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Forsmark site investigation

Overcoring rock stress measurements in borehole KFM01B

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April 2004

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

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Summary

Overcoring stress measurements were conducted in the inclined borehole KFM01B at the Forsmark site. The equipment used for the measurements was the three-dimensional *Borre* probe. Measurements were attempted at two measurement levels in borehole KFM01B. The first level included overcoring attempts between 235 and 242 m borehole length. For the second level, measurements were initiated at 404 m borehole length but not finalized until at 475 m borehole length. This large depth interval for Level 2 was required to obtain a complete test series, due to problems with fractured rock, mainly between 415 and 458 m borehole length, and core discing (at all depths).

Core discing appeared on both measurement levels. For Level 1, discing was confined to the lower portions of the overcore samples, enabling biaxial testing to be conducted. For Level 2, core discing occurred for the entire, or almost entire, overcore samples, with a few exceptions. Thus, only a few successful overcoring measurements were obtained for this measurement level.

Calculated stresses from measured overcoring strain relief indicated high stresses for both measurement levels. The major principal stress was around 40 MPa and dipping subhorizontally. A slight stress rotation of the maximum horizontal stress orientation, from E-W to NW-SE, could be inferred between Level 1 and Level 2. Stress gradients were small over the measured depth range.

The measured vertical stress is clearly overestimated (compared to the overburden weight) for all measurements. This is likely an effect of the extensive core discing and associated core damage, which mostly influences axial strain readings. Additional interpretation using transient strain analysis confirmed that samples were highly susceptible to tensile core damage. This effect was more pronounced for Level 2, which can be directly correlated to the more extensive core discing at this level. The only successful measurements were from those tests in which core discing was less extensive. Thus, it is plausible that these measurements represent a lower bound to the actual stress state. Transient strain analysis with the inverse solution confirmed stress orientations and magnitudes for Level 1, in particular for the horizontal stress component, whereas larger uncertainties prevail for Level 2. Even higher stresses are possible at larger depth in borehole KFM01B, but this cannot be confirmed conclusively from the reported measurements. Neither can the vertical stress component be estimated with any confidence. The results should be evaluated further, with respect to geological context, strength properties, observed core discing, and possible microcracking in the overcore samples, to be able to increase the confidence of the stress determination.

Contents

1 Introduction

This document reports the data gained from three-dimensional overcoring rock stress measurements in borehole KFM01B, which is one of the activities within the site investigation at Forsmark. This borehole was originally planned to 100 m depth, but was extended to 500 m borehole length to accommodate hydraulic characterization and rock stress measurements. The borehole is located at the first drilling site, DS1, as shown in Figure 1-1.

The borehole was drilled at approximately 75° dip from the ground surface and with 76 mm diameter to 500.52 m borehole length. The projection on the ground surface of the boreholes at drilling site DS1 is displayed in Figure 1-2. Overcoring rock stress measurements were planned to be conducted at approximately 236, 430 and 500 m depth, during drilling of the hole, according to the activity plan AP PF 400-03-41 (SKB internal controlling document). The selection of measurement levels were, in turn, based on a prediction of fractures in borehole KFM01B conducted by Staub (2003). All results are stored in the SKB database SICADA, Field Note No. Forsmark 292.

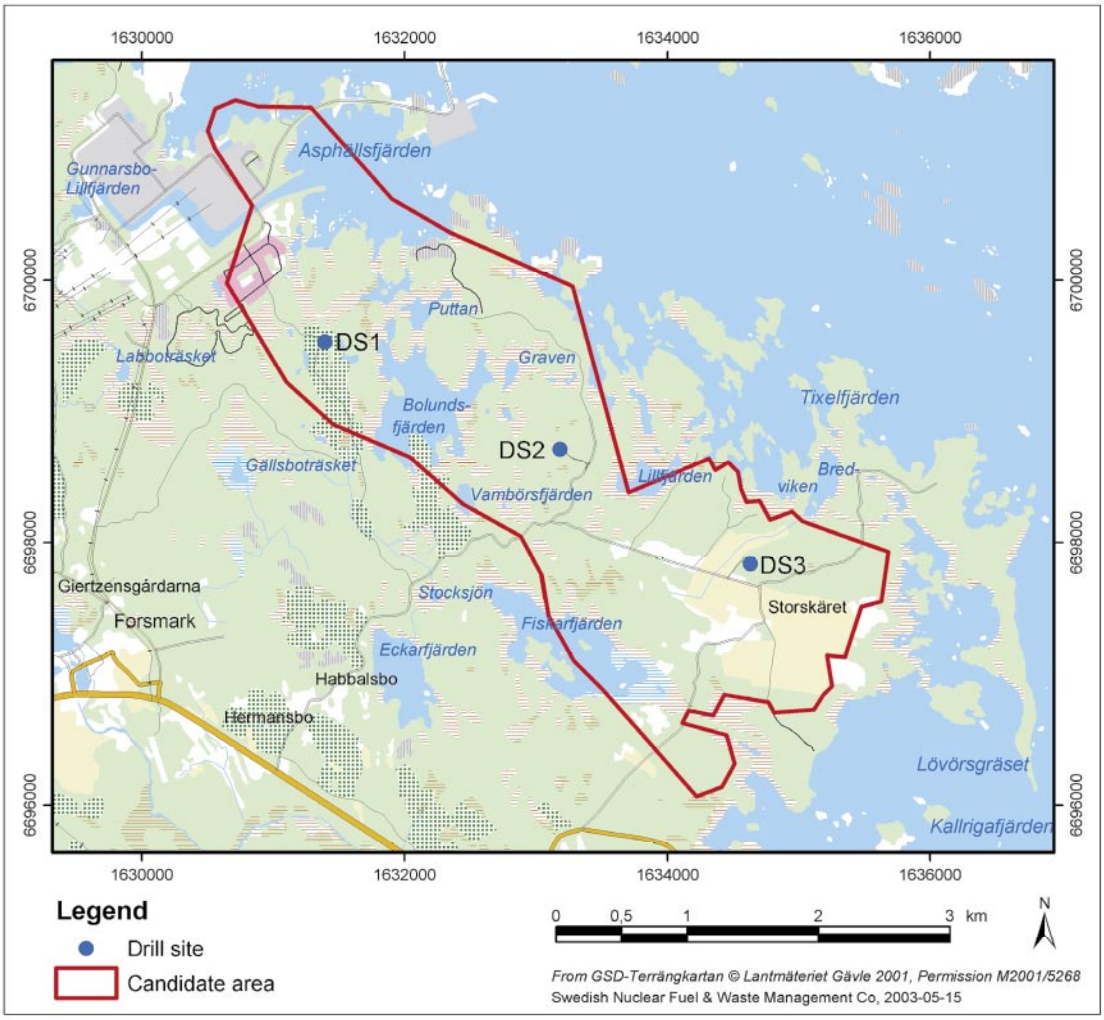

Figure 1-1. *Location of the first three drilling sites (DS1, DS2, DS3) within the Forsmark candidate area. Borehole KFM01B is located at drilling site DS1.*

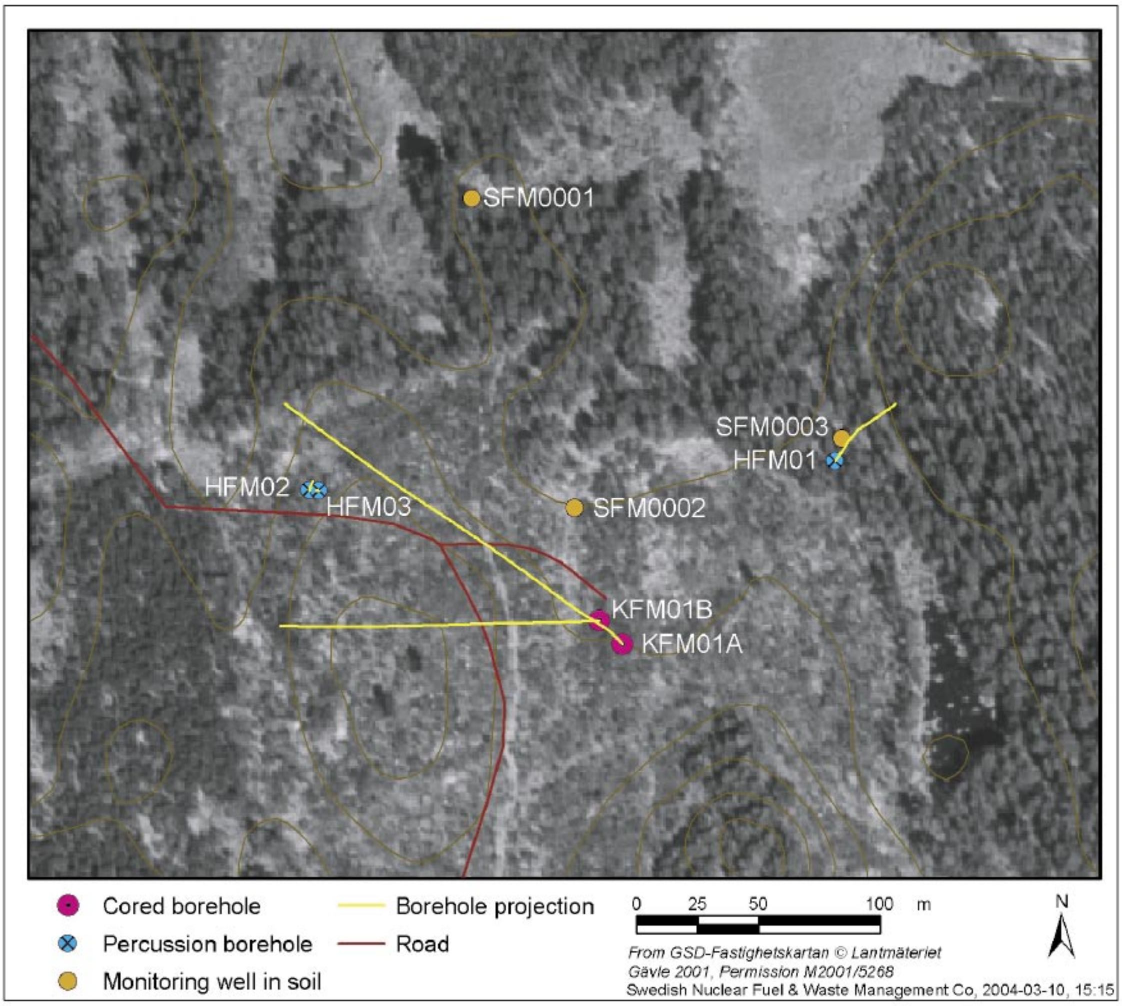

Figure 1-2. *Drilling site DS1 at Forsmark. Position and projection on the horizontal plane at the reference level (top of casing) of each borehole.*

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: 236, 430, 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 during two periods. The first period started September 15 and was completed October 10 (2003). The second field period commenced October 27, 2003, and was completed January 9, 2004 (with a break during the holidays from December 19 to January 6).

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. 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 G.

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 & Hayes, 1966; Leeman, 1968).

3.2 Description of field equipment

The *Borre* probe (Sjöberg & 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 Hagby WL76 Metric Thinwall Wireline System 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 conventional Craelius T2-76 core barrel and coring bit, producing a nominal core diameter of 61.7 mm. 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 45º 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 120º 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 & Klasson (2003) and in SKB MD 181.001 (SKB internal controlling document).

Figure 3-1. *The Borre probe.*

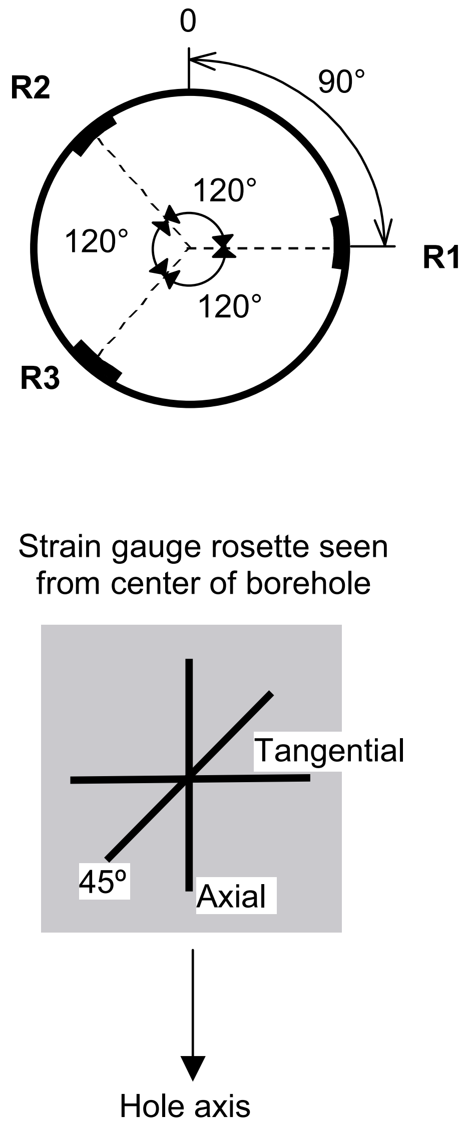

Figure 3-2. Strain gauge configuration of the Borre probe. Axial strain gauges are denoted L1, L2, and L3 (gauge nos. 1, 4, 7), tangential gauges are denoted T1, T2, and T3 (gauge nos. 2, 5, 8), and inclined gauges are denoted 45-1, 45-2, and 45-3 (gauge nos. 3, 6, 9).

4 Execution

4.1 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.

4.2 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.

4.2.1 Pilot hole drilling

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

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

- 3-25 cm: (length) Continuous core, mechanical fractures accepted. No healed fracture that can be extrapolated to cross close to the gauge position at 16 cm during the subsequent overcoring process.

- 15-17 cm: (length) No larger and/or different mineral crystals than elsewhere on the core 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.

4.2.2 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.

4.2.3 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. 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 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.

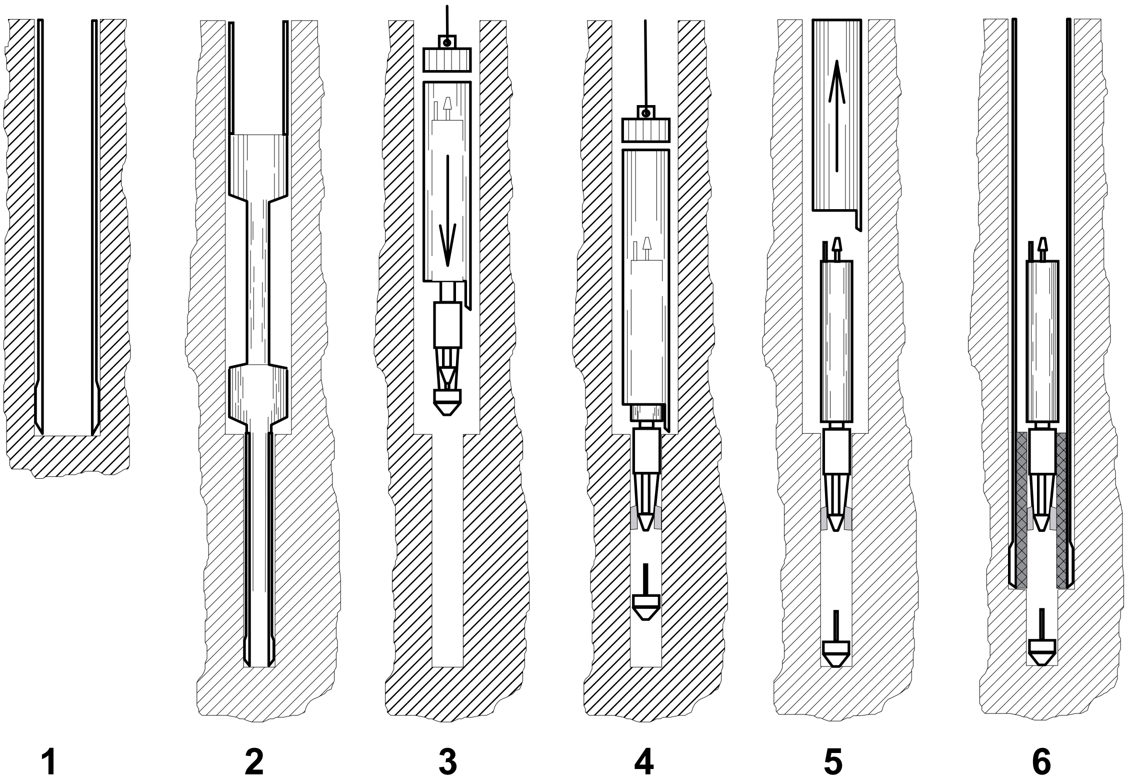

Figure 4-1. Installation and measurement procedure with the Borre probe:

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.*

4.2.4 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. For a few selected tests from KFM01B, strains were also sampled at 0.3, 0.6, and 1.5 MPa applied pressure, to check possible non-linear response during the initial loading of the overcore sample. 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 is also measured.

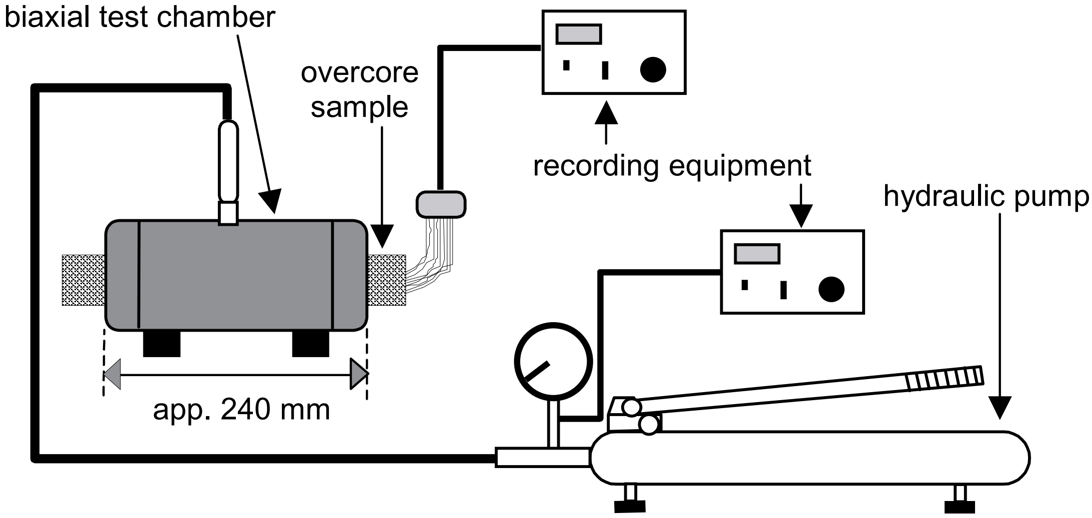

Figure 4-2. *Schematic drawing of the biaxial load cell with pressure generator and recording equipment.*

4.3 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.

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.

4.4 Data analyses

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

Calculation of stresses from measured strains is based on the classical theory by Leeman (1968). The details of the formulation can also be found in e.g., Amadei & 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 & 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.

4.4.2 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). For each test (measurement point), the reported stress state and accompanying field parameters were input to the transient strain analysis program. Transient and final strains were calculated and the final strains compared with the measured final strains. The strain differences (measured vs. calculated strains) were evaluated and the maximum difference calculated for each strain gauge as follows:

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

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

where

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

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

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

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

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

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

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

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

where

AUS = amount of unexplained strain (%),

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

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

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

The stress path developing during the overcoring process was also calculated, including the maximum tensile stress acting on the overcore sample. A high value on the tensile stress is an indicator of high possibility of tensile damage of the rock during overcoring. At this stage, strength values are not known for this site. For illustrative purposes, a uniaxial compressive strength of 230 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 KFM01B, overcoring was attempted at a constant rate for each test (overcoring rates of between 1 and 3 cm/min were used for the different measurements). The coring advance was registered manually using a watch and markers on the drill string for 0, 16, and 30 cm. For measurements on Level 2, coring advance was also registered for 3, 5, 8, 10, 14, 18, 20, and 25 cm drill bit position. However, errors in length correlation (e.g., drill string extension) often resulted in that 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 KFM01B, as described in the following.

5 Results

5.1 Overview

Measurements were attempted at two measurement levels in borehole KFM01B. The first measurement level included overcoring attempts between 235 and 242 m borehole length. For the second level, measurements were initiated at 404 m borehole length but not finalized until at 475 m borehole length. This large depth interval for Level 2 was required to obtain a complete test series, due to problems with fractured rock, mainly between 415 and 458 m borehole length, and core discing (at all depths). Consequently, no further attempts were made for a third level in borehole KFM01B.

A brief summary of conducted measurements is given in Table 5-1. All tests have been numbered as follows: *measurement level : test no. : pilot hole no.*. Thus, e.g., test 2:8:2 denotes measurement level 2, test (or measurement) no. 8 at that level, and pilot hole no. 2 (to reach an acceptable measurement location for this test). Each test is presented with a rating reflecting successfulness and reliability of that particular measurement. Ratings were assigned per the following criteria:

Rating	Description and criteria
a	**Successful test**
	• 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 discing 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	**Core discing / partly failed test**
	• Extensive core discing at gauge position but stable strain response prior to overcoring start.
	• Biaxial testing failed or inhibited due to extensive core discing.
	• Stress calculation attempted 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 (core discing excluded).

Table 5-1. General test data from measurements in borehole KFM01B, Forsmark.

Test no. (pilot hole no. *)	Hole length [m]	Vertical depth [m] **)	Overcoring	Biaxial testing	Transient strain analysis	Rating	Comments
1:1:1	235.89	229.83	Yes	Yes, unstable response	No	*c*	Installation partly failed due to stub in the borehole. Gauge wires were cut during overcoring resulting in incomplete strain record.
1:2:1	237.02	230.92	No	No	No	*c*	Probe did not release from installation tool (adapter) for unknown reasons.
1:3:1	237.99	231.85	No	No	No	*c*	Probe did not relase from the adapter, probably due to debris and/or drill cuttings in the pilot hole.
1:4:1	238.94	232.77	Yes	Yes	Yes	*a*	Succesful test. Core discing observed at the end of the overcore sample.
1:5:1	240.01	233.80	Yes	Yes, failed	Yes	*a*	Successful test. Core discing at the end of the overcore sample. Sample broke during biaxial testing. Stresses calculated using elastic constants from test no. 1:4:1.
1:6:1	240.95	234.70	Yes	Yes, unstable response	No	*c*	Successful overcoring but large strain drift during overcoring and biaxial testing due to debonding of strain gauges.
1:7:1	242.05	235.76	Yes	Yes	Yes	*a*	Succesful test. Slightly larger temperature increase (4.5° C). Fracture at 34 cm position of the overcore sample. Core discing observed at the end of the overcore sample.
2:1:3	406.92	393.59	Yes	No	Yes	*a*	Successful test but extensive core discing observed with only upper 19 cm of sample intact. No biaxial testing. Stresses calculated using elastic constants from test no. 1:7:1.
2:2:2	408.57	395.16	No	No	No	*c*	Probe did not release from the adapter for unknown reasons.
2:3:1	412.79	399.18	Yes	Yes	Yes	*a*	Successful test. Core discing at the end of the overcore sample.
2:4:1	413.83	400.17	No	No	No	*c*	Installation incomplete due to remnants of an o-ring in the pilot hole.
2:5:1	415.16	401.43	Yes	No	Yes	*b*	Extensive core discing resulting in debonding of strain gauges.
2:6:1	458.65	442.76	No	No	No	*c*	Installation incomplete as the probe did not enter the pilot hole completely for unknown reasons.
2:7:3	465.05	448.84	Yes	No	Yes	*b*	Core discing resulting in debonding of strain gauges. Gauges ceased to function after approximately 2 minutes (≈ 5 cm) of overcoring.
2:8:2	471.69	455.15	Yes	No	Yes	*a*	Successful test. Core discing observed with only upper 20 cm of sample intact. Extremely high temperature increase (15.5° C). No biaxial testing. Stresses calculated using elastic constants from test no. 2:3:1.

