue to gauges	05-12-02	16:46:00
Probe installation in pilot hole	05-12-02	16:59:00
Start time for dense sampling (5 s interval)	05-12-03	07:30:00
Adapter retrieved	05-12-03	08:50:50
Adapter on surface	05-12-03	08:56:30
Drill string fed down the hole	05-12-03	09:05:00
Drill string in place	05-12-03	09:52:00
Flushing start	05-12-03	09:57:00
Rotation start	05-12-03	10:26:00
Overcoring start	05-12-03	10:28:35
Overcoring 4 cm	05-12-03	10:29:30
Overcoring 8 cm	05-12-03	10:31:15
Overcoring 12 cm	05-12-03	10:33:20
Overcoring 16 cm	05-12-03	10:35:30
Overcoring 20 cm	05-12-03	10:36:40
Overcoring 24 cm	05-12-03	10:37:30
Overcoring 28 cm	05-12-03	10:38:20
Overcoring 32 cm	05-12-03	10:40:15
Overcoring stop (107 cm)	05-12-03	10:54:35
Flushing off	05-12-03	10:55:00
Core break	05-12-03	11:25:50
Core retrieval start	05-12-03	13:00:00
Core and probe on surface	05-12-03	13:35:00
End of strain registration	05-12-03	13:38:00
Calculation of strain difference: OC Start	05-12-03	10:18:30
Calculation of strain difference: OC Stop	05-12-03	10:53:35

Overcoring advance	Overcoring rate [cm/min]
0–16 cm	2.3
16–32 cm	2.8
32 cm–overcoring stop	5.4

Table A-6. Key measurement data for test no. 2:1:4, 350.10 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	05-12-16	14:45:00
Mixing of glue	05-12-16	15:10:00
Application of glue to gauges	05-12-16	15:13:00
Probe installation in pilot hole	05-12-16	15:28:00
Start time for dense sampling (5 s interval)	05-12-17	07:00:00
Adapter retrieved	05-12-17	07:45:00
Adapter on surface	05-12-17	07:53:00
Drill string fed down the hole	05-12-17	08:08:00
Drill string in place	05-12-17	09:10:00
Flushing start	05-12-17	09:20:00
Rotation start	05-12-17	09:41:00
Overcoring start	05-12-17	09:52:05
Overcoring 4 cm	05-12-17	09:53:35
Overcoring 8 cm	05-12-17	09:54:50
Overcoring 12 cm	05-12-17	09:57:00
Overcoring 16 cm	05-12-17	09:59:15
Overcoring 20 cm	05-12-17	10:01:15
Overcoring 24 cm	05-12-17	10:02:40
Overcoring 28 cm	05-12-17	10:04:00
Overcoring 32 cm	05-12-17	10:05:20
Overcoring stop (100 cm)	05-12-17	10:19:15
Flushing off	05-12-17	10:35:00
Core break	05-12-17	10:50:50
Core retrieval start	05-12-17	11:05:00
Core and probe on surface	05-12-17	12:01:00
End of strain registration	05-12-17	12:29:20
Calculation of strain difference: OC Start	05-12-17	09:52:05
Calculation of strain difference: OC Stop	05-12-17	10:34:45
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	2.3	
16–32 cm	2.7	
32 cm–overcoring stop	5.6	

Table A-7. Key measurement data for test no. 2:2:1, 351.28 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	05-12-18	13:15:00
Mixing of glue	05-12-18	13:52:00
Application of glue to gauges	05-12-18	13:56:00
Probe installation in pilot hole	05-12-18	14:10:00
Start time for dense sampling (5 s interval)	05-12-19	05:15:00
Adapter retrieved	05-12-19	06:05:00
Adapter on surface	05-12-19	06:10:00
Drill string fed down the hole	05-12-19	06:15:00
Drill string in place	05-12-19	07:20:00
Flushing start	05-12-19	07:40:00
Rotation start	05-12-19	07:54:15
Overcoring start	05-12-19	07:57:15
Overcoring 4 cm	05-12-19	07:58:20
Overcoring 8 cm	05-12-19	07:59:55
Overcoring 12 cm	05-12-19	08:01:50
Overcoring 16 cm	05-12-19	08:04:05
Overcoring 20 cm	05-12-19	08:06:25
Overcoring 24 cm	05-12-19	08:08:35
Overcoring 28 cm	05-12-19	08:11:00
Overcoring 32 cm	05-12-19	08:13:10
Overcoring stop (100 cm)	05-12-19	08:25:30
Flushing off	05-12-19	08:43:20
Core break	05-12-19	08:59:00
Core retrieval start	05-12-19	09:15:20
Core and probe on surface	05-12-19	10:09:05
End of strain registration	05-12-19	10:56:35
Calculation of strain difference: OC Start	05-12-19	07:57:15
Calculation of strain difference: OC Stop	05-12-19	08:25:30
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	2.3	
16–34 cm	1.8	
34 cm–overcoring stop	5.7	

Table A-8. Key measurement data for test no. 2:5:2, 359.58 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	06-01-07	12:00:00
Mixing of glue	06-01-07	12:16:00
Application of glue to gauges	06-01-07	12:20:00
Probe installation in pilot hole	06-01-07	12:35:00
Start time for dense sampling (5 s interval)	06-01-08	07:00:00
Adapter retrieved	06-01-08	07:45:00
Adapter on surface	06-01-08	07:52:00
Drill string fed down the hole	06-01-08	08:10:00
Drill string in place	06-01-08	09:25:00
Flushing start	06-01-08	09:30:00
Rotation start	06-01-08	09:57:00
Overcoring start	06-01-08	10:01:50
Overcoring 4 cm	06-01-08	10:02:55
Overcoring 8 cm	06-01-08	10:04:05
Overcoring 12 cm	06-01-08	10:05:25
Overcoring 16 cm	06-01-08	10:06:40
Overcoring 20 cm	06-01-08	10:07:50
Overcoring 24 cm	06-01-08	10:08:50
Overcoring 28 cm	06-01-08	10:09:55
Overcoring 32 cm	06-01-08	10:11:00
Overcoring stop (101 cm)	06-01-08	10:30:15
Flushing off	06-01-08	10:47:40
Core break	06-01-08	10:57:30
Core retrieval start	06-01-08	11:08:15
Core and probe on surface	06-01-08	12:10:00
End of strain registration	06-01-08	12:44:50
Calculation of strain difference: OC Start	06-01-08	09:53:50
Calculation of strain difference: OC Stop	06-01-08	10:46:15
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	3.2	
16–32 cm	3.4	
32 cm–overcoring stop	3.6	

Table A-9. Key measurement data for test no. 2:8:1, 366.38 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	06-01-12	18:30:00
Mixing of glue	06-01-12	20:49:00
Application of glue to gauges	06-01-12	20:59:00
Probe installation in pilot hole	06-01-12	21:15:00
Start time for dense sampling (5 s interval)	06-01-13	07:00:00
Adapter retrieved	06-01-13	08:21:00
Adapter on surface	06-01-13	08:30:00
Drill string fed down the hole	06-01-13	08:35:00
Drill string in place	06-01-13	09:30:00
Flushing start	06-01-13	09:54:00
Rotation start	06-01-13	10:20:00
Overcoring start	06-01-13	10:23:30
Overcoring 4 cm	06-01-13	10:25:25
Overcoring 8 cm	06-01-13	10:26:30
Overcoring 12 cm	06-01-13	10:28:10
Overcoring 16 cm	06-01-13	10:29:50
Overcoring 20 cm	06-01-13	10:31:20
Overcoring 24 cm	06-01-13	10:32:40
Overcoring 28 cm	06-01-13	10:34:10
Overcoring 32 cm	06-01-13	10:35:40
Overcoring stop (100 cm)	06-01-13	10:49:30
Flushing off	06-01-13	11:06:00
Core break	06-01-13	11:22:10
Core retrieval start	06-01-13	11:36:30
Core and probe on surface	06-01-13	12:56:00
End of strain registration	06-01-13	13:15:00
Calculation of strain difference: OC Start	06-01-13	10:23:30
Calculation of strain difference: OC Stop	06-01-13	10:49:30
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	2.5	
16–45 cm	3.3	
45 cm–overcoring stop	5.0	

Table A-10. Key measurement data for test no. 2:9:1, 367.40 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	06-01-14	16:45:00
Mixing of glue	06-01-14	17:13:00
Application of glue to gauges	06-01-14	17:20:00
Probe installation in pilot hole	06-01-14	17:39:00
Start time for dense sampling (5 s interval)	06-01-15	07:00:00
Adapter retrieved	06-01-15	07:55:00
Adapter on surface	06-01-15	08:03:00
Drill string fed down the hole	06-01-15	08:18:00
Drill string in place	06-01-15	09:50:00
Flushing start	06-01-15	09:53:00
Rotation start	06-01-15	10:06:50
Overcoring start	06-01-15	10:09:30
Overcoring 4 cm	06-01-15	10:10:35
Overcoring 8 cm	06-01-15	10:11:40
Overcoring 12 cm	06-01-15	10:12:40
Overcoring 16 cm	06-01-15	10:13:20
Overcoring 20 cm	06-01-15	10:14:40
Overcoring 24 cm	06-01-15	10:15:50
Overcoring 28 cm	06-01-15	10:16:40
Overcoring 32 cm	06-01-15	10:17:50
Overcoring stop (107 cm)	06-01-15	10:29:40
Flushing off	06-01-15	10:45:00
Core break	06-01-15	11:03:40
Core retrieval start	06-01-15	11:19:00
Core and probe on surface	06-01-15	12:15:00
End of strain registration	06-01-15	12:31:00
Calculation of strain difference: OC Start	06-01-15	10:09:30
Calculation of strain difference: OC Stop	06-01-15	10:29:40
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	2.5	
16–32 cm	3.7	
32 cm–overcoring stop	6.3	

Table A-11. Key measurement data for test no. 3:2:1, 468.48 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	06-01-27	15:44:00
Mixing of glue	06-01-27	16:14:00
Application of glue to gauges	06-01-27	16:18:00
Probe installation in pilot hole	06-01-27	16:35:00
Start time for dense sampling (5 s interval)	06-01-28	07:00:00
Adapter retrieved	06-01-28	07:35:10
Adapter on surface	06-01-28	07:44:00
Drill string fed down the hole	06-01-28	07:52:30
Drill string in place	06-01-28	09:41:40
Flushing start	06-01-28	09:45:00
Rotation start	06-01-28	10:00:50
Overcoring start	06-01-28	10:03:40
Overcoring 4 cm	06-01-28	10:05:00
Overcoring 8 cm	06-01-28	10:06:20
Overcoring 12 cm	06-01-28	10:07:40
Overcoring 16 cm	06-01-28	10:09:05
Overcoring 20 cm	06-01-28	10:10:25
Overcoring 24 cm	06-01-28	10:11:45
Overcoring 28 cm	06-01-28	10:13:10
Overcoring 32 cm	06-01-28	10:14:30
Overcoring stop (100 cm)	06-01-28	10:30:35
Flushing off	06-01-28	10:53:45
Core break	06-01-28	11:09:40
Core retrieval start	06-01-28	12:00:40
Core and probe on surface	06-01-28	13:10:00
End of strain registration	06-01-28	13:34:00
Calculation of strain difference: OC Start	06-01-28	09:57:40
Calculation of strain difference: OC Stop	06-01-28	10:53:00
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	2.9	
16–46 cm	3.1	
46 cm–overcoring stop	4.6	

Table A-12. Key measurement data for test no. 3:3:2, 470.79 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	06-01-29	15:49:00
Mixing of glue	06-01-29	16:28:00
Application of glue to gauges	06-01-29	16:32:00
Probe installation in pilot hole	06-01-29	16:48:00
Start time for dense sampling (5 s interval)	06-01-30	07:00:00
Adapter retrieved	06-01-30	07:33:10
Adapter on surface	06-01-30	07:39:00
Drill string fed down the hole	06-01-30	07:50:00
Drill string in place	06-01-30	09:37:00
Flushing start	06-01-30	09:40:00
Rotation start	06-01-30	09:56:15
Overcoring start	06-01-30	09:59:05
Overcoring 4 cm	06-01-30	10:00:25
Overcoring 8 cm	06-01-30	10:01:45
Overcoring 12 cm	06-01-30	10:03:15
Overcoring 16 cm	06-01-30	10:04:50
Overcoring 20 cm	06-01-30	10:07:05
Overcoring 24 cm	06-01-30	10:09:20
Overcoring 28 cm	06-01-30	10:11:25
Overcoring 32 cm	06-01-30	10:12:45
Overcoring stop (102 cm)	06-01-30	10:28:55
Flushing off	06-01-30	10:52:40
Core break	06-01-30	11:08:50
Core retrieval start	06-01-30	12:05:00
Core and probe on surface	06-01-30	13:18:00
End of strain registration	06-01-30	13:38:00
Calculation of strain difference: OC Start	06-01-30	09:59:05
Calculation of strain difference: OC Stop	06-01-30	10:49:55
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	3.6	
16–35 cm	4.5	
35 cm–overcoring stop	7.4	

Table A-13. Key measurement data for test no. 3:4:1, 471.92 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	06-01-31	14:33:00
Mixing of glue	06-01-31	14:58:15
Application of glue to gauges	06-01-31	15:02:00
Probe installation in pilot hole	06-01-31	15:19:45
Start time for dense sampling (5 s interval)	06-02-01	07:00:00
Adapter retrieved	06-02-01	07:45:20
Adapter on surface	06-02-01	07:53:40
Drill string fed down the hole	06-02-01	08:14:00
Drill string in place	06-02-01	09:45:50
Flushing start	06-02-01	10:13:15
Rotation start	06-02-01	10:33:45
Overcoring start	06-02-01	10:38:15
Overcoring 4 cm	06-02-01	10:39:05
Overcoring 8 cm	06-02-01	10:40:20
Overcoring 12 cm	06-02-01	10:41:45
Overcoring 16 cm	06-02-01	10:42:40
Overcoring 20 cm	06-02-01	10:43:20
Overcoring 24 cm	06-02-01	10:44:10
Overcoring 28 cm	06-02-01	10:45:10
Overcoring 32 cm	06-02-01	10:46:10
Overcoring stop (100 cm)	06-02-01	10:56:05
Flushing off	06-02-01	11:12:00
Core break	06-02-01	11:27:40
Core retrieval start	06-02-01	11:44:00
Core and probe on surface	06-02-01	14:12:00
End of strain registration	06-02-01	14:29:55
Calculation of strain difference: OC Start	06-02-01	10:15:00
Calculation of strain difference: OC Stop	06-02-01	11:11:00
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	3.6	
16–46 cm	4.6	
46 cm–overcoring stop	7.1	

Table A-14. Key measurement data for test no. 3:6:2, 475.41 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	06-02-04	16:51:00
Mixing of glue	06-02-04	17:09:00
Application of glue to gauges	06-02-04	17:14:00
Probe installation in pilot hole	06-02-04	17:29:00
Start time for dense sampling (5 s interval)	06-02-05	07:00:00
Adapter retrieved	06-02-05	07:37:15
Adapter on surface	06-02-05	07:44:35
Drill string fed down the hole	06-02-05	08:14:00
Drill string in place	06-02-05	09:40:00
Flushing start	06-02-05	10:54:40
Rotation start	06-02-05	11:28:40
Overcoring start	06-02-05	11:31:30
Overcoring 4 cm	06-02-05	11:32:10
Overcoring 8 cm	06-02-05	11:32:45
Overcoring 12 cm	06-02-05	11:33:25
Overcoring 16 cm	06-02-05	11:34:30
Overcoring 20 cm	06-02-05	11:36:10
Overcoring 24 cm	06-02-05	11:37:00
Overcoring 28 cm	06-02-05	11:37:45
Overcoring 32 cm	06-02-05	11:38:40
Overcoring stop (102 cm)	06-02-05	11:46:40
Flushing off	06-02-05	12:02:00
Core break	06-02-05	12:17:45
Core retrieval start	06-02-05	13:22:00
Core and probe on surface	06-02-05	14:47:00
End of strain registration	06-02-05	15:11:45
Calculation of strain difference: OC Start	06-02-05	10:44:30
Calculation of strain difference: OC Stop	06-02-05	12:16:10
Overcoring advance	**Overcoring rate [cm/min]**	
0–16 cm	5.3	
16–40 cm	4.4	
40 cm–overcoring stop	10.0	

Appendix B

Overcoring strain data and graphs

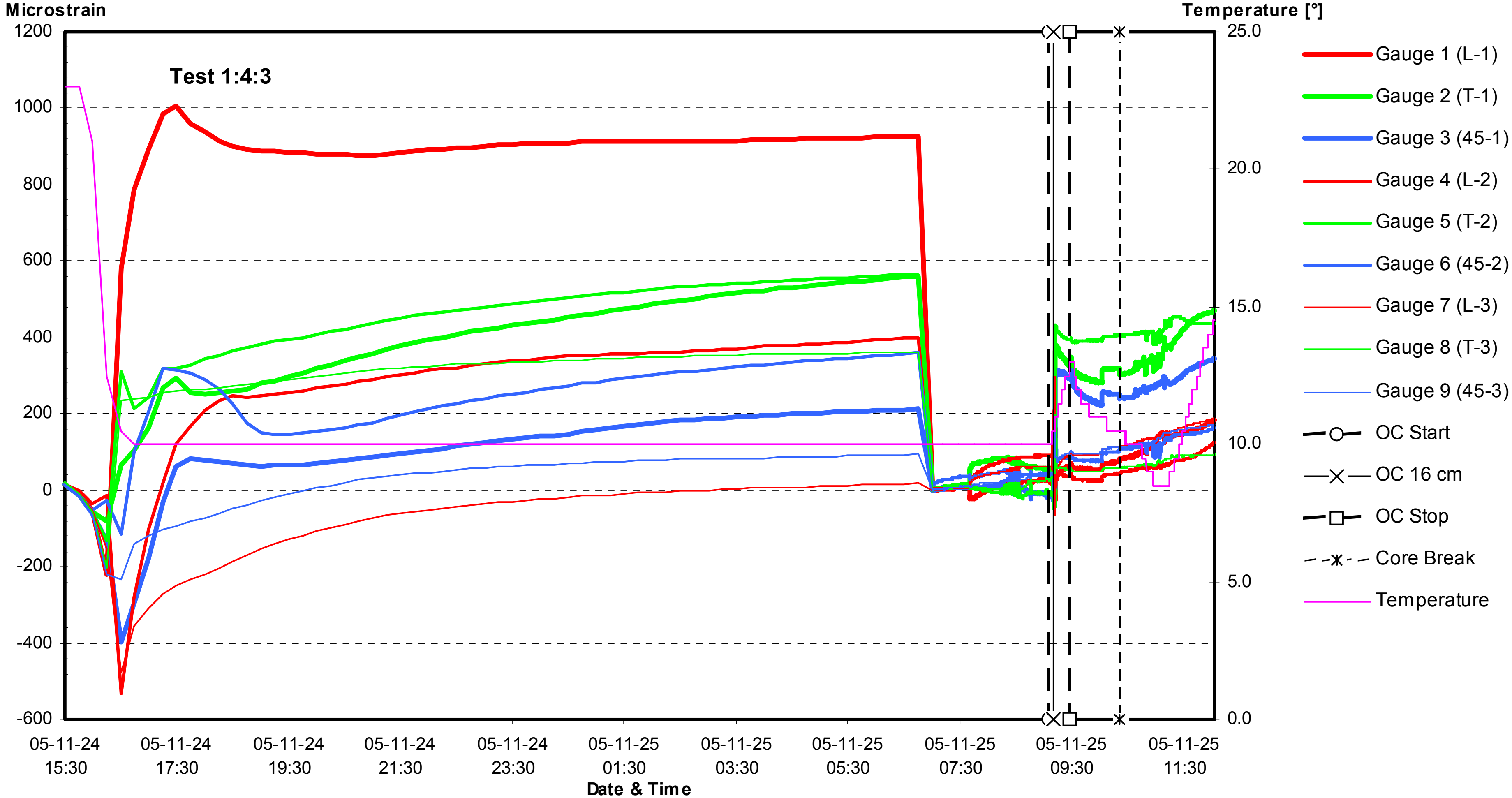


Figure B-1. All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:4:3, 231.36 m borehole length.

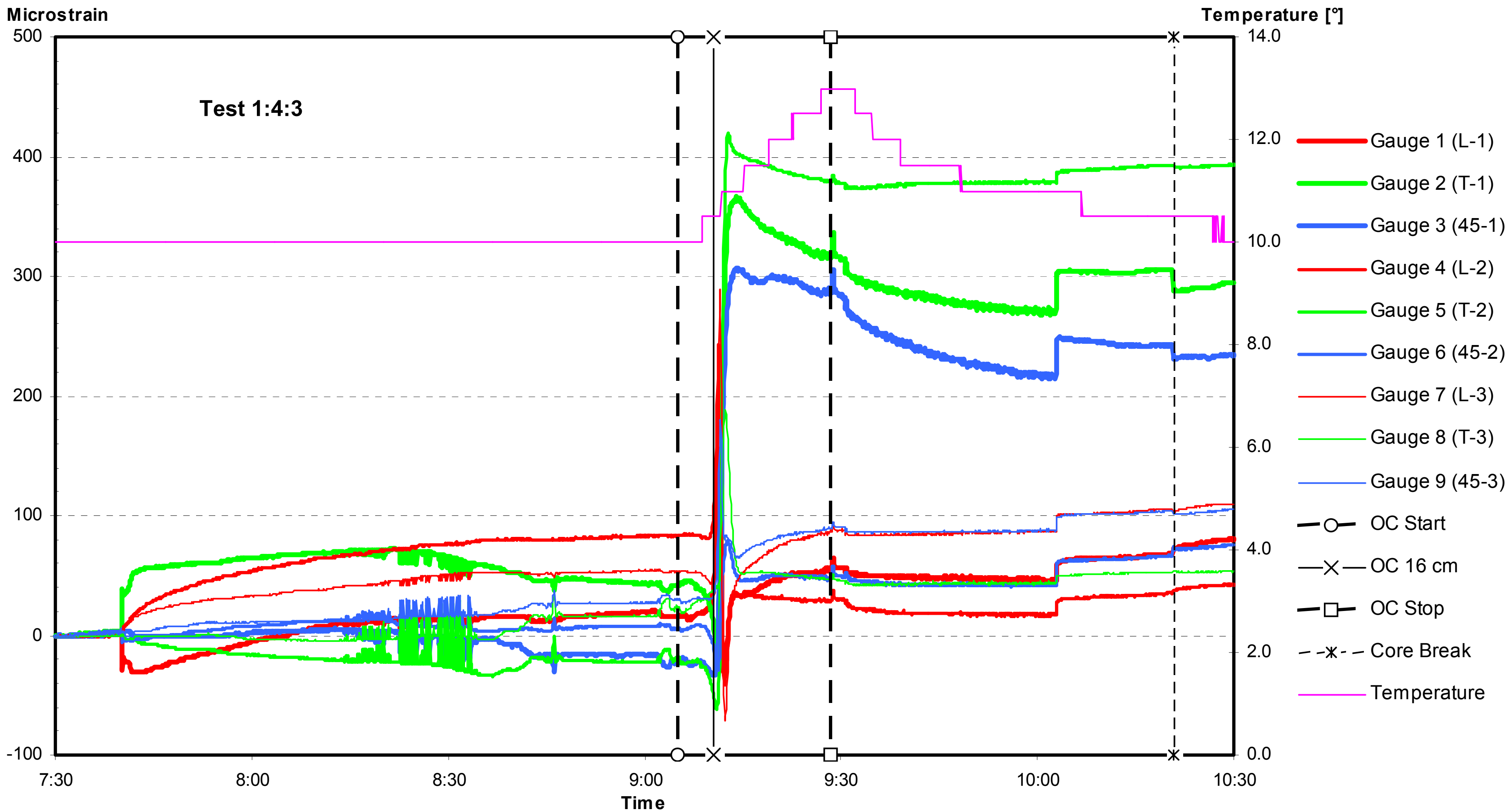


Figure B-2. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:4:3, 231.36 m borehole length. Strain values reset to zero at 07:30.*

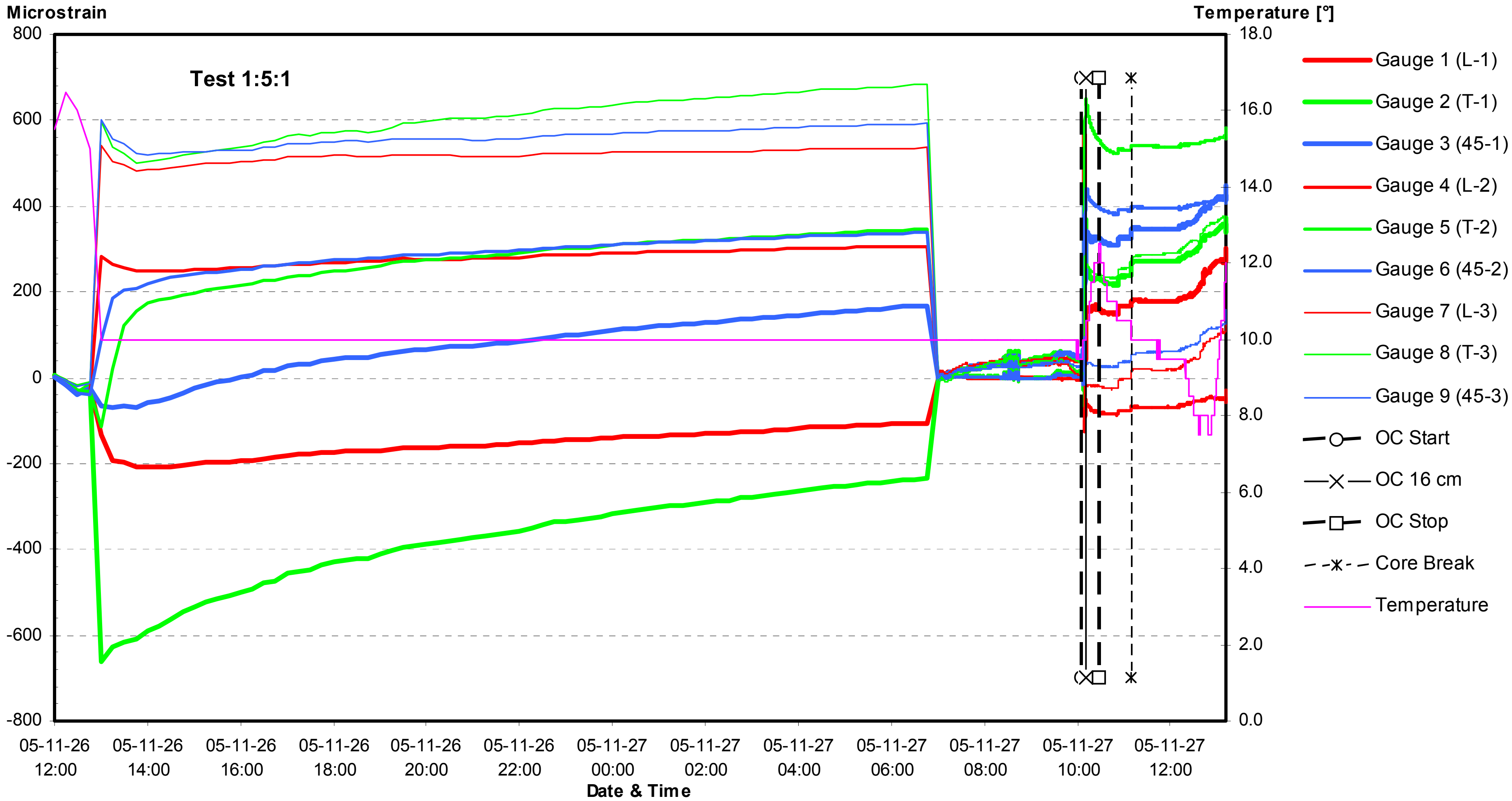


Figure B-3. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:5:1, 232.40 m borehole length.*

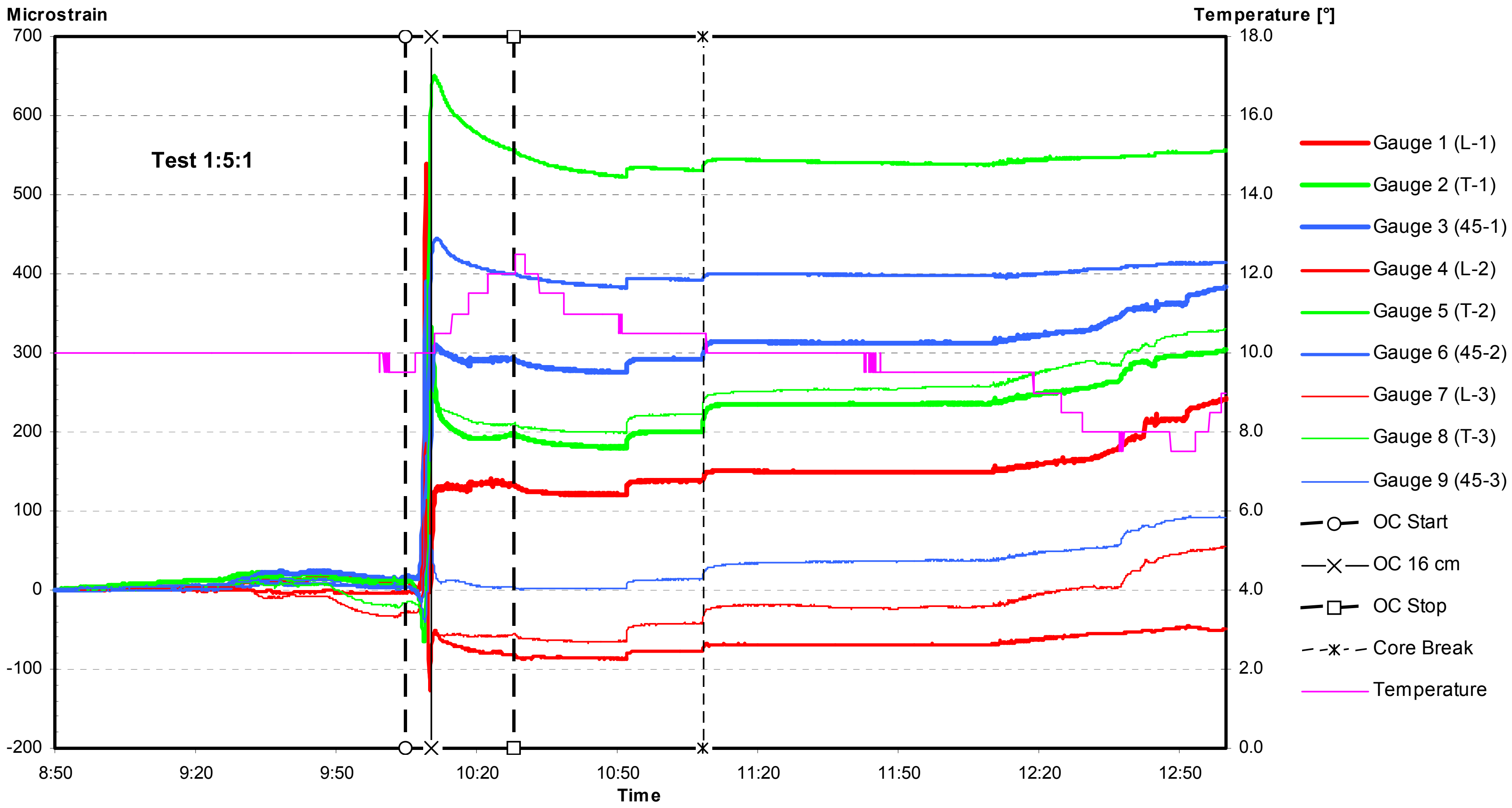


Figure B-4. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:5:1, 232.40 m borehole length. Strain values reset to zero at 08:50.*

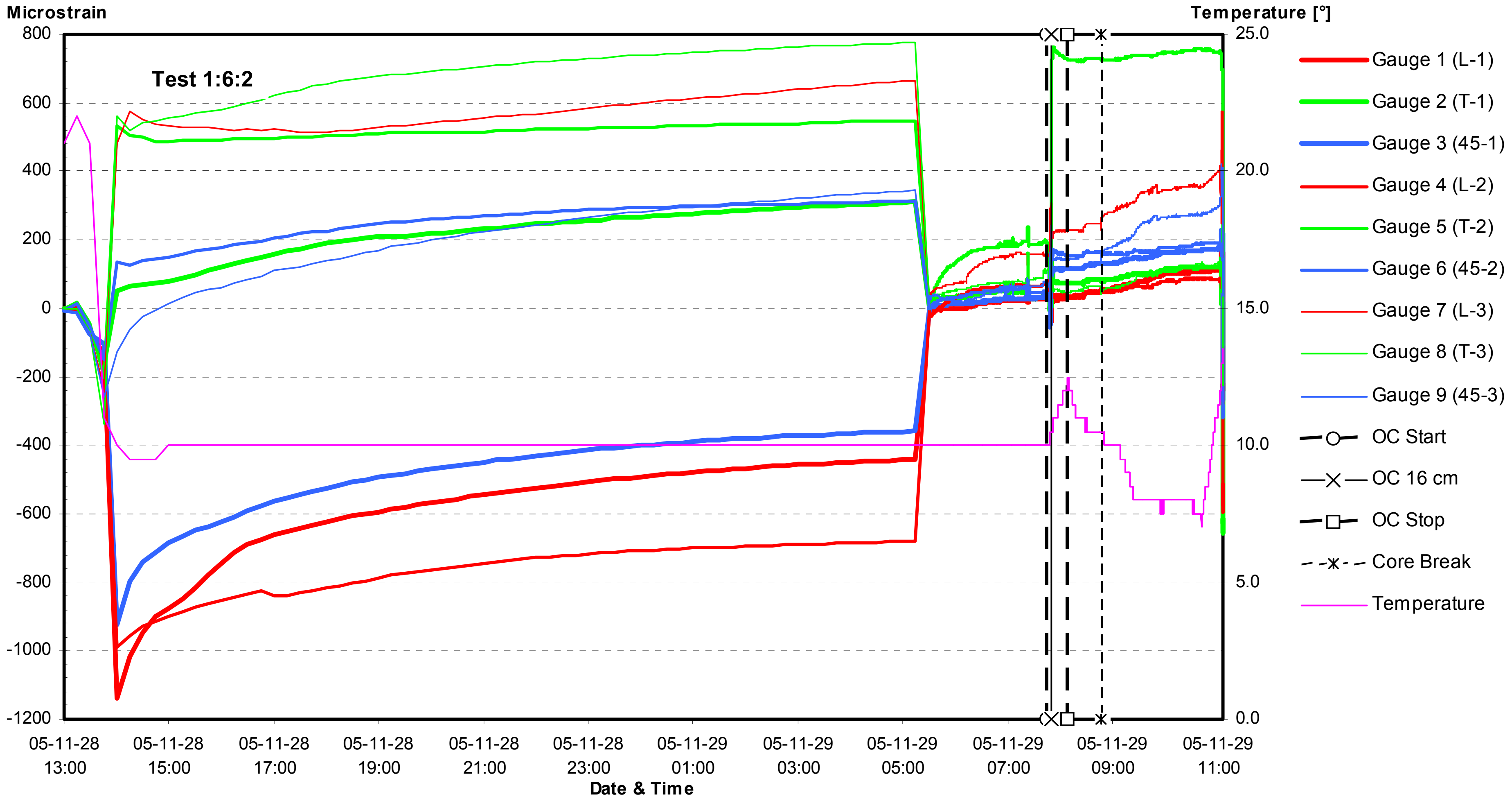


Figure B-5. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:6:2, 236.26 m borehole length.*

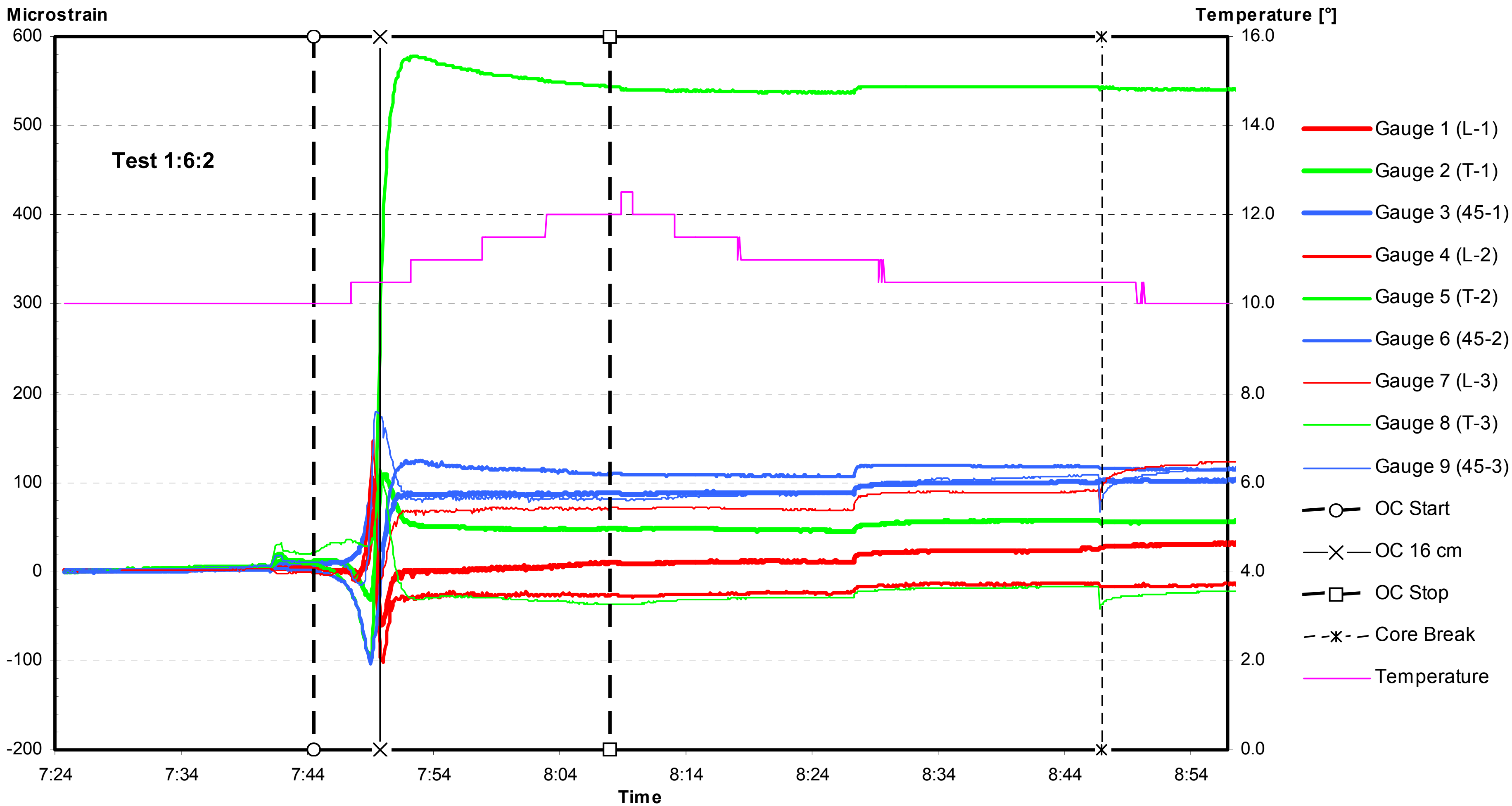


Figure B-6. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:6:2, 236.26 m borehole length. Strain values reset to zero at 07:24.*

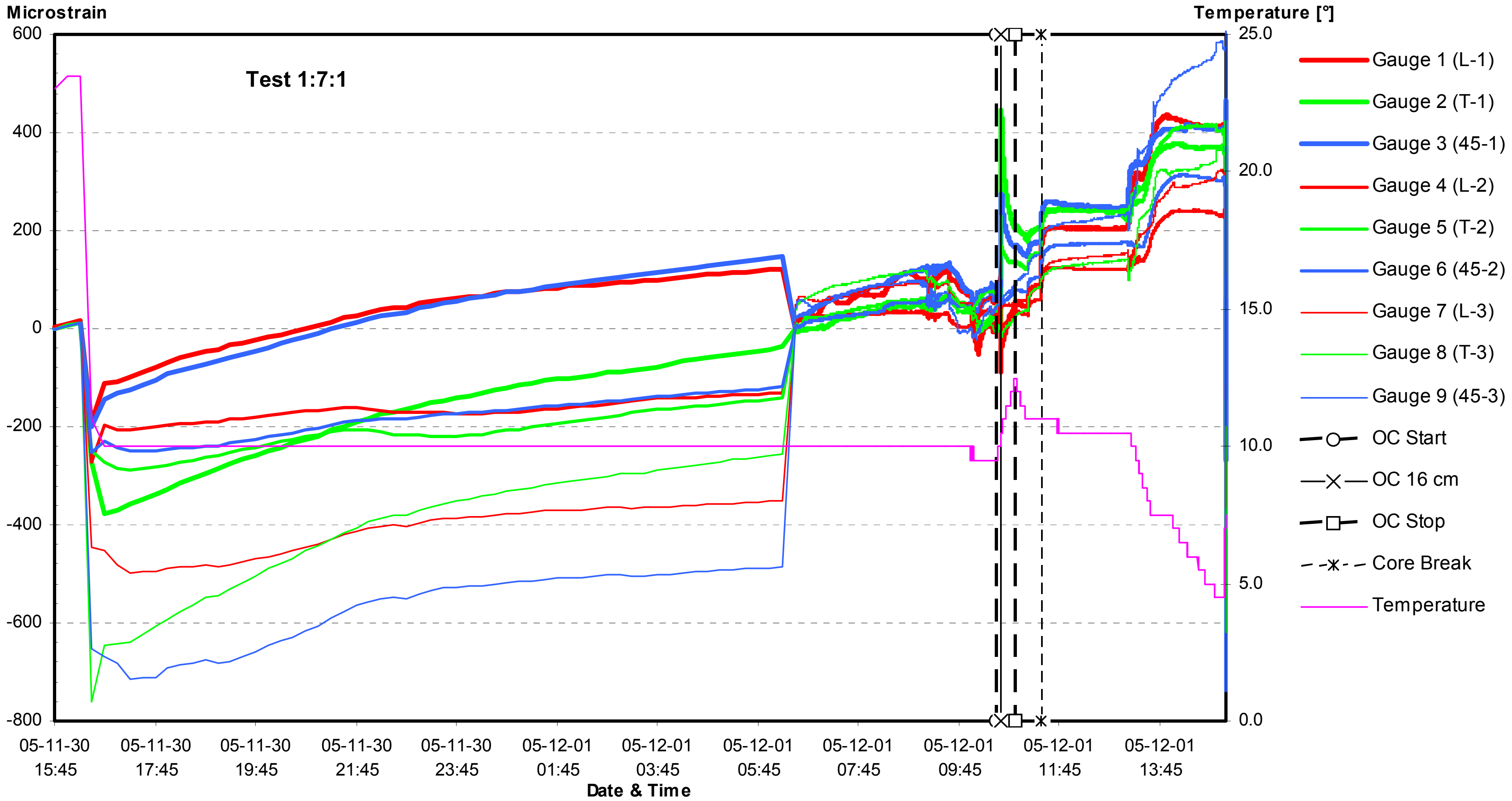


Figure B-7. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:7:1, 237.33 m borehole length.*

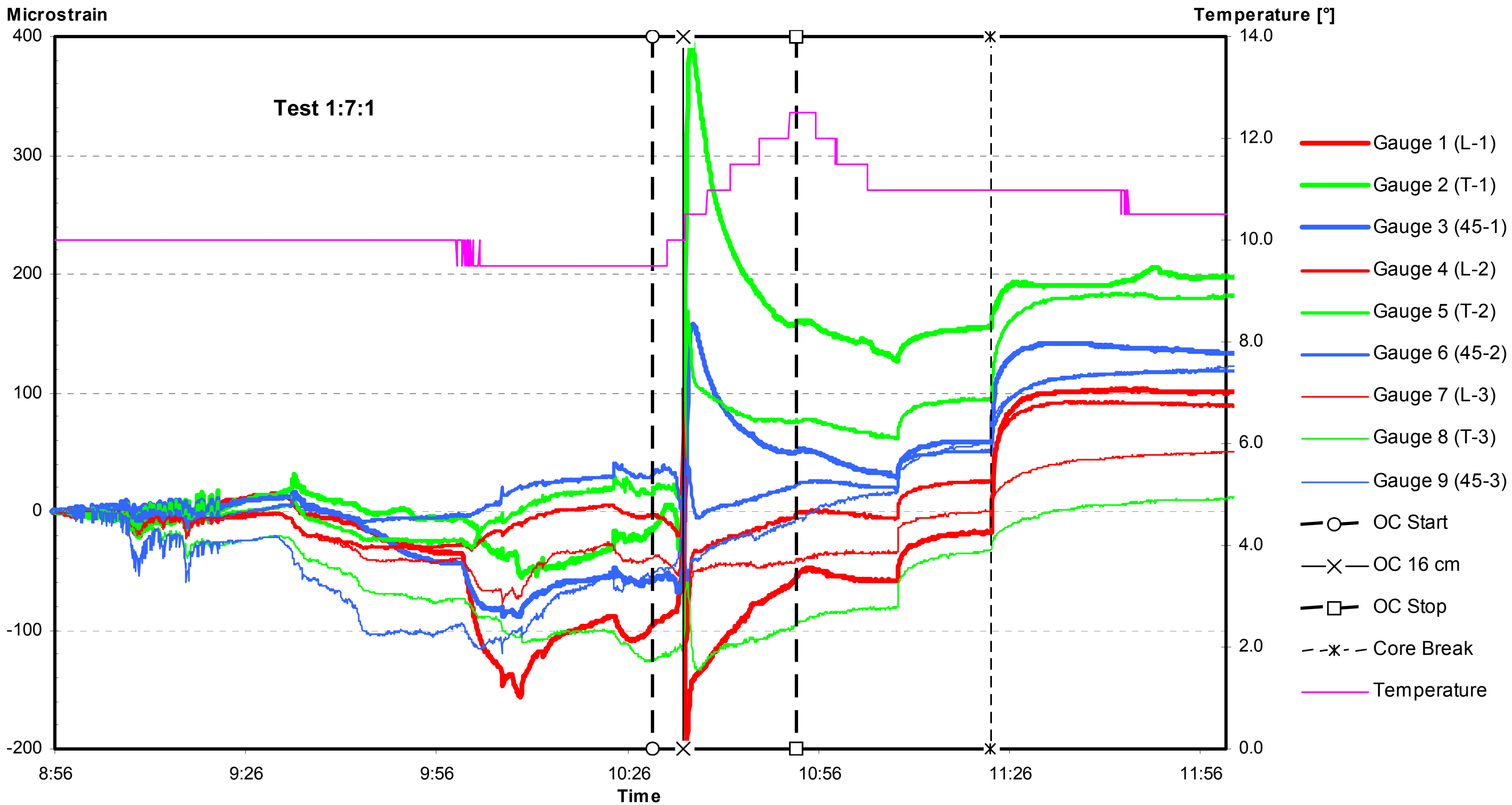


Figure B-8. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:7:1, 237.33 m borehole length. Strain values reset to zero at 08:55.*

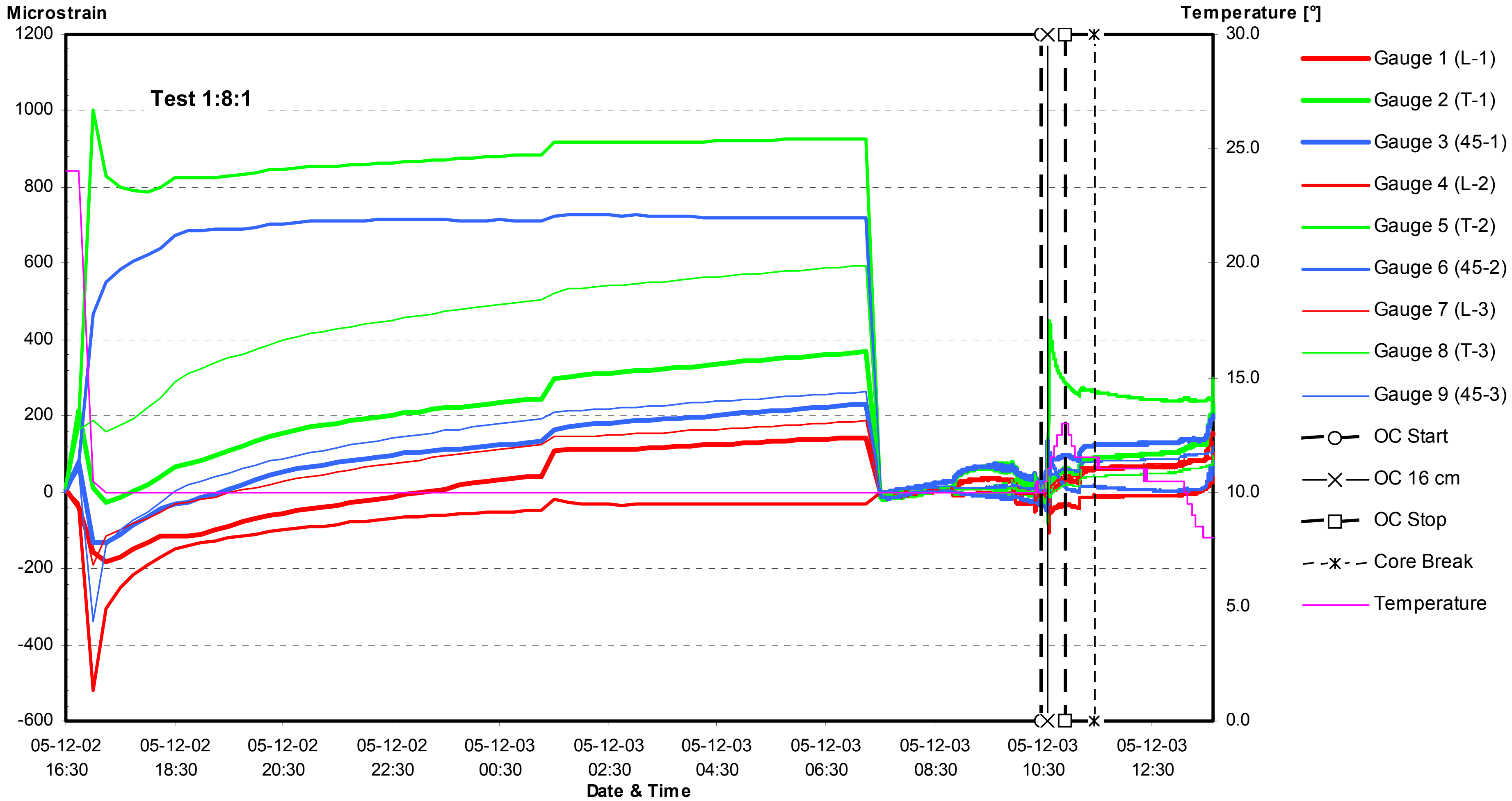


Figure B-9. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:8:1, 239.37 m borehole length.*

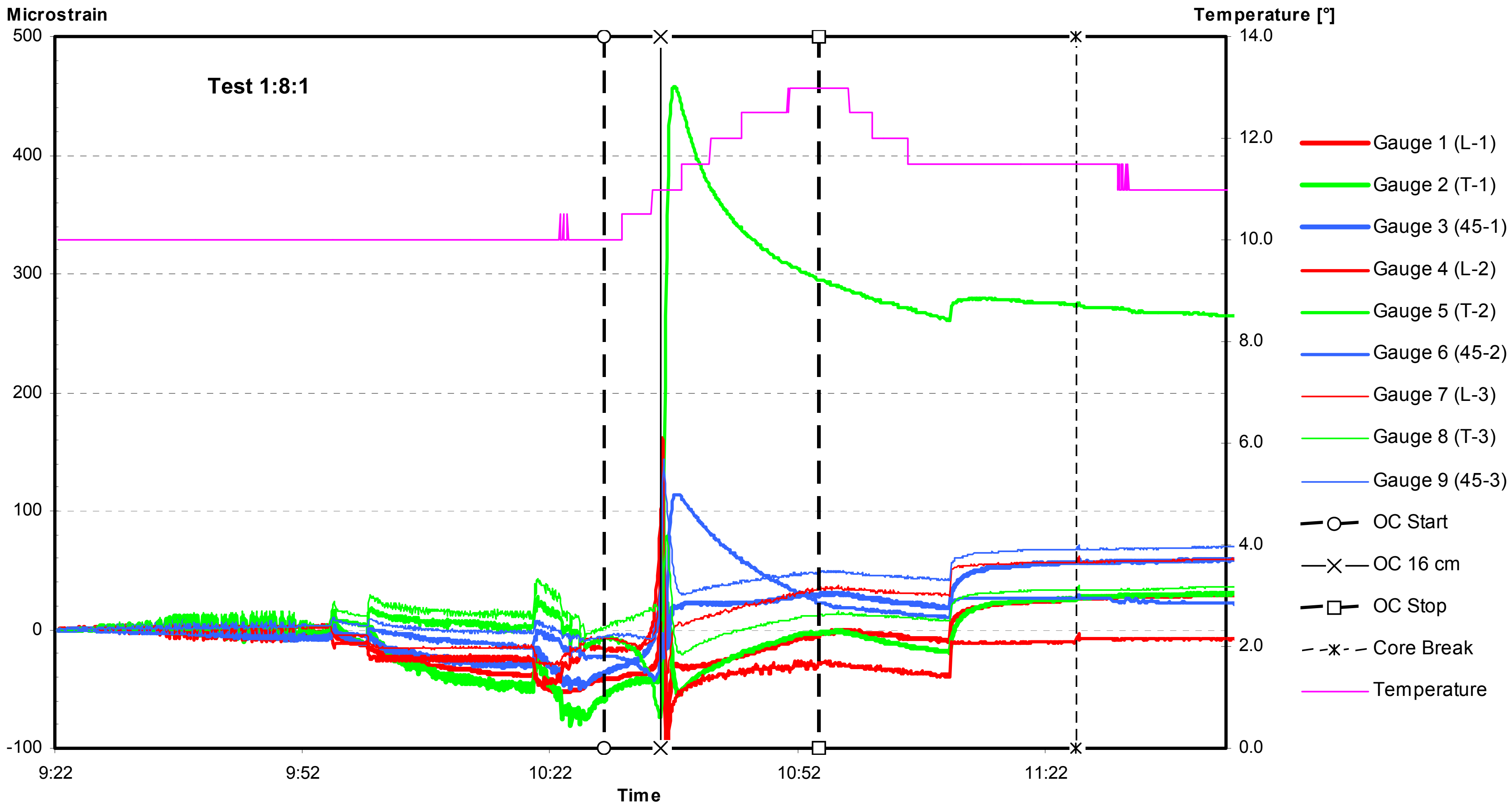


Figure B-10. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:8:1, 239.37 m borehole length. Strain values reset to zero at 09:22.*

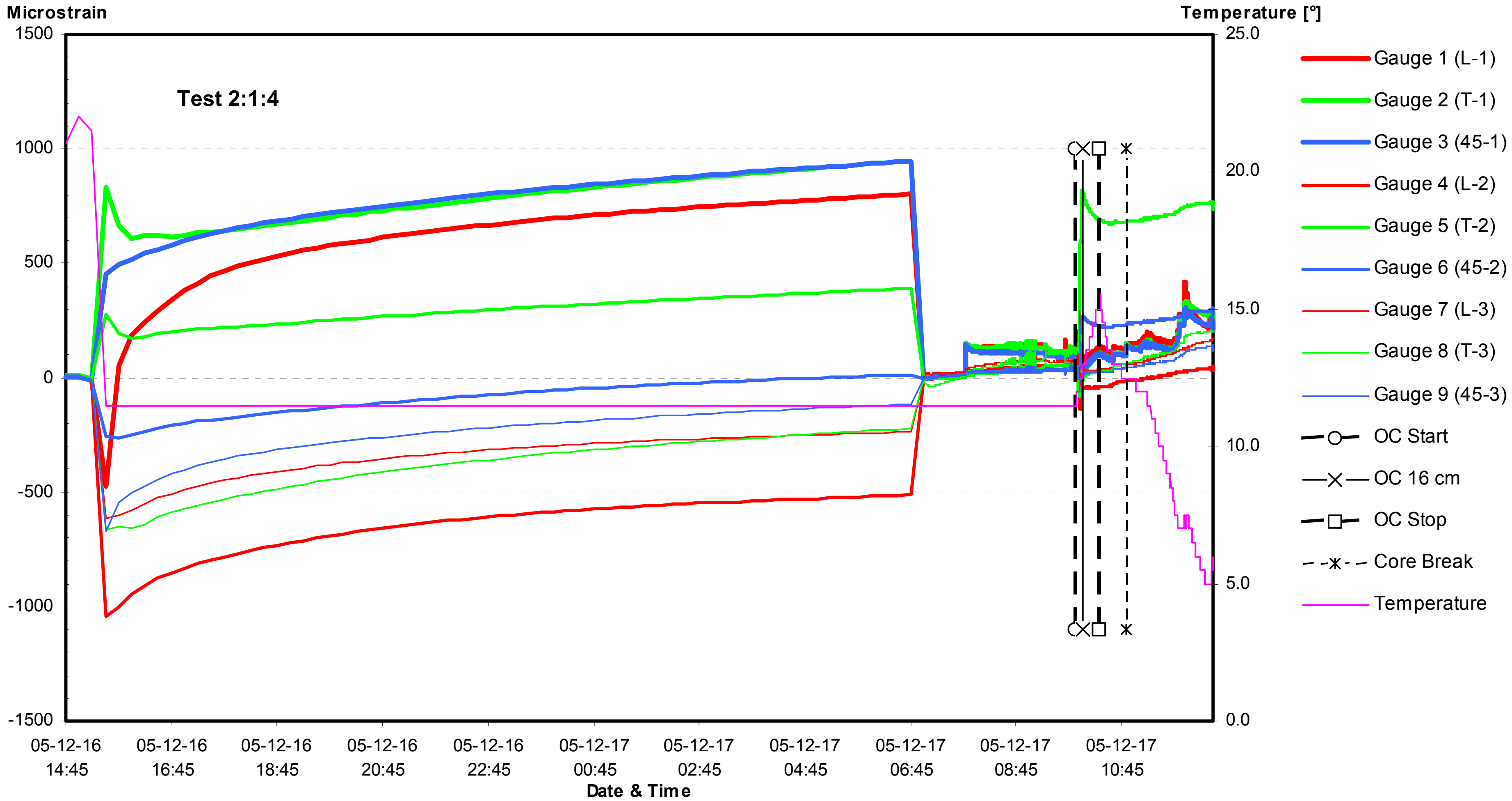


Figure B-11. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:1:4, 350.10 m borehole length.*

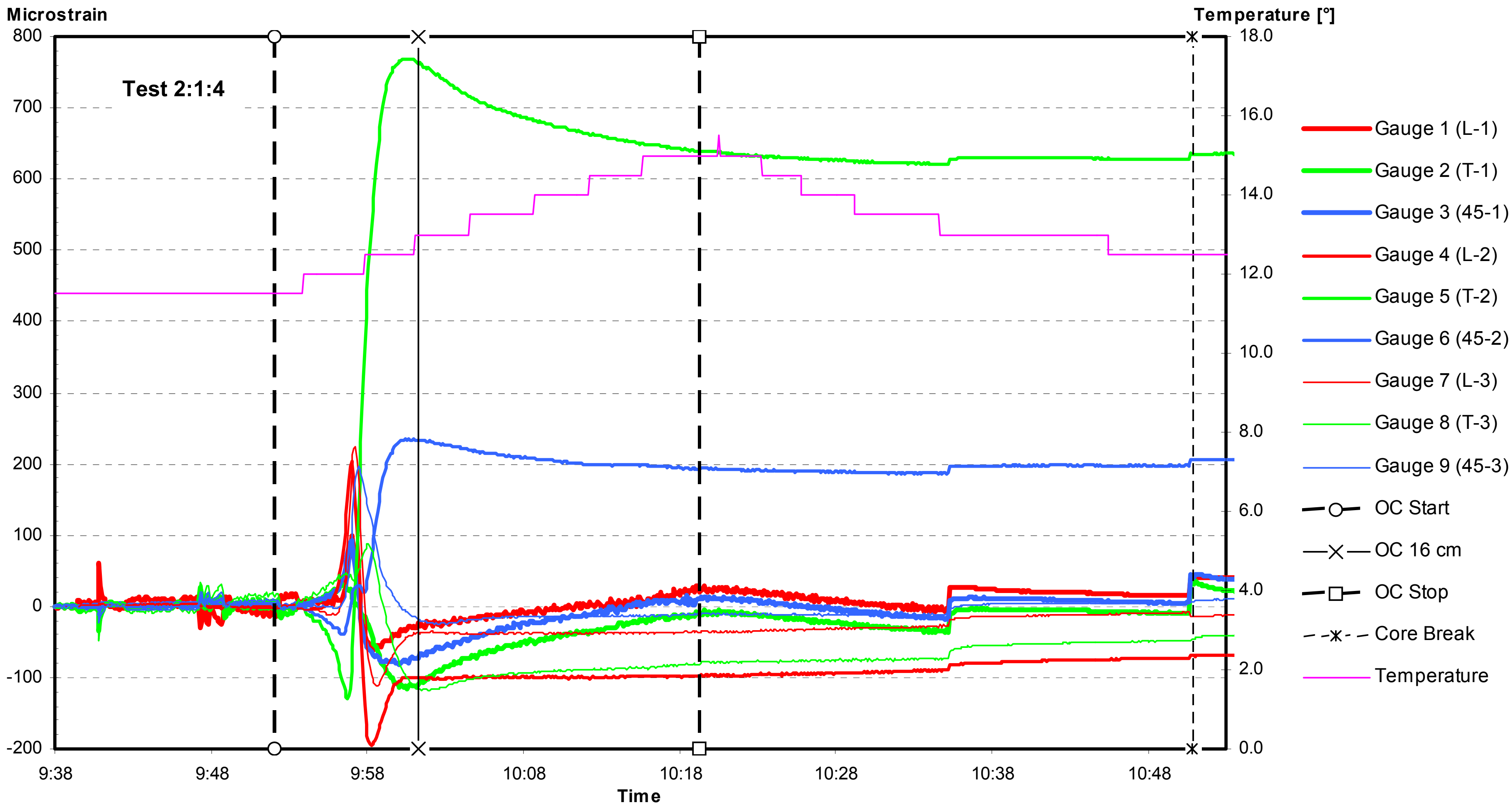


Figure B-12. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:1:4, 350.10 m borehole length. Strain values reset to zero at 09:38.*

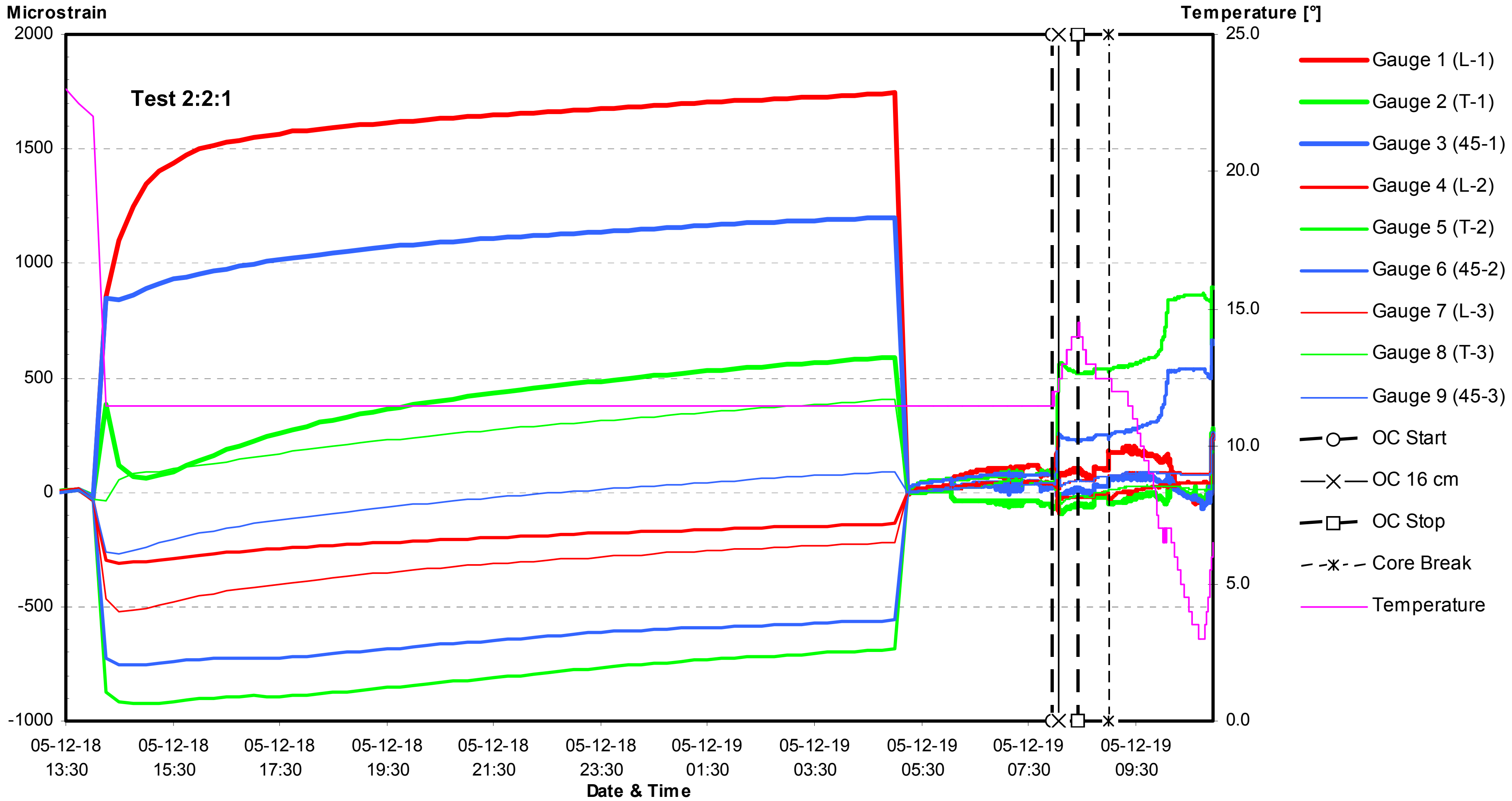


Figure B-13. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:2:1, 351.28 m borehole length.*