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*
**) vertical depth interpolated from borehole orientation measurements (every three metre)

Table 5-1. (concluded.)

Test no. (pilot hole no. *)	Hole length [m]	Vertical depth [m] **)	Overcoring	Biaxial testing	Transient strain analysis	Rating	Comments
2:9:1	472.98	456.36	Yes	Yes	Yes	*a*	Successful test. No core discing observed. Large temperature increase (8.5° C). Different geology compared to all other tests.
2:10:1	474.25	457.57	Yes	No	Yes	*b*	Extensive core discing of entire overcore sample. Gauges ceased to function after approximately 6 minutes (≈ 12 cm) of overcoring. Large temperature increase (> 7° C).
2:11:1	475.34	458.60	Yes	No	Yes	*b*	Extensive core discing of entire overcore sample resulting in large strain drift. Large temperature increase (8.0° C).

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*
**) vertical depth interpolated from borehole orientation measurements (every three metre)

It must be noted that for borehole KFM01B, overcoring was done in a very cautious manner, and in particular for Level 2. This was done to, as far as possible, minimize core discing induced by drilling. For several tests, core discing did not occur other than at the end of the overcore sample (cf. Table 5-1), probably due to difficulties in maintaining cautious drilling at the very end of the overcoring process.

Borehole orientations for the measurement depths in question are shown in Table 5-2, as measured after completed drilling of the hole with an optical method (Maxibor). These orientation data were used in the stress calculations described below, together with the measured orientations of the installed *Borre* probe. Magnetic declination was not accounted for in the latter orientation measurements.

Table 5-2. Borehole orientation for overcoring measurement points in borehole KFM01B.

Level no.	Test no. (pilot hole no. *)	Hole length [m]	Borehole bearing [°] **)	Borehole dip [°] ***)
1	1:1:1	235.89	268.24	74.42
1	1:2:1	237.02	268.22	74.37
1	1:3:1	237.99	268.22	74.37
1	1:4:1	238.94	268.22	74.34
1	1:5:1	240.01	268.22	74.34
1	1:6:1	240.95	268.22	74.34
1	1:7:1	242.05	268.15	74.32
2	2:1:3	406.92	269.71	72.05
2	2:2:2	408.57	269.71	72.05
2	2:3:1	412.79	269.73	72.01
2	2:4:1	413.83	269.80	71.97
2	2:5:1	415.16	269.80	71.97
2	2:6:1	458.65	270.49	71.73
2	2:7:3	465.05	270.51	71.68
2	2:8:2	471.69	270.60	71.62
2	2:9:1	472.98	270.60	71.62
2	2:10:1	474.25	270.72	71.59
2	2:11:1	475.34	270.72	71.59

*) 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 (noted times for borehole activities) are presented in Appendix A. Furthermore, core logs and photos are presented in Appendices F and G. Logging was not possible for tests with extensive core discing of the entire overcore sample (cf. Appendix G) and are thus not included in Appendix F.

The strain response for each test is shown in Appendix B. Each test is presented with three plots showing (i) the complete strain record (from activation of probe to core recovery), (ii) the strain response during overcoring and core recovery, and (iii) the strain response from overcoring start to overcoring stop. The latter was used to define strain differences for later input to stress calculation. 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 measurement levels. All original data are stored in the SKB database SICADA, Field Note No. Forsmark 292.

5.2.1 Measurement level 1

For the first measurement level in borehole KFM01B, a total of 7 installation attempts were made. Three successful tests were obtained (test nos. 1:4:1, 1:5:1, and 1:7:1). Installation failed for tests 1:1:1, 1:2:1, and 1:3:1. For test 1:6:1, the probe was installed but at least one strain rosette showed clear signs of debonding during both overcoring and biaxial testing. Hence, this test was excluded from the evaluation.

Core discing was abundant for all conducted measurements at the first level. However, discing was limited to the bottom portion of the samples, thus not affecting the strain gauge positions, nor the ability to conduct biaxial testing. The strain response is extremely stable and with minimal drift for test 1:4:1, whereas test 1:5:1 and 1:7:1 displayed some post-overcoring strain drift. For test 1:5:1, strain differences (after vs. prior to overcoring) were determined from the peak strain value at approximately 27 cm drill bit position. For test 1:7:1, a fracture was discovered at 34 cm coring depth, which is likely to have influenced the strain response. Thus, strain differences were calculated from the values corresponding to the drill bit position just before 34 cm coring depth. Temperature increases were moderate for all tests (between 3° and 4.5° C).

5.2.2 Measurement level 2

For the second measurement level, a total of 11 installation attempts were made. Installation failed in three cases. Of the remaining tests, four successful measurements were obtained (test nos. 2:1:3, 2:3:1, 2:8:2, and 2:9:1). The strain responses for these four tests are fairly stable, but not ideal, probably as a result of the more extensive core discing observed for Level 2. For test no. 2:1:3, strain differences were determined from stable, near-peak, values corresponding to approximately 45 cm drill bit position.

Temperature increases were higher for all tests at this level compared to Level 1. For test nos. 2:1:3, 2:3:1, and 2:5:1, temperatures increased during overcoring by between 4.5° and 5.5° C. For test nos. 2:8:2, an extremely high temperature increase of 15.5° C was recorded, whereas for test nos. 2:9:1, 2:10:1, and 2:11:1, temperatures increased by between 7° and 8.5° C during overcoring. Possible reasons for the extreme temperature increase of test 2:8:2 are insufficient flushing and/or drill bit wear. Strain differences for this test were calculated at the end of overcoring, but elevated temperatures remain also at this stage, which may affect the resulting stresses.

Test nos. 2:5:1, 2:7:3, 2:10:1, and 2:11:1 all resulted in extensive core discing of the entire, or almost entire, overcore sample. Debonding and/or large strain drift for several gauges inhibited conventional evaluation of these tests. Biaxial testing was not possible for any of these four tests. They were, however, further analysed using transient strain analysis as presented in Section 5.5 below.

5.3 Biaxial test data

All suitable overcore rock samples were tested in the biaxial cell to determine the elastic properties. For borehole KFM01B, only two successful tests were conducted for each of the two measurement levels. One sample (1:5:1) broke during testing, whereas two tests (1:1:1 and 1:6:1) showed unstable strain readings due to unsuccessful installation and/or debonding of strain gauges. All the other samples were too short and/or fractured from core discing to enable testing. The results from the successful biaxial tests are shown in Table 5-3.

The gauge response-curves from these tests are shown in Appendix C. For test nos. 1:4:1 and 1:7:1, strains were also sampled at 0.3, 0.6, and 1.5 MPa applied pressure, to check possible non-linear response during the initial loading of the overcore sample. The corresponding strain response during loading up to 3 MPa is shown in Appendix C (Figure C2 and Figure C4, respectively). No clear signs of non-linear response could be noted. Hysteresis was also minor for both these tests. The value on Poisson's ratio is, however, relatively high, which may be a sign of microcracking of the samples.

The strain response of test 2:3:1 was somewhat non-linear and with larger hysteresis, but the calculated values on the elastic constants were very realistic. The strain response for test 2:9:1 was very linear and ideal, but with markedly lower values on Young's modulus. The latter can probably be attributed to the difference in rock type (more pegmatite) compared to the other tests. All original data are stored in the SKB database SICADA, Field Note No. Forsmark 292.

Table 5-3. Results from biaxial testing on overcore samples from borehole KFM01B.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	Young's modulus, E [GPa]	Poisson's ratio, ν
1	1:4:1	238.94	56.6	0.32
1	1:7:1	242.05	67.8	0.35
2	2:3:1	412.79	77.8	0.29
2	2:9:1	472.98	52.6	0.22

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

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. Since biaxial test data were not available for all samples, data on the elastic constants from the nearest test (in similar geology) was used in the stress calculation, see also Table 5-1.

The resulting stresses 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 Level 1 and Level 2, respectively. All original data are stored in the SKB database SICADA, Field Note No. Forsmark 292.

The average stresses for Level 2 were determined from only two measurements (2:3:1 and 2:8:2). These gave very consistent results, despite the large temperature increase in test 2:8:2. Both test 2:1:3 and 2:9:1 showed widely different stresses. Test 2:1:3 resulted in very high stresses and different orientation compared to all other measurements. Test no. 2:9:1 gave significantly lower stress magnitudes than the other measurements at the second measurement level. Values for the intermediate and minor principal stress were clearly unrealistic. The obtained values on elastic constants were also notably different, as the test was located predominantly in pegmatite-like rock. The calculated values for these two tests are also presented in Appendix D.

Table 5-4. Magnitudes of principal stress as determined by overcoring in borehole KFM01B.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	σ_1 [MPa]	σ_2 [MPa]	σ_3 [MPa]
1	1:4:1	238.94	50.5	37.4	29.6
1	1:5:1 [a)]	240.01	38.7	22.3	15.6
1	1:7:1	242.05	40.2	32.4	19.0
1	Average	-	40.3	28.6	26.4
2	2:3:1	412.79	42.3	25.2	10.3
2	2:8:2 [c)]	471.69	46.8	14.5	10.0
2	Average	-	44.1	19.7	10.7
2 **)	2:1:3 **) [b)]	406.92	56.0	36.5	15.7
2 **)	2:9:1 **)	472.98	19.5	2.6	-3.1

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*
**) not included in calculation of average stress for Level 2
a) Young's modulus taken from test no. 1:4:1
b) Young's modulus taken from test no. 1:7:1
c) Young's modulus taken from test no. 2:3:1

Table 5-5. Orientations of principal stress as determined by overcoring in borehole KFM01B. Trend clockwise from geographic north, plunge from the horizontal plane.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	σ_1 Trend/Plunge [°]	σ_2 Trend/Plunge [°]	σ_3 Trend/Plunge [°]
1	1:4:1	238.94	102/42	324/39	214/23
1	1:5:1 [a)]	240.01	282/12	187/19	043/67
1	1:7:1	242.05	289/12	195/17	053/69
1	Average	-	289/02	198/29	022/61
2	2:3:1	412.79	141/28	030/34	261/43
2	2:8:2 [c)]	471.69	156/23	011/62	252/14
2	Average	-	150/24	035/43	261/37
*2 **)*	*2:1:3 **) [b)]*	*406.92*	*222/35*	*074/50*	*324/16*
*2 **)*	*2:9:1 **)*	*472.98*	*132/14*	*032/34*	*240/52*

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*
**) not included in calculation of average stress for Level 2
a) Young's modulus taken from test no. 1:4:1
b) Young's modulus taken from test no. 1:7:1
c) Young's modulus taken from test no. 2:3:1

Table 5-6. Horizontal and vertical stress components calculated from measured principal stresses in borehole KFM01B.

Level no.	Measurement no. (pilot hole no. *)	Hole length [m]	σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
1	1:4:1	238.94	44.1	31.3	42.2	112
1	1:5:1 [a)]	240.01	37.7	21.6	17.4	103
1	1:7:1	242.05	39.4	31.1	21.1	114
1	Average	-	40.3	28.1	26.9	109
2	2:3:1	412.79	37.2	18.6	21.9	152
2	2:8:2 [c)]	471.69	41.7	10.4	19.3	157
2	Average	-	39.4	14.5	20.6	155
2 **)	2:1:3 **) [b)]	406.92	49.1	17.7	41.4	049
2 **)	2:9:1 **)	472.98	18.4	0.7	0.0	134

*) numbering scheme: *(measurement level : test no. : pilot hole no.)*
**) not included in calculation of average stress for Level 2
[a)] Young's modulus taken from test no. 1:4:1
[b)] Young's modulus taken from test no. 1:7:1
[c)] Young's modulus taken from test no. 2:3:1

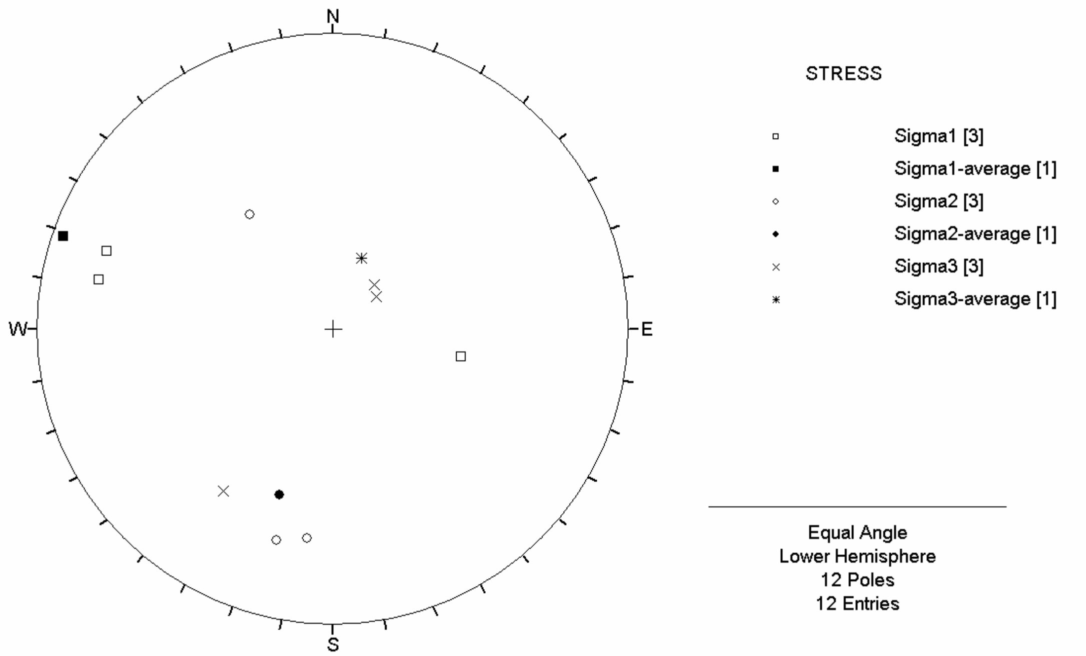

***Figure 5-1.** Orientations of measured principal stresses in borehole KFM01B, Level 1, shown in a lower hemisphere projection (test nos. 1:4:1, 1:5:1, and 1:7:1).*

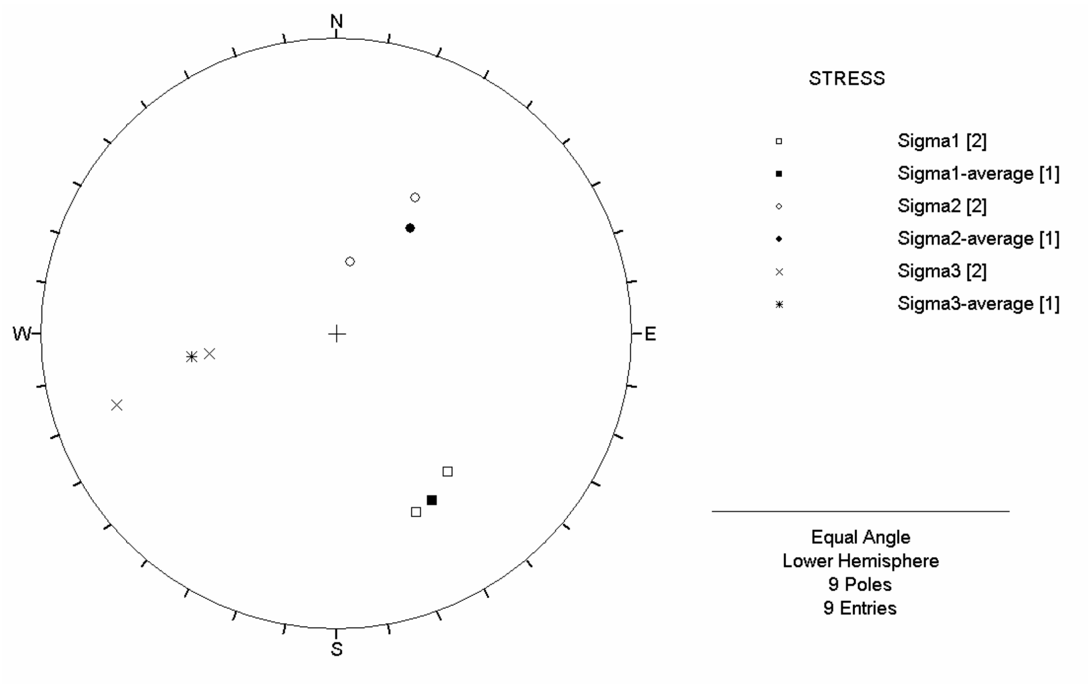

Figure 5-2. *Orientations of measured principal stresses in borehole KFM01B, Level 2, shown in a lower hemisphere projection (test nos. 2:3:1 and 2:8:2).*

5.5 Transient strain analysis

5.5.1 Transient strain response

Transient strain analysis was conducted for selected tests (see Table 5-1). The resulting calculated strain differences (compared to measured strains), amount of unexplained strain, and maximum tensile stress are presented in Appendix E. Strain differences and amount of unexplained strains could only be calculated for those measurements that comprised a complete strain record and from which the *in situ* stress state was determined using classical analysis (test nos. 1:4:1, 1:5:1, 1:7:1, 2:1:3, 2:3:1, 2:8:2, and 2:9:1, cf. Section 5.4).

Common for almost all conducted measurements are that the tangential gauges show the best agreement between measured and theoretical (calculated transient) strains. An example is presented in Figure 5-3. The axial and inclined gauges display larger deviations. In general, the axial gauges show the largest discrepancies (cf. Figure 5-4). These discrepancies are clear signs of non-ideal behaviour and induced microcracks in the axial direction of the sample.

The calculated value on the maximum tensile stress that develops during overcoring is very high, ranging between 30 and 46 MPa for all analysed tests, except test 2:9:1. An example is shown in Figure 5-5. With such high tensile stresses, damage to the overcored samples is nearly inevitable. Test 2:9:1 was located in a different geological environment and yielded lower stresses. Still, the calculated tensile stress was 20 MPa, which is high enough to cause tensile damage to most Fennoscandian rock types.

The amount of unexplained strain is relatively small for final strain values. For Level 1, the unexplained strain varies between 5 and 8 %, which can be considered low and indicative of a good stress determination. For Level 2, slightly higher values were found for tests 2:1:3, 2:8:2 and 2:9:1, implying that stress determinations are less confident for these tests.