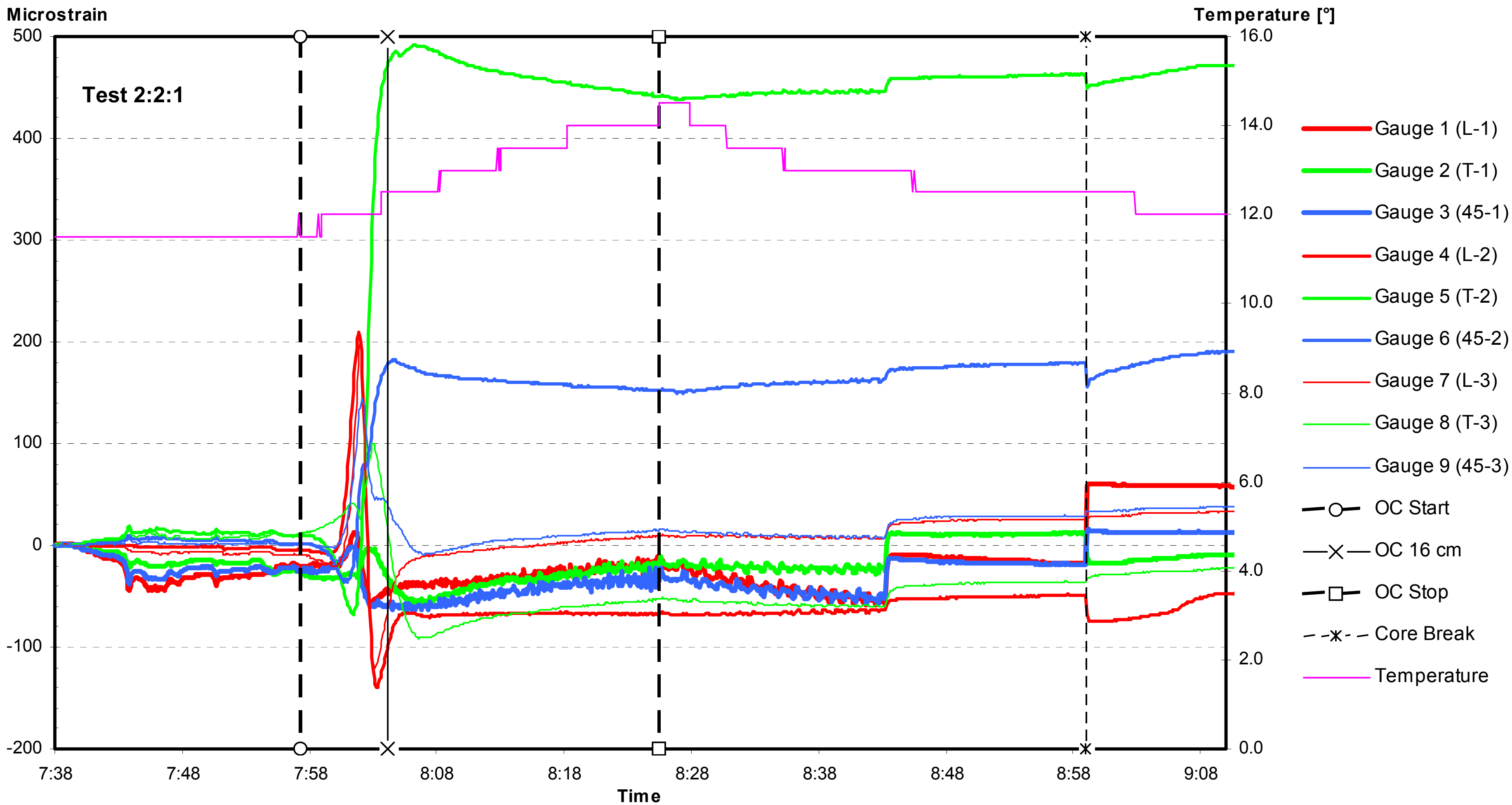


Figure B-14. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:2:1, 351.28 m borehole length. Strain values reset to zero at 07:37.*

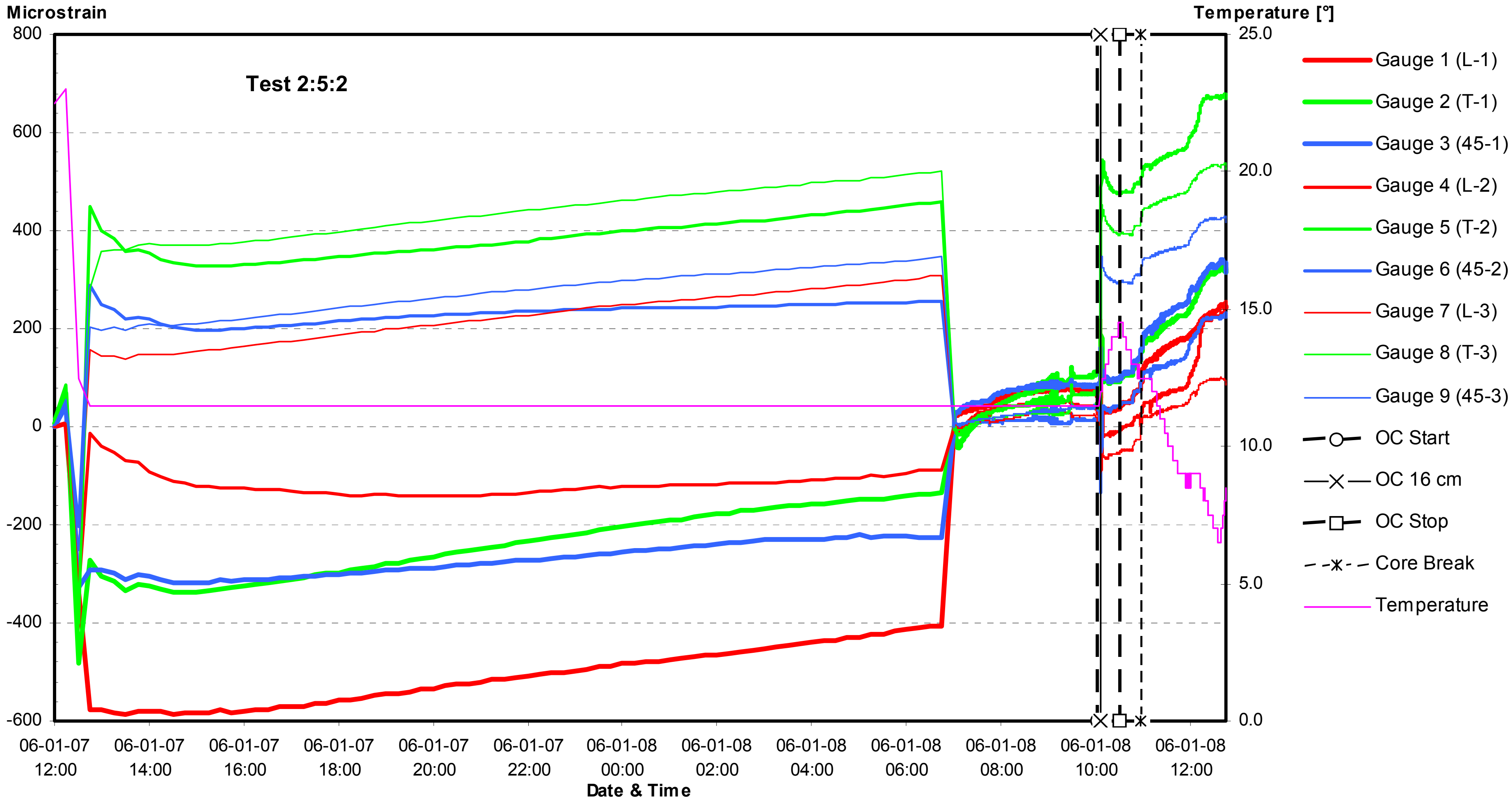


Figure B-15. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:5:2, 359.58 m borehole length.*

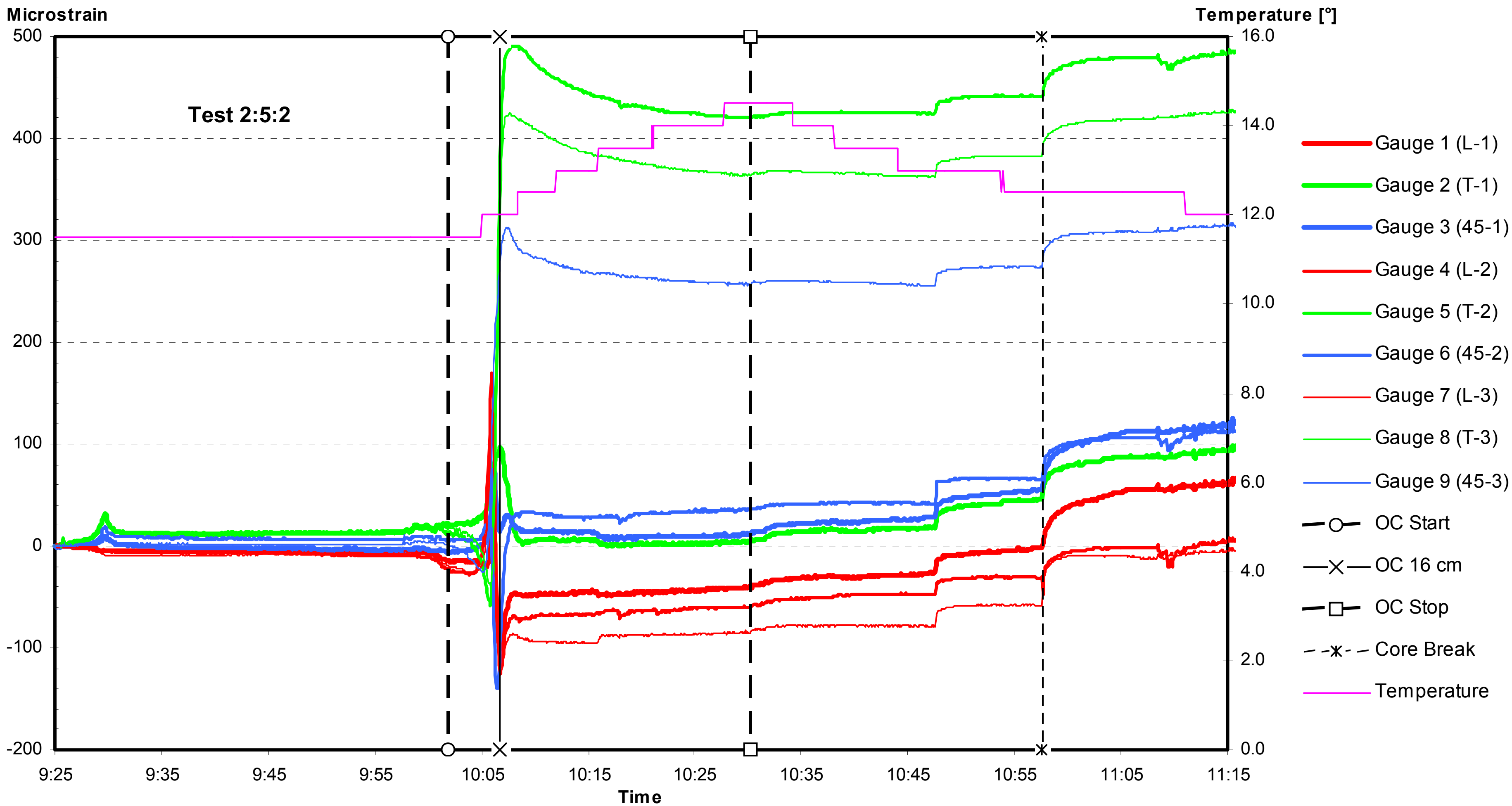


Figure B-16. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:5:2, 359.58 m borehole length. Strain values reset to zero at 09:25.*

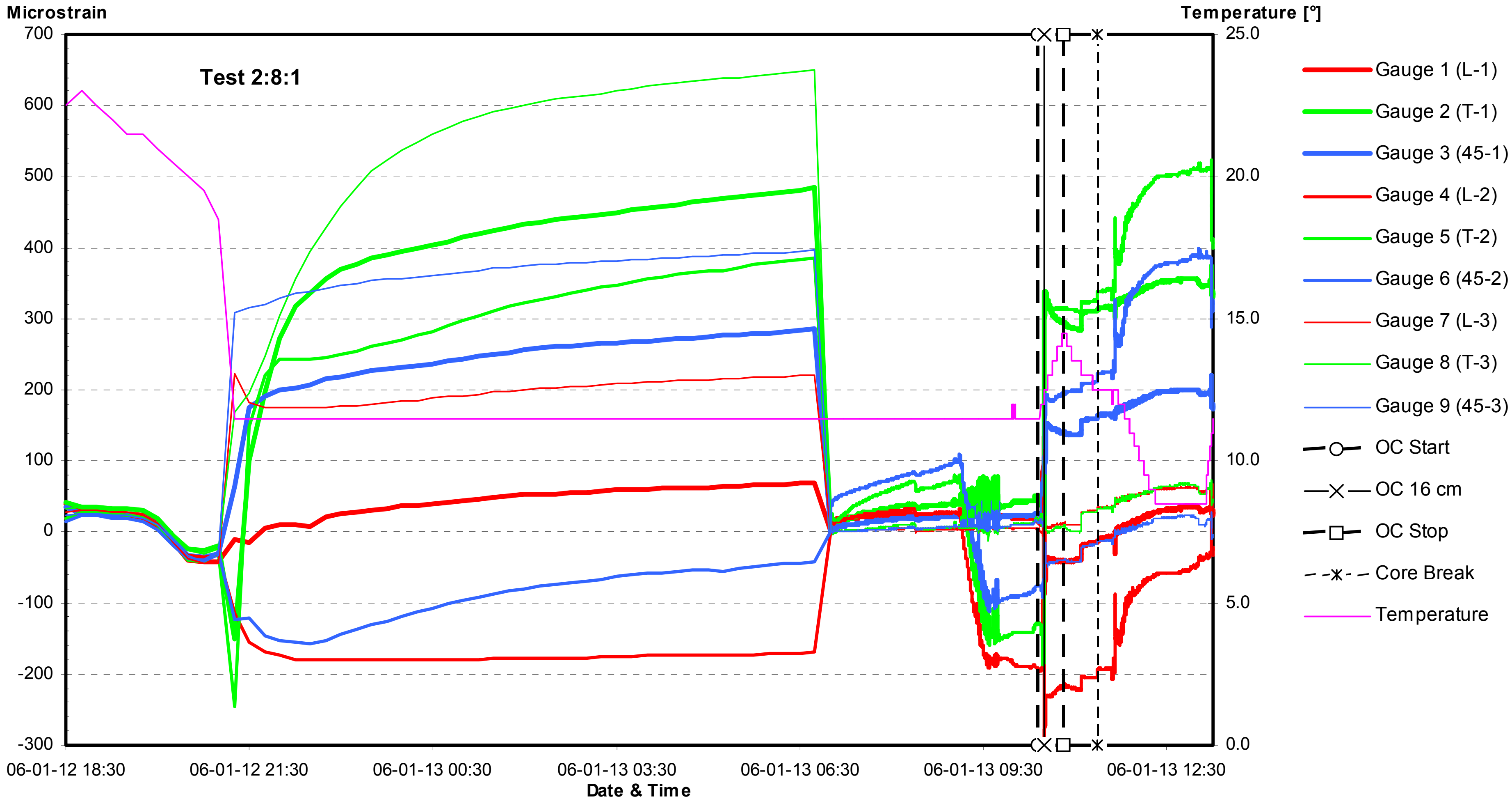


Figure B-17. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:8:1, 366.38 m borehole length.*

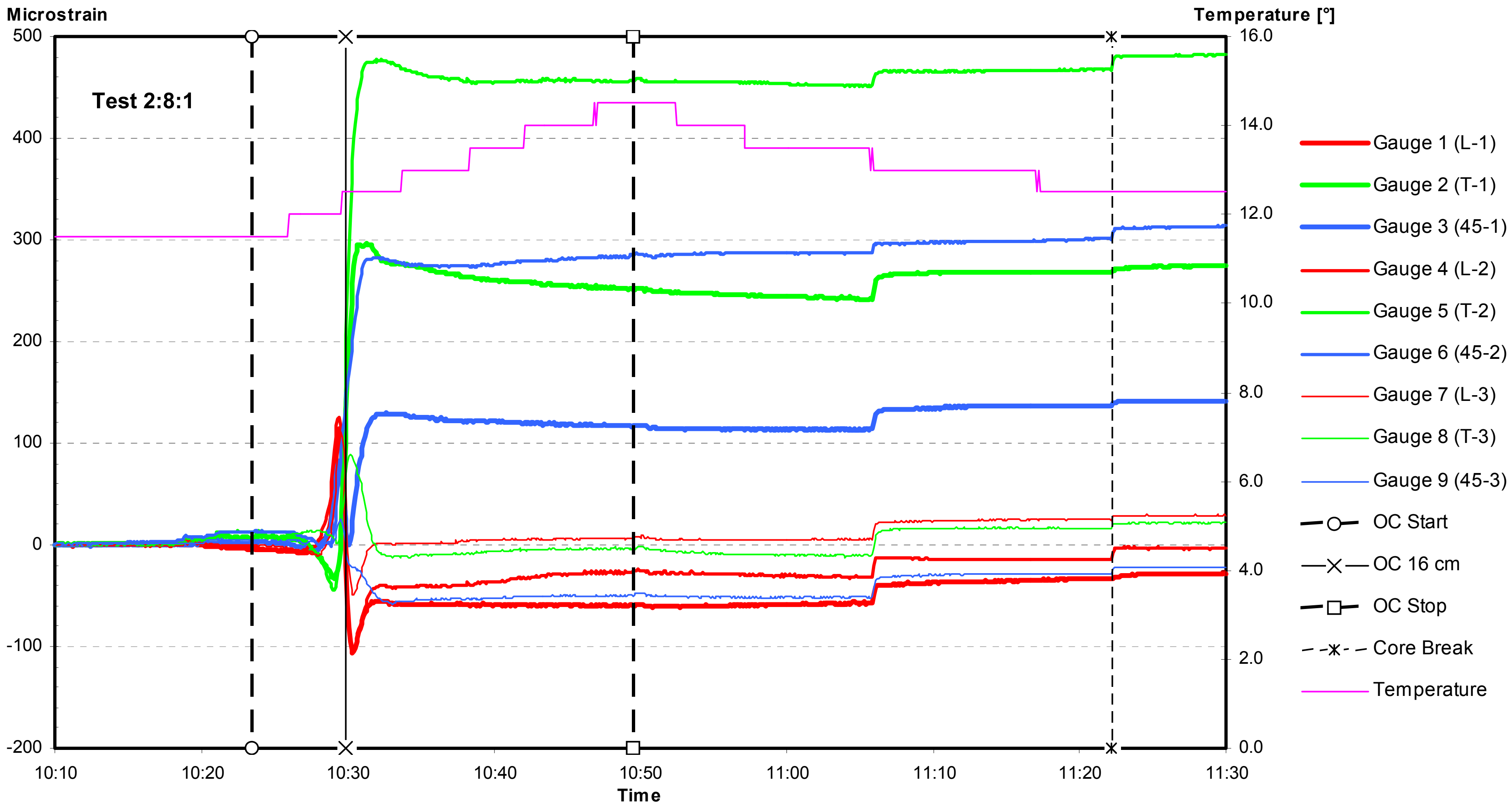


Figure B-18. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:8:1, 366.38 m borehole length. Strain values reset to zero at 10:10.*

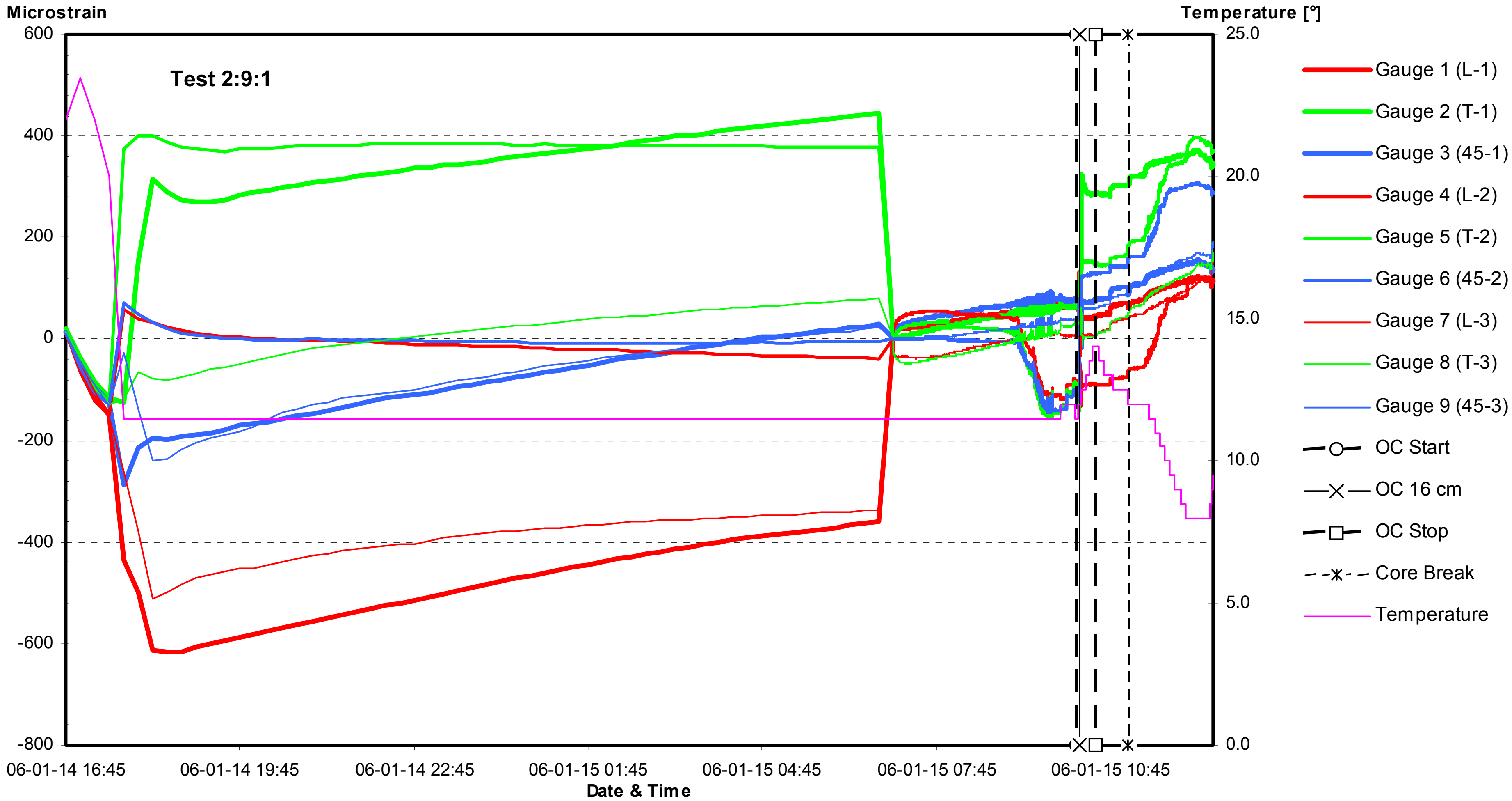


Figure B-19. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:9:1, 367.40 m borehole length.*

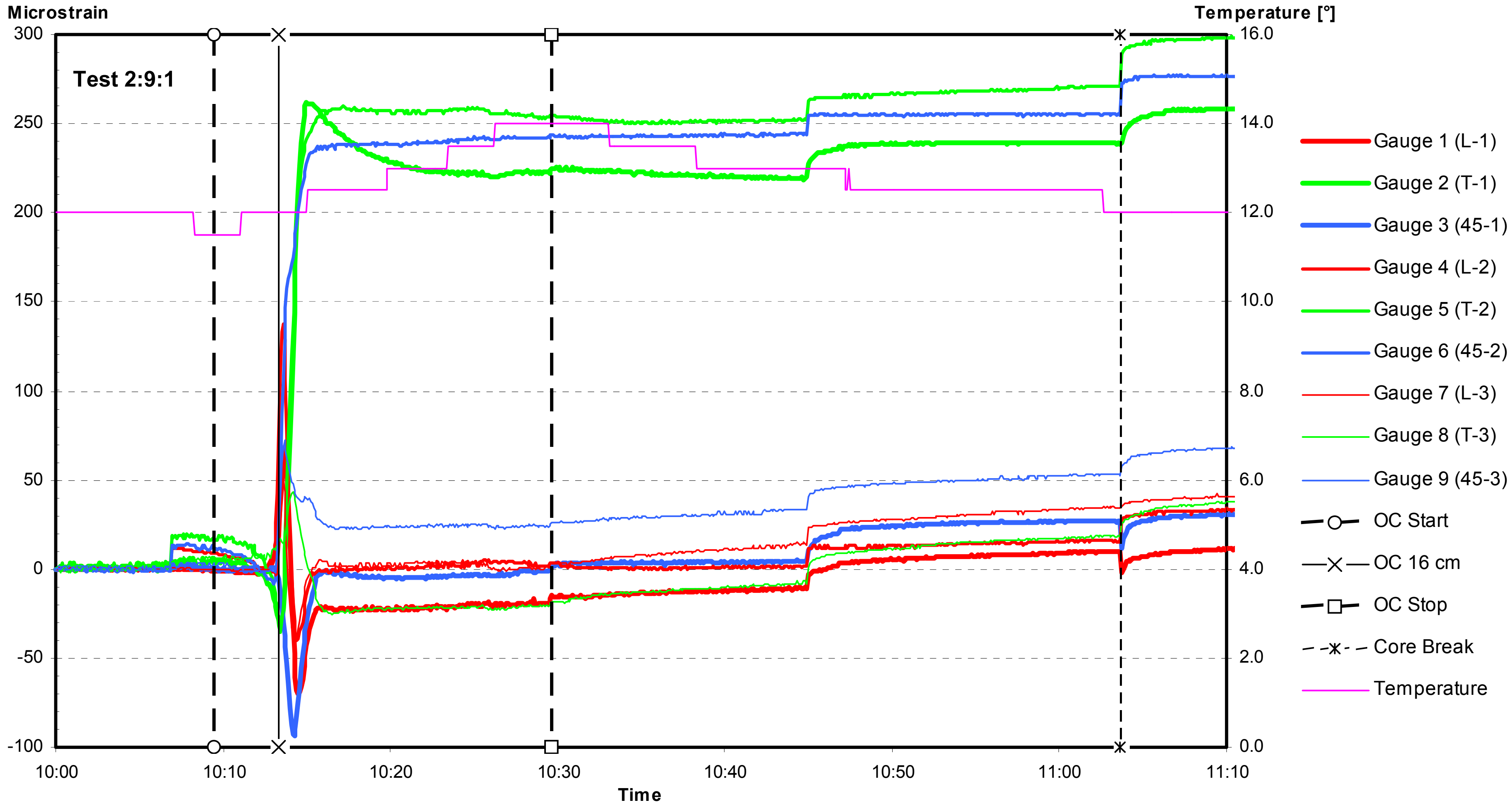


Figure B-20. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:9:1, 367.40 m borehole length. Strain values reset to zero at 10:00.*

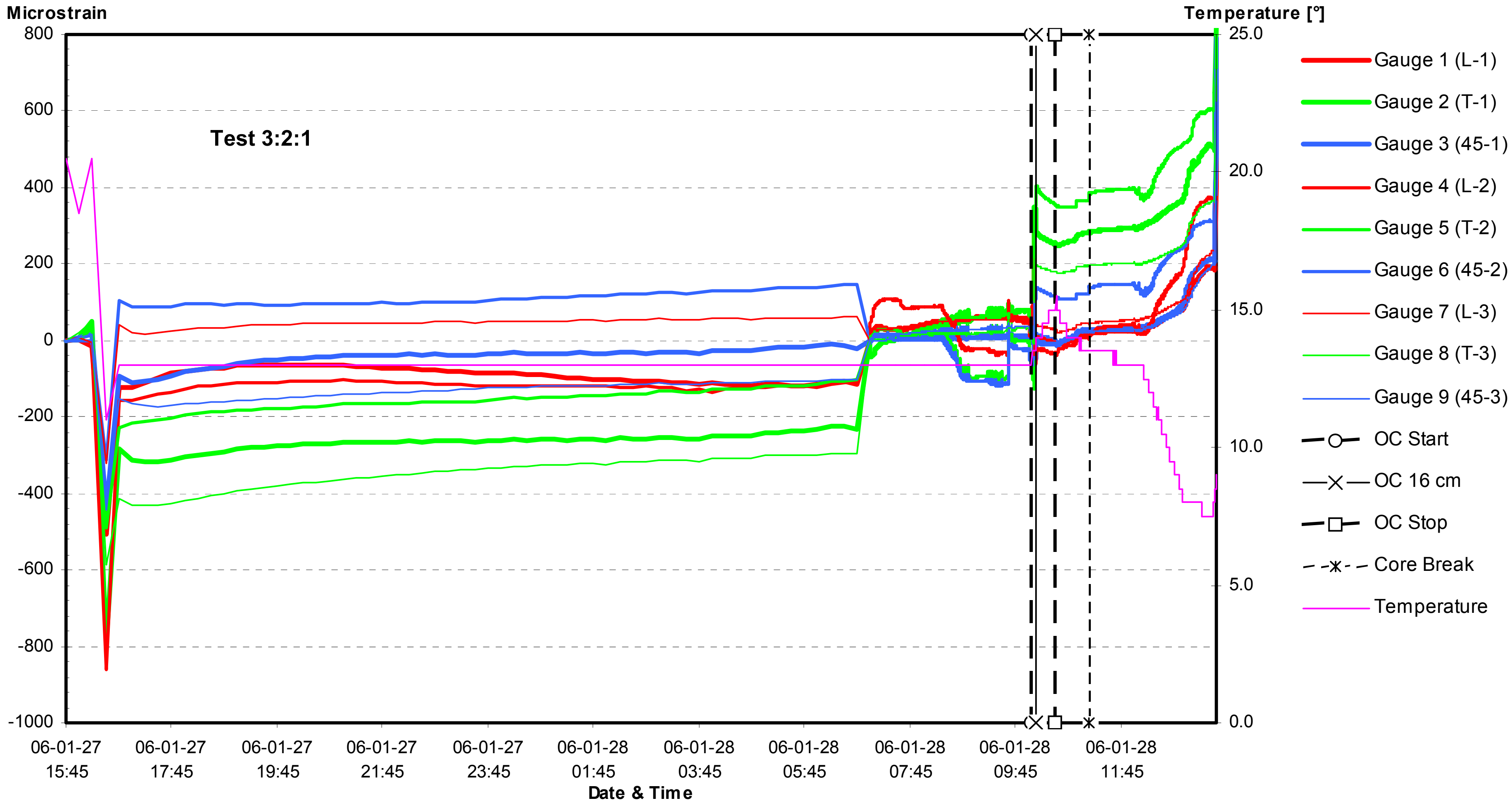


Figure B-21. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:2:1, 468.48 m borehole length.*