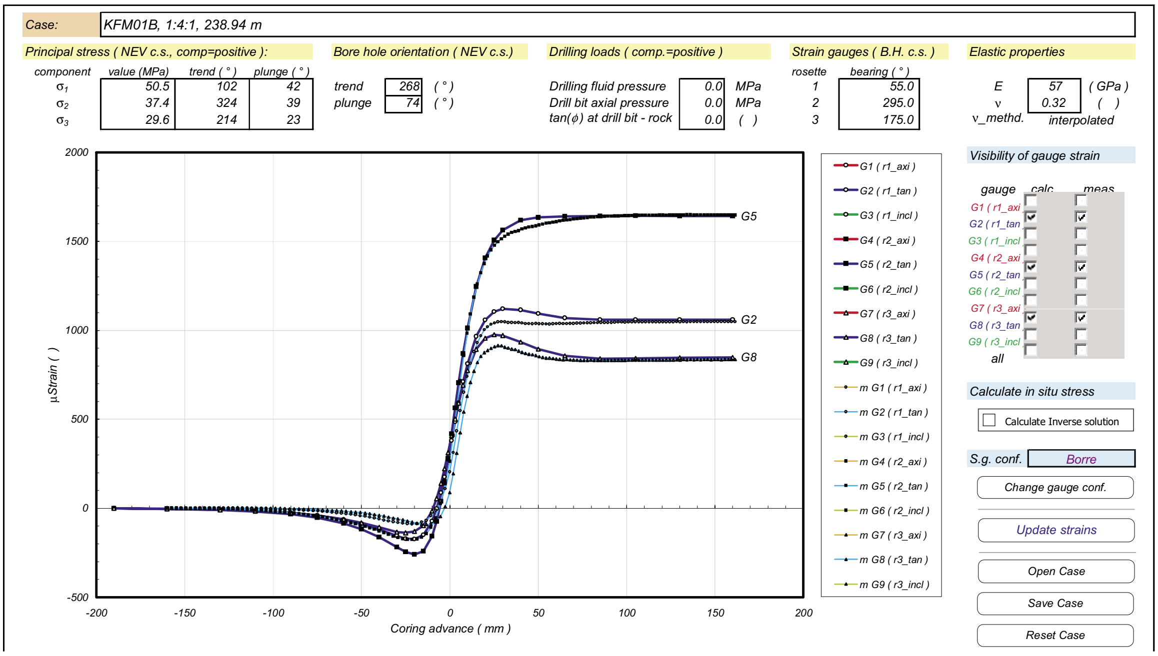

Figure 5-3. *Calculated vs. measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no. 1:4:1 and all tangential gauges.*

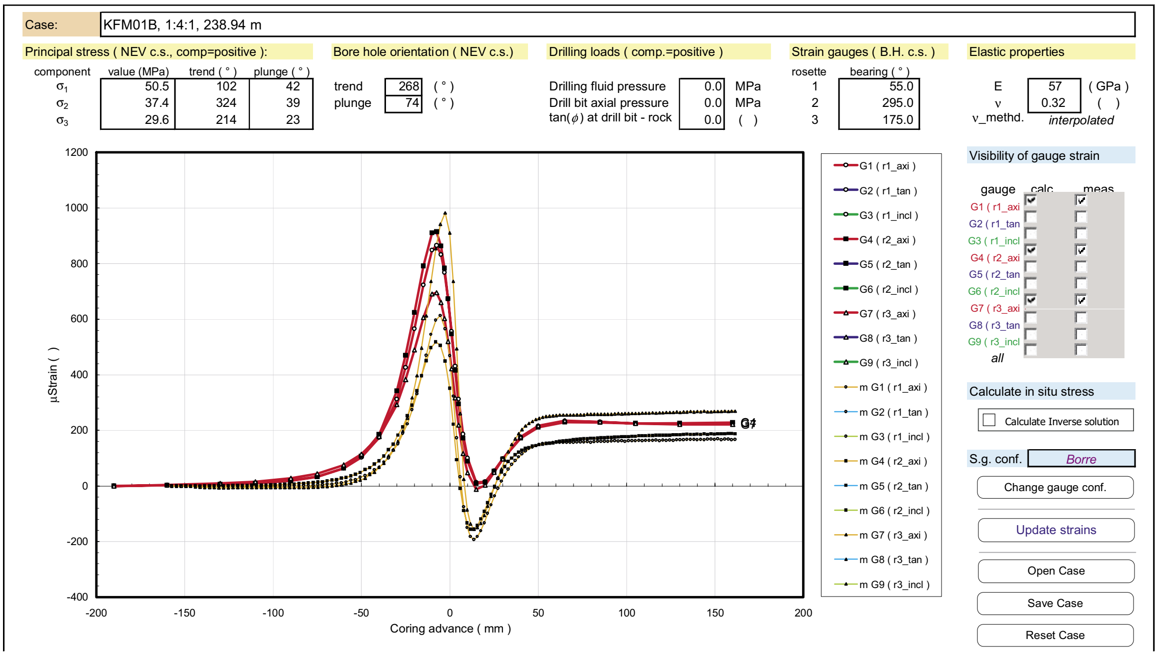

Figure 5-4. *Calculated vs. measured strain response during overcoring as a function of coring advance (gauge position at 0 mm) for test no. 1:4:1 and all axial gauges.*

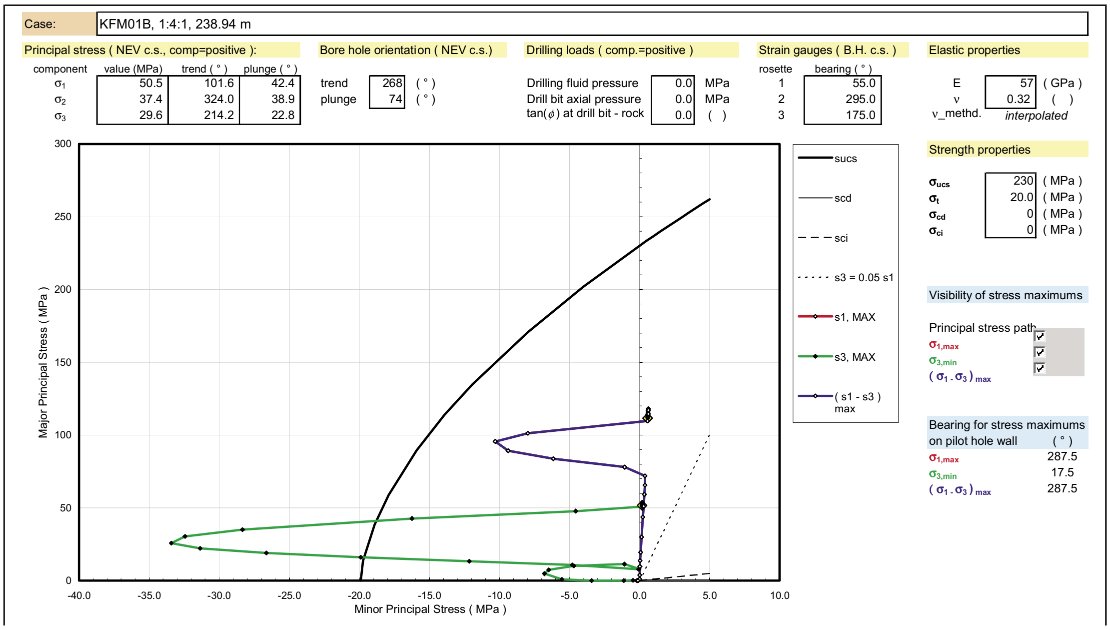

Figure 5-5. Calculated induced stresses in the overcore sample during overcoring for test no. 1:4:1.

5.5.2 Inverse solution stress estimate

In this work, the inverse solution was used to try to estimate the stress state from the early (transient) strain response of the overcoring process. If this is successful, also samples with extensive core discing (leading to incomplete strain record) can be used to assess the stress state. Generally, the stress calculated with the inverse solution varies 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.

The inverse solution was applied for all tests with rating *a* or *b* in Table 5-1. For those tests with no values from biaxial testing, values on the elastic constants from the nearest test (in similar geology) was used. Water pressure was not included in the analysis. While this may have some effect on the calculated stresses, it is shadowed by the inaccuracies of coring advance measurements.

The results using the inverse solution were of varying quality. Consistent values on the stress states were difficult to define in the pre-overcoring phase, and only three tests could be used to estimate the *in situ* stress state — test nos. 1:4:1, 2:3:1, and 2:5:1. The resulting stresses are presented in Table 5-7 through Table 5-9. The obtained stress state from classical analysis is shown for comparison for each test. Note that for the inverse solution, stresses are calculated for each sampled strain value (every 5 s, corresponding to between 1 and 3 mm of coring advance) — hence, the values in the tables below are only excerpts of the complete results.

For test no. 1:4:1, the high strains recorded permitted applying the inverse solution with, at least, some confidence. Relatively consistent stress states were found for coring advances between approximately -90 and -50 mm (measured relative to the gauge position at 0 mm, cf. Figure 5-6). An average stress state was also calculated for this coring advance range (values every 3 mm). For test 2:3:1, consistent and realistic stress states were only found between -60 and -50 mm coring advance, for which average stresses also were calculated (values every 1 mm).

For test 2:5:1, the variation in calculated stresses was large during the pre-overcoring phase. Somewhat consistent values were found between -70 and -60 mm coring advance. However, the resulting stress state for this point comprises a maximum horizontal stress of 78 MPa, and a vertical stress of 30 MPa. The maximum horizontal stress is trending 155°. The vertical stress is lower for coring advances >-60 mm, but for these cases, the minor principal stress displays large tensile values. This is clearly unrealistic and was not included in the tables below. Furthermore, the large variation makes reliable averaging difficult, and is possibly misleading, and was thus not conducted for test no. 2:5:1.

For all other tests (1:5:1, 1:7:1, 2:1:3, 2:7:3, 2:8:2, 2:9:1, 2:10:1, 2:11:1), the inverse solution gave unrealistic stresses (negative or extremely high), or non-stable stresses in the early overcoring phase (due to inexact measurement of coring advance or non-ideal strain response) for a reliable stress estimation to be possible. Since the stress state could not be determined unambiguously for these tests, they were not included in the tables below.

Comparing the results with those of the classical analysis, the stresses are, in general, lower from the inverse solution. Stress orientations are, however, relatively similar. Interestingly, the stress orientations are much less susceptible to change vs. coring advance, compared to the stress magnitudes. This may be taken as an indication that stress orientations are determined with relatively good confidence in these measurements.

In conclusion, an improved stress estimate is obtained for test 1:4:1, with lower, and more realistic, vertical stress. Also, the major principal stress is nearly horizontal in the inverse solution for pre-overcoring strains. These values can thus be used instead of those from classical analysis as representative for this test. Unfortunately, the same cannot be said for the other tests. Only test 2:3:1 and 2:5:2 gave realistic and somewhat stable values in the pre-overcoring phase. However, the variation between the results for the presented coring advances in the pre-overcoring phase is still large — thus, stresses cannot be said to be unequivocally determined through this analysis. The results from these two measurements should thus not be used in place of those from classical analysis.

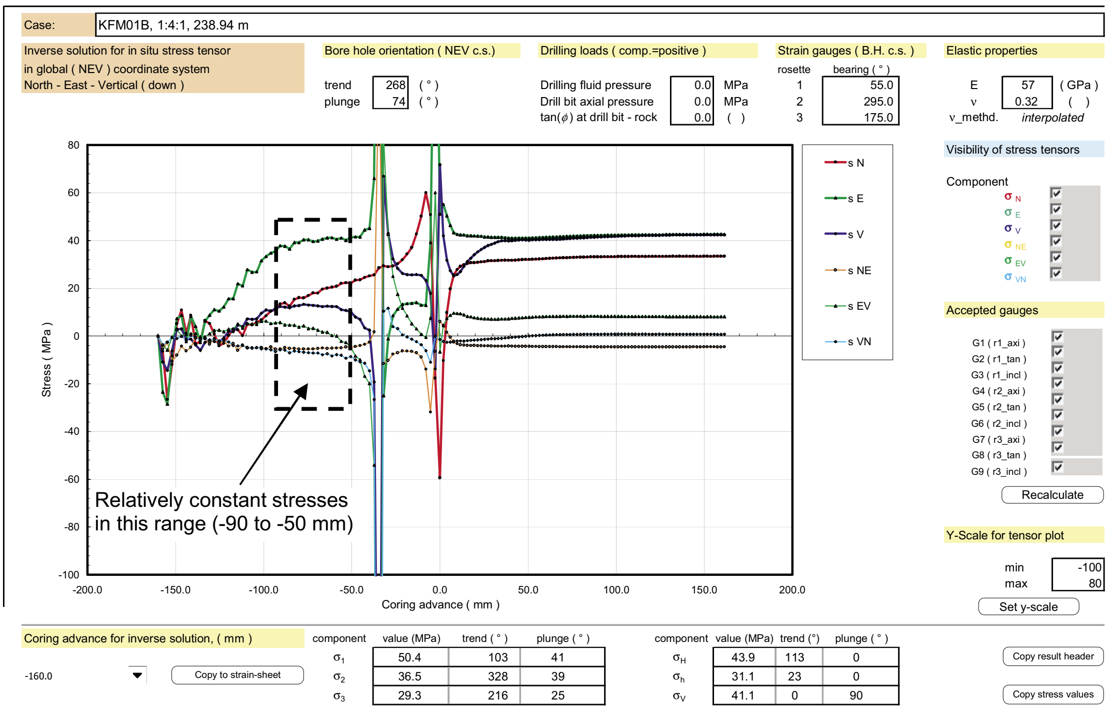

Figure 5-6. *Inverse stress solution for test no. 1:4:1.*

Table 5-7. Magnitudes of principal stress as determined from transient strain analysis (inverse solution).

Measurement no. (pilot hole no. *)	Coring advance [mm]	σ_1 [MPa]	σ_2 [MPa]	σ_3 [MPa]
1:4:1 (inverse)	-90	40.6	15.9	7.1
	-50	42.6	26.4	4.5
	Average	41.3	21.9	6.9
1:4:1 (classical)	-	50.5	37.4	29.6
2:3:1 (inverse)	-60	33.8	11.5	2.1
	-50	38.6	11.9	4.7
	Average	35.6	8.8	7.1
2:3:1 (classical)	-	42.3	25.2	10.3
2:5:1 (inverse)	-70	90.6	67.6	14.7
	-60	77.7	72.7	3.3
2:5:1 (classical)	-	No solution	No solution	No solution

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

Table 5-8. Orientations of principal stress as determined from transient strain analysis (inverse solution).

Measurement no. (pilot hole no. *)	Coring advance [mm]	σ_1 Trend/Plunge [°]	σ_2 Trend/Plunge [°]	σ_3 Trend/Plunge [°]
1:4:1 (inverse)	-90	104/14	205/39	358/48
	-50	281/05	188/29	020/60
	Average	104/06	198/34	006/55
1:4:1 (classical)	-	102/42	324/39	214/23
2:3:1 (inverse)	-60	336/26	202/55	078/22
	-50	335/27	068/04	166/63
	Average	336/26	228/33	097/46
2:3:1 (classical)	-	141/28	030/34	261/43
2:5:1 (inverse)	-70	346/08	081/32	244/57
	-60	340/04	074/38	244/52
2:5:1 (classical)		No solution	No solution	No solution

*) 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).

Measurement no. (pilot hole no. *)	Coring advance [mm]	σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
1:4:1 (inverse)	-90	39.0	12.2	12.4	102
	-50	42.4	21.0	10.1	103
	Average	41.0	17.1	11.9	103
1:4:1 (classical)	-	44.1	31.3	42.2	112
2:3:1 (inverse)	-60	29.3	3.5	14.5	160
	-50	31.7	11.8	11.6	155
	Average	30.2	8.2	13.2	157
2:3:1 (classical)	-	37.2	18.6	21.9	152
2:5:1 (inverse)	-70	89.8	52.5	30.6	162
	-60	77.6	46.5	29.6	155
2:5:1 (classical)		No solution	No solution	No solution	No solution

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

5.6 Summary and discussion

Based on the results and findings presented above, a summary of the stress state in borehole KFM01B is presented in Table 5-10 and Table 5-11 — based on both classical and transient strain analysis.

Table 5-10. Magnitudes and orientations of principal stresses as determined from overcoring and transient strain analysis (marked * and in italic) in borehole KFM01B.

Test no.	Hole length [m]	Magnitude and Trend/Plunge of principal stresses					
		σ_1		σ_2		σ_3	
		[MPa]	[°]	[MPa]	[°]	[MPa]	[°]
*1:4:1 *)*	*238.94*	*41.3*	*104/06*	*21.9*	*198/34*	*6.9*	*006/55*
1:5:1	240.01	38.7	282/12	22.3	187/19	15.6	043/67
1:7:1	242.05	40.2	289/12	32.4	195/17	19.0	053/69
Average Level 1 **)		39.5	283/05	25.4	191/25	14.6	024/64
2:3:1	412.79	42.3	141/28	25.2	030/34	10.3	261/43
2:8:2	471.69	46.8	153/23	14.5	011/62	10.0	252/14
Average Level 2		44.1	150/24	19.7	035/43	10.7	261/37

*) data from transient strain analysis (inverse solution)
**) average based on inverse solution of 1:4:1 and classical analysis of 1:5:1, 1:7:1

Table 5-11. Horizontal and vertical stress components calculated from principal stresses from overcoring and transient strain analysis (marked * and in italic) in KFM01B.

Test no.	Hole length [m]	σ_H [MPa]	σ_h [MPa]	σ_v [MPa]	Trend σ_H [°]
*1:4:1 *)*	*238.94*	*41.0*	*17.1*	*11.9*	*103*
1:5:1	240.01	37.7	21.6	17.4	103
1:7:1	242.05	39.4	31.1	21.1	114
Average Level 1 **)		39.3	23.4	16.8	105
2:3:1	412.79	37.2	18.6	21.9	152
2:8:2	471.69	41.7	10.4	19.3	157
Average Level 2		39.4	14.5	20.6	155

*) data from transient strain analysis (inverse solution)
**) average based on inverse solution of 1:4:1 and classical analysis of 1:5:1, 1:7:1

The measured stress state in borehole KFM01B indicates a high horizontal stress component. For Level 1, a reasonably precise stress estimate was obtained through the three successful measurements (using the inverse solution for one of these). The average stress state indicates a major principal stress of around 40 MPa magnitude, which is oriented horizontally and trending nearly E-W. The intermediate principal stress is shallow-dipping and striking nearly north-south, whereas the minor principal stress is dipping more steeply and trending NNE. Observed core discing in all overcore samples confirms that stresses are high perpendicular to the borehole axis. The core damage, as well as the fairly high values on Poisson's ratio obtained from the two successful biaxial tests, indicate probable damage to the overcore sample (induced during overcoring). Transient strain analysis confirmed that tensile damage was very likely to have occurred, due to high tensile stresses developing along the core axis during overcoring. This damage affects the readings on the axial and inclined strain gauges, which are different from theory, which, in turn, influences the value on the vertical stress component. The latter is also greatly overestimated (compared to overburden pressure) for all measurements. All tangential strain gauges remain, however, almost unaffected, and the value and orientation of the horizontal stresses can be regarded as more confident for measurements at Level 1.

For Level 2, extensive core discing was observed for nearly all tests, and involving almost the entire overcore sample. Only two successful overcoring tests were obtained. Despite the relatively large vertical distance between these two tests (> 50 m), the results from both measurements were very consistent — both in terms of magnitude and orientation, and in good agreement with the expected precision of the method as such. These values reveal a major principal stress of around 45 MPa magnitude, dipping around 25° (toward SE) and trending SSE. The intermediate and minor principal stresses are lower in magnitude compared to Level 1. The vertical stress component is clearly overestimated also for this level. A slight stress rotation of the maximum horizontal stress orientation, from E-W to NW-SE, can also be inferred between Level 1 and Level 2.

Transient strain analysis showed that tensile damage was very likely, as very high tensile stresses developed along the core axis. Similar to Level 1, this affects mostly the axial and inclined strain gauges, yielding a poor resolution of the vertical stress component. However, for Level 2, larger deviations were also found for the tangential strain gauges, and the tensile stresses are also higher compared to Level 1. The higher stresses can be directly correlated to the more extensive core discing at this level. In fact, the only successful measurements were from those tests in which core discing was less extensive. Thus, it is plausible that these measurements represent a lower bound to the actual stress state. The inferred stress gradients for the horizontal stress components from Level 1 to Level 2 are also small, considering the measured depth range, which further adds to the above hypothesis.

Using transient strain analysis and the inverse solution, stress estimates from the pre-overcoring strains can be obtained for test nos. 1:4:1, 2:3:1, and 2:5:1. These results confirm the high stress magnitudes obtained through classical overcoring analysis. For test 1:4:1, the inverse solution gave significantly lower values on the intermediate and minor principal stress, resulting in a lower vertical stress component. The maximum horizontal stress is slightly lower, but still high. Stress orientations are in good agreement with those from classical analysis for all measurements on Level 1. This finding lends further confidence to the measured stresses in the horizontal plane, and the inverse solution for pre-overcoring strains for test 1:4:1 was also used in calculation of the average stress state for Level 1 as presented in Table 5-10 and Table 5-11 above.

For Level 2, the inverse solution of test 2:3:1 gave lower values than measured ones, whereas stress orientations were similar. Test 2:5:1 also indicated a NNW-SSE major stress orientation, similar to the measured stress state. Taken together, the transient analysis confirms high horizontal stresses also at Level 2, but orientations are somewhat uncertain.

In conclusion, the stress state in borehole KFM01B is characterized by high horizontal stresses, reaching 40 MPa or more already from approximately 250 m depth. The major principal stress appears to be oriented E-W to NW-SE and dipping subhorizontally. Even higher stress magnitudes can be expected at larger depth, but this cannot be confirmed conclusively from the reported measurements. Neither can the vertical stress component be estimated with any confidence. The results should be evaluated further, with respect to geological context, strength properties, observed core discing, and possible microcracking in the overcore samples, to be able to increase the confidence of the stress determination.

6 References

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Appendix A

Key measurement data

Table A1. Key measurement data for test no. 1:4:1, 238.94 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	03-10-01	16:45:00
Mixing of glue	03-10-01	17:05:00
Application of glue to gauges	03-10-01	17:10:00
Probe installation in pilot hole	03-10-01	17:21:00
Start time for dense sampling (5 s interval)	03-10-02	07:00:00
Adapter retrieved	03-10-02	07:35:00
Drill string fed down the hole	03-10-02	07:40:00
Drill string in place	03-10-02	08:00:00
Flushing start	03-10-02	08:30:00
Rotation start	03-10-02	08:40:00
Overcoring start	03-10-02	08:41:00
Overcoring 16 cm	03-10-02	08:46:00
Overcoring 30 cm	03-10-02	08:52:00
Overcoring stop	03-10-02	09:07:00
Flushing off	03-10-02	09:23:00
Core break	03-10-02	09:38:00
Core retrieval start	03-10-02	09:55:00
Core & probe on surface	03-10-02	10:20:00
End of strain registration	03-10-02	10:40:15
Calculation of strain difference: OC Start	03-10-02	08:40:00
Calculation of strain difference: OC Stop	03-10-02	09:07:00

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	3
16 – 30 cm	3
30 cm – overcoring stop	3

Table A2. Key measurement data for test no. 1:5:1, 240.01 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	03-10-06	17:45:00
Mixing of glue	03-10-06	18:24:00
Application of glue to gauges	03-10-06	18:33:00
Probe installation in pilot hole	03-10-06	18:42:00
Start time for dense sampling (5 s interval)	03-10-07	07:30:00
Adapter retrieved	03-10-07	08:08:00
Drill string fed down the hole	03-10-07	08:25:00
Drill string in place	03-10-07	08:55:00
Flushing start	03-10-07	08:56:00
Rotation start	03-10-07	09:12:00
Overcoring start	03-10-07	09:13:00
Overcoring 16 cm	03-10-07	09:18:00
Overcoring 30 cm	03-10-07	09:22:00
Overcoring stop	03-10-07	09:32:00
Flushing off	03-10-07	09:47:00
Core break	03-10-07	10:08:00
Core retrieval start	03-10-07	10:23:00
Core & probe on surface	03-10-07	10:47:00
End of strain registration	03-10-07	11:14:40
Calculation of strain difference: OC Start	03-10-07	09:12:00
Calculation of strain difference: OC Stop	03-10-07	09:21:00

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	3
16 – 30 cm	3
30 cm – overcoring stop	6

Table A3. Key measurement data for test no. 1:7:1, 242.05 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	03-10-08	19:42:25
Mixing of glue	03-10-08	20:10:00
Application of glue to gauges	03-10-08	20:15:00
Probe installation in pilot hole	03-10-08	20:24:40
Start time for dense sampling (5 s interval)	03-10-09	08:00:00
Adapter retrieved	03-10-09	08:37:00
Drill string fed down the hole	03-10-09	08:40:00
Drill string in place	03-10-09	08:50:00
Flushing start	03-10-09	08:50:00
Rotation start	03-10-09	09:14:30
Overcoring start	03-10-09	09:15:00
Overcoring 16 cm	03-10-09	09:21:30
Overcoring 30 cm	03-10-09	09:26:40
Overcoring stop	03-10-09	09:35:10
Flushing off	03-10-09	09:54:40
Core break	03-10-09	10:17:40
Core retrieval start	03-10-09	10:35:15
Core & probe on surface	03-10-09	10:53:30
End of strain registration	03-10-09	11:27:15
Calculation of strain difference: OC Start	03-10-09	09:15:00
Calculation of strain difference: OC Stop	03-10-09	09:28:45
Overcoring advance	Overcoring rate [cm/min]	
0 – 16 cm	2.7	
16 – 30 cm	2.7	

Table A4. Key measurement data for test no. 2:1:3, 406.92 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	03-10-29	18:00:00
Mixing of glue	03-10-29	18:17:00
Application of glue to gauges	03-10-29	18:26:00
Probe installation in pilot hole	03-10-29	18:37:00
Start time for dense sampling (5 s interval)	03-10-30	06:30:00
Adapter retrieved	03-10-30	07:45:00
Drill string fed down the hole	03-10-30	08:48:00
Drill string in place	03-10-30	09:45:00
Flushing start	03-10-30	09:50:20
Rotation start	03-10-30	10:20:00
Overcoring start	03-10-30	10:22:30
Overcoring 16 cm	03-10-30	10:27:00
Overcorign 50 cm	03-10-30	10:37:00
Overcoring stop	03-10-30	10:49:15
Flushing off	03-10-30	11:10:15
Core break	03-10-30	11:27:05
Core retrieval start	03-10-30	11:46:35
Core & probe on surface	03-10-30	12:26:00
End of strain registration	03-10-30	12:52:45
Calculation of strain difference: OC Start	03-10-30	10:16:30
Calculation of strain difference: OC Stop	03-10-30	10:35:00
Overcoring advance	Overcoring rate [cm/min]	
0 – 16 cm	3.5	
16 – 30 cm	3.5	

Table A5. Key measurement data for test no. 2:3:1, 412.79 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	03-11-10	22:20:00
Mixing of glue	03-11-10	22:37:00
Application of glue to gauges	03-11-10	22:44:00
Probe installation in pilot hole	03-11-10	22:54:00
Start time for dense sampling (5 s interval)	03-11-11	10:00:00
Adapter retrieved	03-11-11	10:45:00
Drill string fed down the hole	03-11-11	10:50:00
Drill string in place	03-11-11	11:55:00
Flushing start	03-11-11	11:55:00
Rotation start	03-11-11	13:13:07
Overcoring start	03-11-11	13:14:00
Overcoring 3 cm	03-11-11	13:15:30
Overcoring 5 cm	03-11-11	13:17:15
Overcoring 8 cm	03-11-11	13:20:00
Overcoring 13 cm	03-11-11	13:24:00
Overcoring 16 cm	03-11-11	13:26:55
Overcoring 18 cm	03-11-11	13:29:20
Overcoring 20 cm	03-11-11	13:32:15
Overcoring 23 cm	03-11-11	13:36:20
Overcoring 25 cm	03-11-11	13:37:10
Overcoring 30 cm	03-11-11	13:40:15
Overcoring stop	03-11-11	13:50:15
Flushing off	03-11-11	14:05:00
Core break	03-11-11	14:20:00
Core retrieval start	03-11-11	14:40:00
Core & probe on surface	03-11-11	15:40:00
End of strain registration	03-11-11	16:14:10
Calculation of strain difference: OC Start	03-11-11	13:14:30
Calculation of strain difference: OC Stop	03-11-11	13:48:15

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	1.1
16 – 30 cm	1.1
30 cm – overcoring stop	6

Table A6. Key measurement data for test no. 2:5:1, 415.26 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	03-11-12	19:44:00
Mixing of glue	03-11-12	19:56:00
Application of glue to gauges	03-11-12	20:02:00
Probe installation in pilot hole	03-11-12	20:16:00
Start time for dense sampling (5 s interval)	03-11-13	07:30:00
Adapter retrieved	03-11-13	08:40:00
Drill string fed down the hole	03-11-13	08:42:00
Drill string in place	03-11-13	09:34:00
Flushing start	03-11-13	09:35:00
Rotation start	03-11-13	10:02:58
Overcoring start	03-11-13	10:03:43
Overcoring 3 cm	03-11-13	10:05:53
Overcoring 5 cm	03-11-13	10:08:23
Overcoring 8 cm	03-11-13	10:10:43
Overcoring 10 cm	03-11-13	10:16:45
Overcoring 13 cm	03-11-13	10:15:33
Overcoring 16 cm	03-11-13	10:16:45
Overcoring 18 cm	03-11-13	10:19:03
Overcoring 20 cm	03-11-13	10:20:13
Overcoring 25 cm	03-11-13	10:22:23
Overcoring 30 cm	03-11-13	10:24:43
Overcoring stop	03-11-13	10:41:38
Flushing off	03-11-13	10:58:48
Core break	03-11-13	11:19:10
Core retrieval start	03-11-13	11:37:00
Core & probe on surface	03-11-13	12:15:00
End of strain registration	03-11-13	12:40:55

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	1.0
16 – 30 cm	1.8
30 cm – overcoring stop	3.4

Table A7. Key measurement data for test no. 2:7:3, 465.05 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	03-11-25	19:30:00
Mixing of glue	03-11-25	19:35:00
Application of glue to gauges	03-11-25	19:43:00
Probe installation in pilot hole	03-11-25	19:55:00
Start time for dense sampling (5 s interval)	03-11-26	07:00:00
Adapter retrieved	03-11-26	07:35:00
Drill string fed down the hole	03-11-26	08:45:00
Drill string in place	03-11-26	09:48:00
Flushing start	03-11-26	09:54:00
Rotation start	03-11-26	10:07:00
Overcoring start	03-11-26	10:14:00
Overcoring 3 cm	03-11-26	10:15:00
Overcoring 5 cm	03-11-26	10:16:00
Overcoring 8 cm	03-11-26	10:17:00
Overcoring 10 cm	03-11-26	10:18:00
Overcoring 13 cm	03-11-26	10:19:00
Overcoring 16 cm	03-11-26	10:20:00
Overcoring 18 cm	03-11-26	10:21:00
Overcoring 20 cm	03-11-26	10:22:00
Overcoring 25 cm	03-11-26	10:24:00
Overcoring 30 cm	03-11-26	10:27:00
Overcoring stop	03-11-26	10:36:00
Flushing off	03-11-26	10:51:00
Core break	03-11-26	11:17:00
Core retrieval start	03-11-26	11:37:00
Core & probe on surface	03-11-26	-
End of strain registration	03-11-26	-

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	2.5
16 – 30 cm	2.5
30 cm – overcoring stop	5.5

Table A8. Key measurement data for test no. 2:8:2, 471.69 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	03-12-10	12:43:00
Mixing of glue	03-12-10	12:59:00
Application of glue to gauges	03-12-10	13:05:00
Probe installation in pilot hole	03-12-10	13:17:00
Start time for dense sampling (5 s interval)	03-12-11	07:00:00
Adapter retrieved	03-12-11	07:25:00
Drill string fed down the hole	03-12-11	07:57:00
Drill string in place	03-12-11	08:40:00
Flushing start	03-12-11	08:45:00
Rotation start	03-12-11	09:20:00
Overcoring start	03-12-11	09:22:00
Overcoring 16 cm	03-12-11	09:28:00
Overcoring 30 cm	03-12-11	09:33:00
Overcoring stop	03-12-11	09:47:00
Flushing off	03-12-11	09:59:00
Core break	03-12-11	10:15:00
Core retrieval start	03-12-11	10:30:00
Core & probe on surface	03-12-11	11:28:00
End of strain registration	03-12-11	11:53:50
Calculation of strain difference: OC Start	03-12-11	09:22:00
Calculation of strain difference: OC Stop	03-12-11	09:47:00
Overcoring advance	Overcoring rate [cm/min]	
0 – 16 cm	2.7	
16 – 30 cm	2.8	
30 cm – overcoring stop	5.0	

Table A9. Key measurement data for test no. 2:9:1, 472.98 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	03-12-15	20:55:00
Mixing of glue	03-12-15	21:30:00
Application of glue to gauges	03-12-15	21:39:00
Probe installation in pilot hole	03-12-15	21:53:00
Start time for dense sampling (5 s interval)	03-12-16	08:00:00
Adapter retrieved	03-12-16	08:40:00
Drill string fed down the hole	03-12-16	09:05:00
Drill string in place	03-12-16	10:35:00
Flushing start	03-12-16	10:40:00
Rotation start	03-12-16	11:04:00
Overcoring start	03-12-16	11:05:00
Overcoring 16 cm	03-12-16	11:14:00
Overcoring 30 cm	03-12-16	11:23:00
Overcoring stop	03-12-16	11:25:00
Flushing off	03-12-16	11:55:00
Core break	03-12-16	12:15:00
Core retrieval start	03-12-16	-
Core & probe on surface	03-12-16	14:20:00
End of strain registration	03-12-16	15:14:50
Calculation of strain difference: OC Start	03-12-16	11:05:00
Calculation of strain difference: OC Stop	03-12-16	11:25:00

Overcoring advance	Overcoring rate [cm/min]
0 – 16 cm	1.8
16 – 30 cm	1.8

Table A10. Key measurement data for test no. 2:10:1, 474.25 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	03-12-17	10:34:00
Mixing of glue	03-12-17	11:07:00
Application of glue to gauges	03-12-17	11:12:00
Probe installation in pilot hole	03-12-17	11:22:00
Start time for dense sampling (5 s interval)	03-12-18	07:00:00
Adapter retrieved	03-12-18	07:30:00
Drill string fed down the hole	03-12-18	08:10:00
Drill string in place	03-12-18	09:45:00
Flushing start	03-12-18	09:55:00
Rotation start	03-12-18	10:33:00
Overcoring start	03-12-18	10:34:00
Overcoring 3 cm	03-12-18	10:35:30
Overcoring 5 cm	03-12-18	10:36:15
Overcoring 8 cm	03-12-18	10:38:00
Overcoring 12 cm	03-12-18	10:40:00
Overcoring 16 cm	03-12-18	10:42:00
Overcoring 18 cm	03-12-18	10:43:00
Overcoring 20 cm	03-12-18	10:44:00
Overcoring 30 cm	03-12-18	10:47:00
Overcoring stop	03-12-18	10:59:00
Flushing off	03-12-18	11:18:00
Core break	03-12-18	11:35:00
Core retrieval start	03-12-18	11:50:00
Core & probe on surface	03-12-18	13:05:00
End of strain registration	03-12-18	-
Overcoring advance	**Overcoring rate [cm/min]**	
0 – 16 cm	2.0	
16 – 30 cm	2.8	
30 cm – overcoring stop	3.0	

Table A11. Key measurement data for test no. 2:11:1, 475.34 m borehole length.

Activity	Date [yy-mm-dd]	Time [hh:mm:ss]
Activation time	04-01-08	14:15:00
Mixing of glue	04-01-08	15:43:00
Application of glue to gauges	04-01-08	15:50:00
Probe installation in pilot hole	04-01-08	16:01:00
Start time for dense sampling (5 s interval)	04-01-09	03:00:00
Adapter retrieved	04-01-09	03:20:00
Drill string fed down the hole	04-01-09	03:50:00
Drill string in place	04-01-09	04:55:00
Flushing start	04-01-09	04:59:00
Rotation start	04-01-09	05:28:00
Overcoring start	04-01-09	05:29:00
Overcoring 6 cm	04-01-09	05:33:00
Overcoring 16 cm	04-01-09	05:39:00
Overcoring 20 cm	04-01-09	05:42:00
Overcoring 26 cm	04-01-09	05:45:00
Overcoring 31 cm	04-01-09	05:47:00
Overcoring stop	04-01-09	06:05:00
Flushing off	04-01-09	06:20:00
Core break	04-01-09	06:36:00
Core retrieval start	04-01-09	06:50:00
Core & probe on surface	04-01-09	08:05:00
End of strain registration	04-01-09	-
Overcoring advance	**Overcoring rate [cm/min]**	
0 – 16 cm	1.6	
16 – 30 cm	1.7	

Appendix B

Overcoring strain data and graphs

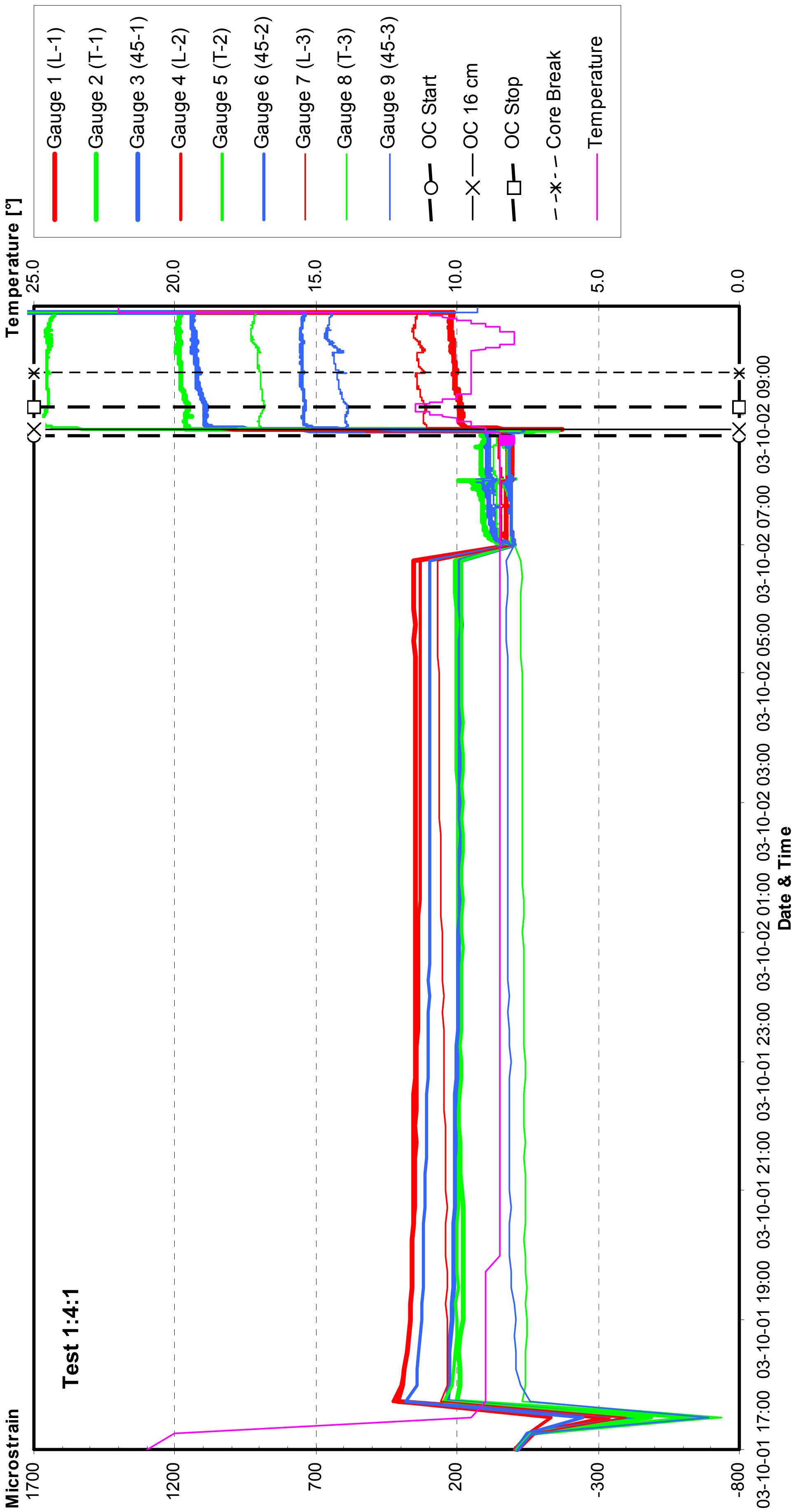


Figure B1. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:4:1, 238.94 m borehole length.*

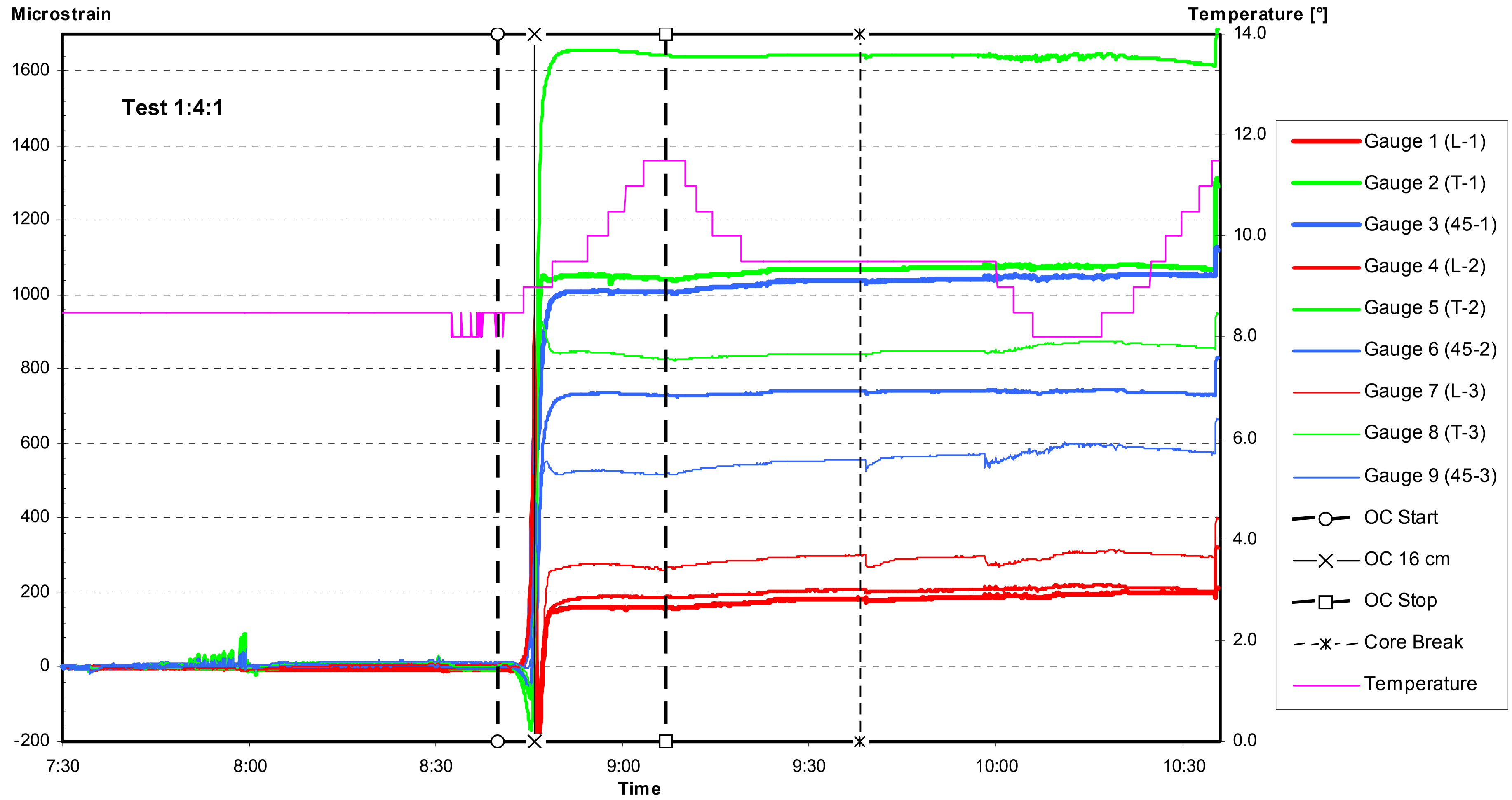


Figure B2. *Recorded strain data and temperature during overcoring and core recovery for test no. 1:4:1, 238.94 m borehole length. Strain values reset to zero at 07:30.*

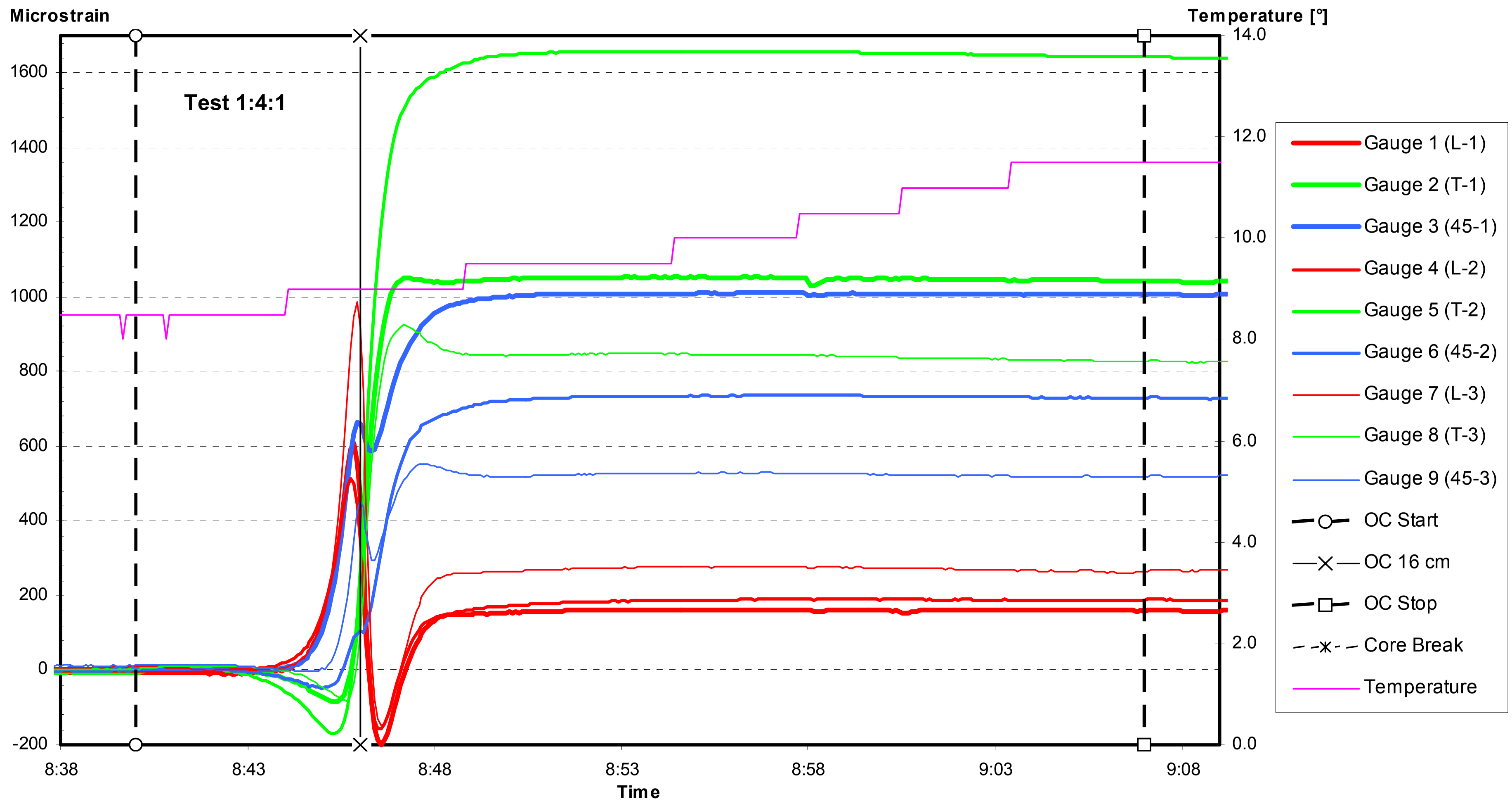


Figure B3. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:4:1, 238.94 m borehole length. Strain values reset to zero at 07:30.*