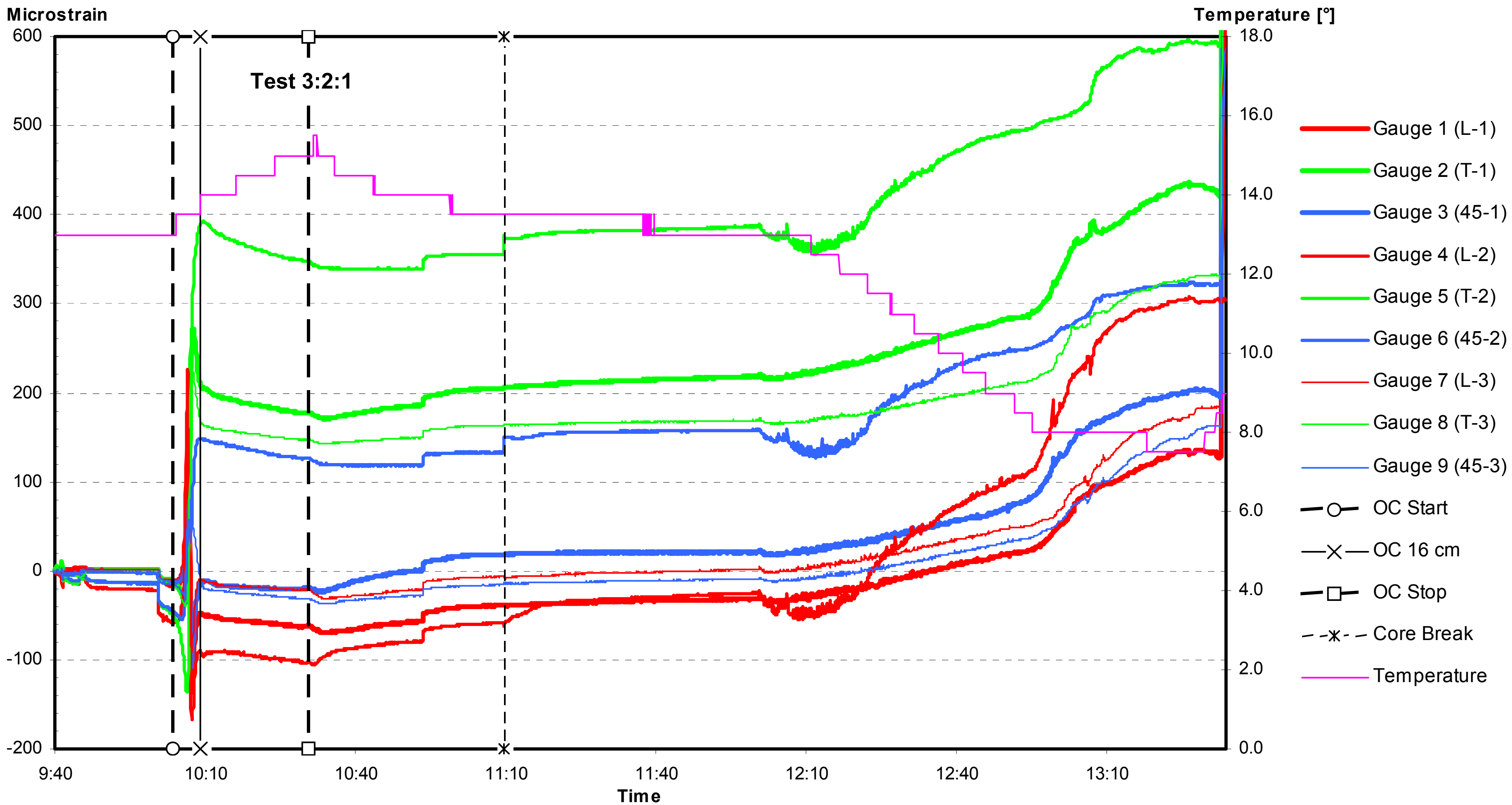


Figure B-22. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 3:2:1, 468.48 m borehole length. Strain values reset to zero at 09:40.*

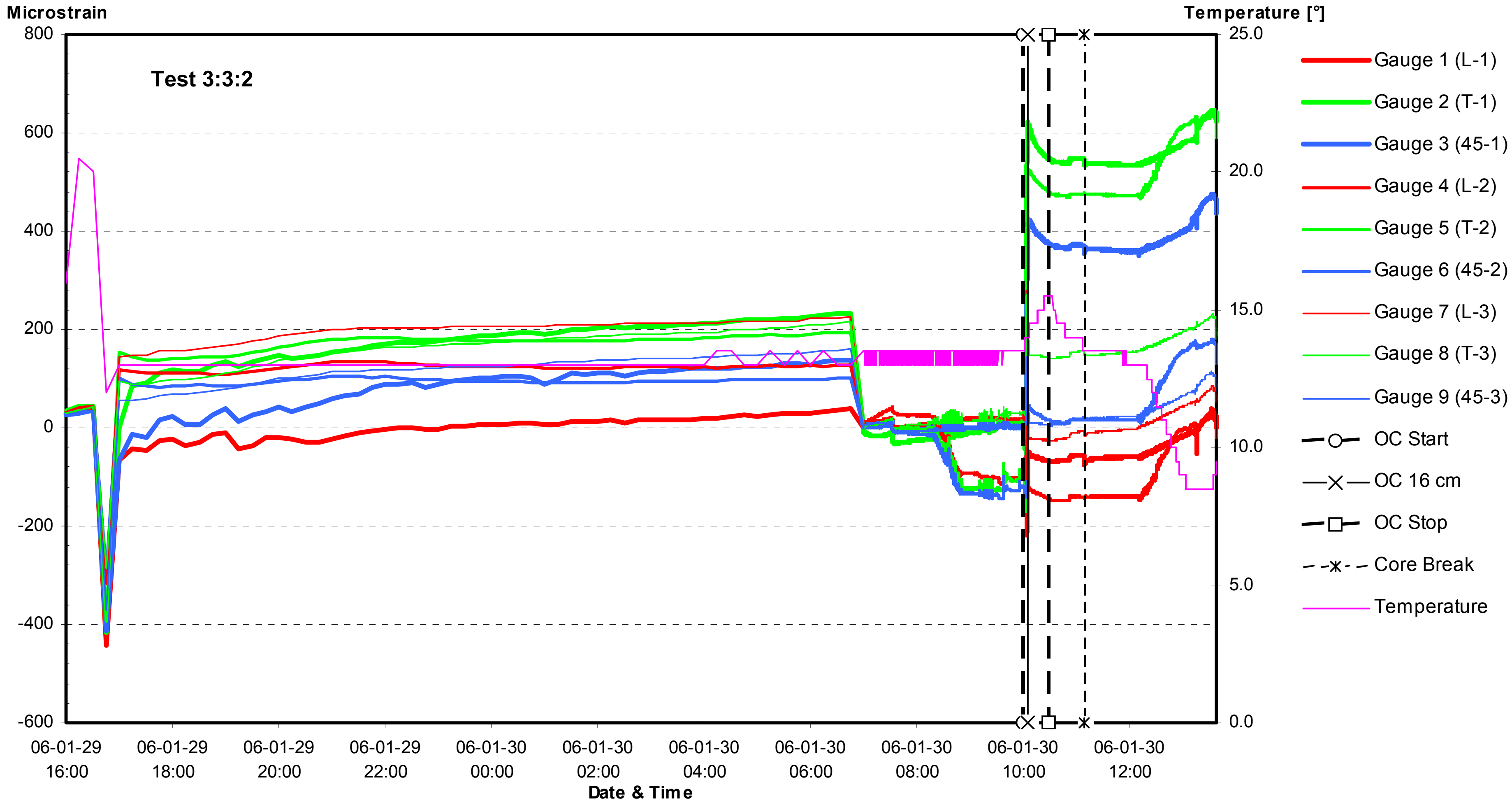


Figure B-23. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:3:2, 470.79 m borehole length.*

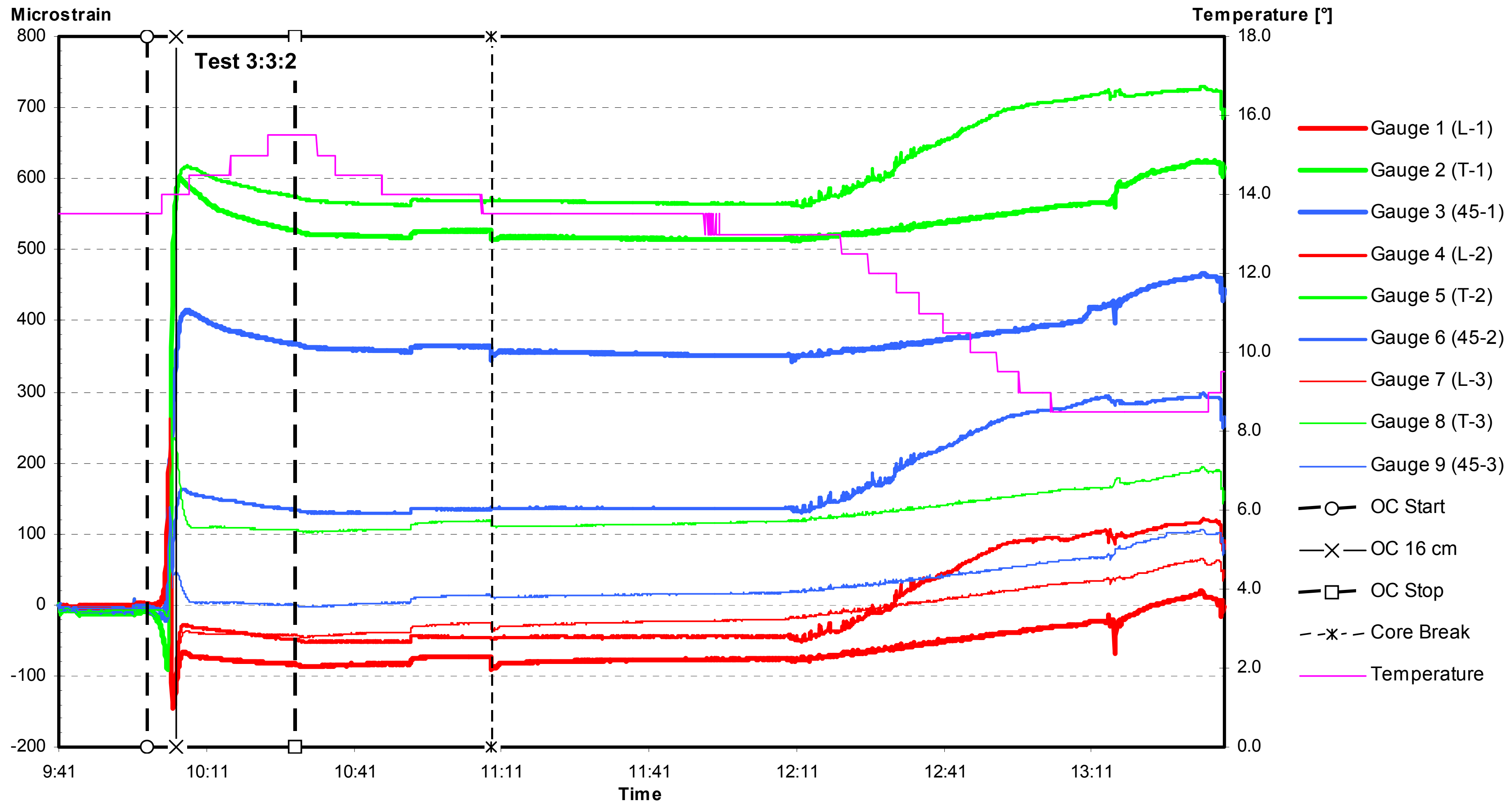


Figure B-24. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 3:3:2, 470.79 m borehole length. Strain values reset to zero at 09:41.*

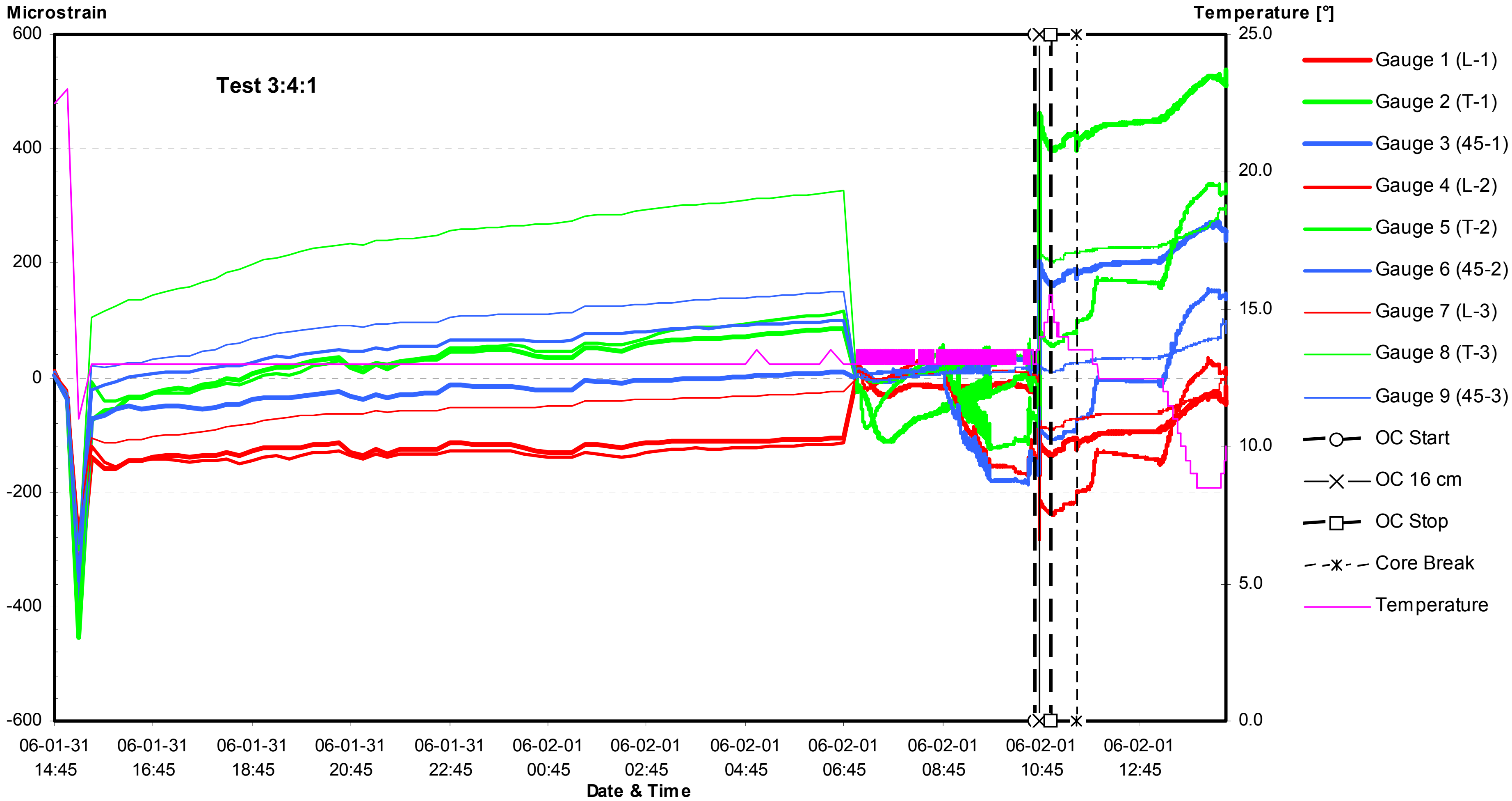


Figure B-25. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:4:1, 471.92 m borehole length.*

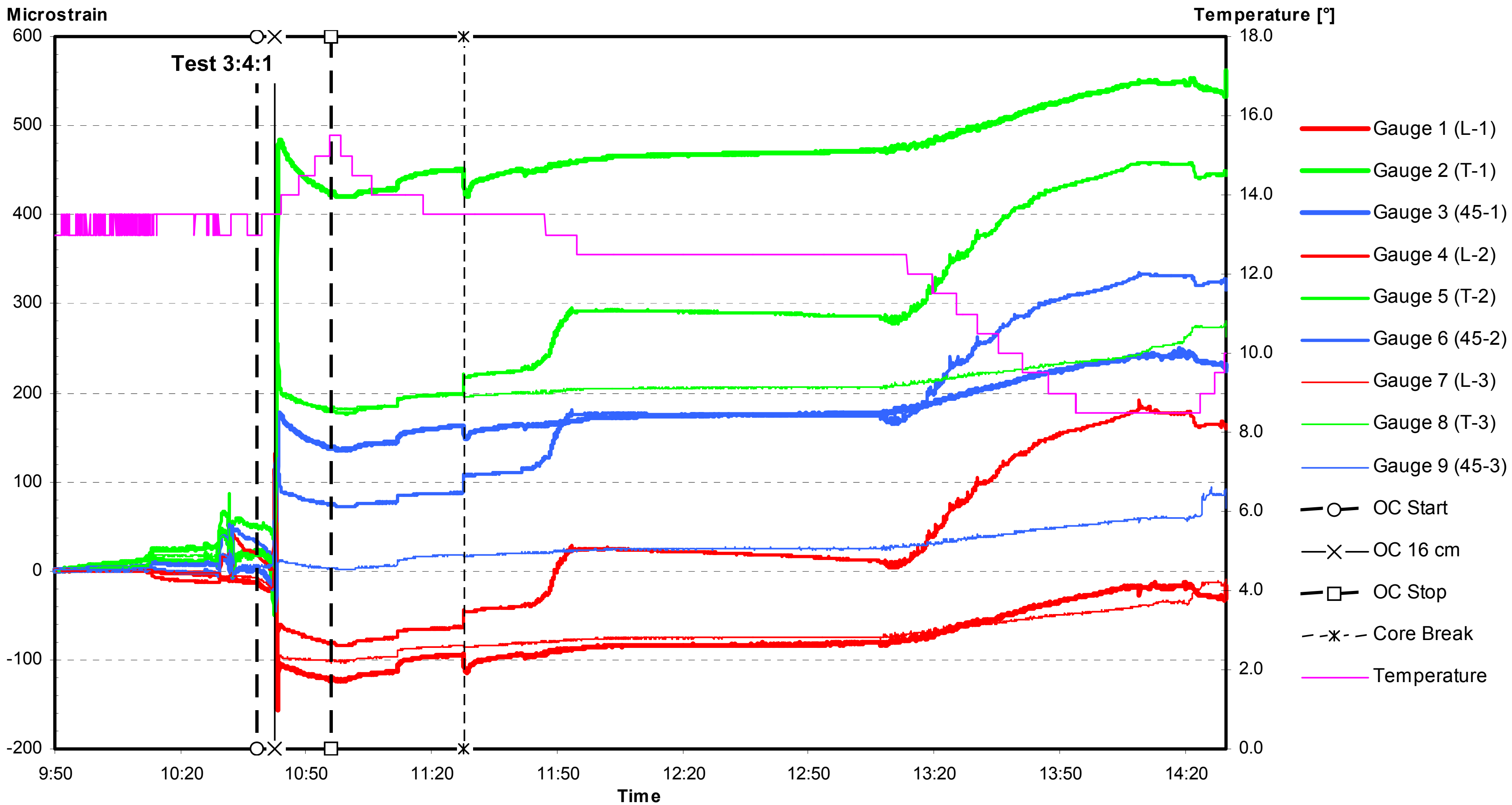


Figure B-26. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 3:4:1, 471.92 m borehole length. Strain values reset to zero at 09:50.*

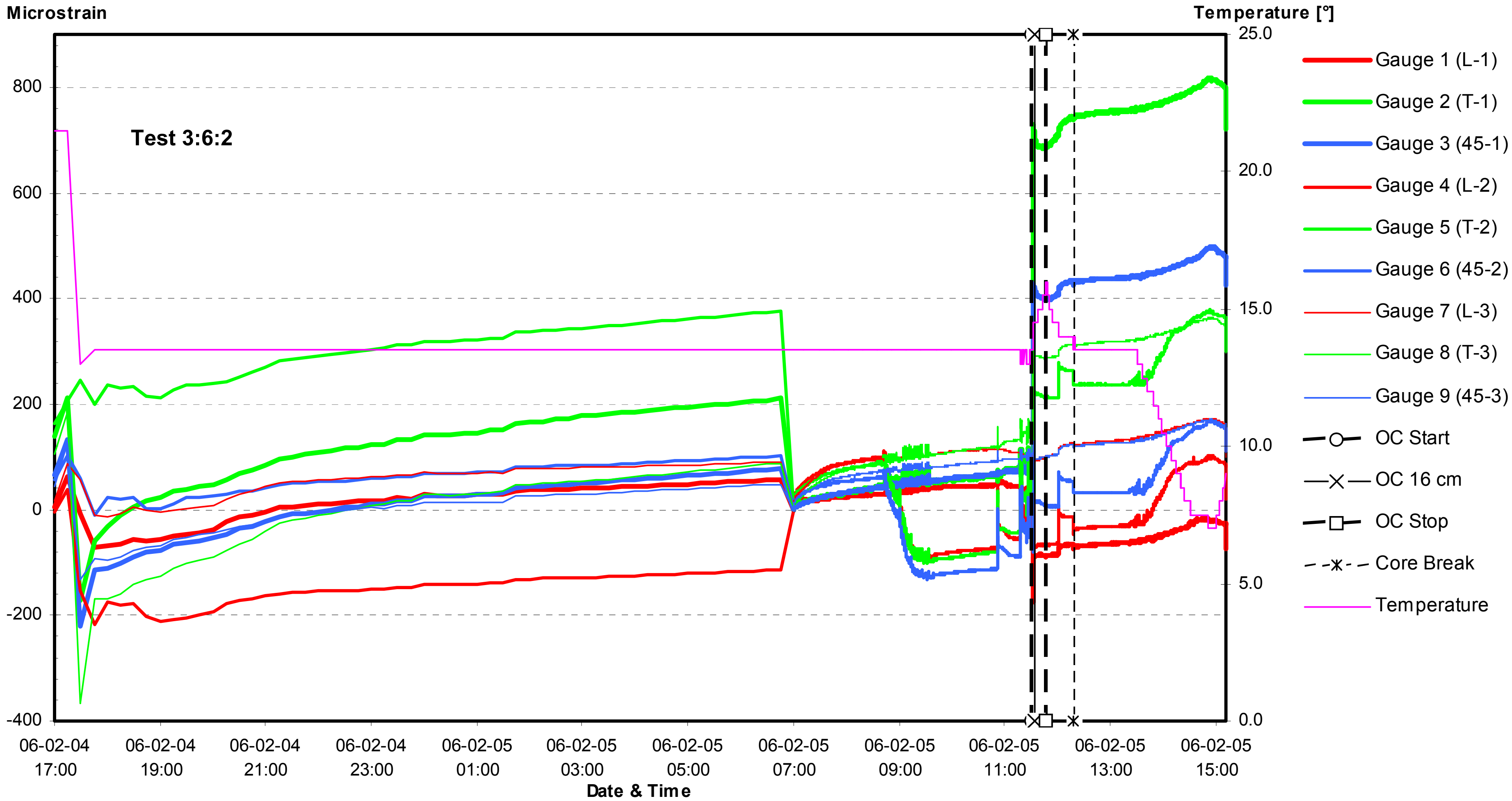


Figure B-27. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 3:6:2, 475.41 m borehole length.*

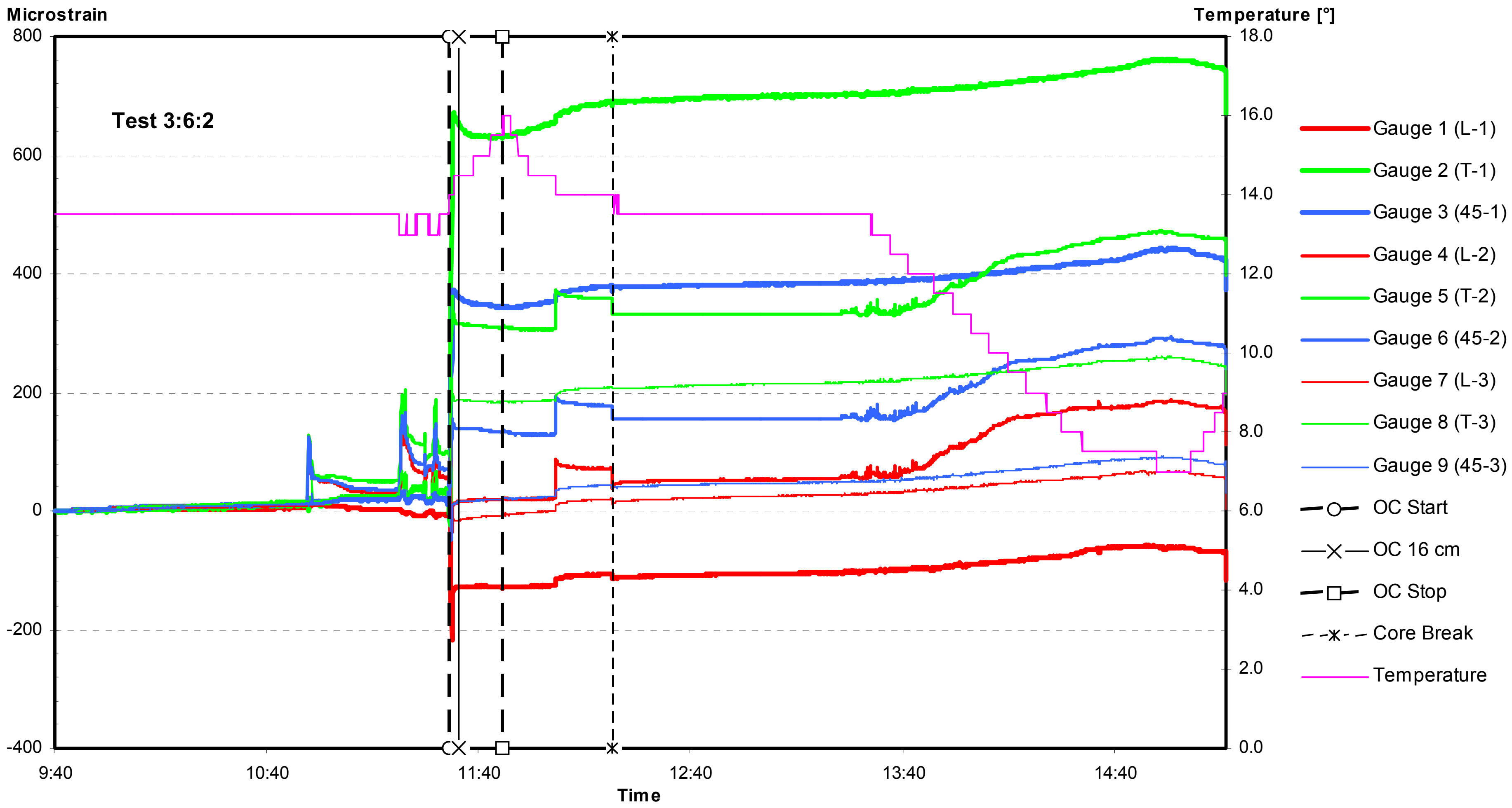


Figure B-28. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 3:6:2, 475.41 m borehole length. Strain values reset to zero at 09:40.*

Appendix C

Biaxial test data

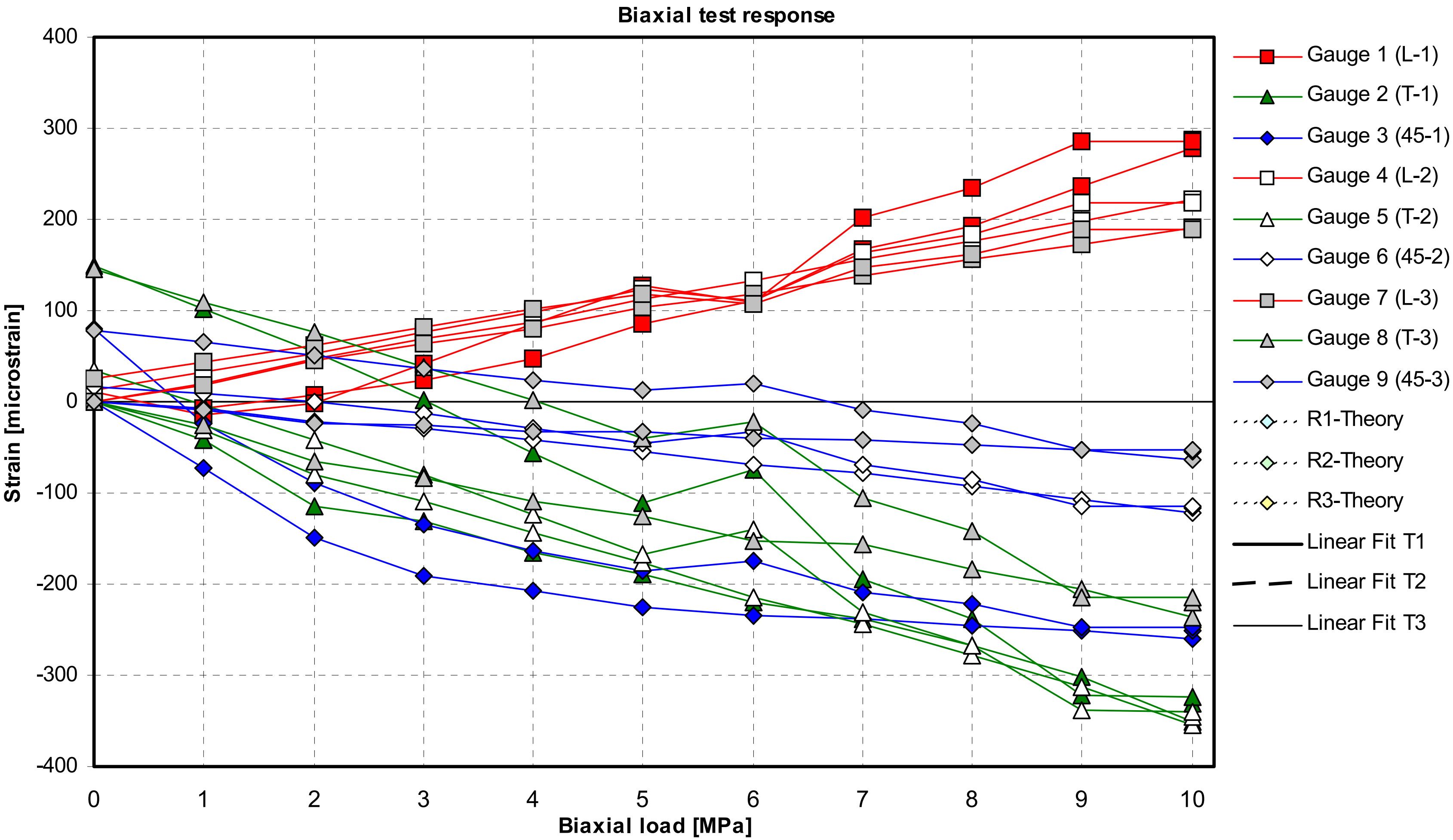


Figure C-1. *Results from biaxial testing of test no. 1:5:1, 232.40 m borehole length.*

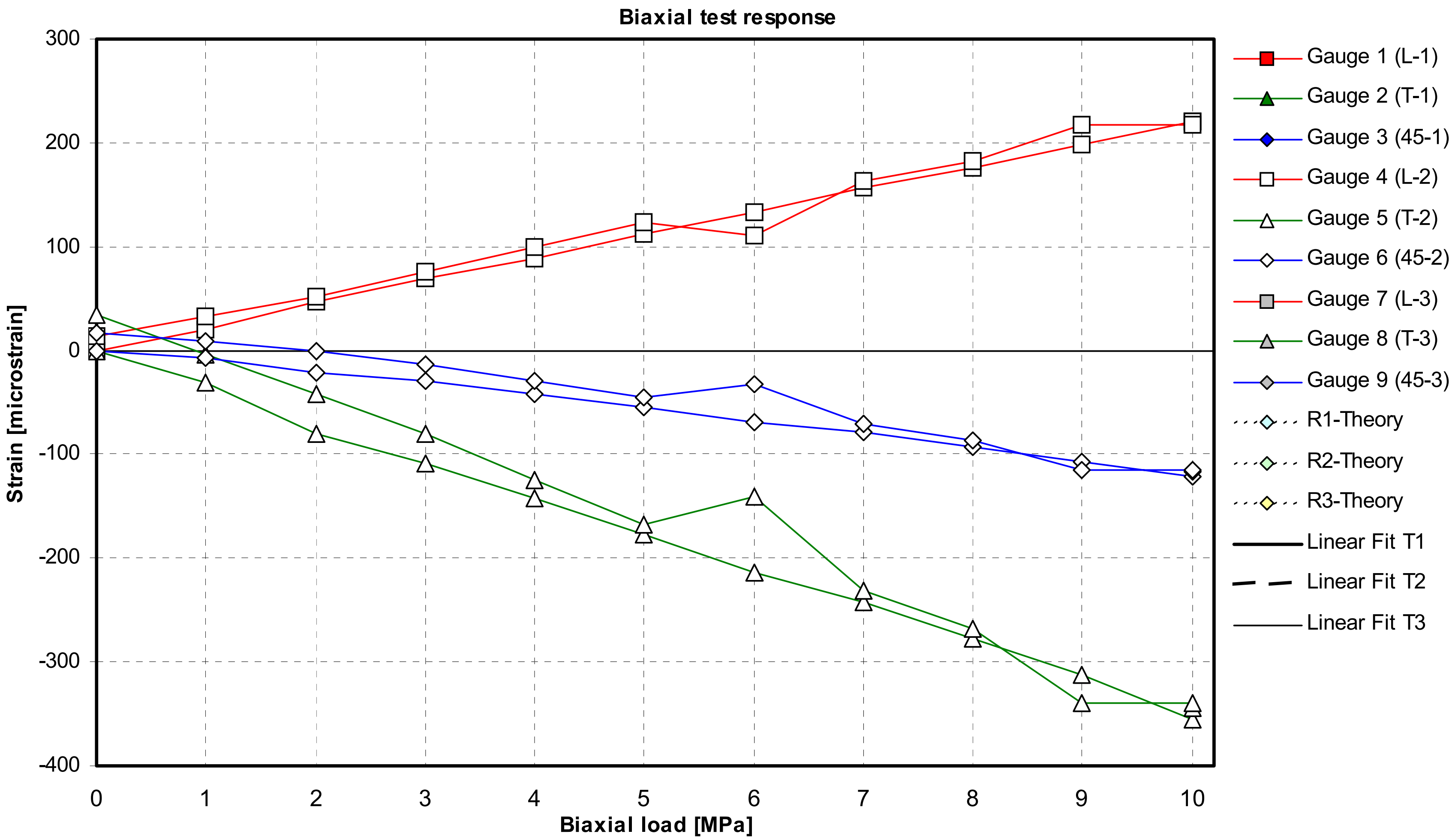


Figure C-2. *Results from biaxial testing of test no. 1:5:1, 232.40 m borehole length. Rosette no. 1 and 3 excluded.*