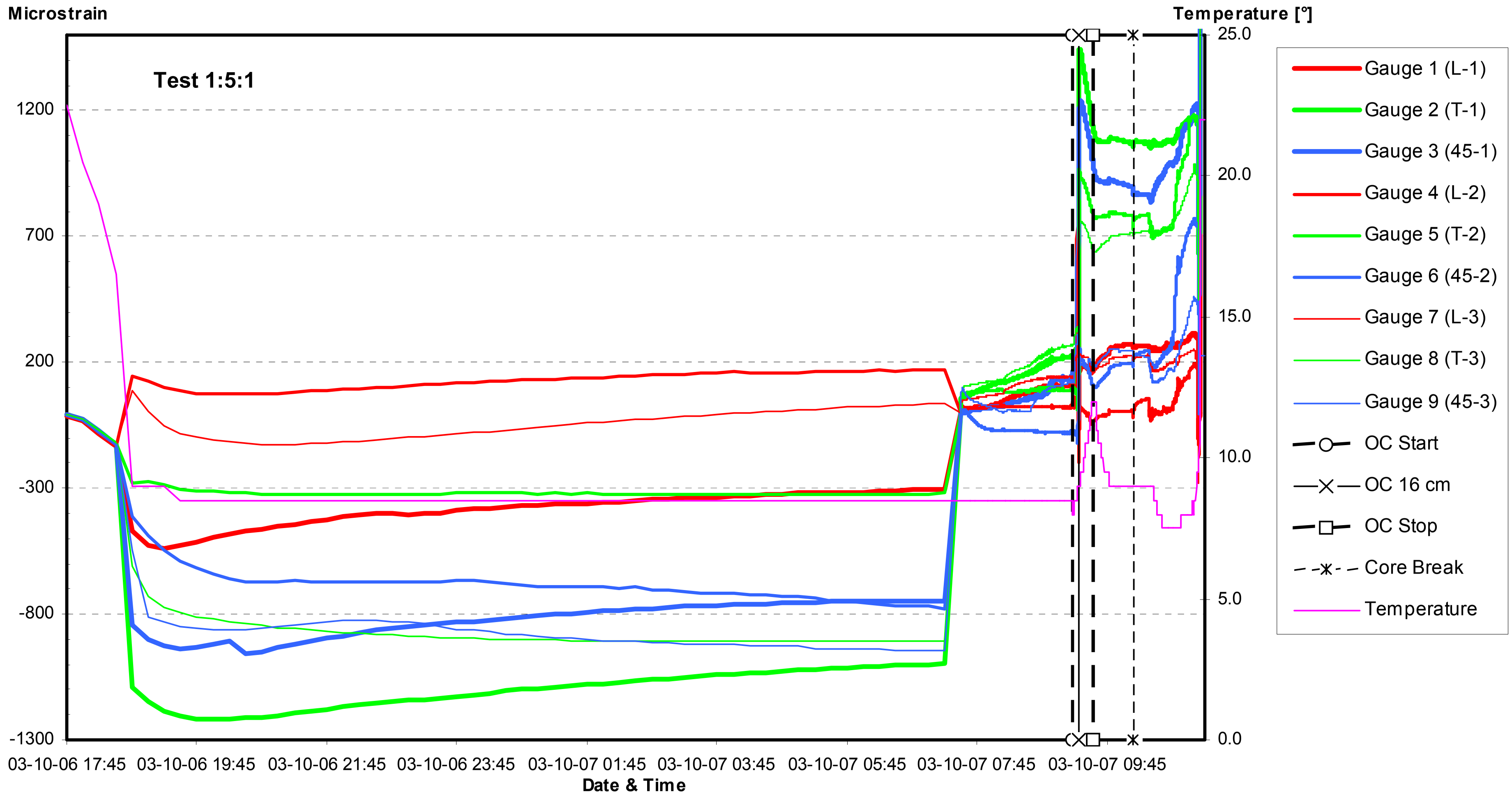


Figure B4. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:5:1, 240.01 m borehole length.*

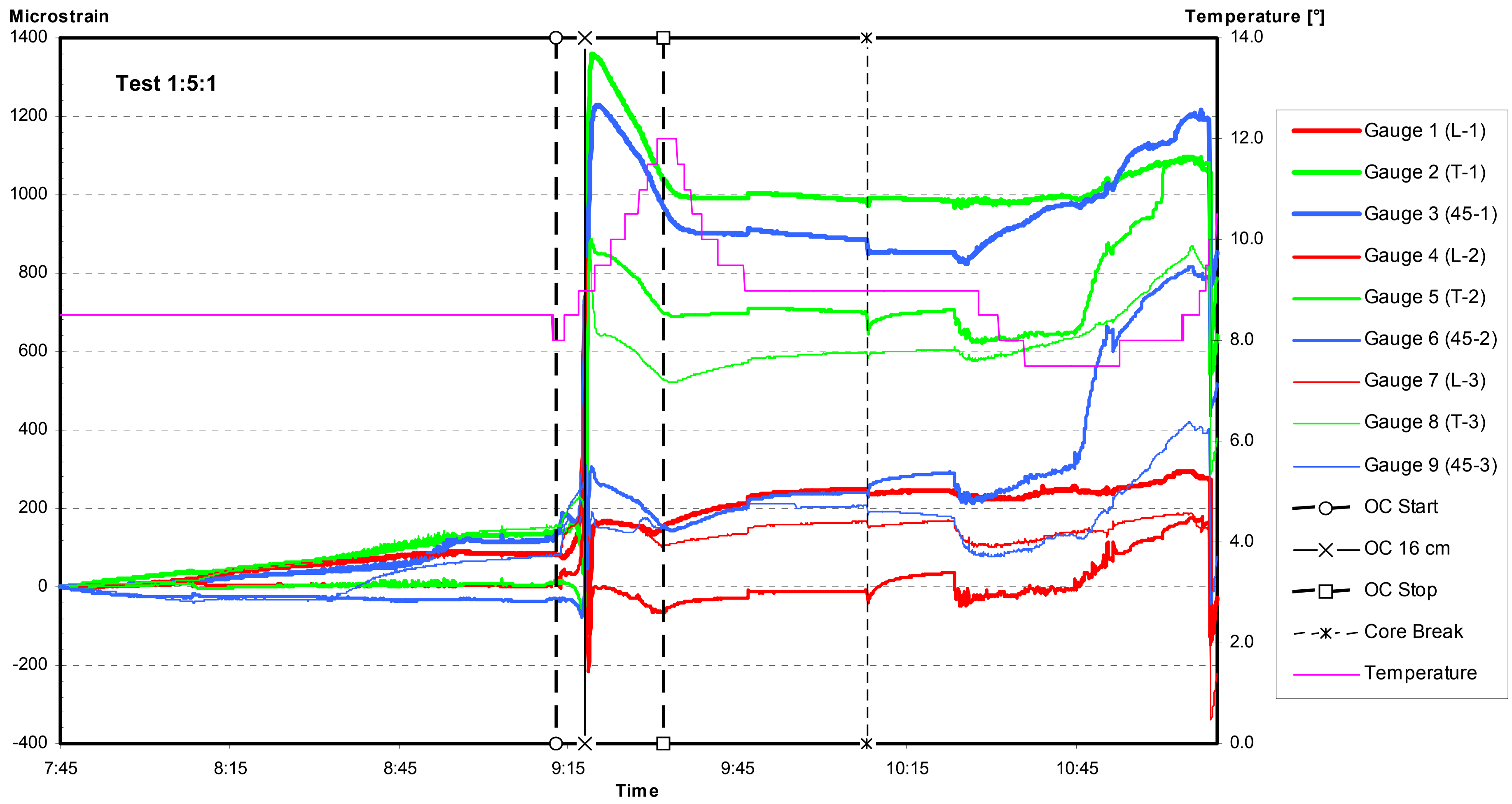


Figure B5. *Recorded strain data and temperature during overcoring and core recovery for test no. 1:5:1, 240.01 m borehole length. Strain values reset to zero at 07:45.*

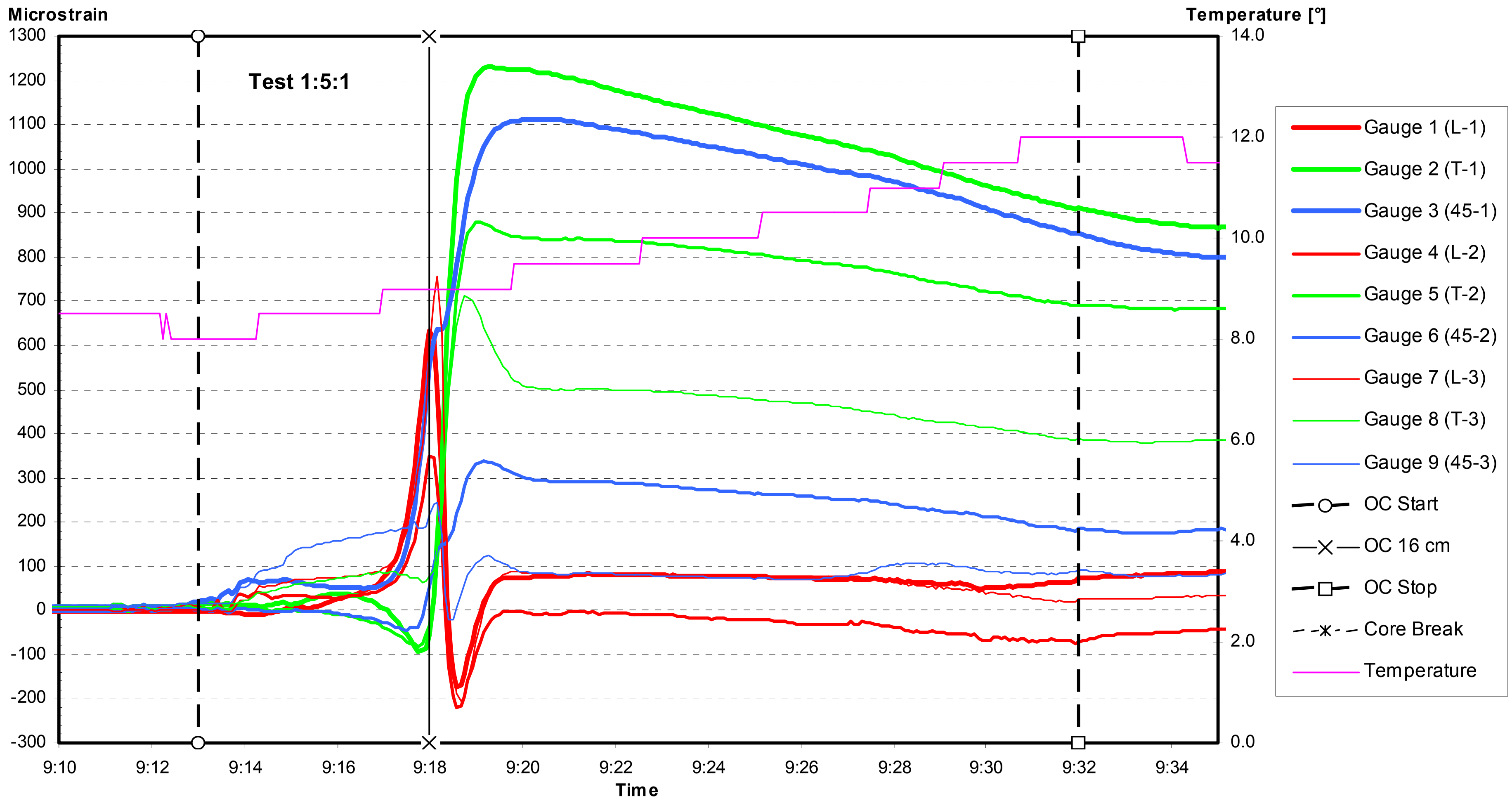


Figure B6. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:5:1, 240.01 m borehole length. Strain values reset to zero at 09:00.*

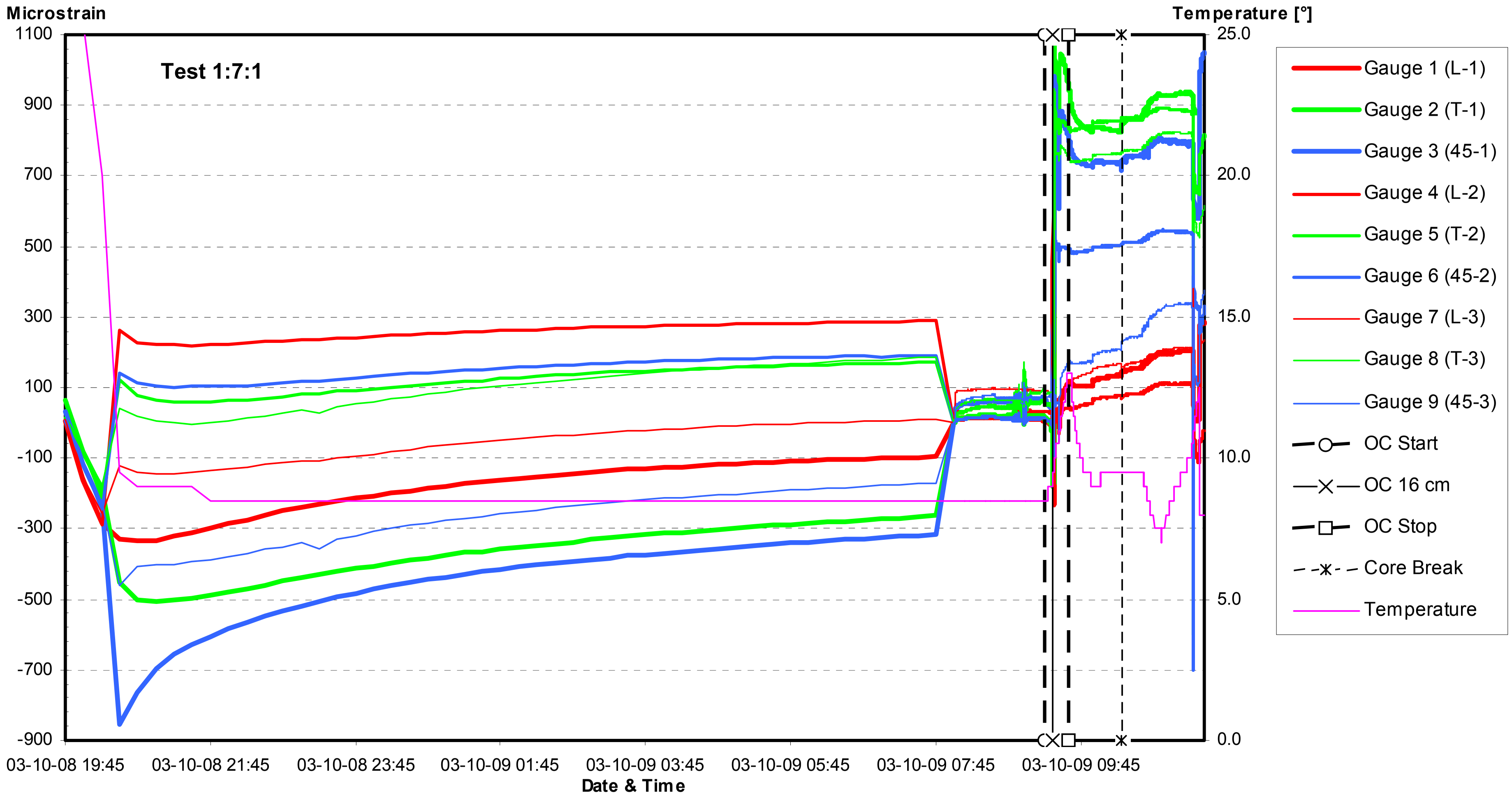


Figure B7. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 1:7:1, 242.05 m borehole length.*

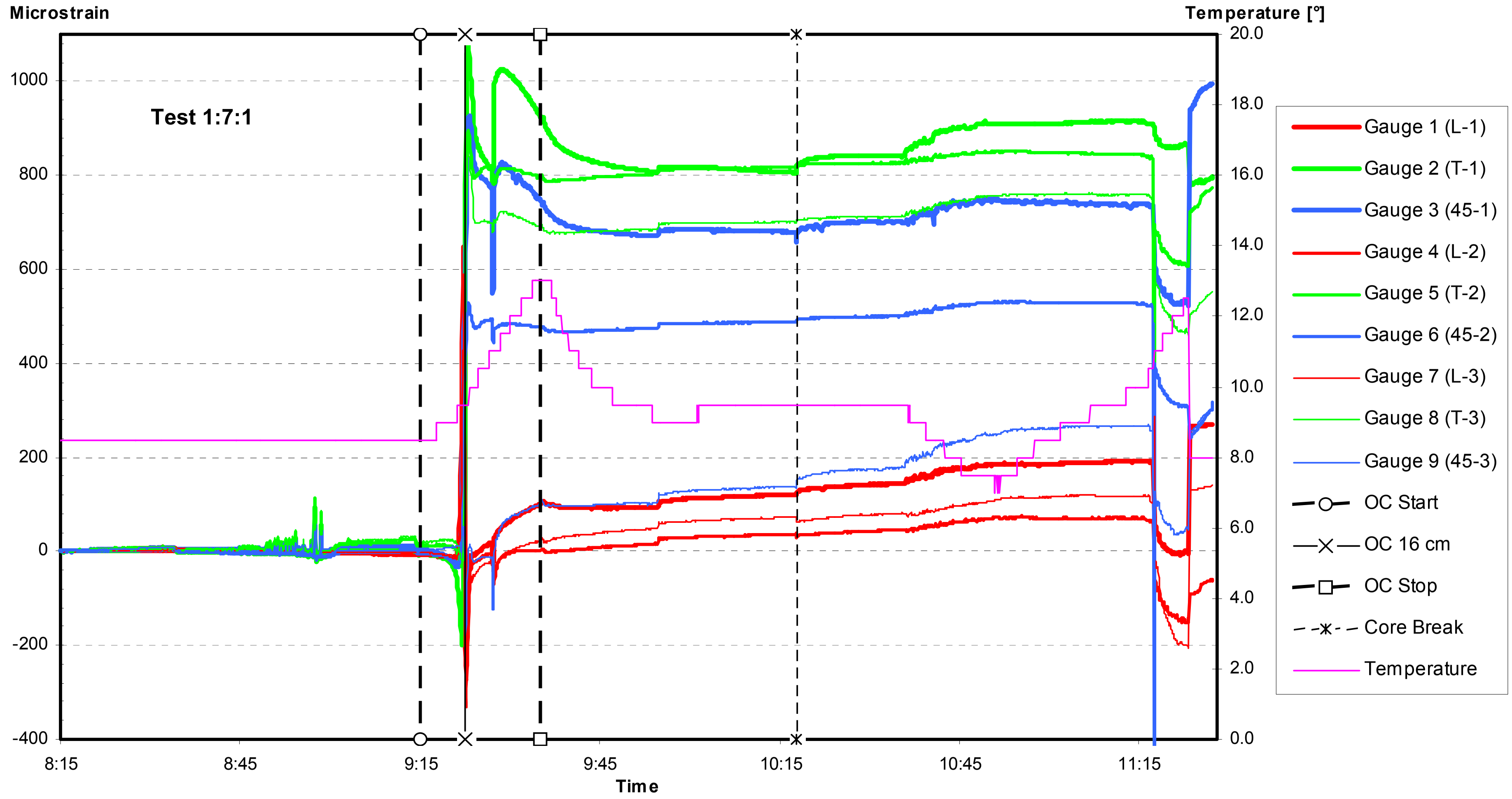


Figure B8. *Recorded strain data and temperature during overcoring and core recovery for test no. 1:7:1, 242.05 m borehole length. Strain values reset to zero at 08:15.*

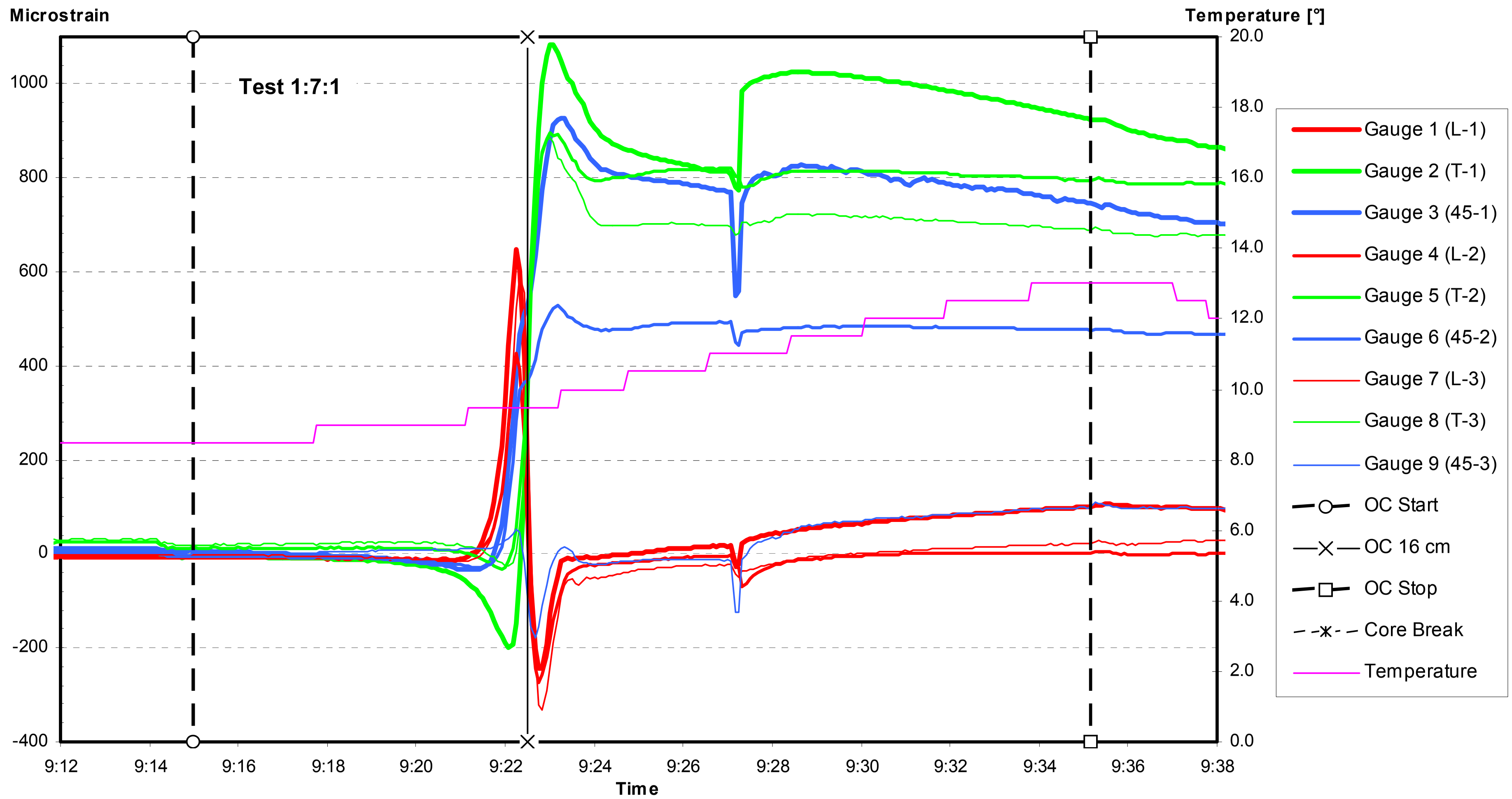


Figure B9. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 1:7:1, 242.05 m borehole length. Strain values reset to zero at 08:15.*

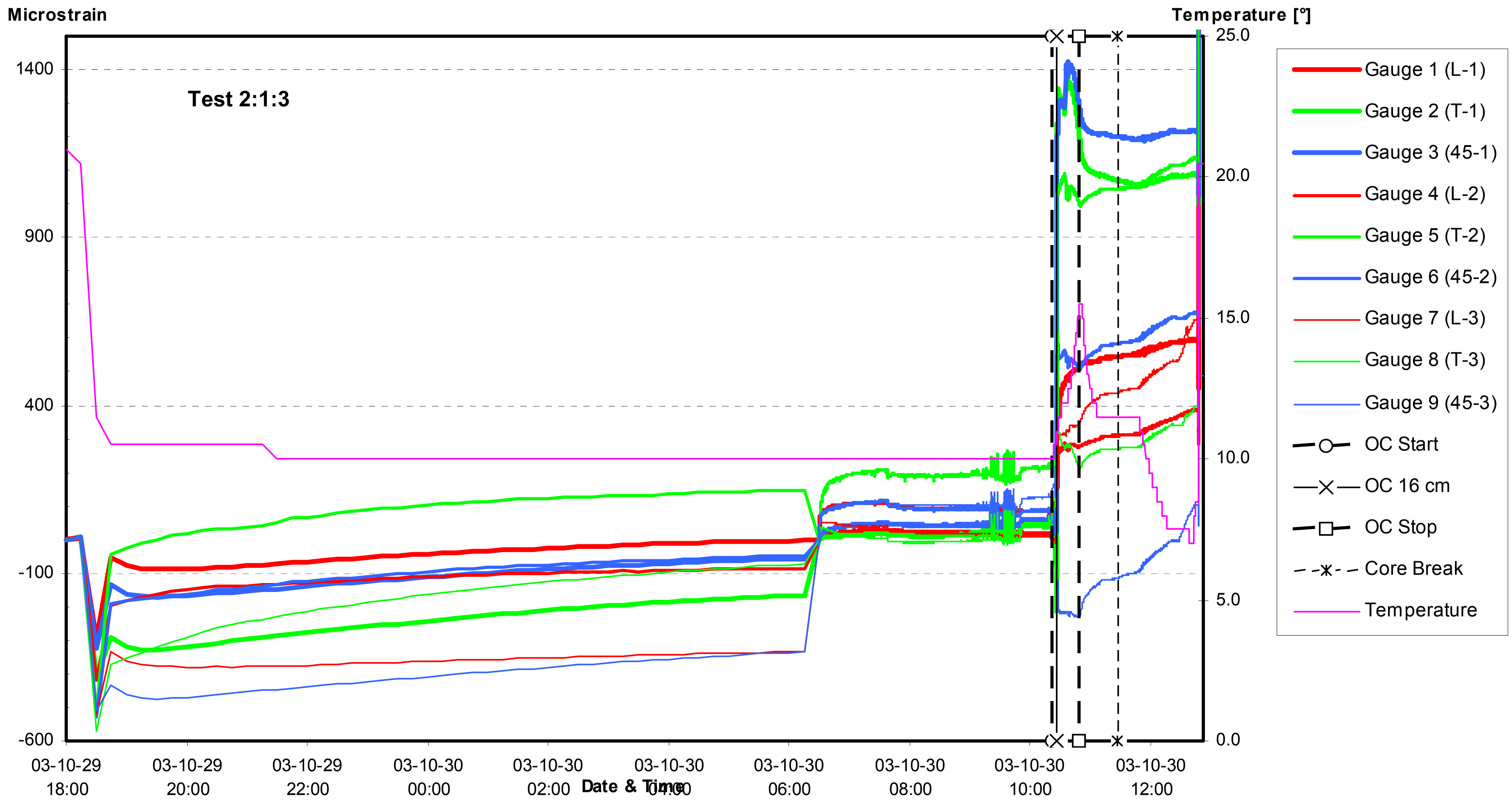


Figure B10. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:1:3, 406.92 m borehole length.*

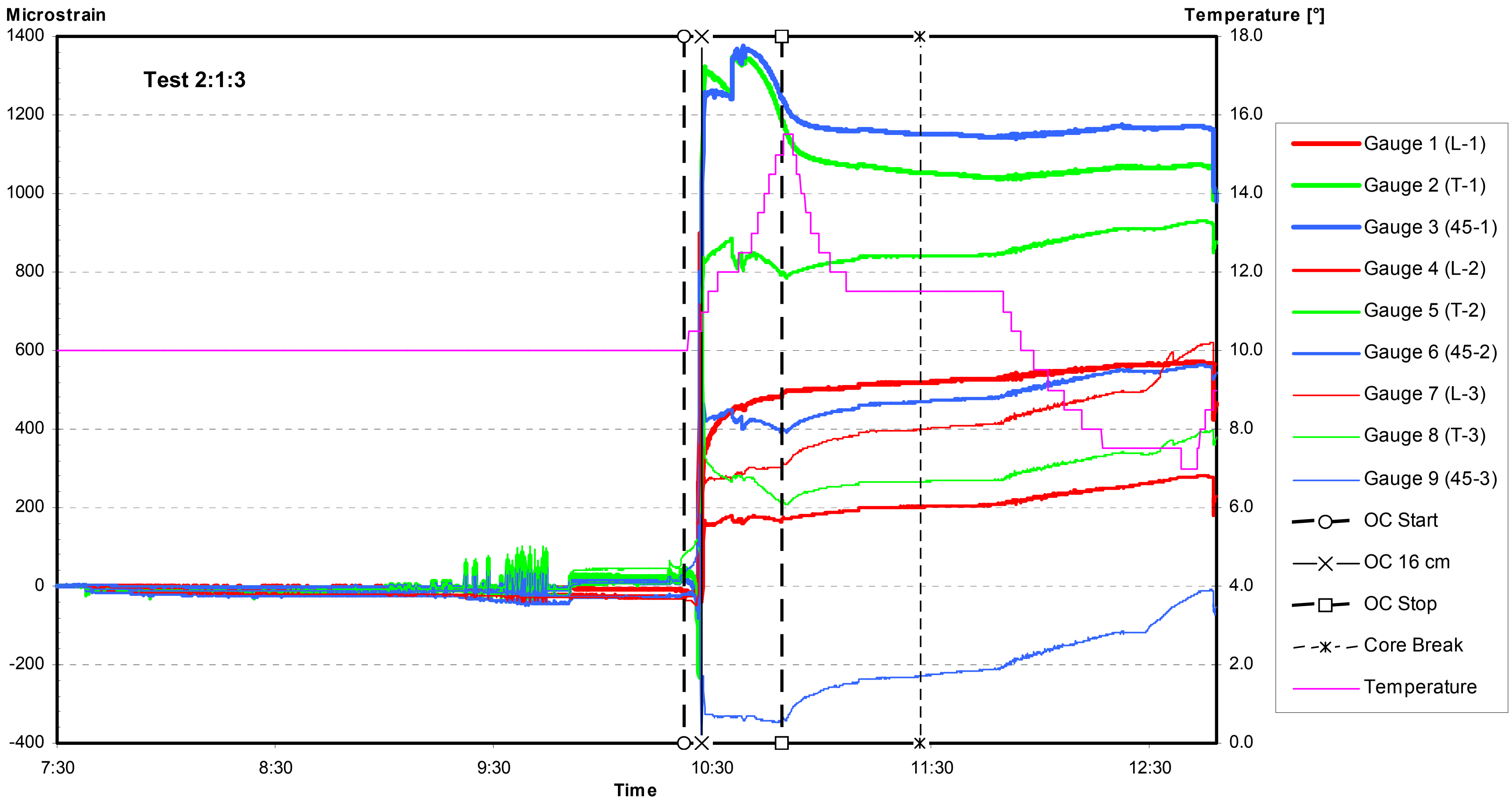


Figure B11. *Recorded strain data and temperature during overcoring and core recovery for test no. 2:1:3, 406.92 m borehole length. Strain values reset to zero at 07:30.*

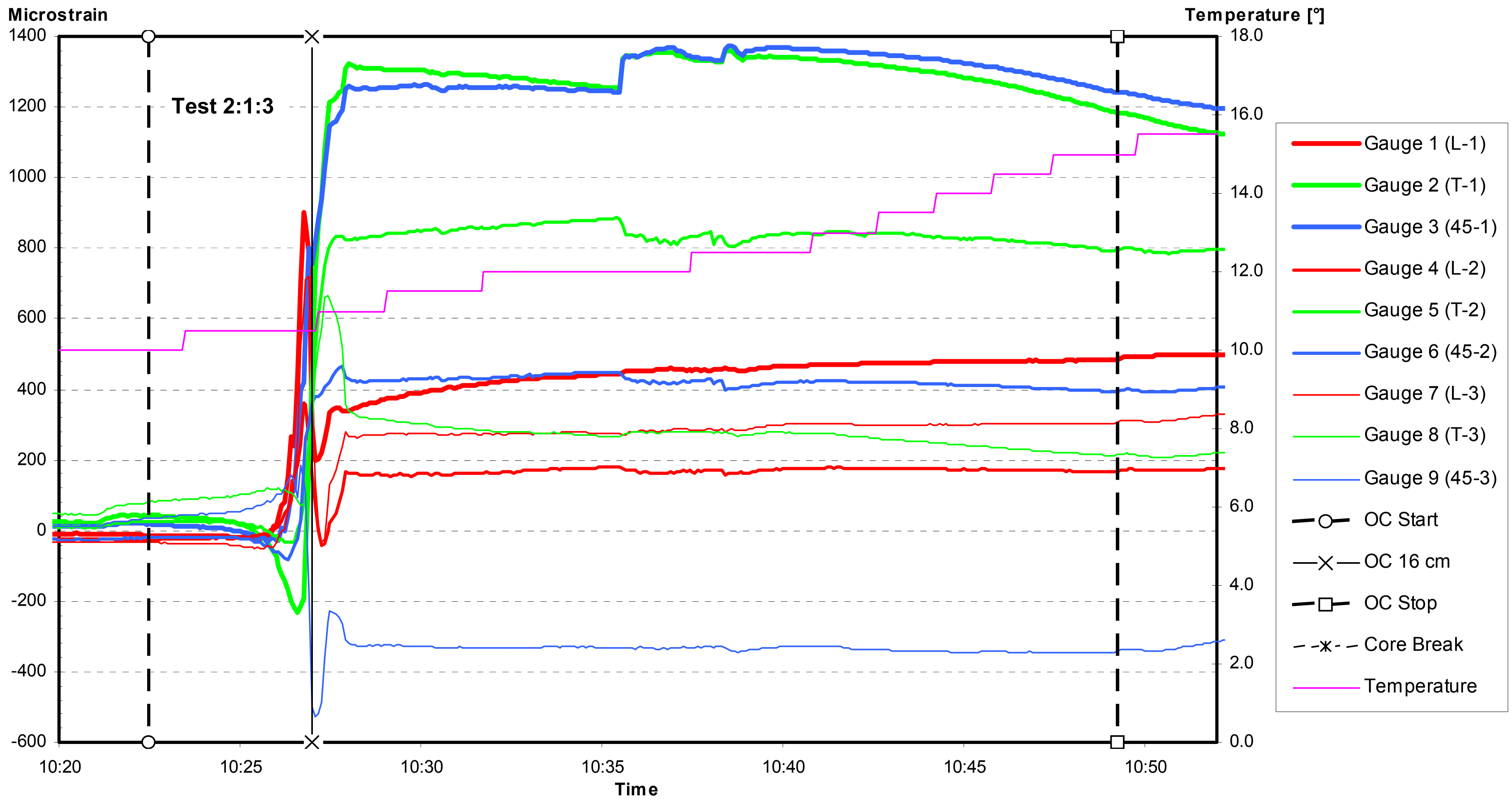


Figure B12. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:1:3, 406.92 m borehole length. Strain values reset to zero at 07:30.*

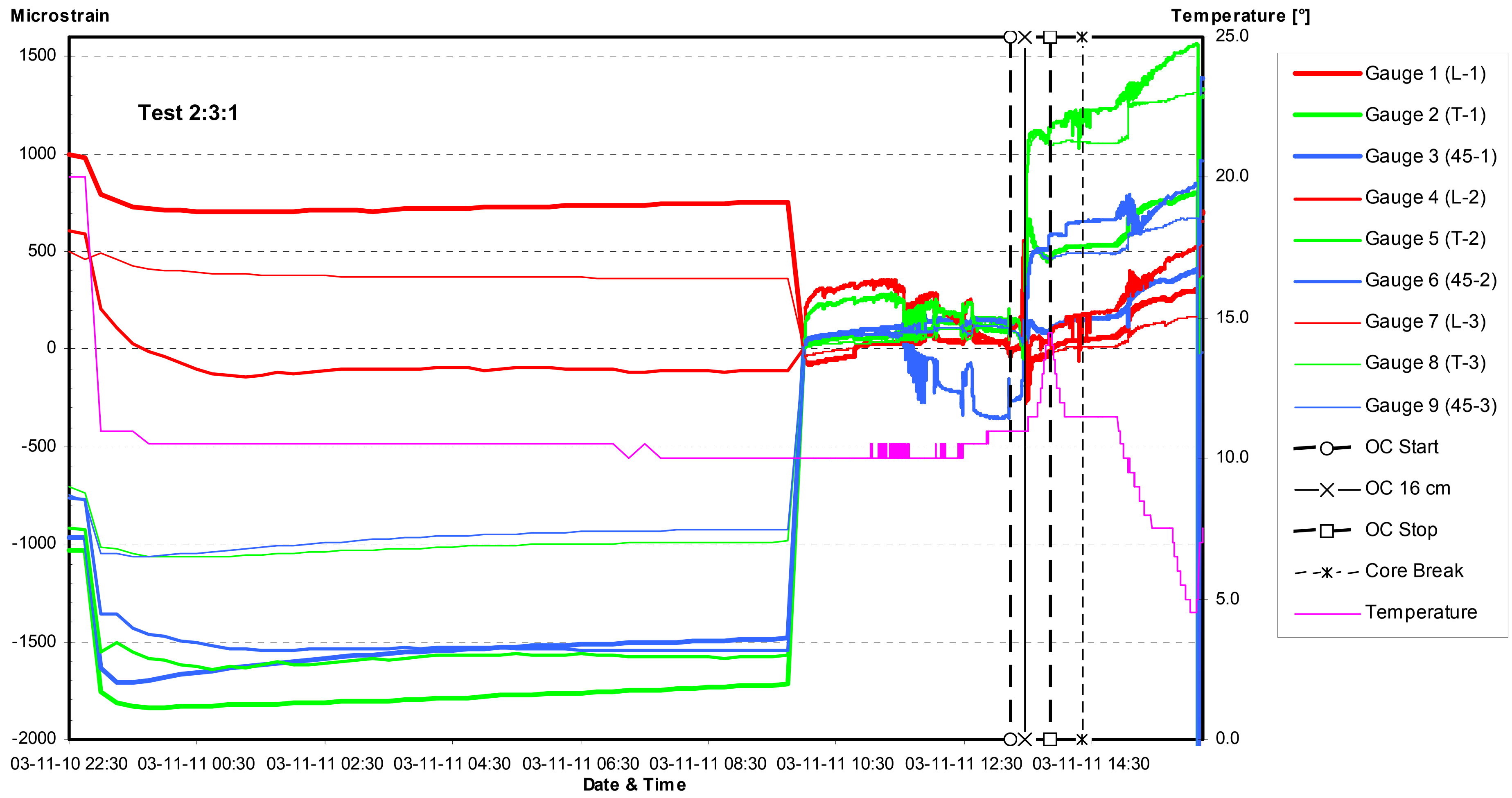


Figure B13. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:3:1, 412.79 m borehole length.*

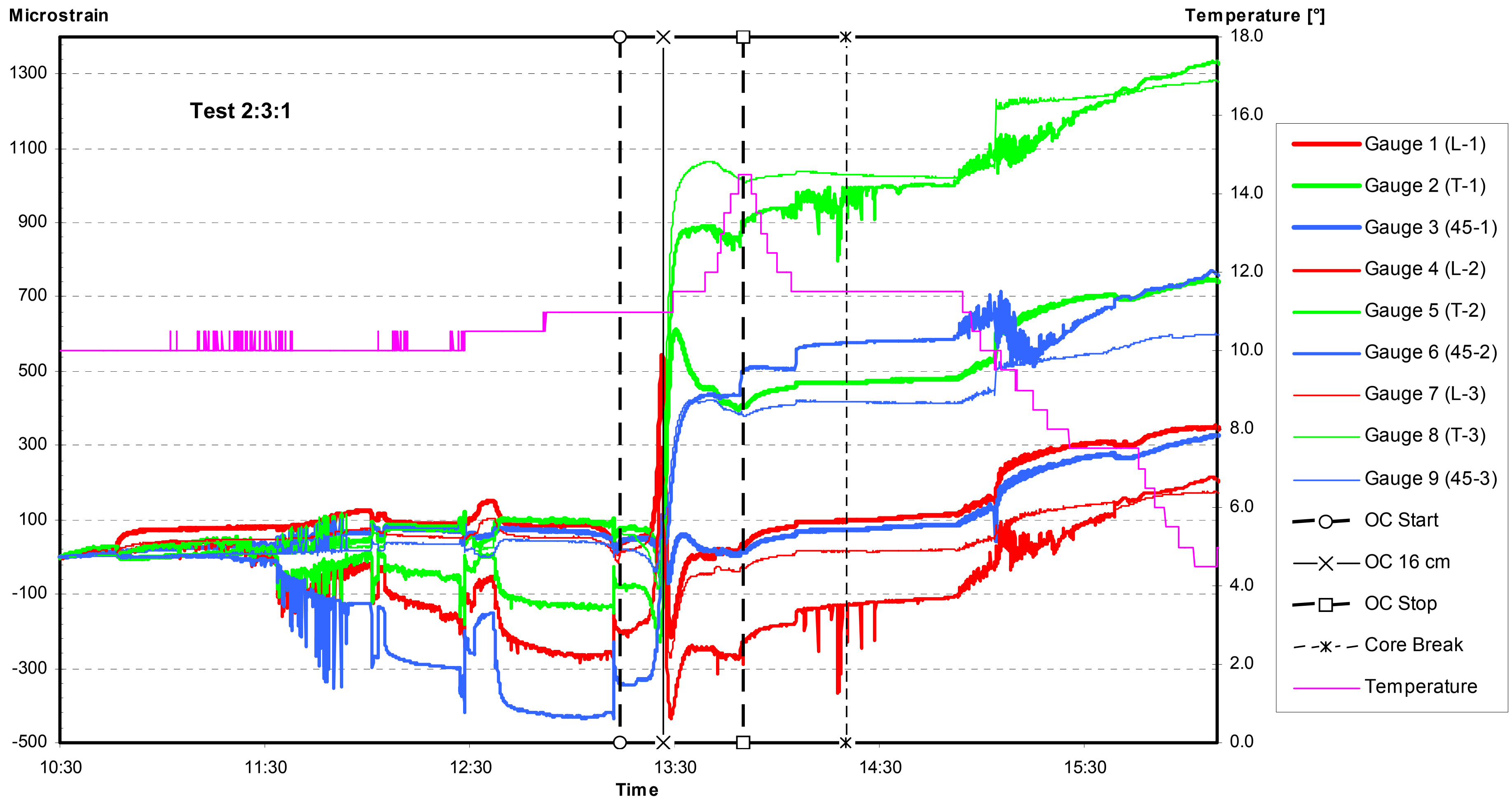


Figure B14. *Recorded strain data and temperature during overcoring and core recovery for test no. 2:3:1, 412.79 m borehole length. Strain values reset to zero at 10:30.*