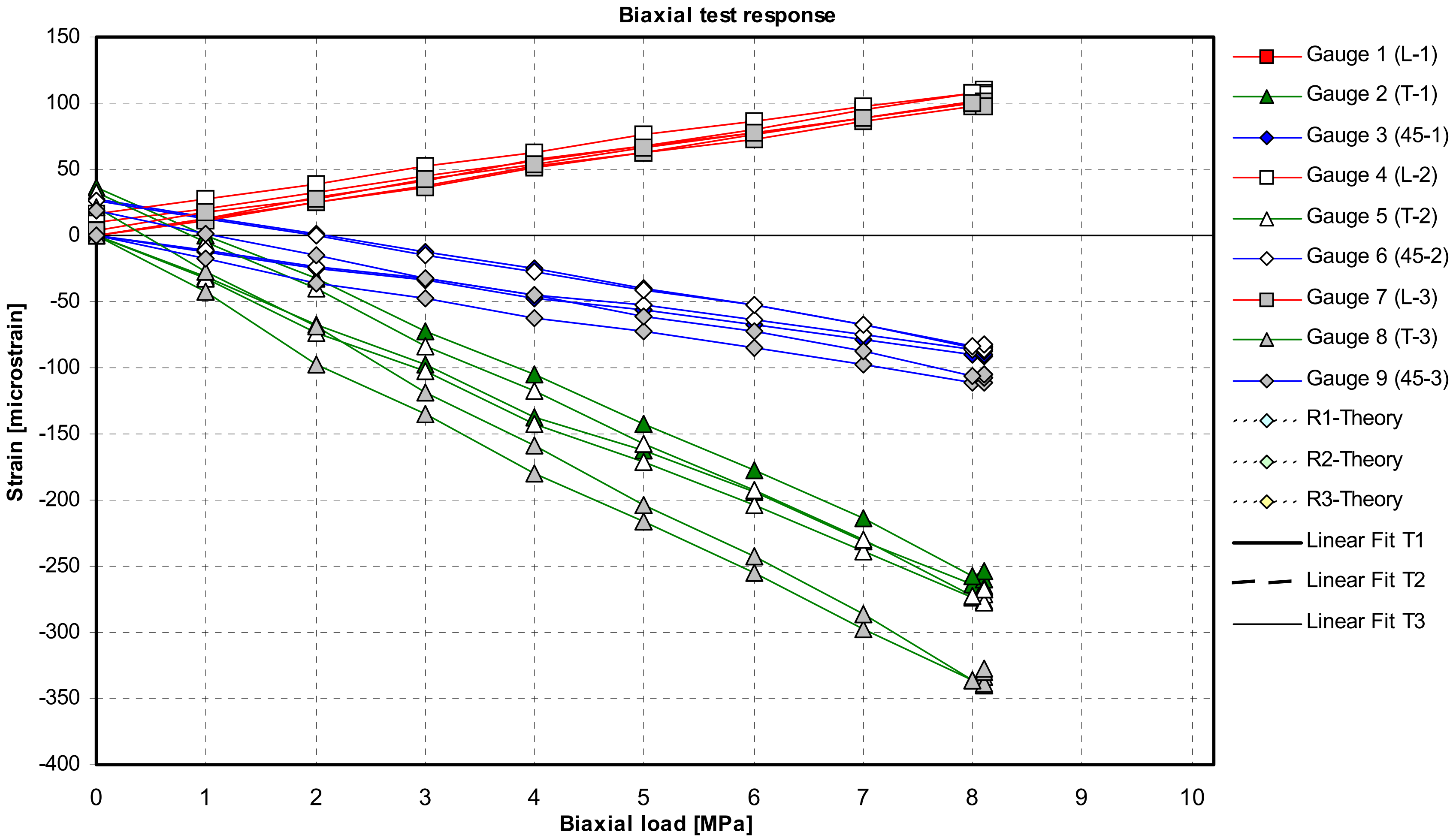


Figure C-3. *Results from biaxial testing of test no. 1:6:2, 236.26 m borehole length.*

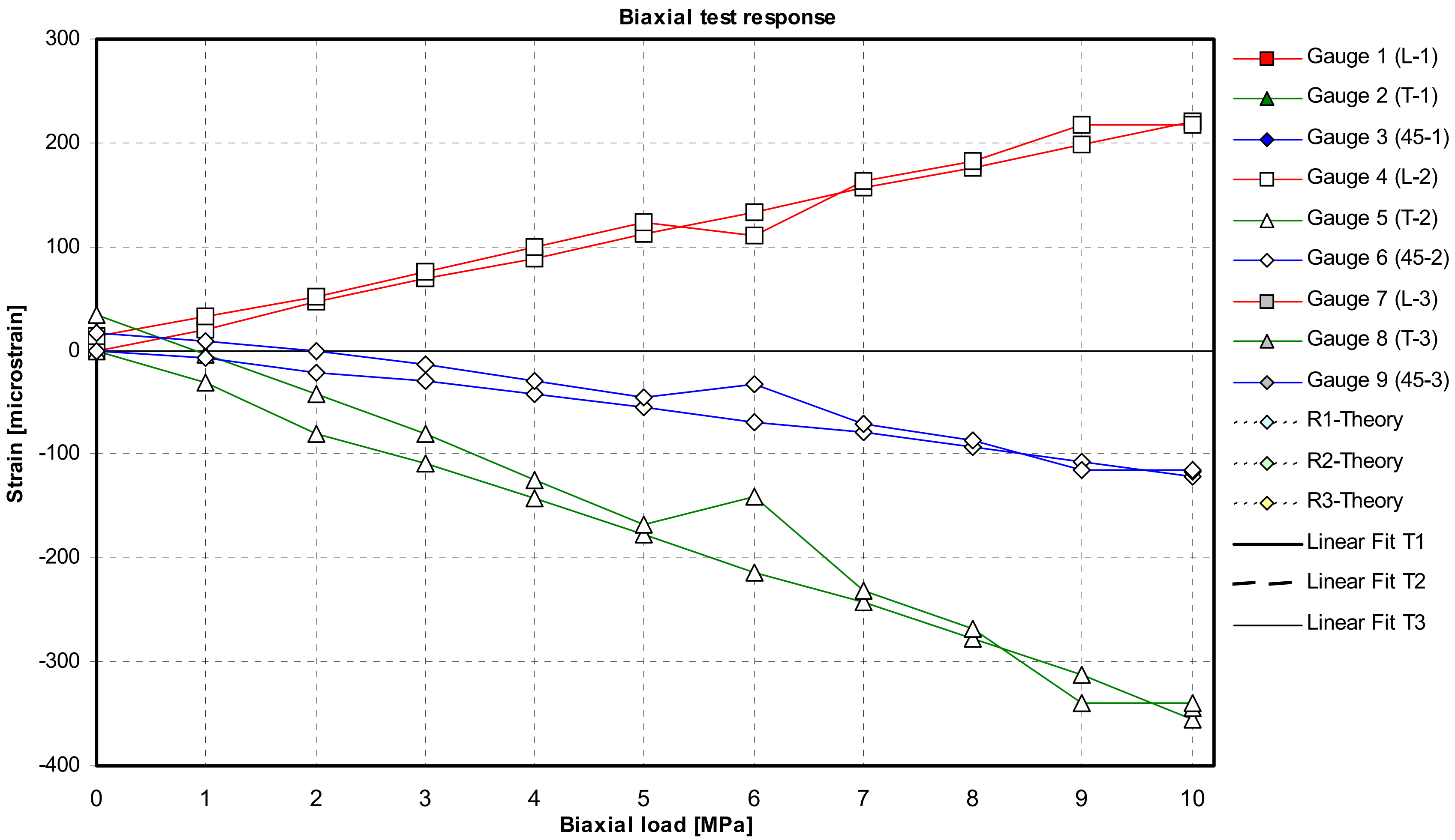


Figure C-4. *Results from biaxial testing of test no. 2:1:4, 350.10 m borehole length.*

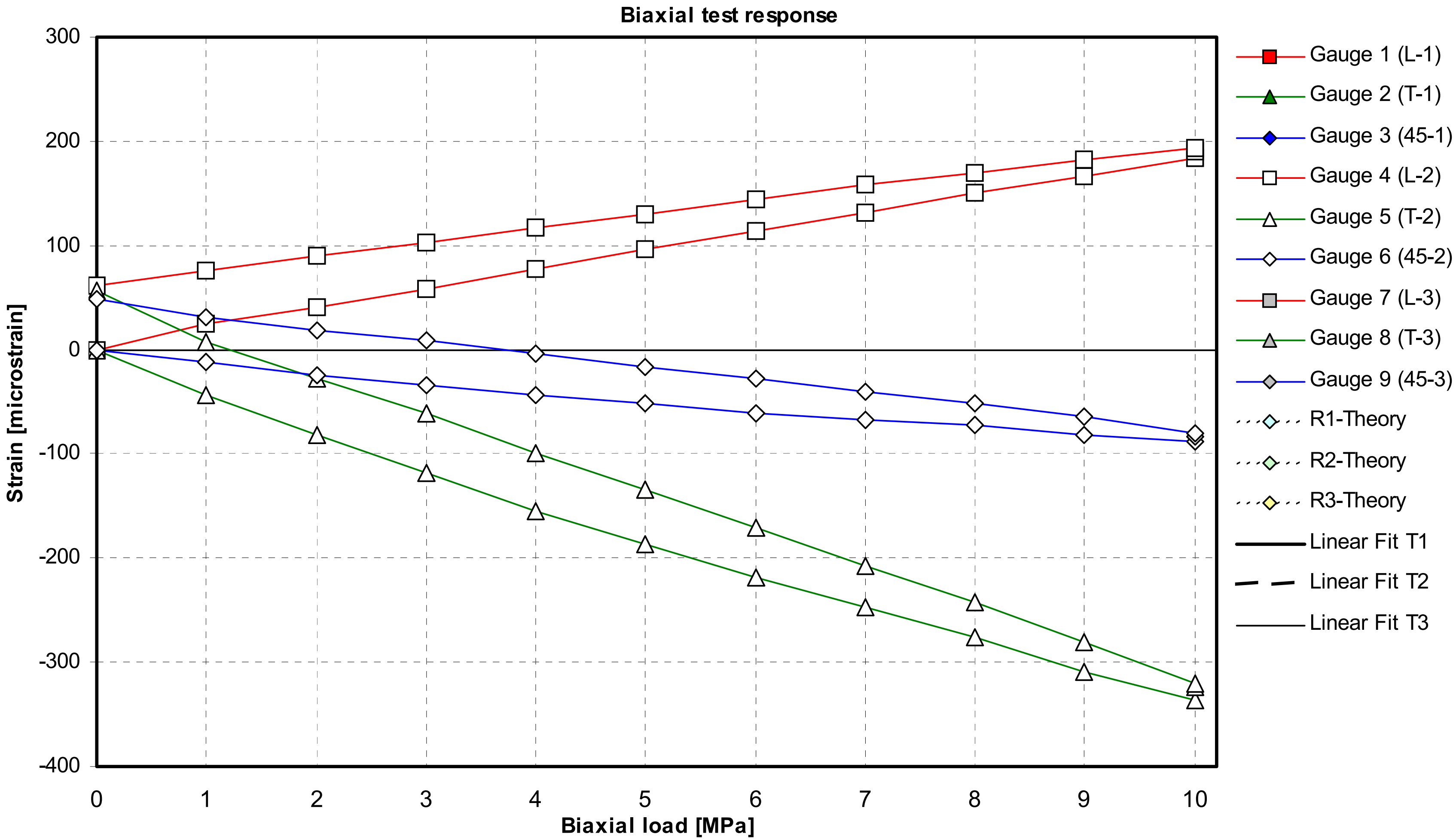


Figure C-5. *Results from biaxial testing of test no. 2:1:4, 350.10 m borehole length, excluding rosette no. 1 and 3.*

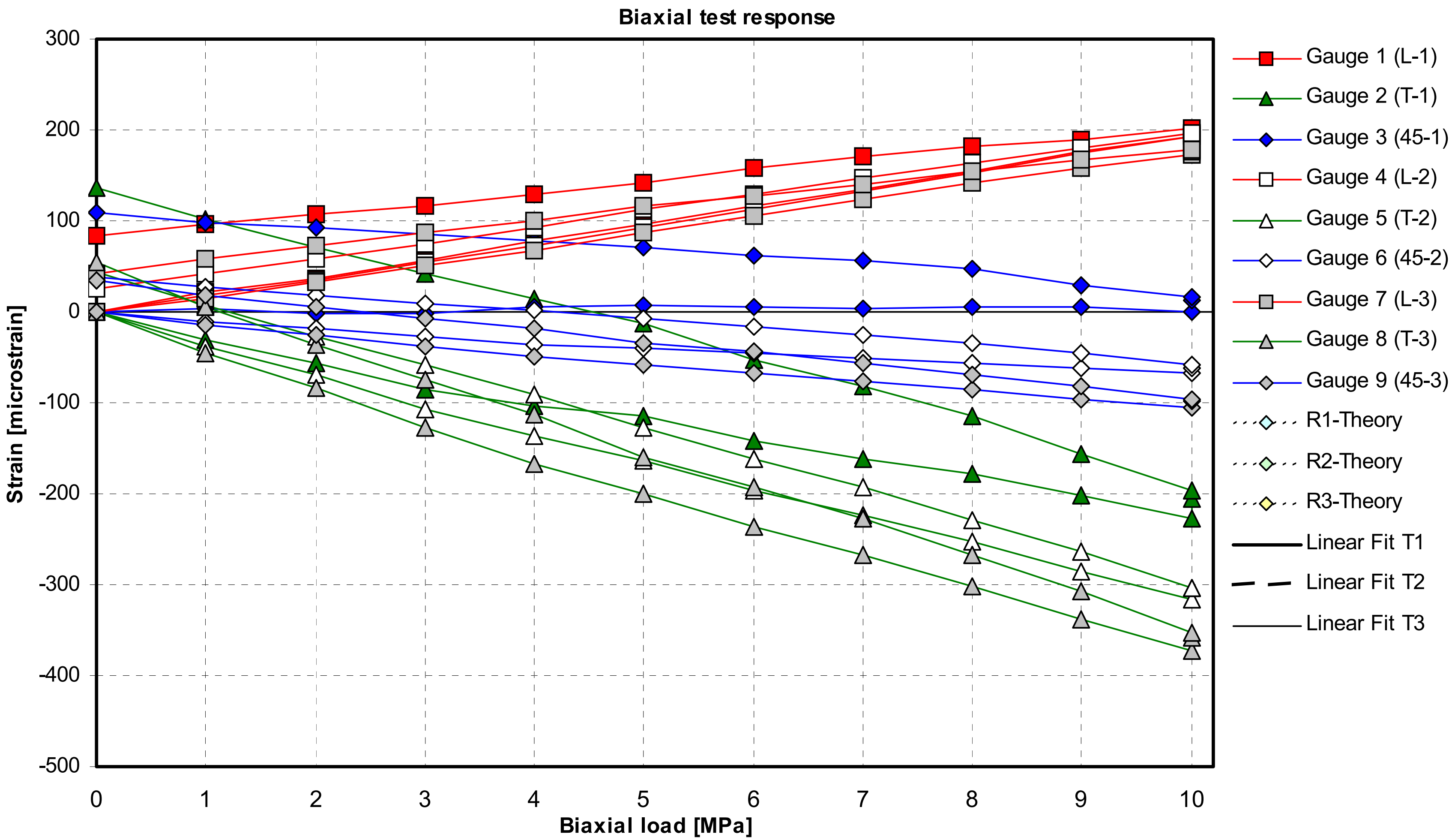


Figure C-6. *Results from biaxial testing of test no. 2:5:2, 359.58 m borehole length.*

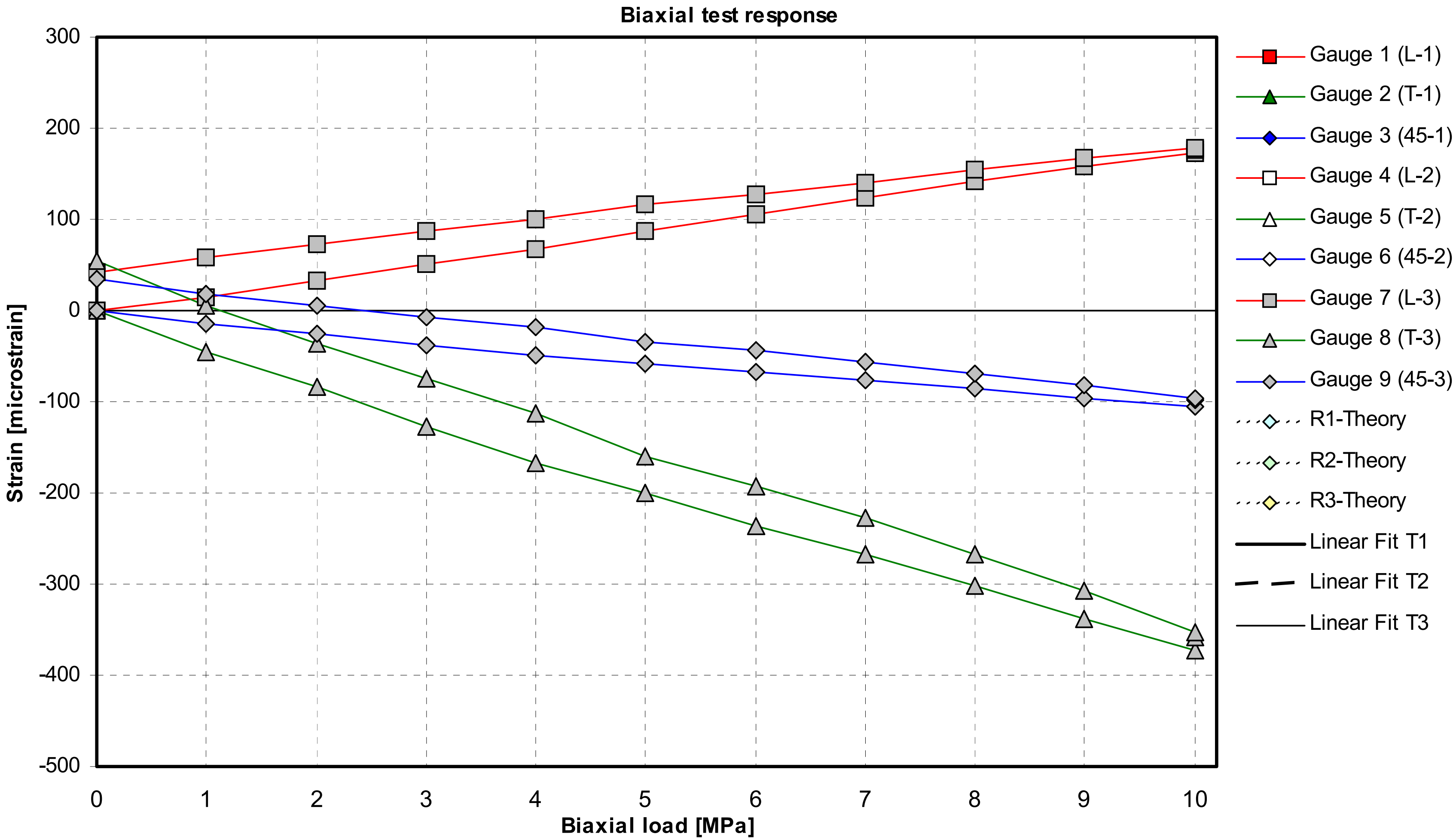


Figure C-7. *Results from biaxial testing of test no. 2:5:2, 359.58 m borehole length, excluding rosette no. 1 and 2.*

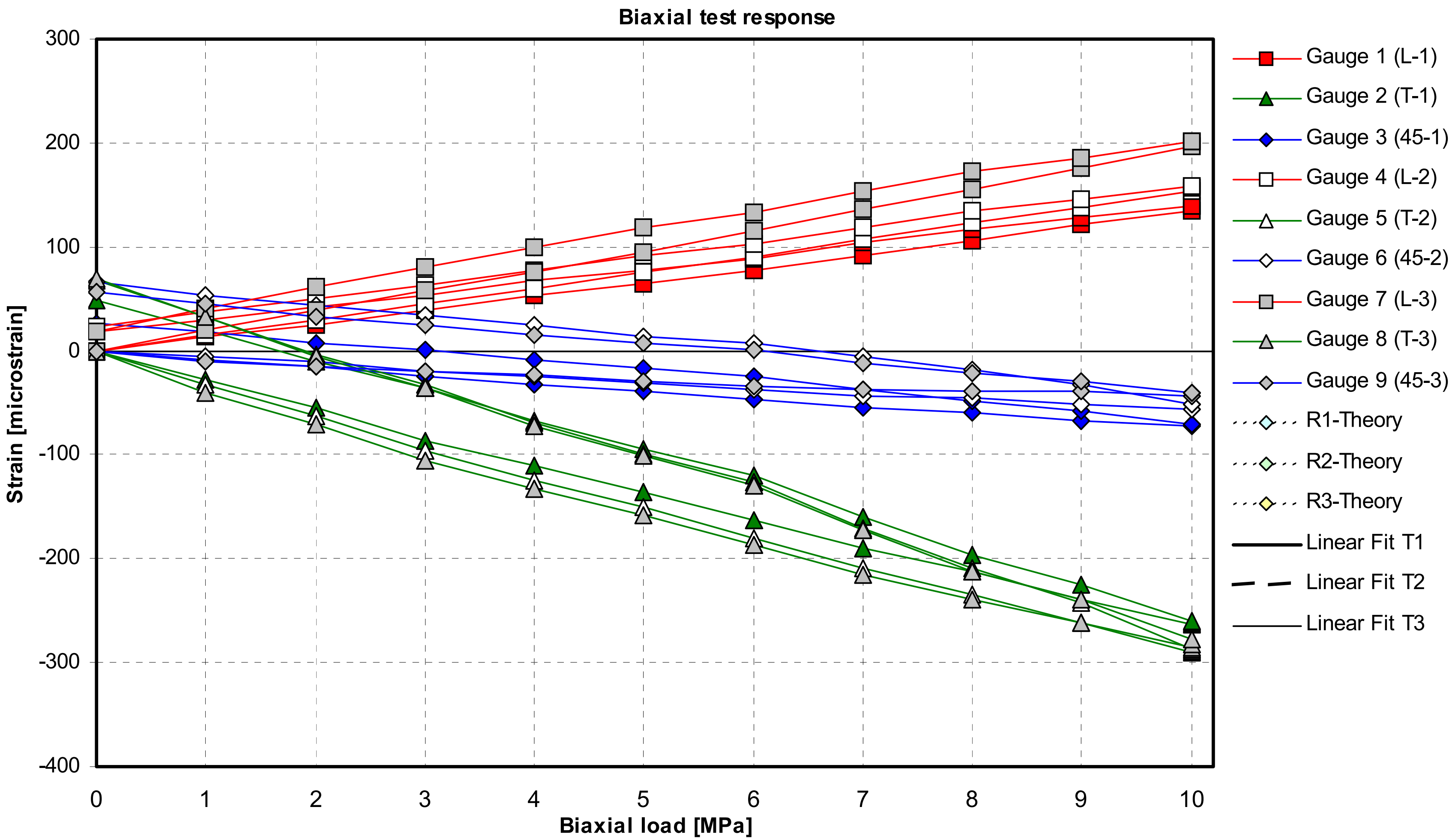


Figure C-8. *Results from biaxial testing of test no. 2:8:1, 366.38 m borehole length.*

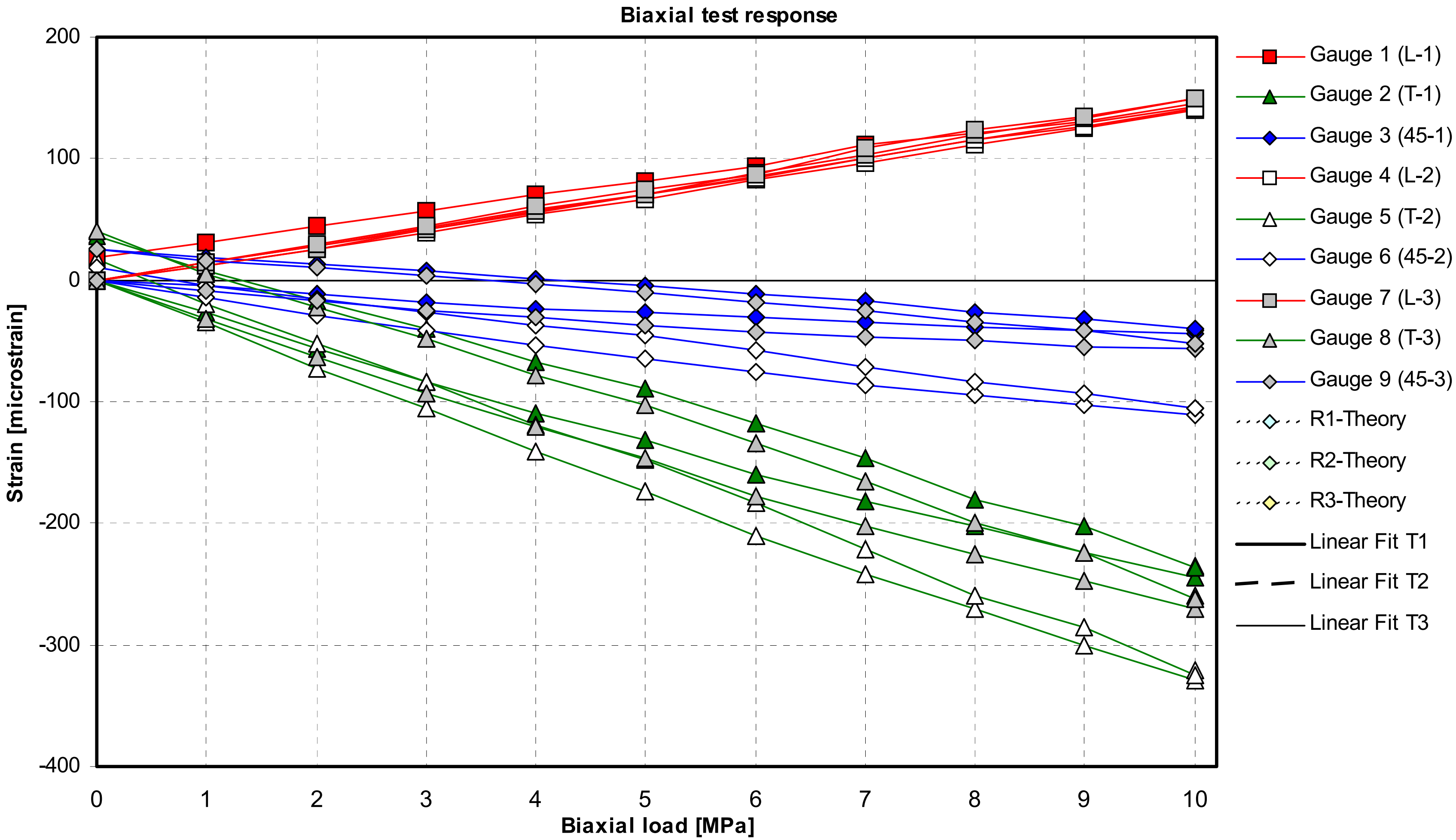


Figure C-9. *Results from biaxial testing of test no. 2:9:1, 367.40 m borehole length.*

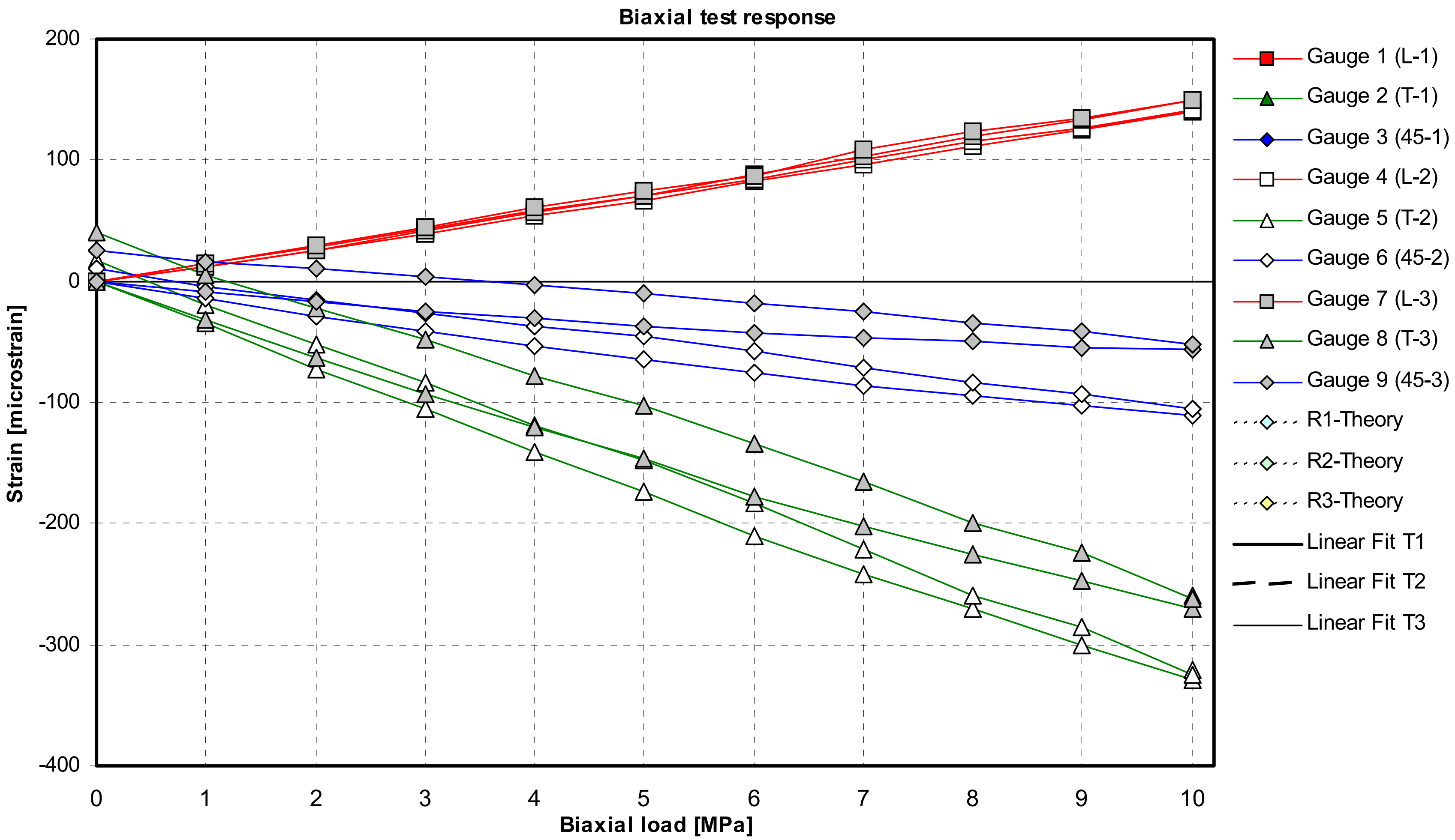


Figure C-10. *Results from biaxial testing of test no. 2:9:1, 367.40 m borehole length, excluding rosette no. 1.*

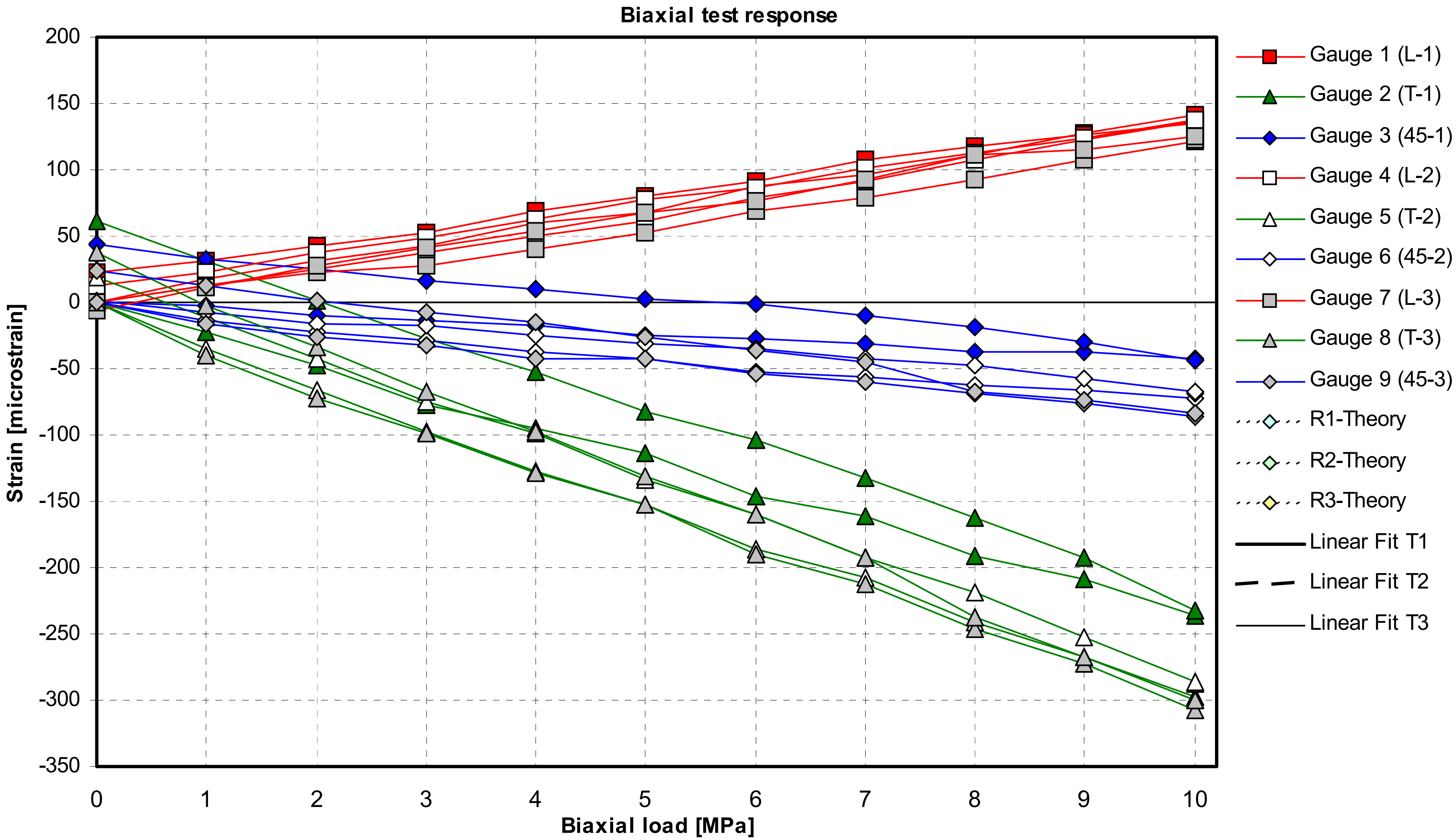


Figure C-11. Results from biaxial testing of test no. 3:2:1, 468.48 m borehole length.