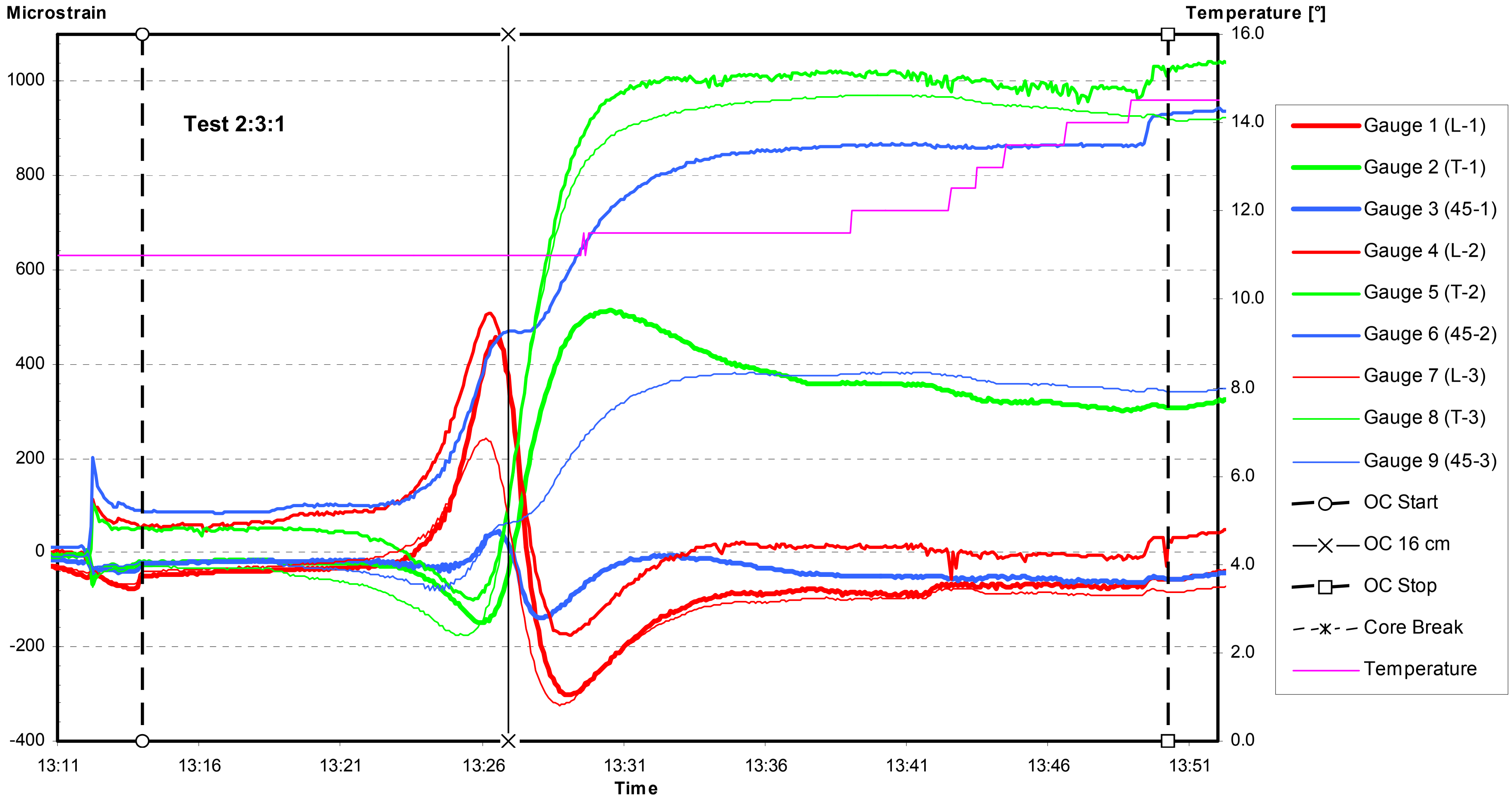


Figure B15. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:3:1, 412.79 m borehole length. Strain values reset to zero at 13:00.*

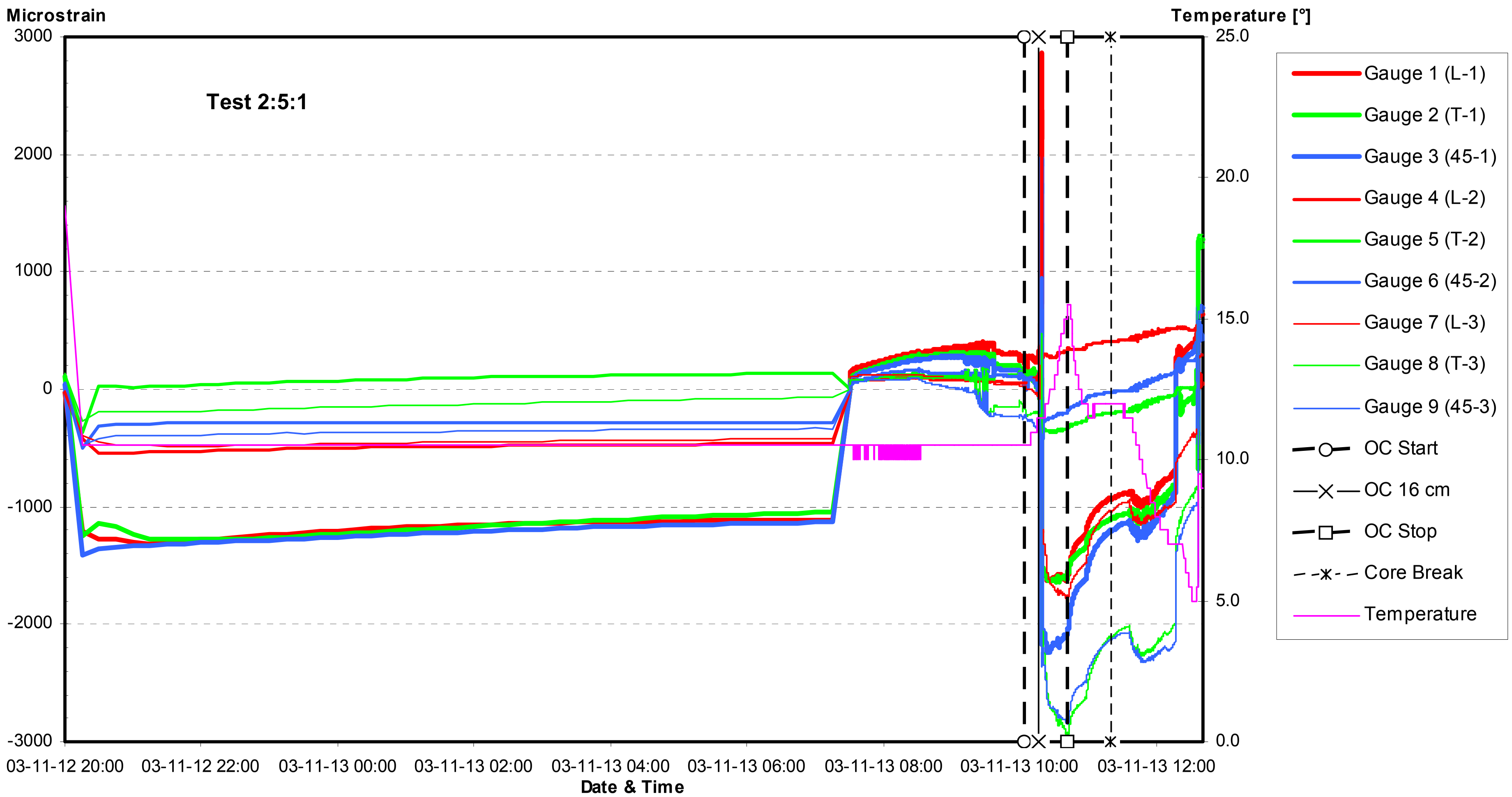


Figure B16. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:5:1, 415.16 m borehole length.*

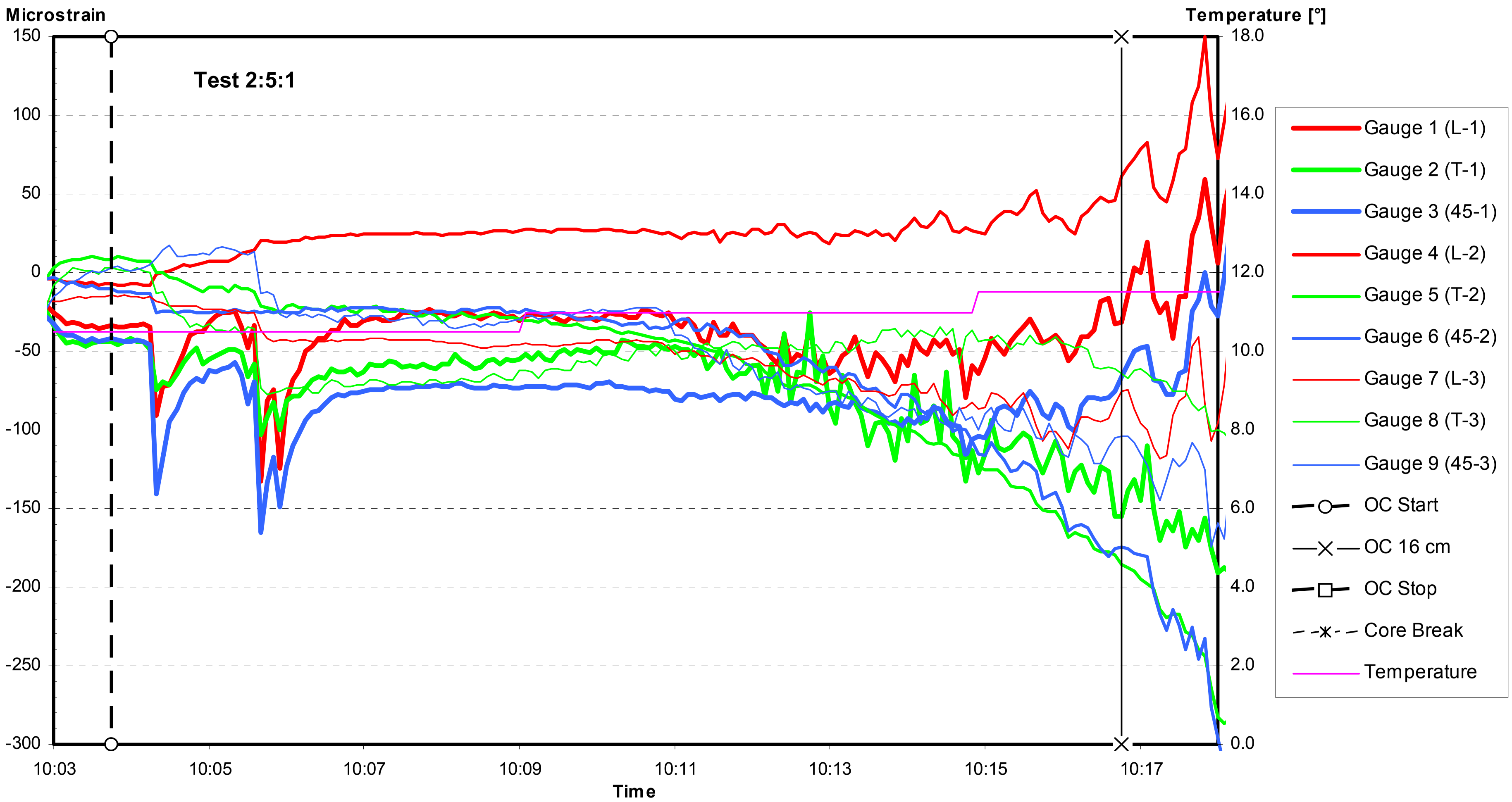


Figure B17. *Recorded strain data and temperature during overcoring (from start to 16 cm drill bit position) for test no. 2:5:1, 415.16 m borehole length. Strain values reset to zero at 09:55.*

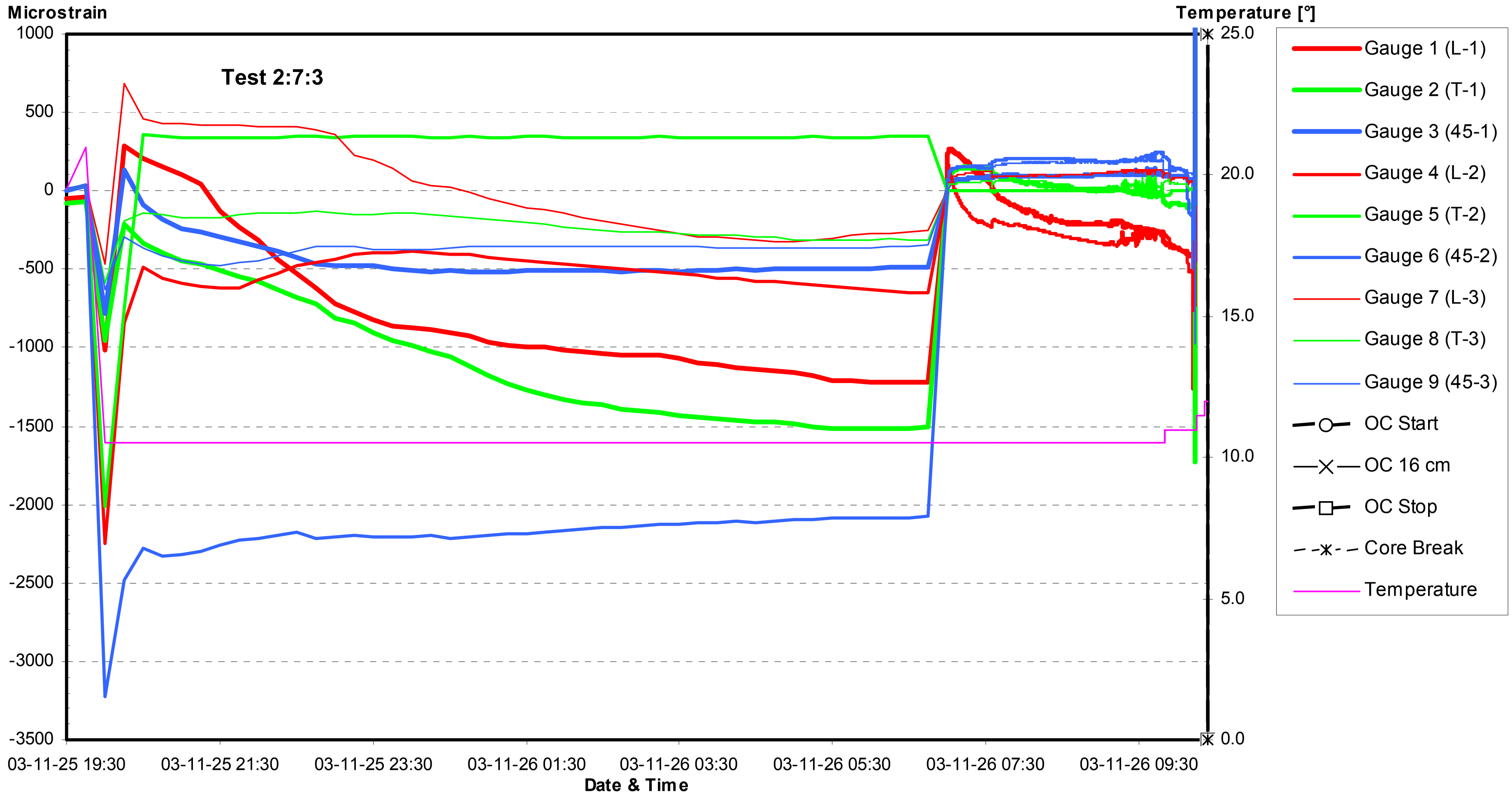


Figure B18. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:7:3, 465.05 m borehole length.*

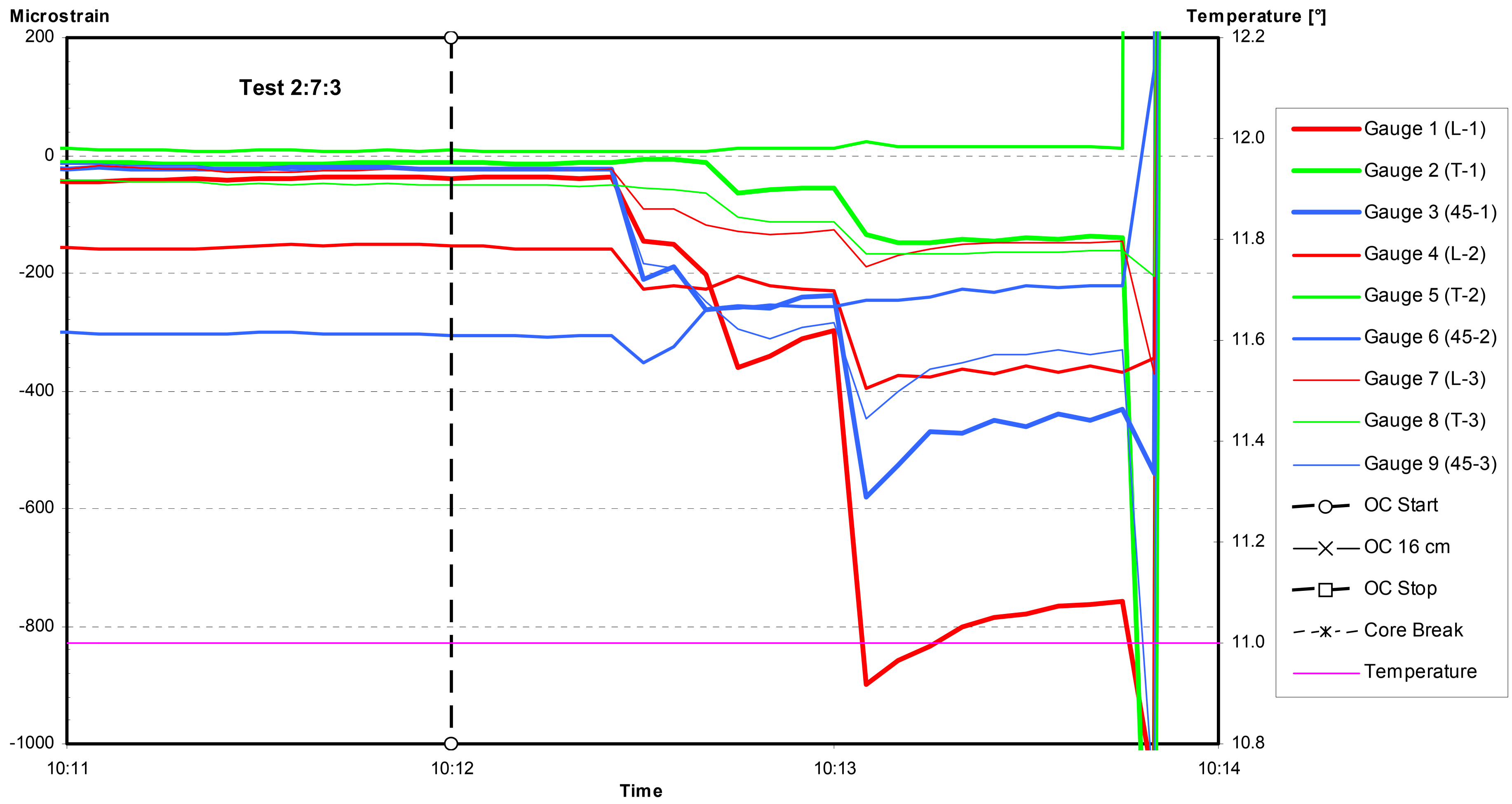


Figure B19. *Recorded strain data and temperature during overcoring (from start to approximately5 cm drill bit position) for test no. 2:7:3, 465.05 m borehole length. Strain values reset to zero at 10:00.*

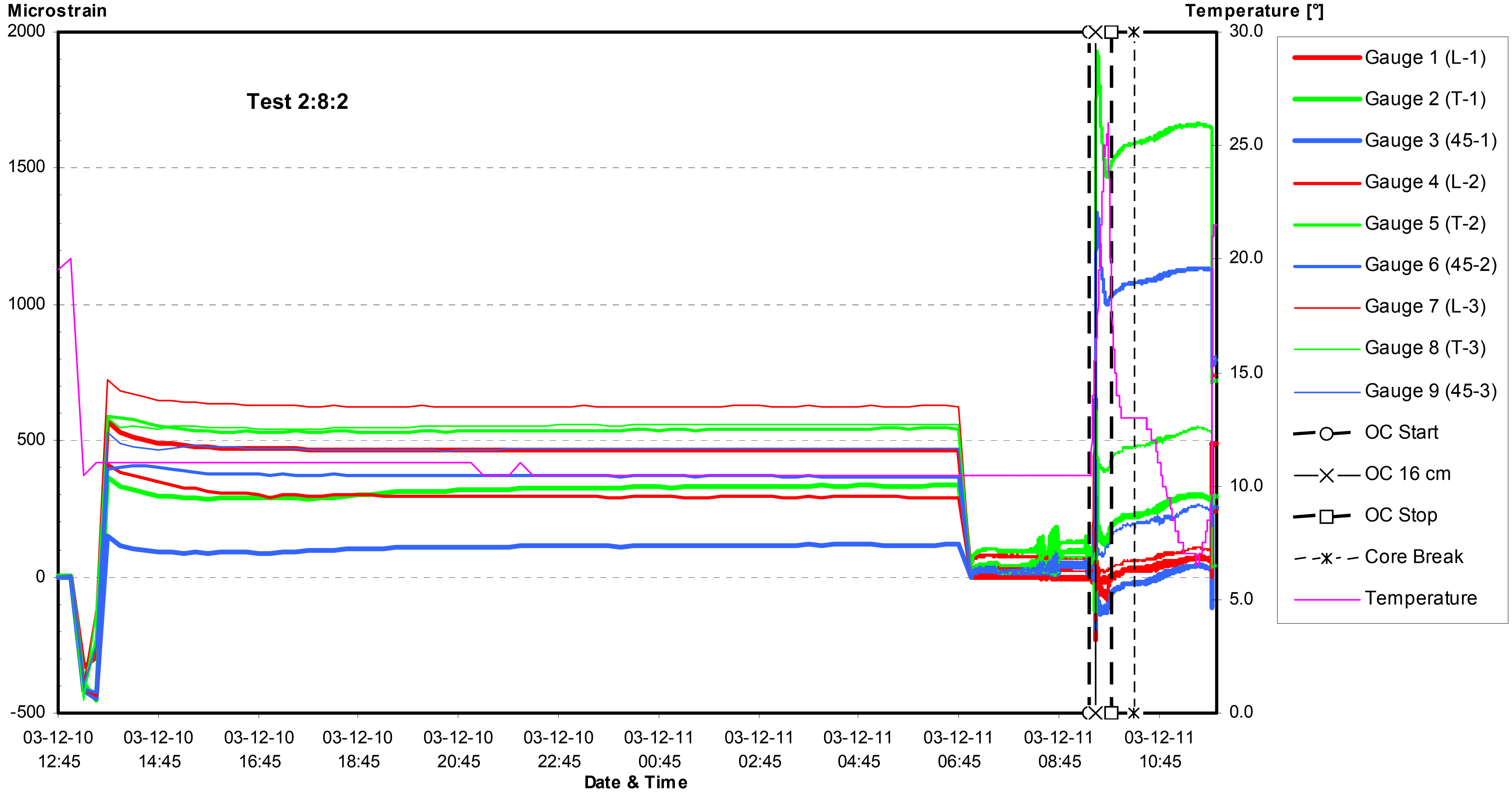


Figure B20. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:8:2, 471.69 m borehole length.*