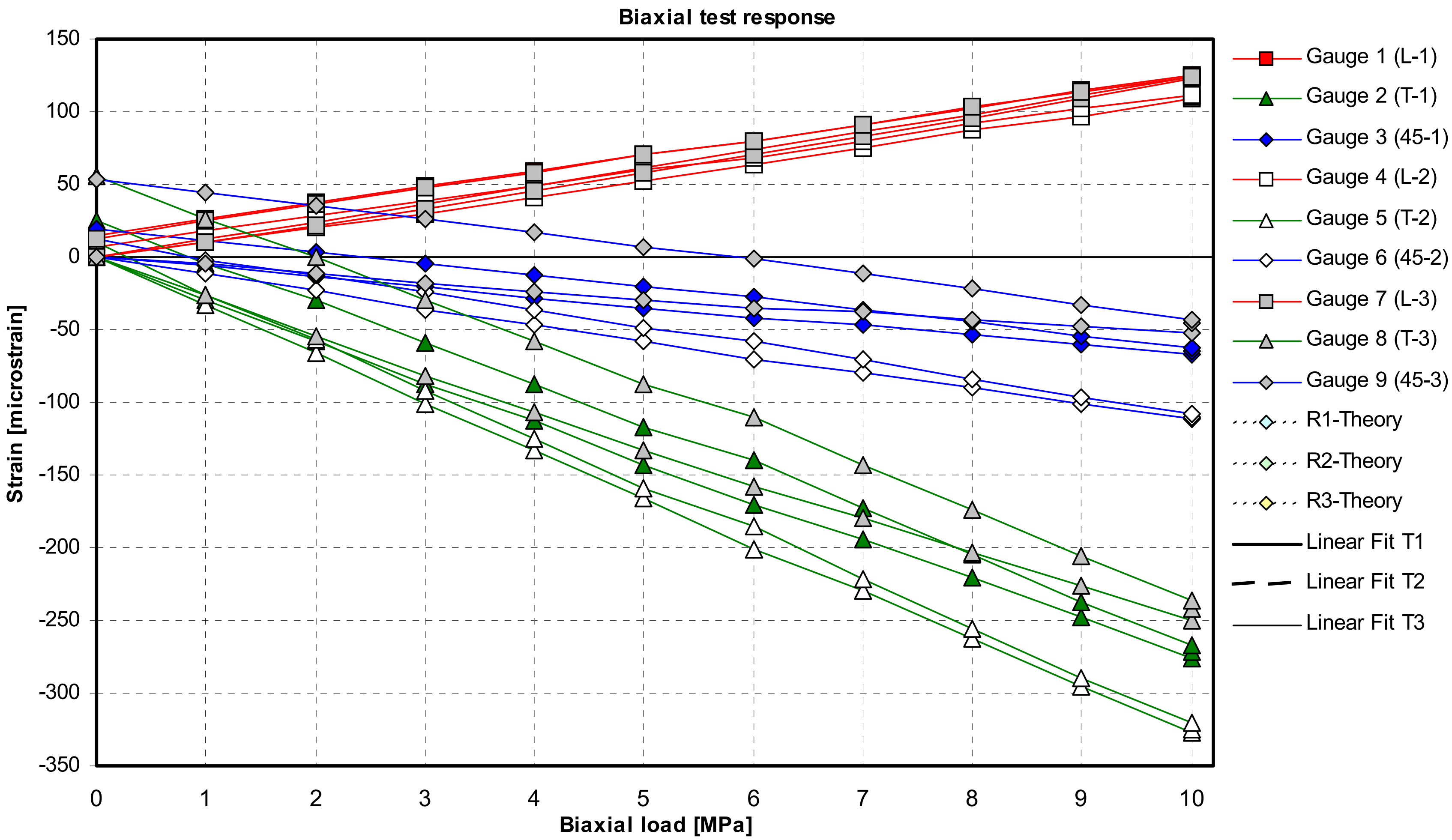


Figure C-12. *Results from biaxial testing of test no. 3:3:2, 470.79 m borehole length.*

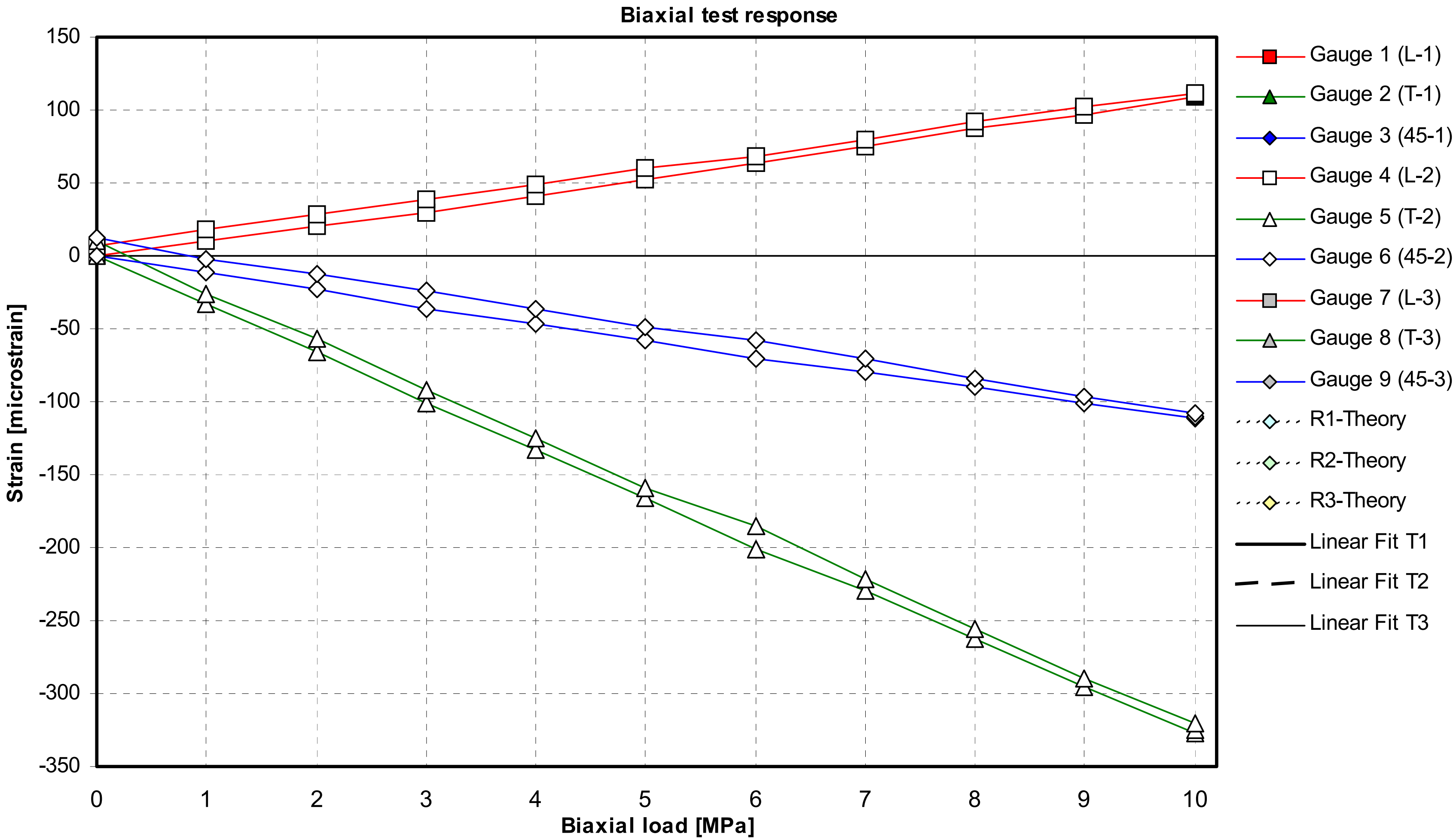


Figure C-13. *Results from biaxial testing of test no. 3:3:2, 470.79 m borehole length, excluding rosette no. 1 and 3.*

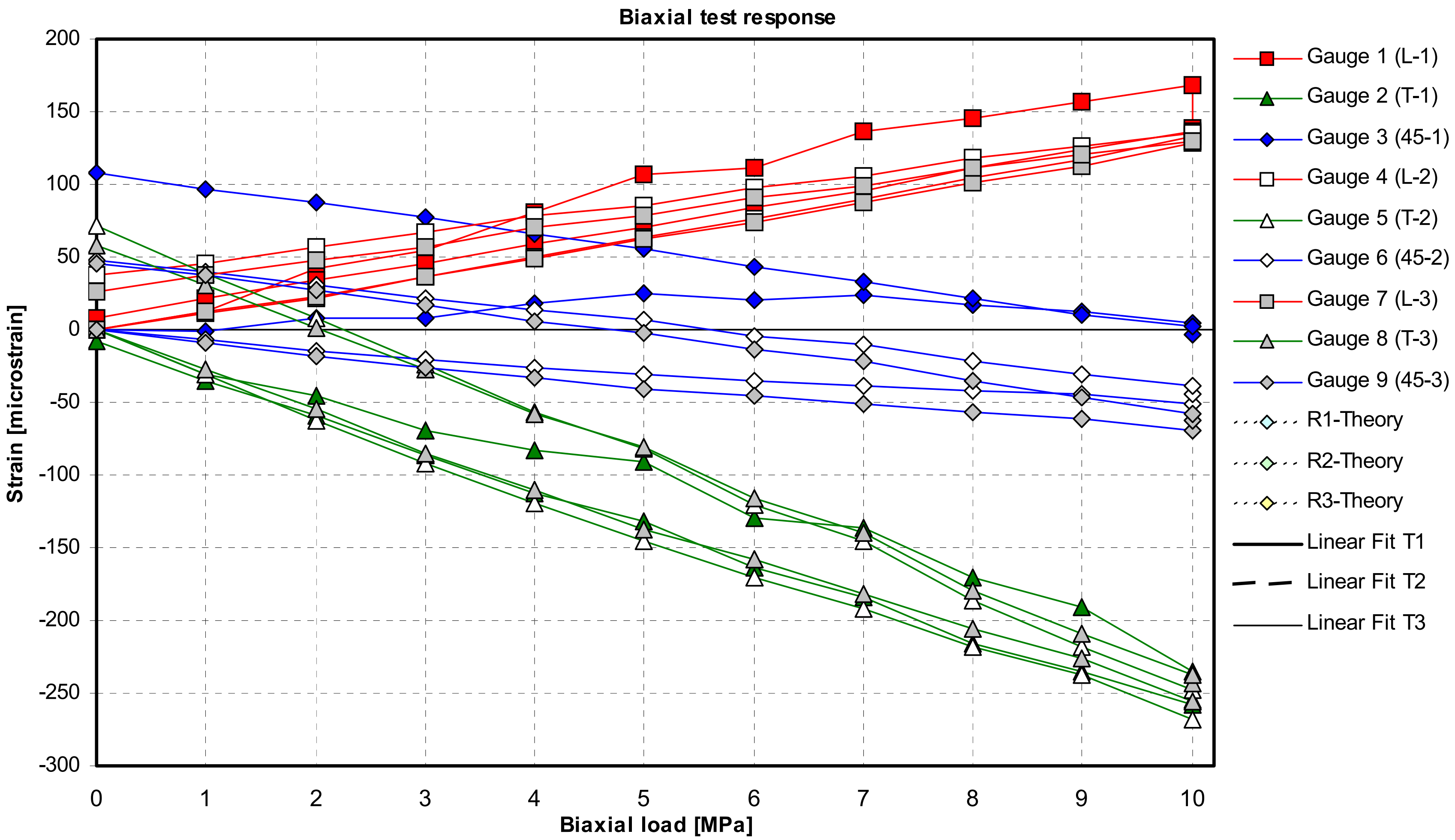


Figure C-14. *Results from biaxial testing of test no. 3:4:1, 471.92 m borehole length.*

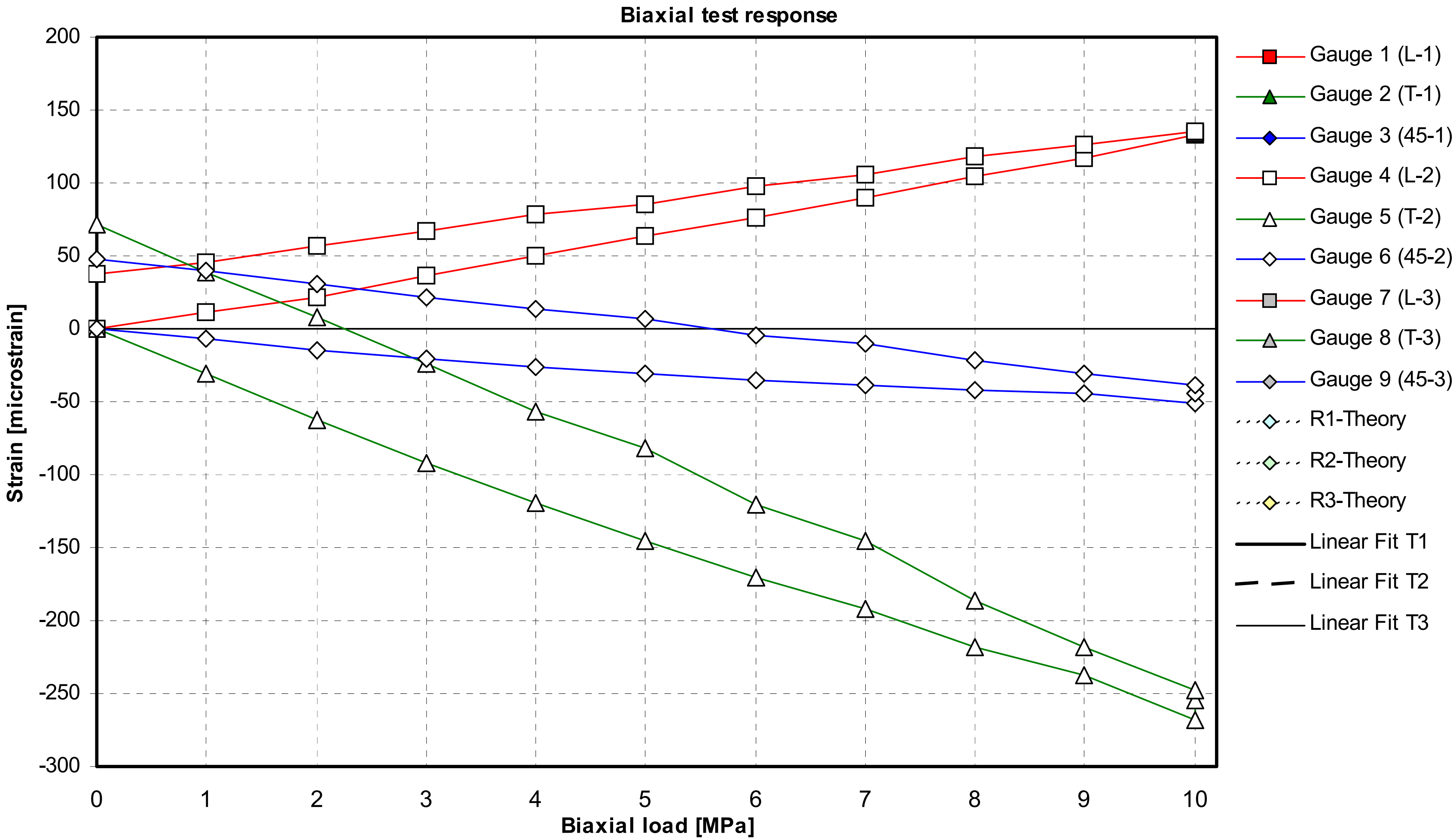


Figure C-15. *Results from biaxial testing of test no. 3:4:1, 471.92 m borehole length, excluding rosette no. 1 and 3.*

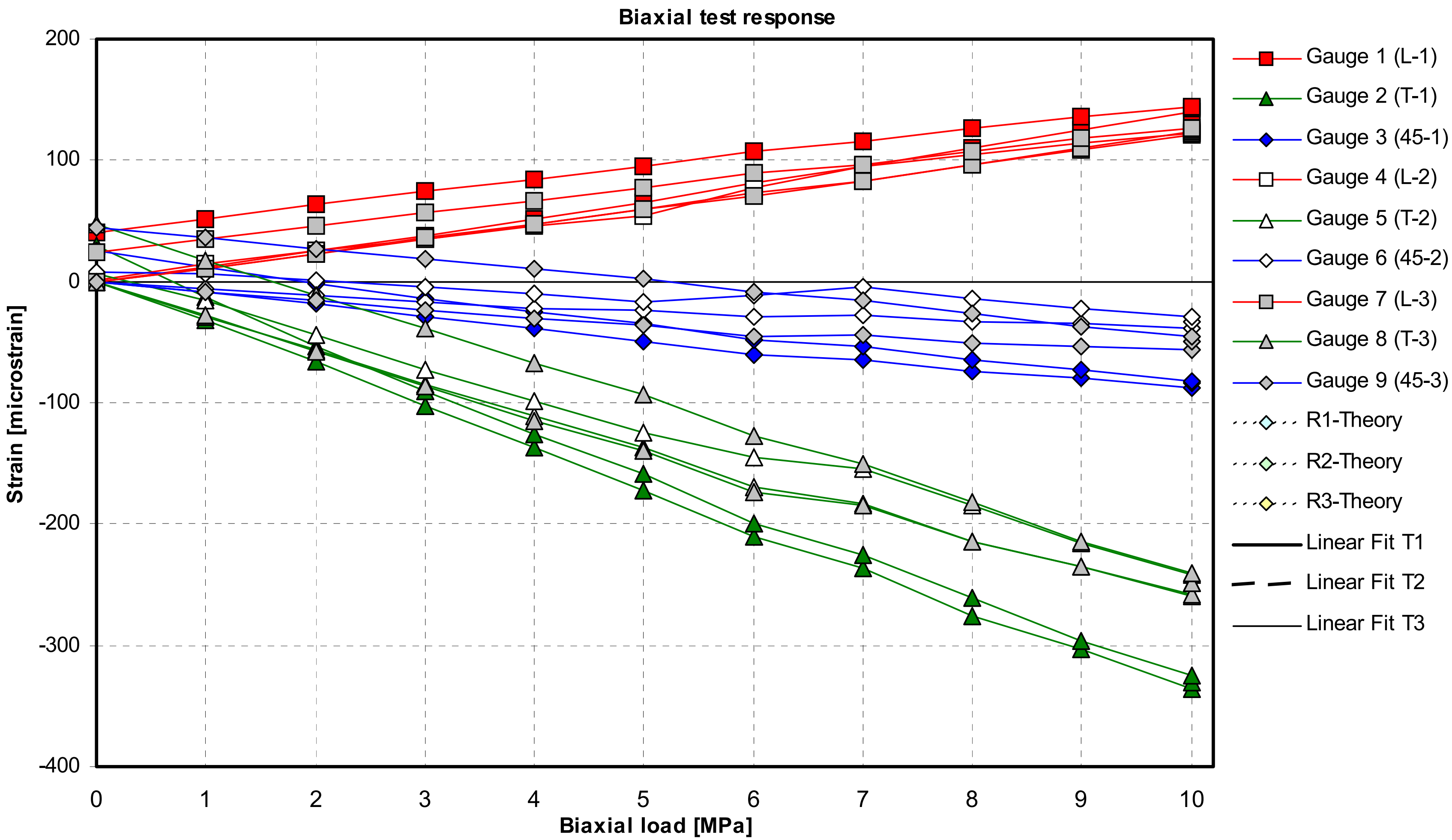


Figure C-16. *Results from biaxial testing of test no. 3:6:2, 475.41 m borehole length.*

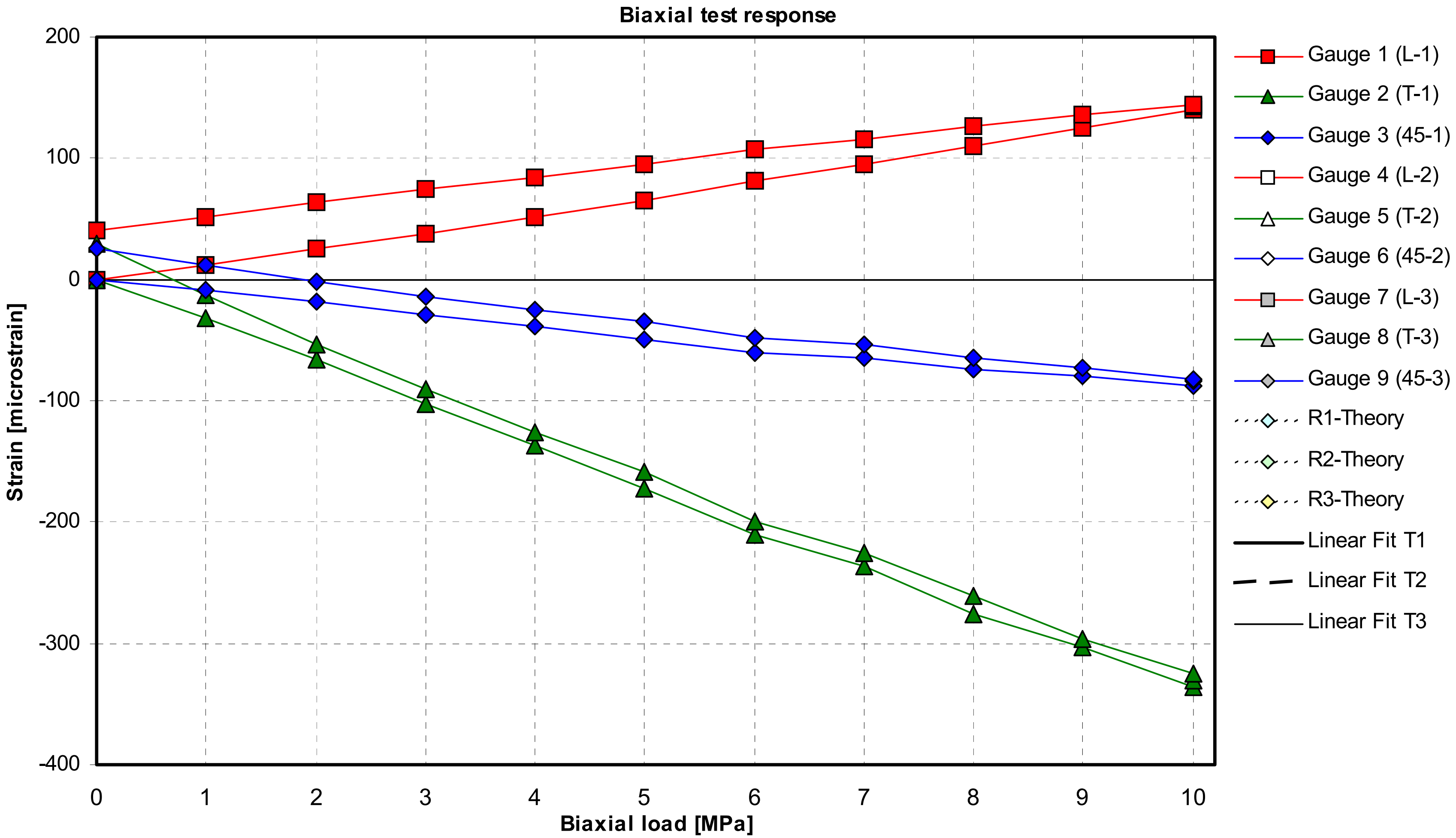


Figure C-17. *Results from biaxial testing of test no. 3:6:2, 475.41 m borehole length, excluding rosette no. 2 and 3.*

Table D-1. Measured and average in situ stresses for borehole KLX12A, Level 1, test nos. 1:4:3, 1:5:1, 1:6:2, 1:7:1, and 1:8:1.

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description : Laxemar, KLX12
Measurement Level : Level 1 - Final Results
Date : 2007-03-30

(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]	Overcoring Time [hh:mm:ss]
231.36	72.25	314.04	350	78.2	0.30	-	Start=09:04:60	Stop=09:28:20
232.40	72.25	313.89	105	78.2	0.30	-	Start=10:04:40	Stop=10:50:50
236.26	72.25	312.74	300	78.2	0.30	-	Start=07:39:30	Stop=08:26:15
237.33	72.25	312.36	340	78.2	0.30	-	Start=10:30:00	Stop=10:36:30
239.37	72.23	311.79	350	78.2	0.30	-	Start=10:18:30	Stop=10:53:35

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]
231.36	41	273	309	-54	400	43	34	22	59
232.40	109	170	259	-83	510	378	-37	215	-1
236.26	8	41	85	-27	534	105	66	-36	83
237.33	-46	395	214	-31	90	-33	-12	-6	11
239.37	31	44	59	-3	299	41	49	-4	49

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]
231.36	18.2	42.8	170.1	5.6	12.6	68.2	4.2	44.5	325.5
232.40	19.2	34.2	130.2	13.9	35.3	248.9	4.6	36.3	10.2
236.26	17.5	40.3	130.0	3.9	48.2	291.1	-0.1	9.5	31.9
237.33	11.8	23.8	118.8	2.8	44.8	234.8	-0.1	35.7	10.3
239.37	10.4	38.0	187.9	2.9	44.1	327.0	0.7	21.8	79.7
Mean	*14.0*	*40.9*	*145.3*	*6.4*	*25.7*	*260.0*	*2.7*	*38.2*	*12.2*

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?
231.36	11.8	172.7	5.5	82.7	10.7	6230.2	No
232.40	16.9	111.1	8.5	21.1	12.3	28462.2	No
236.26	11.8	127.3	0.1	37.3	9.5	4501.6	No
237.33	10.2	115.2	1.0	25.2	3.3	582.7	No
239.37	7.4	2.7	1.1	92.7	5.5	2168.2	No
Mean	*9.9*	*131.8*	*4.9*	*41.8*	*8.2*		

Table D-2. Measured and average in situ stresses for borehole KLX12A, Level 2, test nos. 2:5:2, 2:8:1, and 2:9:1.

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description : Laxemar, KLX12
Measurement Level : Level 2 - Final Results
Date : 2007-03-30

(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]	Overcoring Time [hh:mm:ss]
359.58	75.17	306.96	297	73.2	0.35	-	Start=09:53:50	Stop=10:46:15
366.38	75.16	307.2	335	91.6	0.44	-	Start=10:23:30	Stop=10:49:30
367.40	75.16	307.3	175	102.0	0.47	-	Start=10:09:30	Stop=10:29:40

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]
359.58	-22	5	30	-38	411	35	-70	351	255
366.38	-57	244	115	-24	443	271	7	-11	-54
367.40	-14	223	1	-6	238	233	3	-25	24

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]
359.58	16.6	31.2	151.0	5.1	23.1	46.0	2.2	49.4	286.2
366.38	20.1	7.1	145.7	9.2	76.7	24.0	4.7	11.2	237.1
367.40	17.8	41.0	156.3	7.1	48.2	349.5	4.0	6.6	252.1
Mean	*17.4*	*27.1*	*150.3*	*7.1*	*59.7*	*359.1*	*4.4*	*12.5*	*246.8*

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?
359.58	12.9	155.3	4.5	65.3	6.5	1195.2	No
366.38	19.9	146.1	4.8	56.1	9.2	2262.2	No
367.40	13.2	158.2	4.1	68.2	11.7	667.4	No
Mean	*15.2*	*151.9*	*4.6*	*61.9*	*9.1*		

Table D-3. Measured and average in situ stresses for borehole KLX12A, Level 3, test nos. 3:2:1, 3:3:2, 3:4:1, and 3:6:2.

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description : Laxemark, KLX12
Measurement Level : Level 3 - Final Results
Date : 2007-03-30

(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]
468.48	75.3	307.79	135	101.4	0.42	-	Start=09:57:40	Stop=10:52:60
470.79	75.29	307.76	205	92.4	0.31	-	Start=09:59:05	Stop=10:49:55
471.92	75.29	307.75	10	97.9	0.32	-	Start=10:15:00	Stop=11:11:00
475.41	75.28	307.75	30	81.8	0.29	-	Start=10:44:30	Stop=12:16:10

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]
468.48	-56	185	2	-58	352	133	-22	151	-26
470.79	-84	528	364	-53	570	130	-42	114	6
471.92	-112	405	135	-67	171	76	-95	167	-3
475.41	-112	680	367	60	344	168	11	194	32

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]
468.48	15.3	20.2	139.1	7.5	1.0	229.5	2.9	69.7	322.4
470.79	28.2	5.0	2.5	12.2	6.3	93.1	5.2	81.9	234.2
471.92	16.0	12.8	138.8	7.7	12.3	45.9	-2.0	72.1	273.5
475.41	24.3	15.6	167.7	12.0	31.3	67.9	8.4	54.2	280.5
Mean	*19.4*	*8.5*	*163.4*	*11.0*	*16.6*	*70.9*	*4.0*	*71.3*	*279.5*

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?
468.48	13.8	138.9	7.5	48.9	4.4	7016.2	No
470.79	28.1	2.3	12.1	92.3	5.4	1009.2	No
471.92	15.2	142.1	7.2	52.1	-0.7	1188.7	No
475.41	23.2	169.8	10.9	79.8	10.5	15807.4	No
Mean	*19.1*	*165.3*	*10.4*	*75.3*	*4.9*		

Transient strain analysis results

Appendix E

Table E-1. Results from transient strain analysis of selected overcoring measurements in borehole KLX12A, 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
1:4:3	231.36	Max strain amplitude [μstrain]	210	323	325	196	459	127	103	118	70	13	18	Calculated and measured strains are in good agreement for most gauges, in particular rosette no. 1. Axial gauges shows in general larger deviation. Moderate amount of unexplained strains and relative high calculated tensile stress.
		Max strain difference [%]	45	14	25	58	28	119	168	51	116			
1:5:1	232.40	Max strain amplitude [μstrain]	180	259	246	288	609	351	215	295	152	32	17	Rosette no. 1 shows the largest deviation. Tangential gauges gives good agreement, larger deviation for axial and inclined gauges. Moderate amount of unexplained strains and relative high calculated tensile stress.
		Max strain difference [%]	217	38	102	41	30	34	41	15	120			
1:6:2	236.26	Max strain amplitude [μstrain]	178	97	183	138	597	185	77	96	104	22	21	General good agreement between calculated – measured strains, for tangential strains. Moderate amount of unexplained strains and relative high calculated tensile stress.
		Max strain difference [%]	60	30	83	60	9	46	124	40	102			
1:7:1	237.33	Max strain amplitude [μstrain]	146	445	231	123	120	109	102	61	81	24	13	Fair agreement for measured and calculated strains. Moderate amount of unexplained strains, relative low calculated tensile stress. Rosette no. 3 somewhat larger deviation but in fair agree-ment.
		Max strain difference [%]	47	49	48	45	37	77	84	63	84			
1:8:1	239.37	Max strain amplitude [μstrain]	107	70	117	79	328	98	42	50	64	47	11	Fair agreement for measured and calculated strains for rosette nos 1 and 2, large deviation for rosette 3, due to low absolute strain values. Moderate amount of unexplained strains, relative low calculated tensile stress. Axial gauges shows largest deviation between meas-ured and calculated strains.
		Max strain difference [%]	88	68	79	127	74	117	318	79	134			

Table E-2. Results from transient strain analysis of selected overcoring measurements in borehole KLX12A, 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
2:1:4*	350.10	Max strain amplitude [µstrain]	*163*	*65*	*143*	*149*	*680*	*239*	*105*	*115*	*114*	*36*	*31*	Large deviations between measured and calculated strains. High amount of unexplained strains and high calculated tensile stress.
		Max strain difference [%]	*63*	*173*	*126*	*90*	*41*	*29*	*190*	*43*	*129*			
2:2:1*	351.28	Max strain amplitude [µstrain]	*118*	*50*	*89*	*104*	*479*	*174*	*85*	*83*	*72*	*26*	*21*	Large deviations between measured and calculated strains. High amount of unexplained strains and high calculated tensile stress.
		Max strain difference [%]	*83*	*95*	*125*	*151*	*31*	*61*	*190*	*87*	*109*			
2:5:2	359.58	Max strain amplitude [µstrain]	258	93	127	200	463	72	171	390	267	15	19	In general good agreement between calculated and measured strains, especial for tangential strains. Only larger deviation on gauge G7 (axial). Low amount of unexplained strains, though relative high calculated tensile stress.
		Max strain difference [%]	57	50	53	46	15	180	57	20	45			
2:8:1	366.38	Max strain amplitude [µstrain]	175	293	134	214	512	276	196	88	129	12	23	In general good agreement between calculated and measured strains, especial for tangential strains. Only larger deviation on gauge G3 (inclined). Low amount of unexplained strains, though relative high calculated tensile stress.
		Max strain difference [%]	34	20	76	29	19	20	29	23	38			
2:9:1	367.40	Max strain am-plitude [µstrain]	117	263	42	111	277	233	165	57	91	9	22	In general good agreement between calculated and measured strains, especial for tangential strains. Only larger deviation on gauge G3 (inclined) and possibly for G4 (axial). Low amount of unexplained strains, though relative high calculated tensile stress.
		Max strain difference [%]	38	21	167	74	22	17	64	41	23			

*) Not included in calculation of average stress for Level 2.

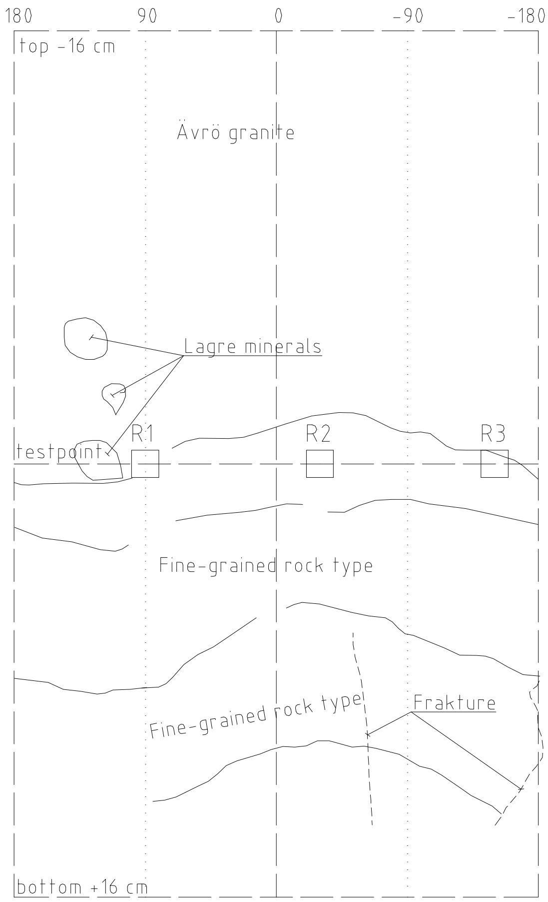
Table E-3. Results from transient strain analysis of selected overcoring measurements in borehole KLX12A, Level 3.

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
3:2:1	468.48	Max strain amplitude [μstrain]	174	203	55	194	380	182	194	175	61	34	17	In general fair agreement between calculated and measured strains, especial for tangential strains. Only larger deviation on gauge G3 and G9 (both inclined). Moderate amount of unexplained strains, and relative high measured tensile stress.
		Max strain difference [%]	73	57	242	97	27	30	37	49	130			
3:3:2	470.79	Max strain amplitude [μstrain]	333	593	402	343	643	182	257	216	75	11	29	In general good agreement between calculated and measured strains, especial for tangential strains. Only larger deviation on gauge G9 (inclined). Low amount of unexplained strains and relative high measured tensile stress.
		Max strain difference [%]	39	37	12	36	29	74	54	35	88			
3:4:1	471.92	Max strain amplitude [μstrain]	196	446	159	211	211	90	219	206	47	11	17	In general good agreement between calculated and measured strains, especial for tangential strains. Only larger deviation on gauge G9 (inclined). Low amount of unexplained strains and relative high measured tensile stress.
		Max strain difference [%]	37	27	37	42	38	48	45	43	151			
3:6:2	475.41	Max strain amplitude [μstrain]	291	756	390	310	414	178	286	282	97	31	20	In general good agreement between calculated and measured strains, especial for tangential strains. Only larger deviation on gauge G3, G4 and possibly for G9 (inclined and axial gauges). Moderate amount of unexplained strains and relative high measured tensile stress.
		Max strain difference [%]	94	45	35	65	35	76	51	39	172			

Appendix F

Overcore logging sheets

OVERCORE SAMPLE LOG
Borehole no., test no., depth : **KLX12, Test no. 1:4:3, 231.36 m depth**



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

GEOLOGY

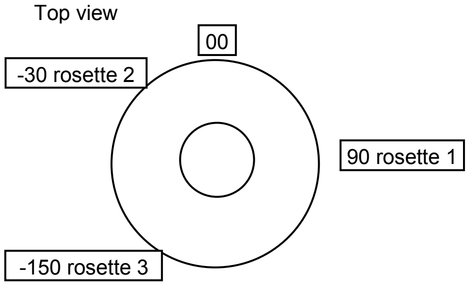
Äspö granite and band of fine-grained rock. Some larger mineral grains of feldspar.

STRUCTURES (JOINTS)

Some fractures at the bottom portion.

Mark any observed fractures

Top view

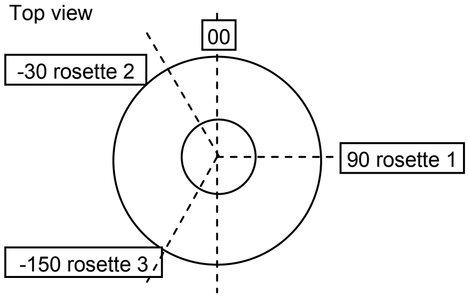


COMMENTS

Strain gauge orientation OK.

Control of strain gauge orientation

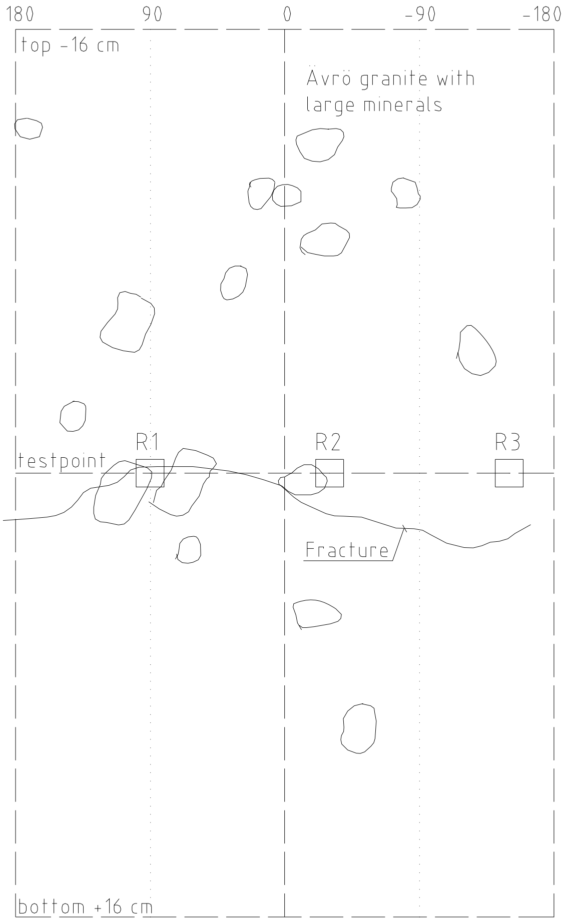
Top view



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 : KLX12, Test no. 1:5:1, 232.40 m depth



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

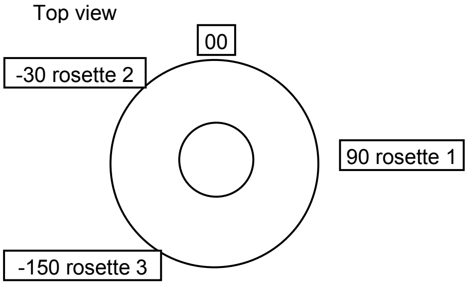
GEOLOGY

Ävrö granite with large minerals

STRUCTURES (JOINTS)

Fracture at test point, not seen on pilot core. The core failed at the fracture after biaxial testing.

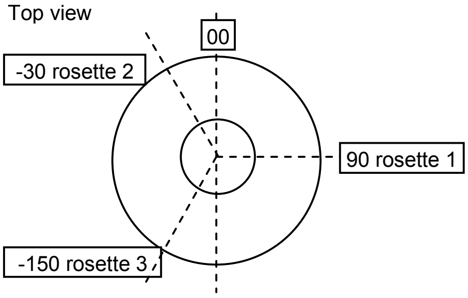
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

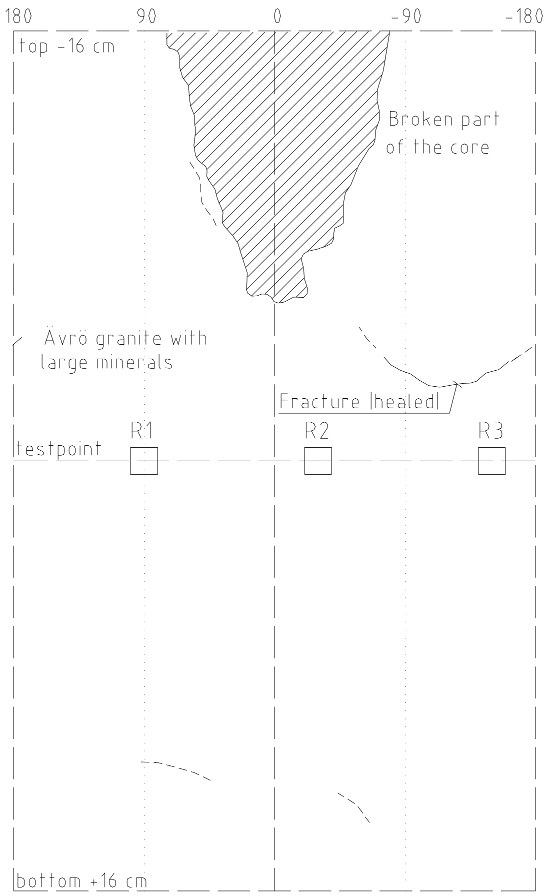
Control of strain gauge orientation



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 : **KLX12, Test no. 1:6:2, 236.26 m depth**



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

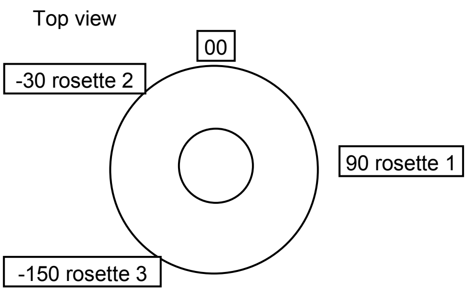
GEOLOGY

Coarse-grained, porous to slightly foliated granite.

STRUCTURES (JOINTS)

Some healed fractures.

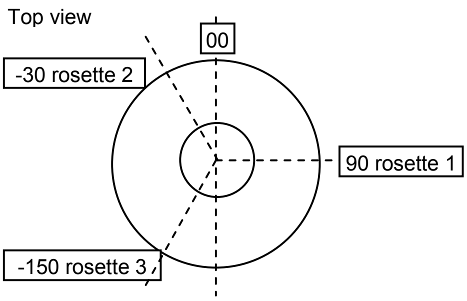
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

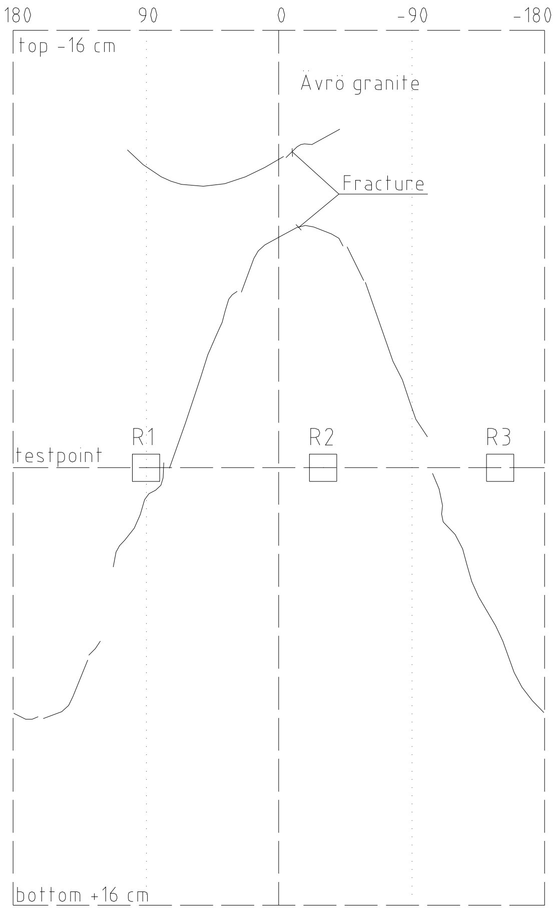
Control of strain gauge orientation



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 : KLX12, Test no. 1:7:1, 237.33 m depth



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

GEOLOGY

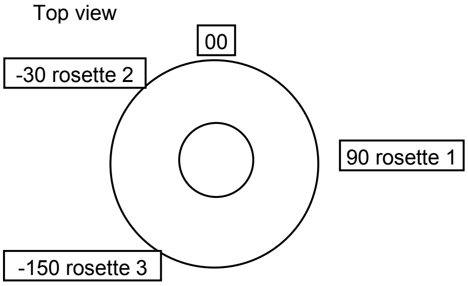
Ävrö granite.

STRUCTURES (JOINTS)

Healed fractures.

Mark any observed fractures

Top view

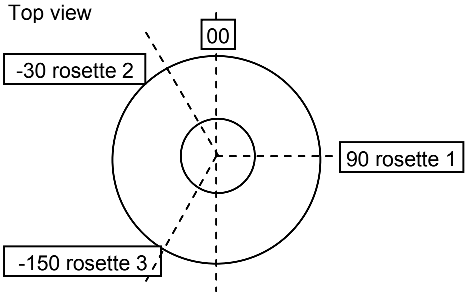


COMMENTS

Strain gauge orientation OK.

Control of strain gauge orientation

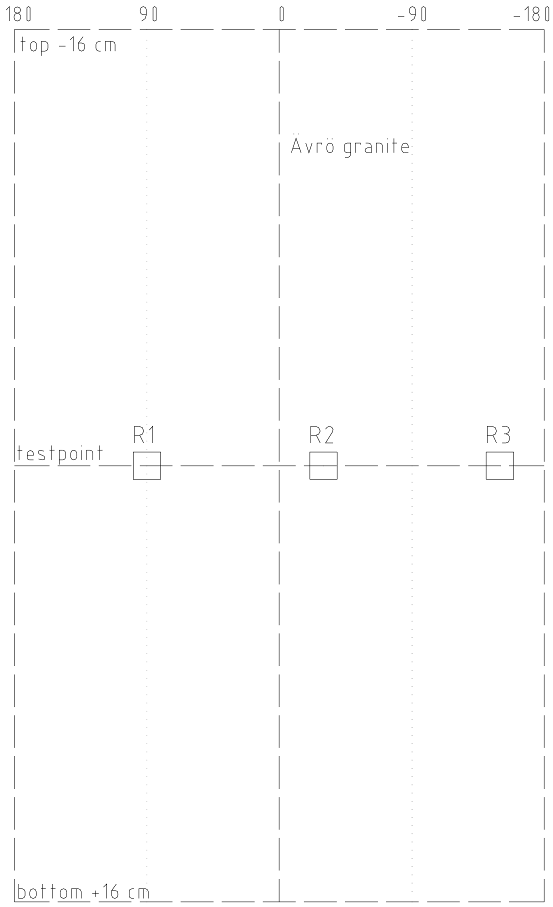
Top view



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 : **KLX12, Test no. 1:8:1, 239.37 m depth**



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

GEOLOGY

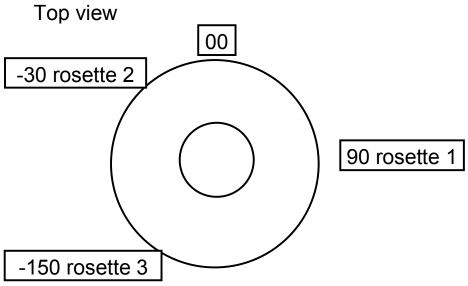
Ävrö granite.

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

Mark any observed fractures

Top view

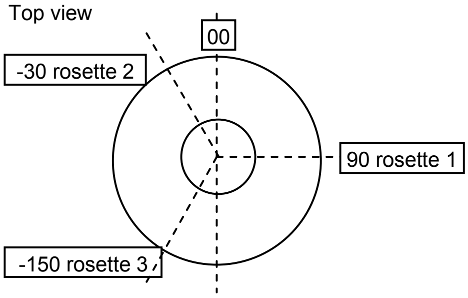


COMMENTS

Strain gauge orientation OK.

Control of strain gauge orientation

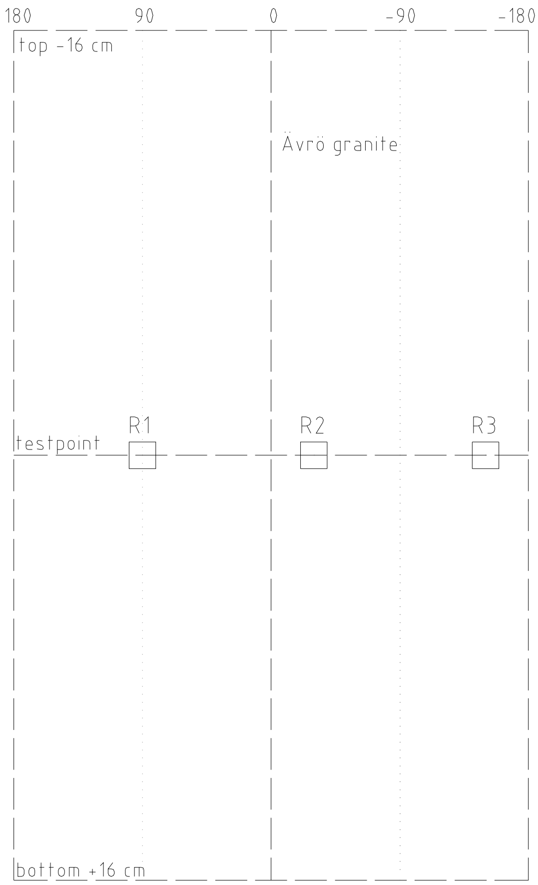
Top view



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 : **KLX12, Test no. 2:1:4, 350.10 m depth**



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

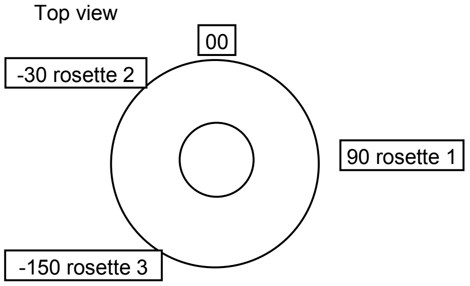
GEOLOGY

Granite

STRUCTURES (JOINTS)

No fractures before or after biaxial testing.

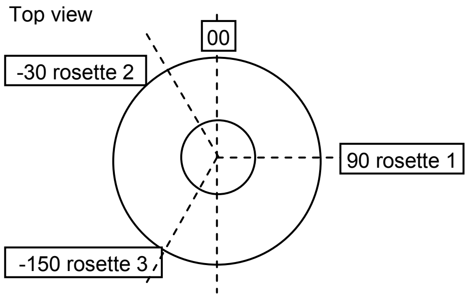
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

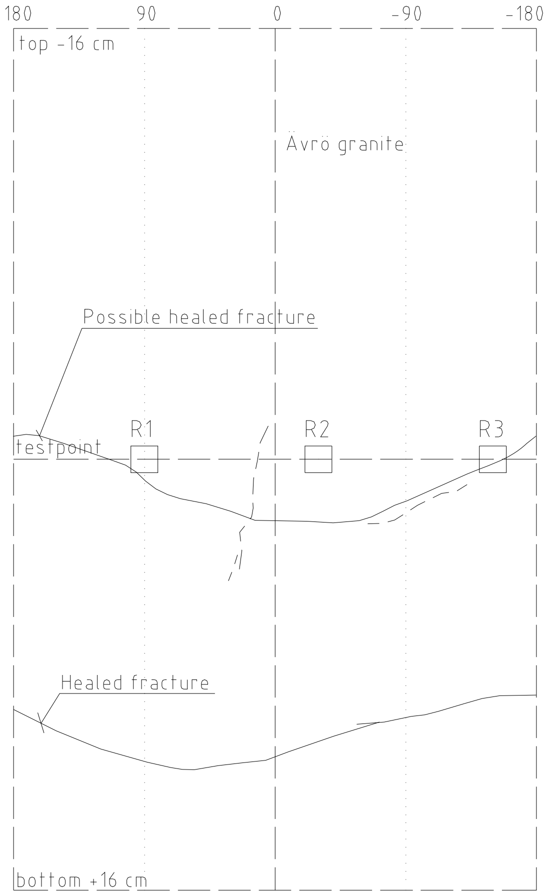
Control of strain gauge orientation



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 : **KLX12, Test no. 2:2:1, 351.28 m depth**



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

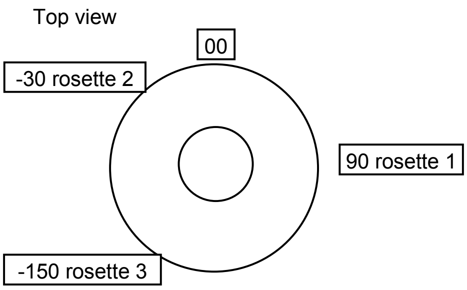
GEOLOGY

Ävrö granite

STRUCTURES (JOINTS)

Healed fractures at test point and at +9 cm.

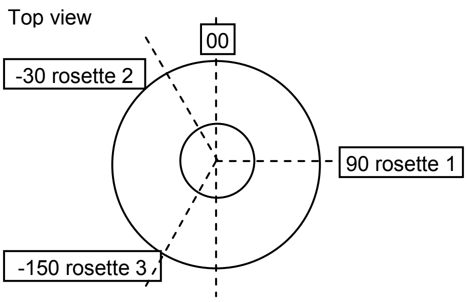
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

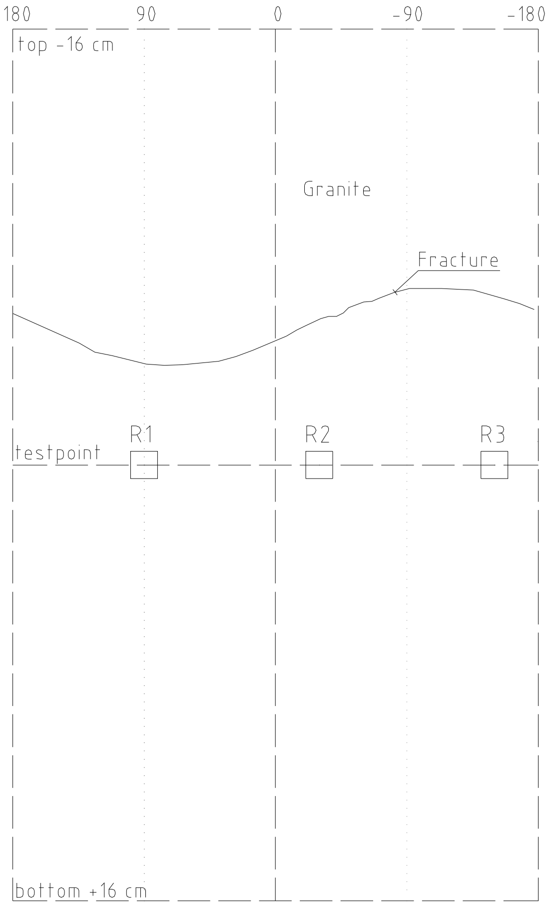
Control of strain gauge orientation



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 : KLX12, Test no. 2:5:2, 359.58 m depth



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

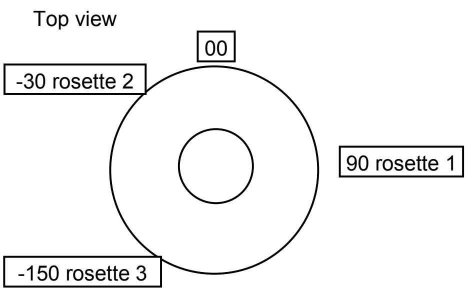
GEOLOGY

Granite with large feldspar grains.

STRUCTURES (JOINTS)

Fracture at -4 cm.

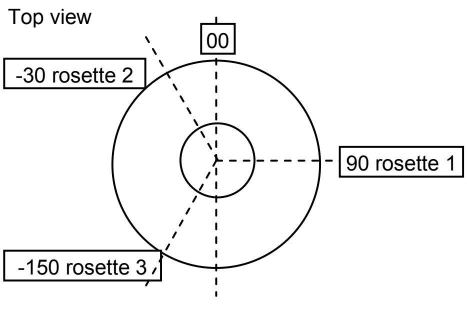
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

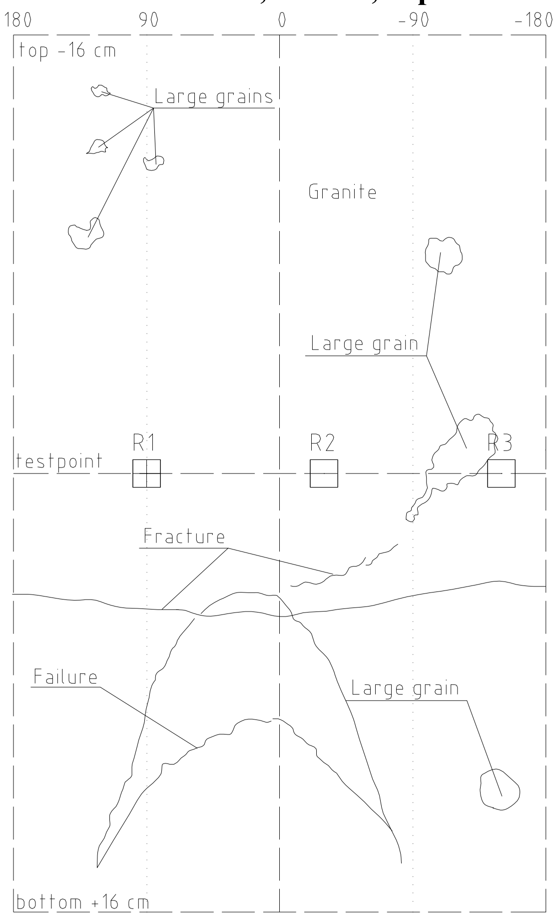
Control of strain gauge orientation



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 : **KLX12, Test no. 2:8:1, 366.38 m depth**



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

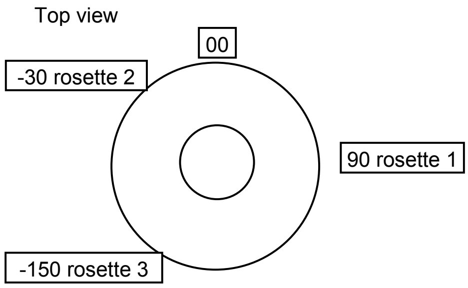
GEOLOGY

Granite. One large grain close to rosette 3 (not visible on the pilot core).

STRUCTURES (JOINTS)

Fractures at +4 cm and below.

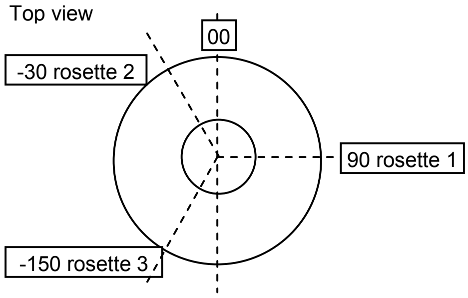
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

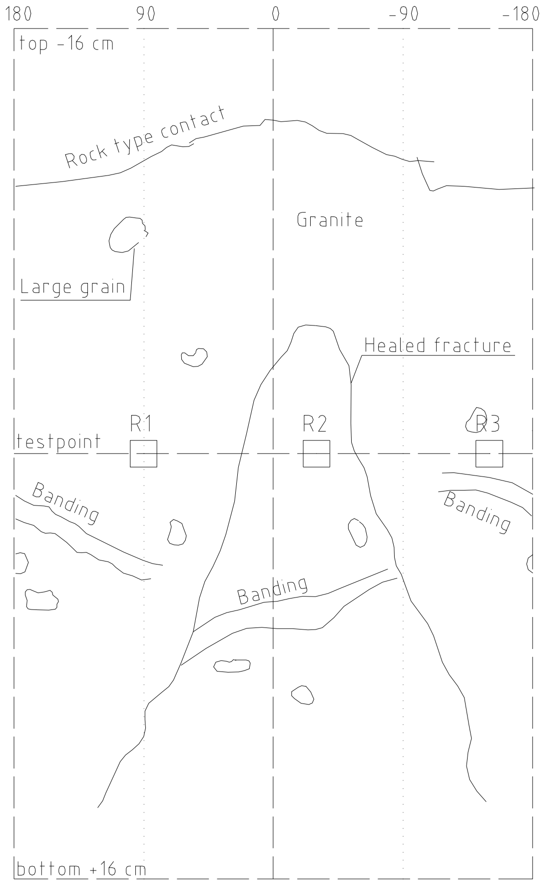
Control of strain gauge orientation



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 : **KLX12, Test no. 2:9:1, 367.40 m depth**



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

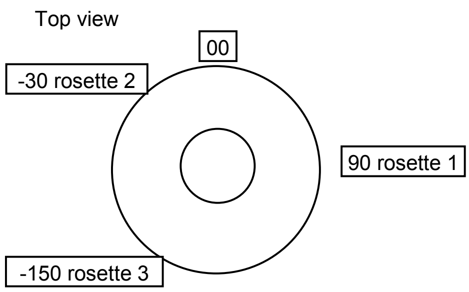
GEOLOGY

Granite with some large grains.

STRUCTURES (JOINTS)

One healed fracture around rosette 2. Some banding at +2 to +8 cm.

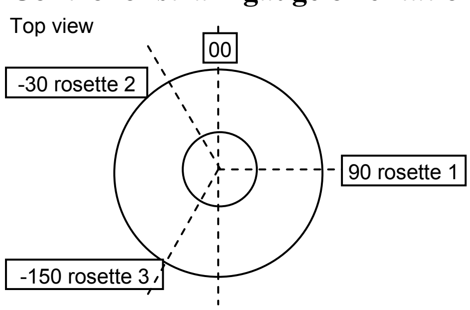
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

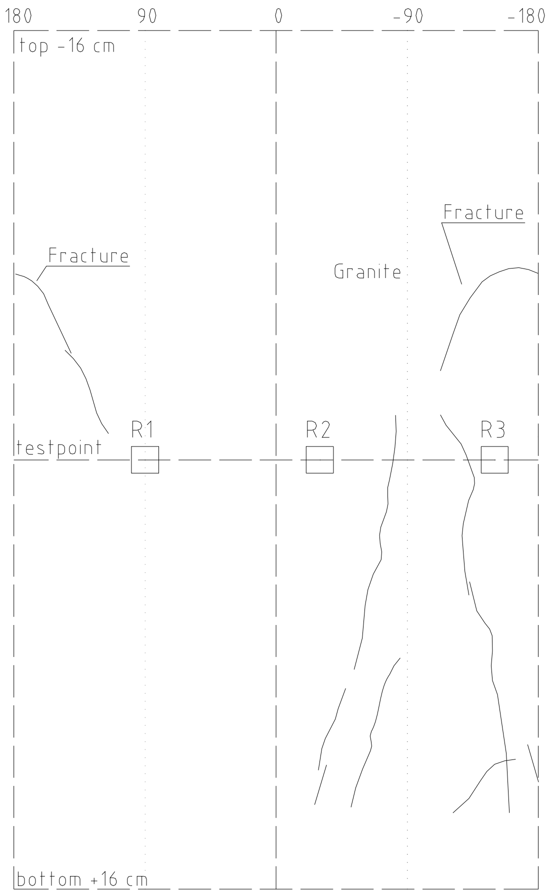
Control of strain gauge orientation



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 : **KLX12, Test no. 3:2:1, 468.48 m depth**



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

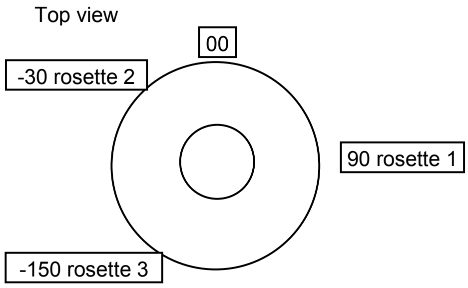
GEOLOGY

Granite.

STRUCTURES (JOINTS)

Some fractures above and below the installation.

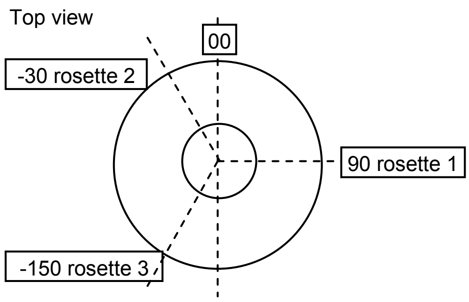
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

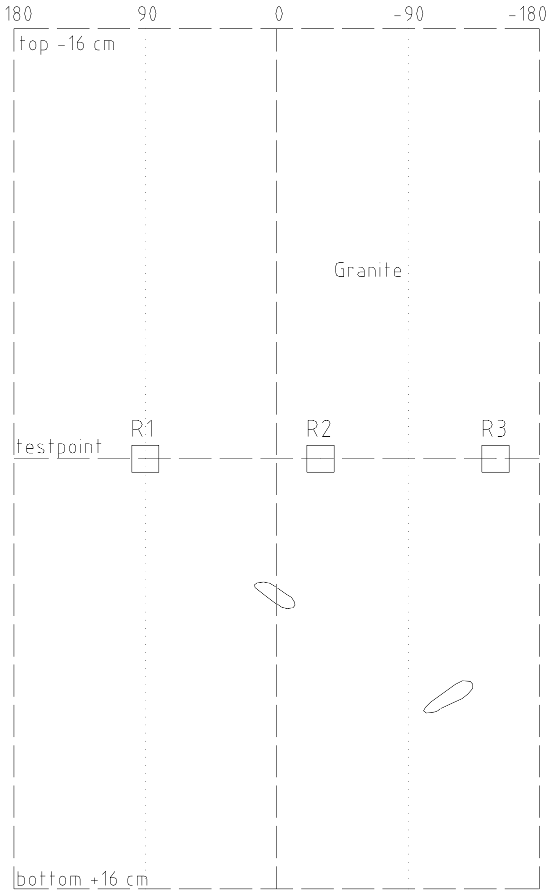
Control of strain gauge orientation



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 : KLX12, Test no. 3:3:2, 470.79 m depth



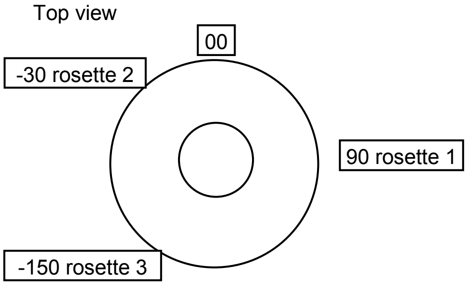
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

Granite with some large grains.

STRUCTURES (JOINTS)

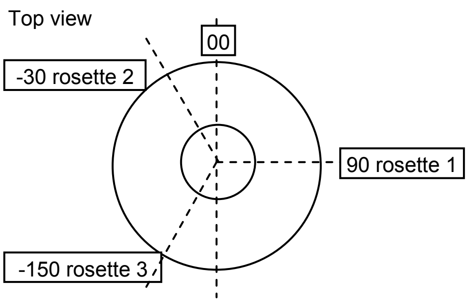
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

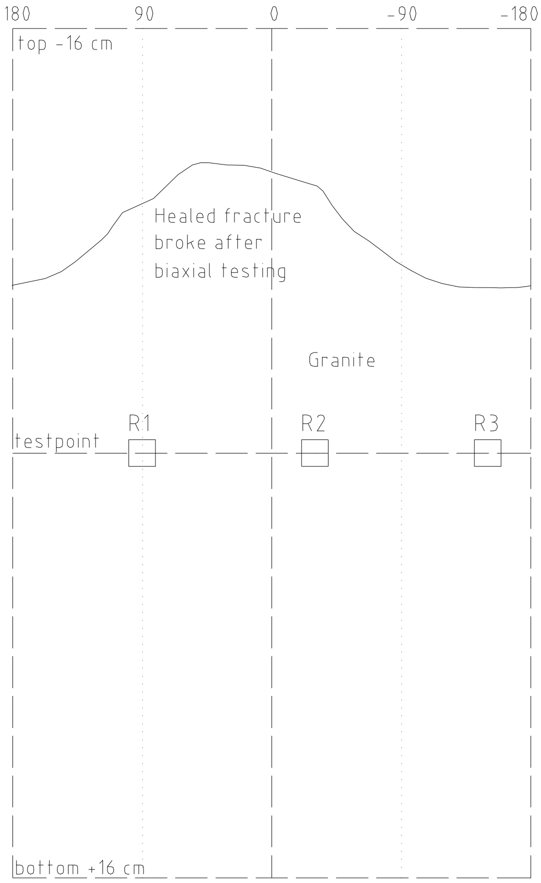
Control of strain gauge orientation



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 : **KLX12, Test no. 3:4:1, 471.92 m depth**



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

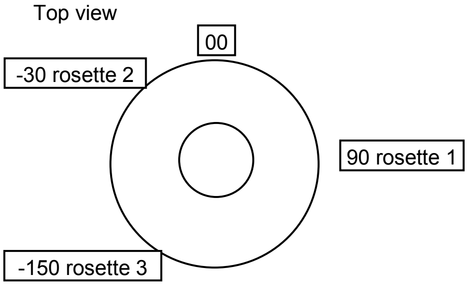
GEOLOGY

Granite.

STRUCTURES (JOINTS)

One healed fracture, broken after biaxial testing.

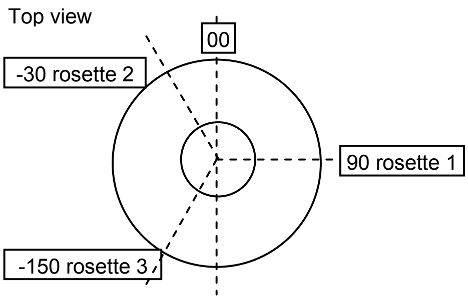
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

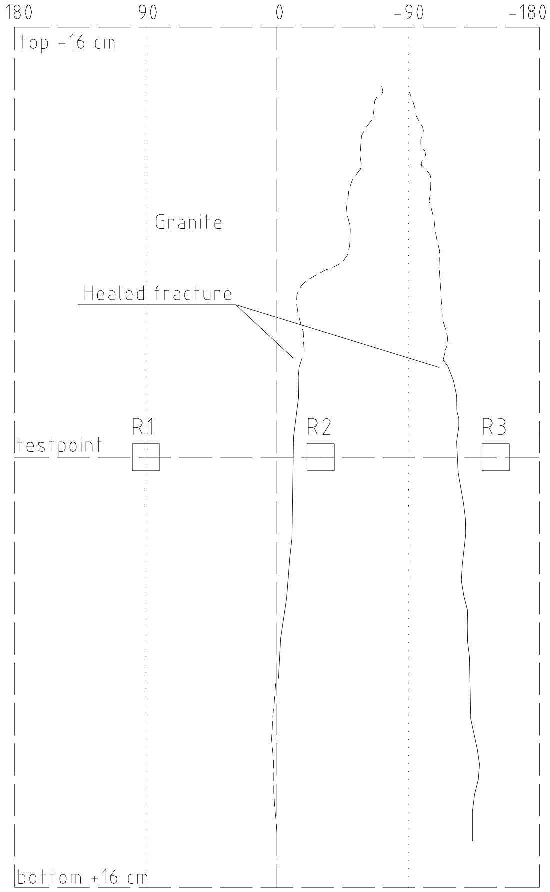
Control of strain gauge orientation



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 : **KLX12, Test no. 3:6:2, 475.41 m depth**



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

GEOLOGY

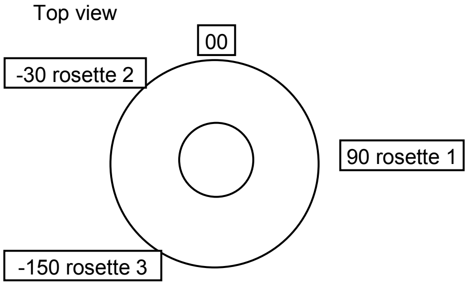
Granite.

STRUCTURES (JOINTS)

One healed fracture around rosette 2.

Mark any observed fractures

Top view

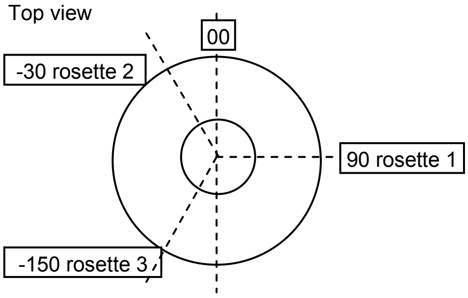


COMMENTS

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.

Appendix G

Photos of core samples

1:3:1, 227.97 m – pilot core

1:3:1, 227.97 m – overcore sample (30 cm)

1:4:3, 231.36 m – pilot core (30 cm)

Photo missing

1:4:3, 231.36 m – overcore sample (30 cm)

Figure G-1. *Photos of pilot core and overcore sample for borehole KLX12A, Level 1.*

1:5:1, 232.40 m – pilot core (30 cm)

1:5:1, 232.40 m – overcore sample (30 cm)

1:6:2, 236.26 m – pilot core (30 cm)

1:6:2, 236.26 m – overcore sample (30 cm)

1:7:1, 237.33 m – pilot core

Figure G-1. *(Continued).*

1:7:1, 237.33 m – overcore sample (30 cm)

1:8:1, 239.37 m – pilot core (fractures occurred during core handling)

1:8:1, 239.37 m – overcore sample (30 cm)

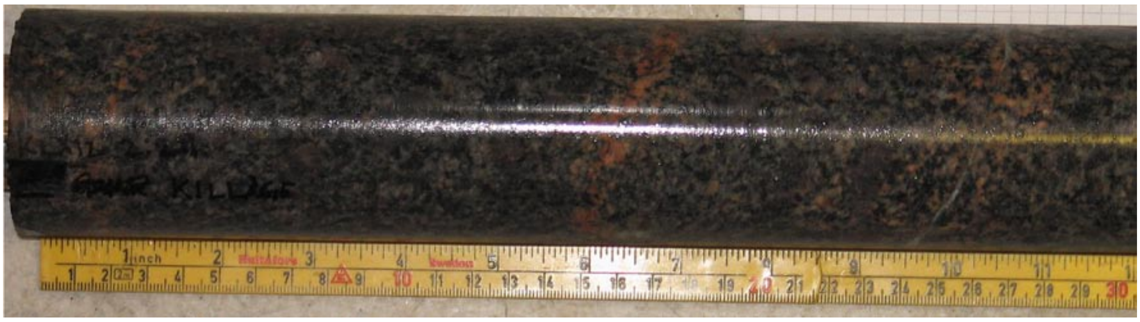
Figure G-1. *(Concluded).*

2:1:4, 350.10 m – pilot core (30 cm)

2:1:4, 350.10 m – overcore sample (30 cm)

2:2:1, 351.28 m – pilot core (30 cm)

2:2:1, 351.28 m – overcore sample (30 cm)



2:3:3, 355.23 m – pilot core (30 cm)

Figure G-2. *Photos of pilot core and overcore sample for borehole KLX12A, Level 2.*

2:3:3, 355.23 m – overcore sample (30 cm)

2:4:2, 357.39 m – pilot core (30 cm)

2:4:2, 357.39 m – overcore sample (30 cm)

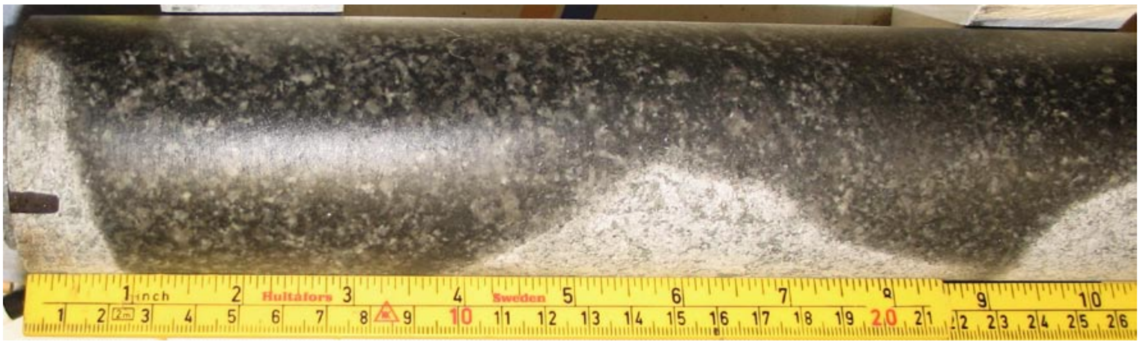
Figure G-2. *(Concluded).*

3:2:1, 468.48 m – pilot core (30 cm)

3:2:1, 468.48 m – overcore sample (30 cm)

3:3:2, 470.79 m – pilot core (30 cm)

3:3:2, 470.79 m – overcore sample (30 cm)



3:4:1, 471.92 m – pilot core (30 cm)

Figure G-3. *Photos of pilot core and overcore sample for borehole KLX12, Level 3.*

3:4:1, 471.92 m – overcore sample (30 cm)

3:6:2, 475.41 m – pilot core (30 cm)

3:6:2, 475.41 m – overcore sample (30 cm)

Figure G-3. *(Concluded).*

Appendix H

Confidence intervals for measured stresses

Table H-1. 90%-confidence intervals for the principal stresses as determined from overcoring measurements in borehole KLX12A.

Level		Magnitude and Trend/Plunge of principal stresses σ_1 [MPa]	[°]	σ_2 [MPa]	[°]	σ_3 [MPa]	[°]
Level 1	Average	14.0	145/41	6.4	260/26	2.7	012/38
	90% lower	7.7	*)	0.8	*)	–4.0	*)
	90% upper	25.0		12.8		5.4	
Level 2	Average	17.4	150/27	7.1	359/60	4.4	247/12
	90% lower	15.8	*)	3.7	*)	–0.6	*)
	90% upper	21.4		13.1		5.1	
Level 3	Average	19.4	163/09	11.0	071/17	4.0	279/71
	90% lower	12.1	*)	4.1	*)	–5.3	*)
	90% upper	32.8		15.0		10.1	

*) All orientation data presented in Figure H-1, Figure H-2 and Figure H-3.

Table H-2. 90%-confidence intervals for the horizontal and vertical stress components as determined from overcoring measurements in borehole KLX12A.

Level		σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
Level 1	Average	9.9	4.9	8.3	132
	90% lower	4.6	–2.5	1.4	*)
	90% upper	19.3	8.8	15.1	
Level 2	Average	15.3	4.6	9.1	152
	90% lower	10.8	2.2	2.4	*)
	90% upper	20.5	6.0	15.7	
Level 3	Average	19.1	10.4	4.9	165
	90% lower	11.2	2.3	–3.3	*)
	90% upper	32.1	13.8	13.2	

*) All orientation data presented in Figure H-5, Figure H-6 and Figure H-7.

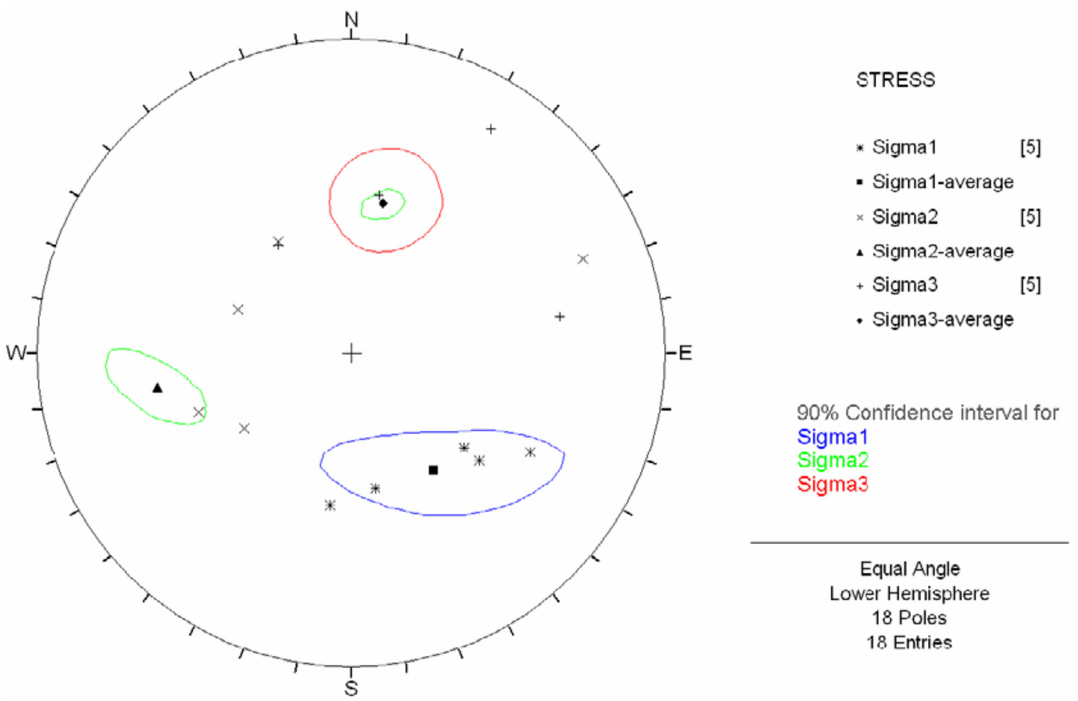


Figure H-1. *90%-confidence interval for the orientation of the principal stresses in borehole KLX12A, Level 1, shown in a lower hemisphere projection.*

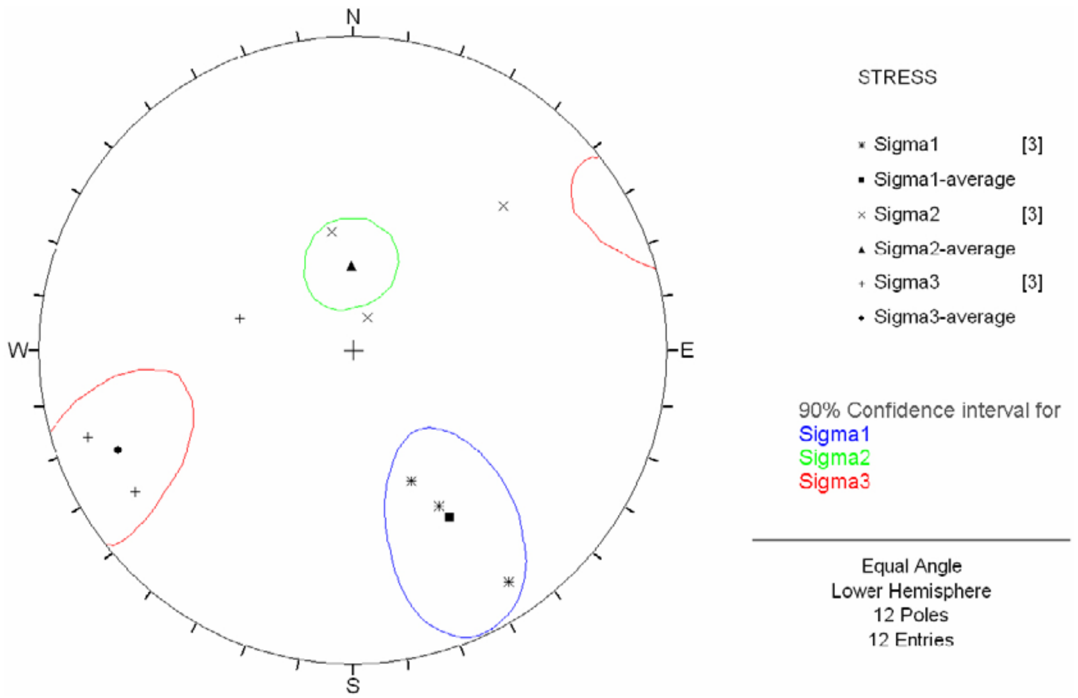


Figure H-2. *90%-confidence interval for the orientation of the principal stresses in borehole KLX12A, Level 2, shown in a lower hemisphere projection.*

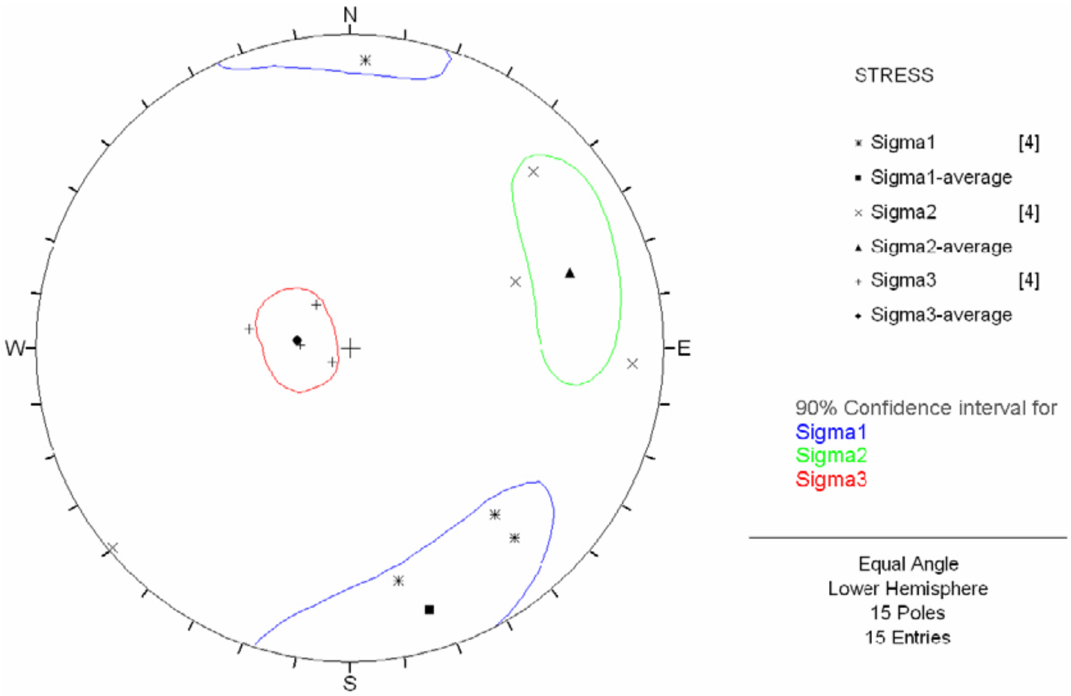


Figure H-3. *90%-confidence interval for the orientation of the principal stresses in borehole KLX12A, Level 3, shown in a lower hemisphere projection.*

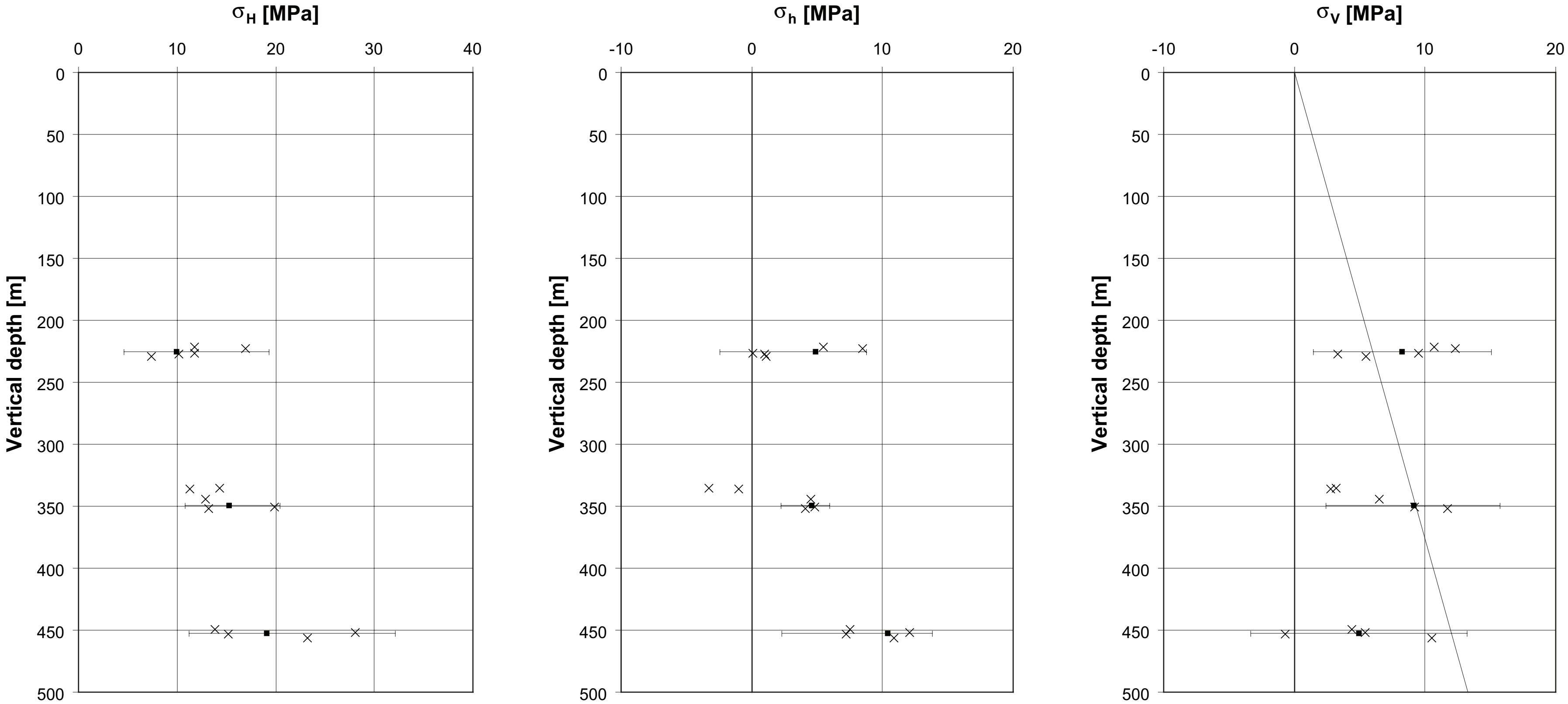


Figure H-4. *Average values (■-markers) and 90%-confidence intervals (├──┤) for the horizontal and vertical stress components, shown together with measured values for each measurement level (x-markers) in borehole KLX12A.*

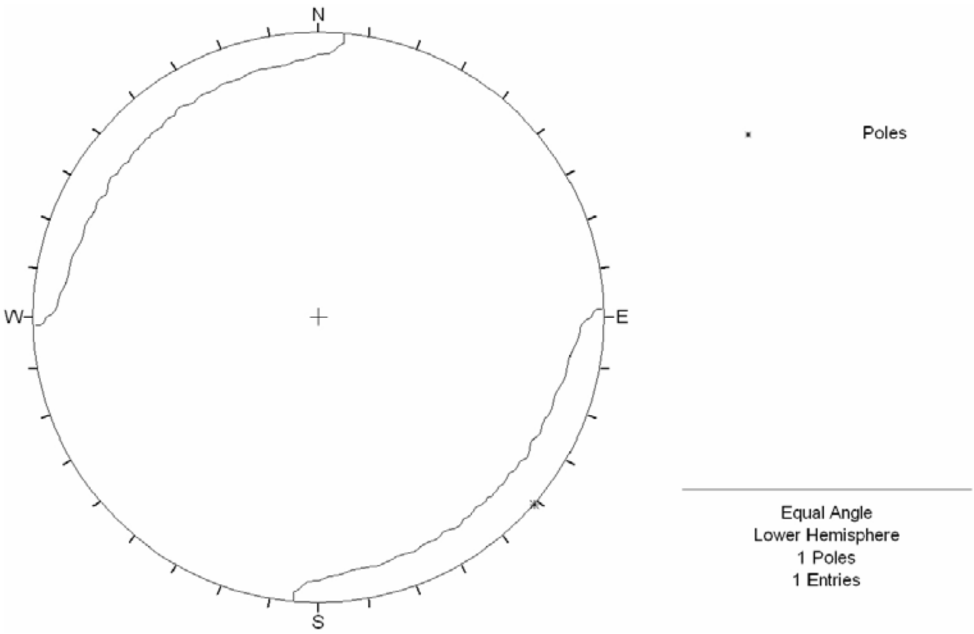


Figure H-5. *90%-confidence interval for the orientation of the maximum horizontal stress for Level 1 in borehole KLX12A, shown in a lower hemisphere projection.*

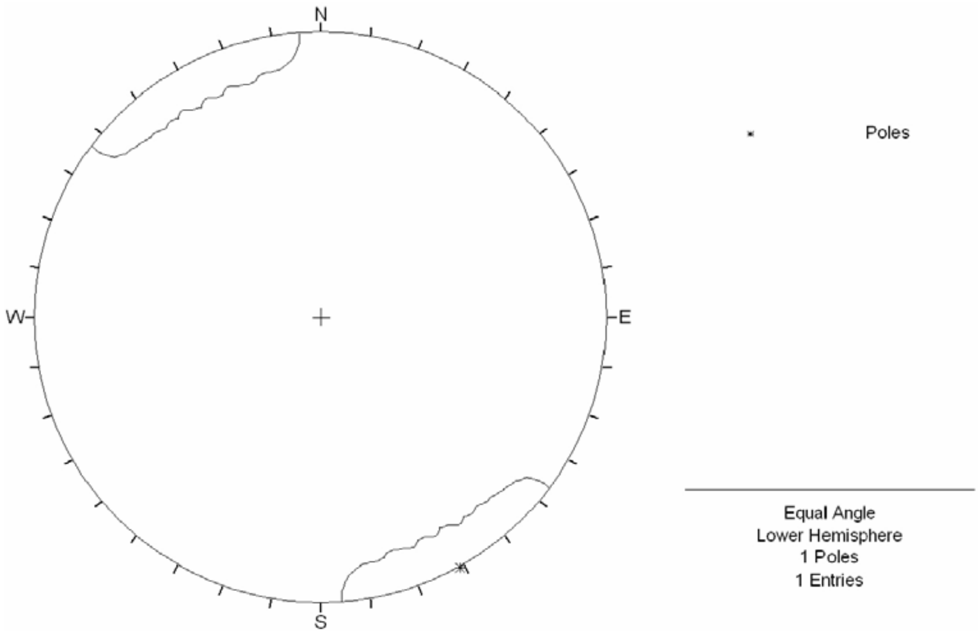


Figure H-6. *90%-confidence interval for the orientation of the maximum horizontal stress for Level 2 in borehole KLX12A, shown in a lower hemisphere projection.*

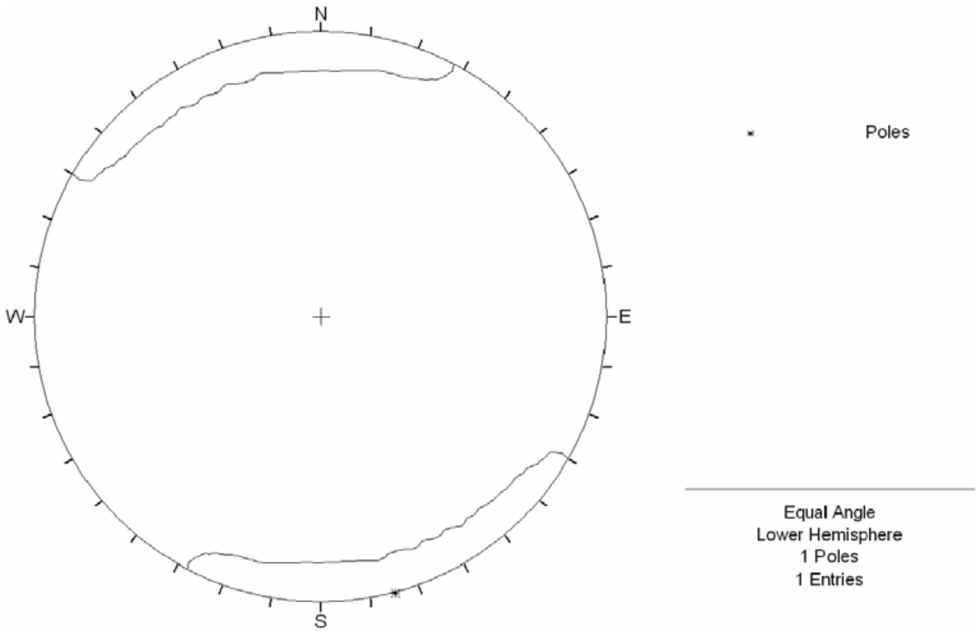


Figure H-7. *90%-confidence interval for the orientation of the maximum horizontal stress for Level 3 in borehole KLX12A, shown in a lower hemisphere projection.*

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.