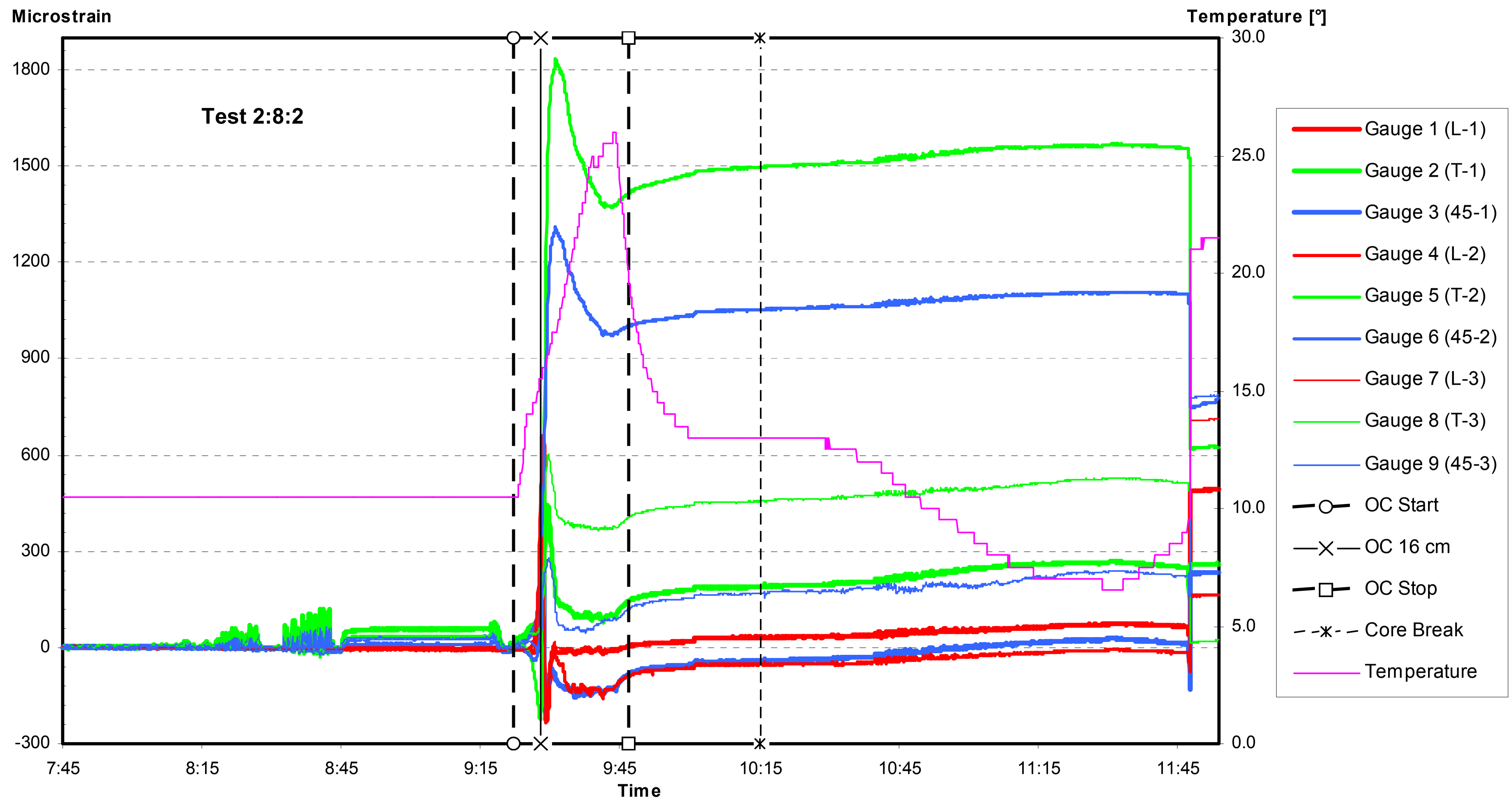


Figure B21. *Recorded strain data and temperature during overcoring and core recovery for test no. 2:8:2, 471.69 m borehole length. Strain values reset to zero at 07:45.*

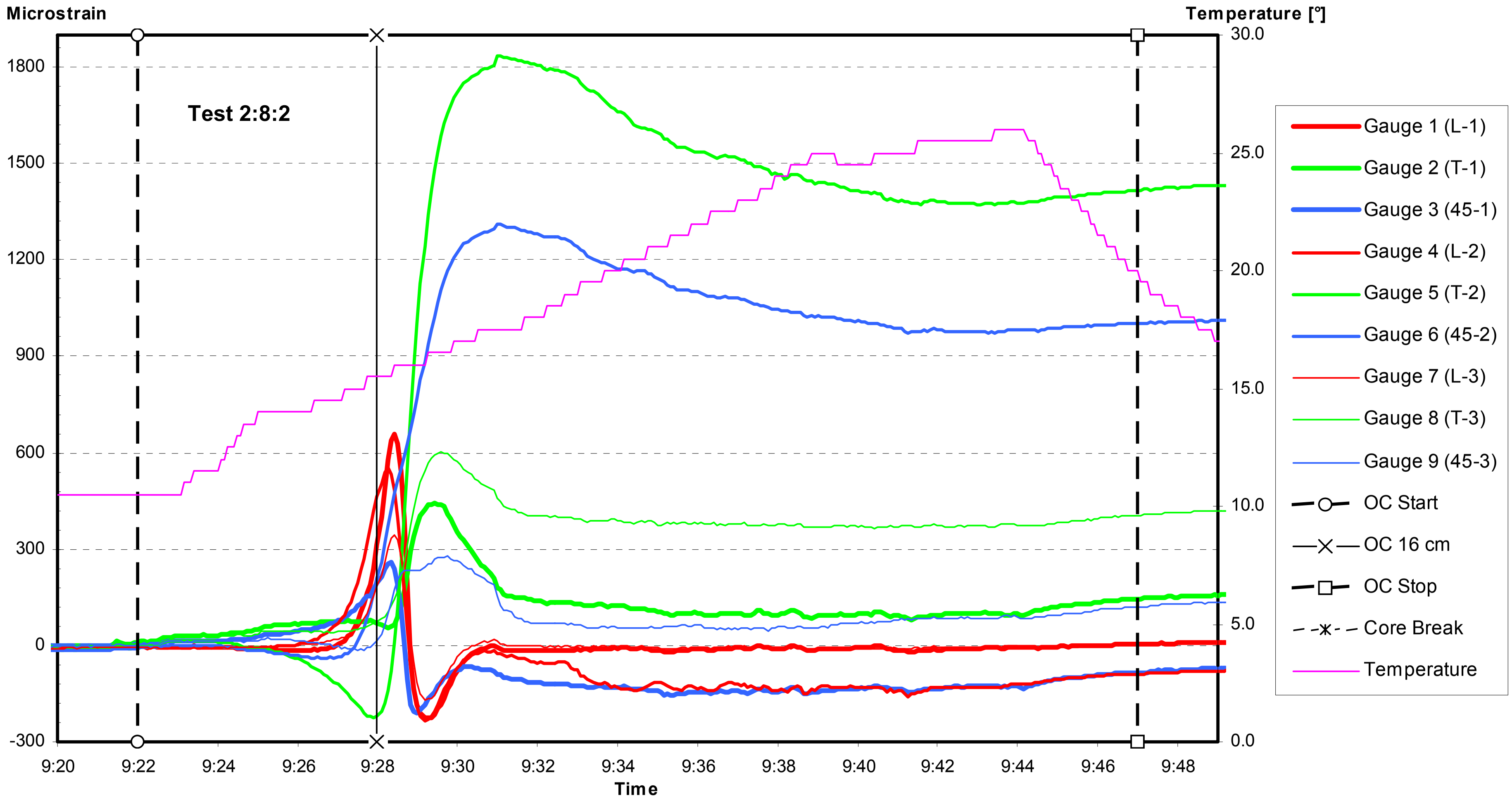


Figure B22. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:8:2, 471.69 m borehole length. Strain values reset to zero at 07:45.*

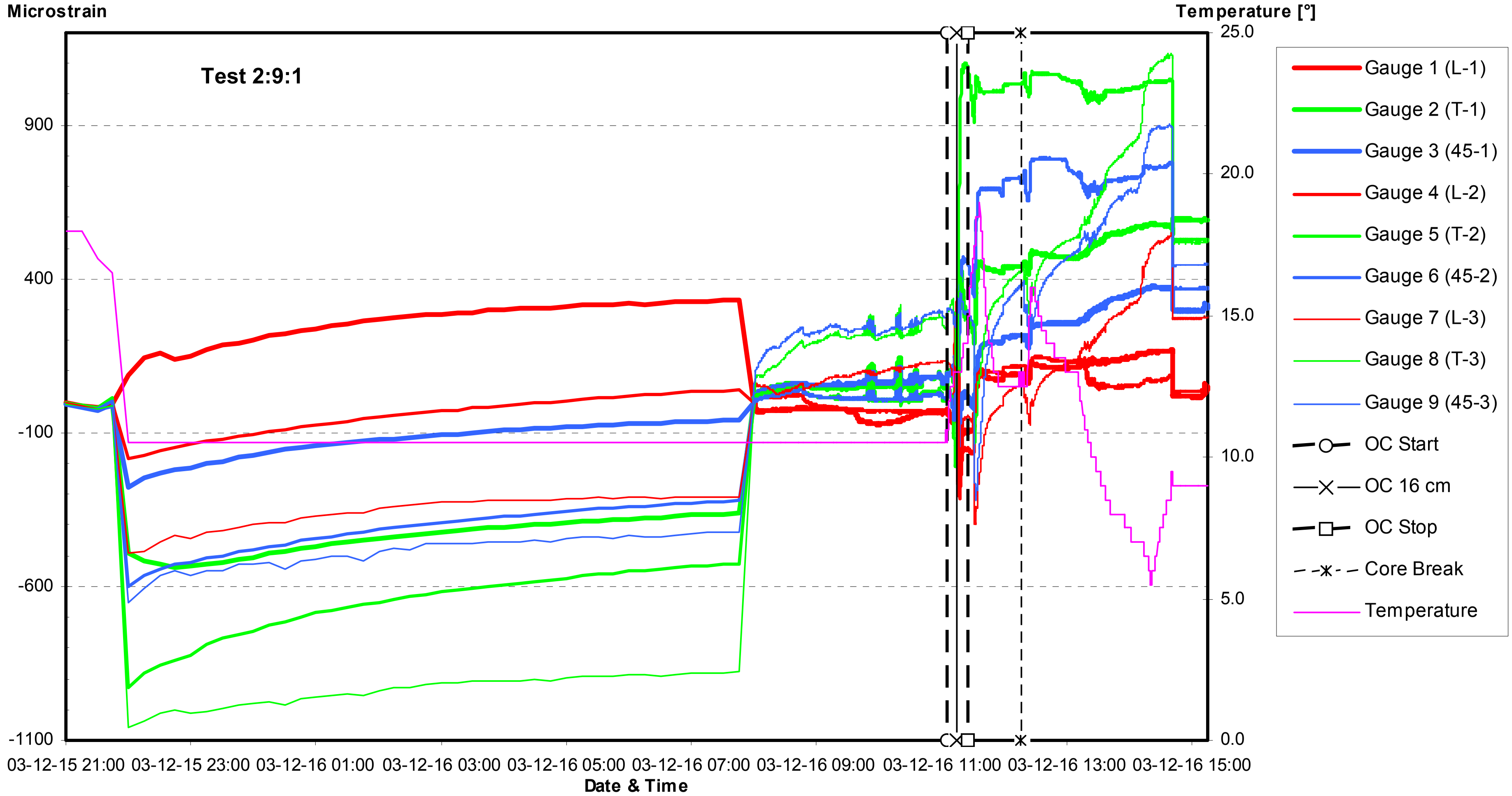


Figure B23. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:9:1, 472.98 m borehole length.*

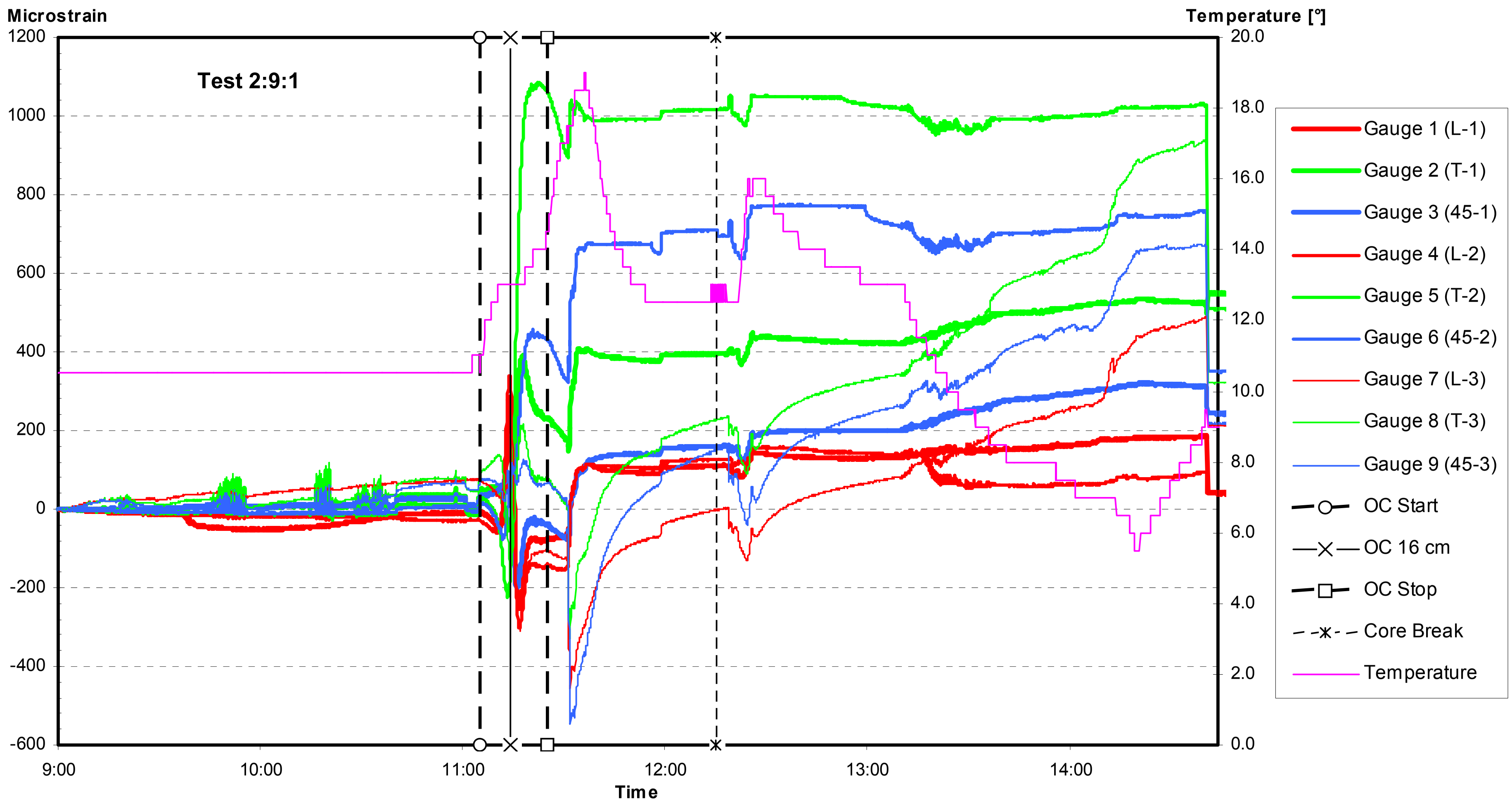


Figure B24. *Recorded strain data and temperature during overcoring and core recovery for test no. 2:9:1, 472.98 m borehole length. Strain values reset to zero at 09:00.*

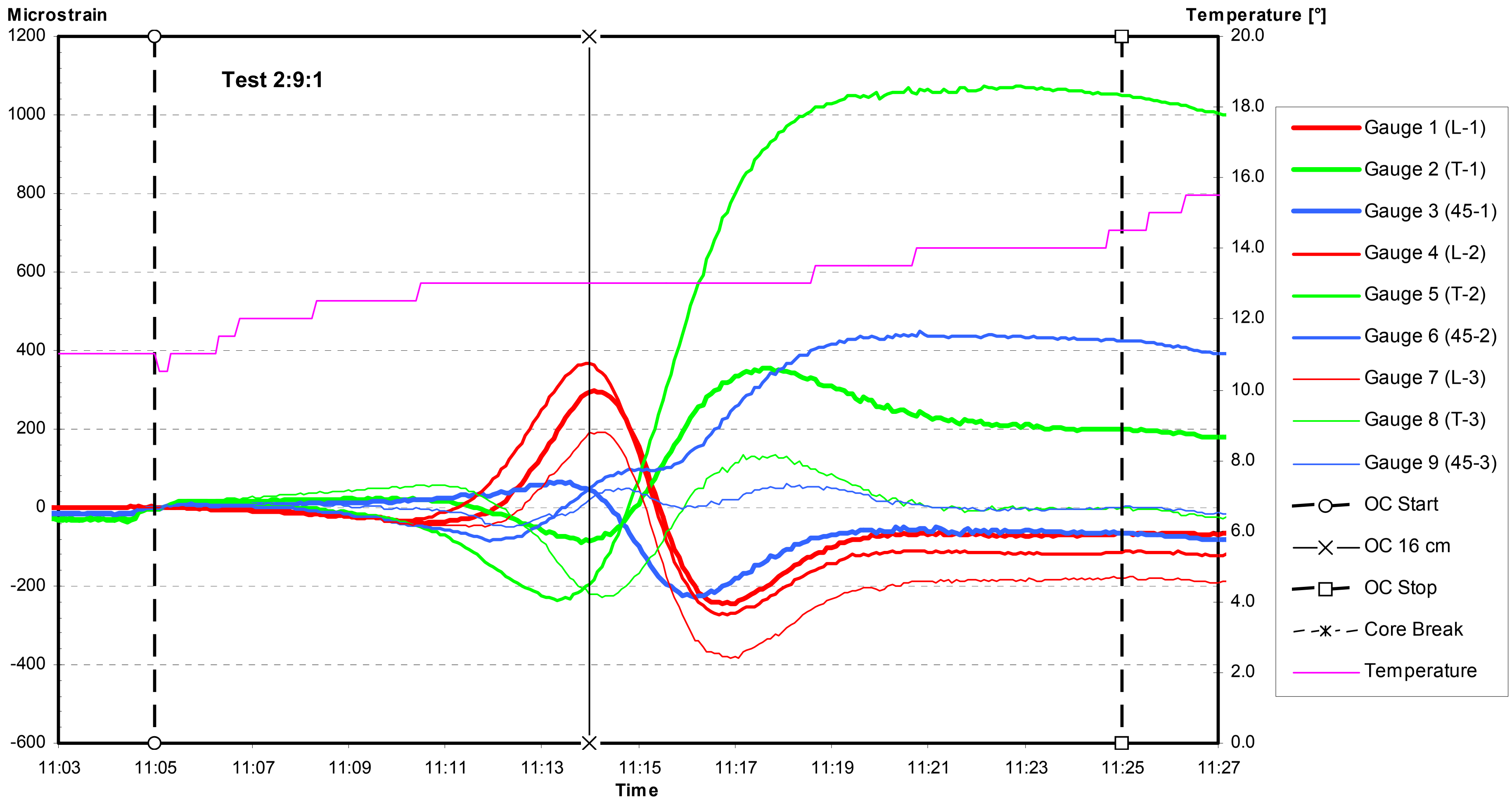


Figure B25. *Recorded strain data and temperature during overcoring (from start to stop) for test no. 2:9:1, 472.98 m borehole length. Strain values reset to zero at 11:00.*

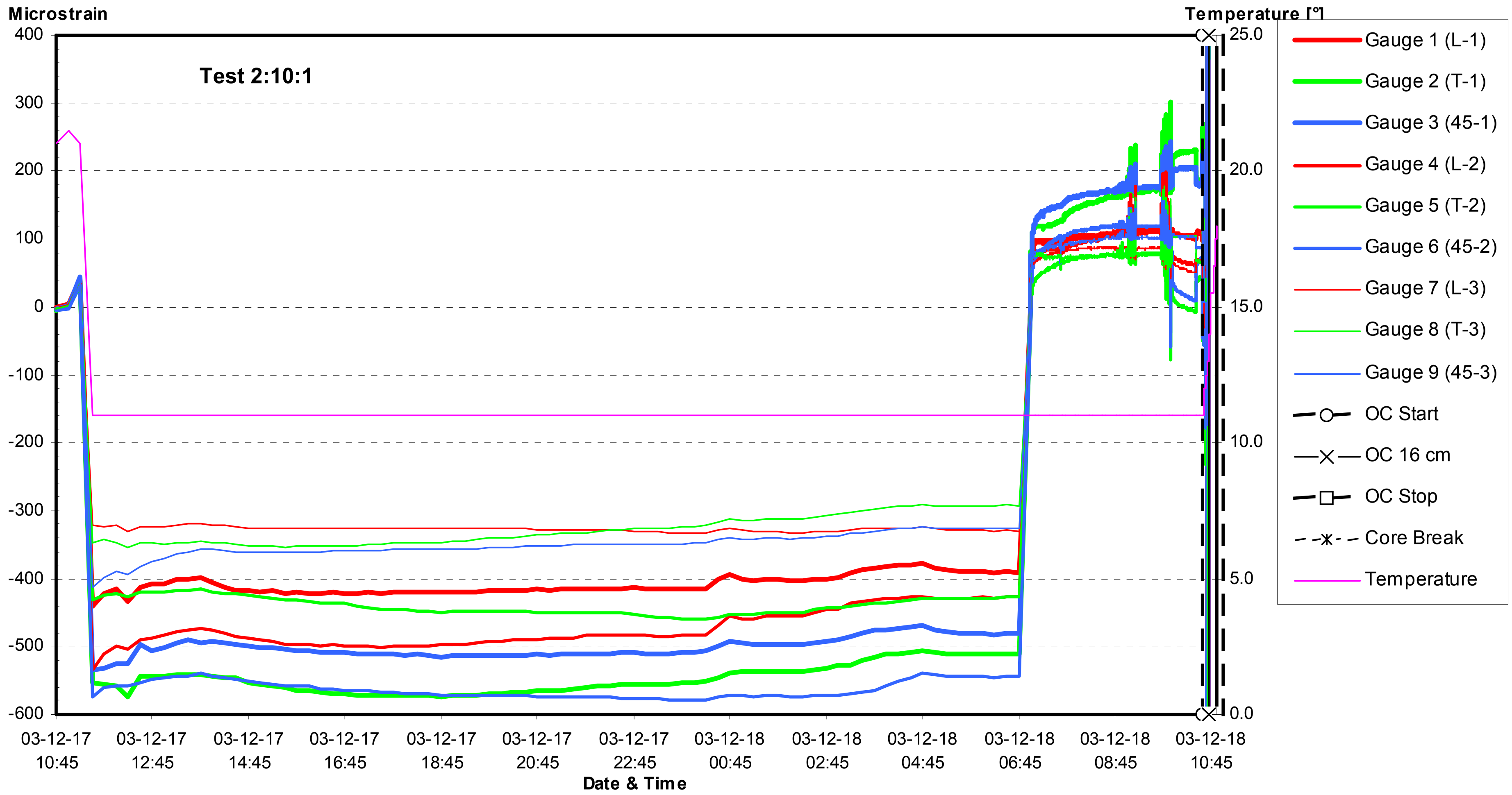


Figure B26. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:10:1, 474.25 m borehole length.*

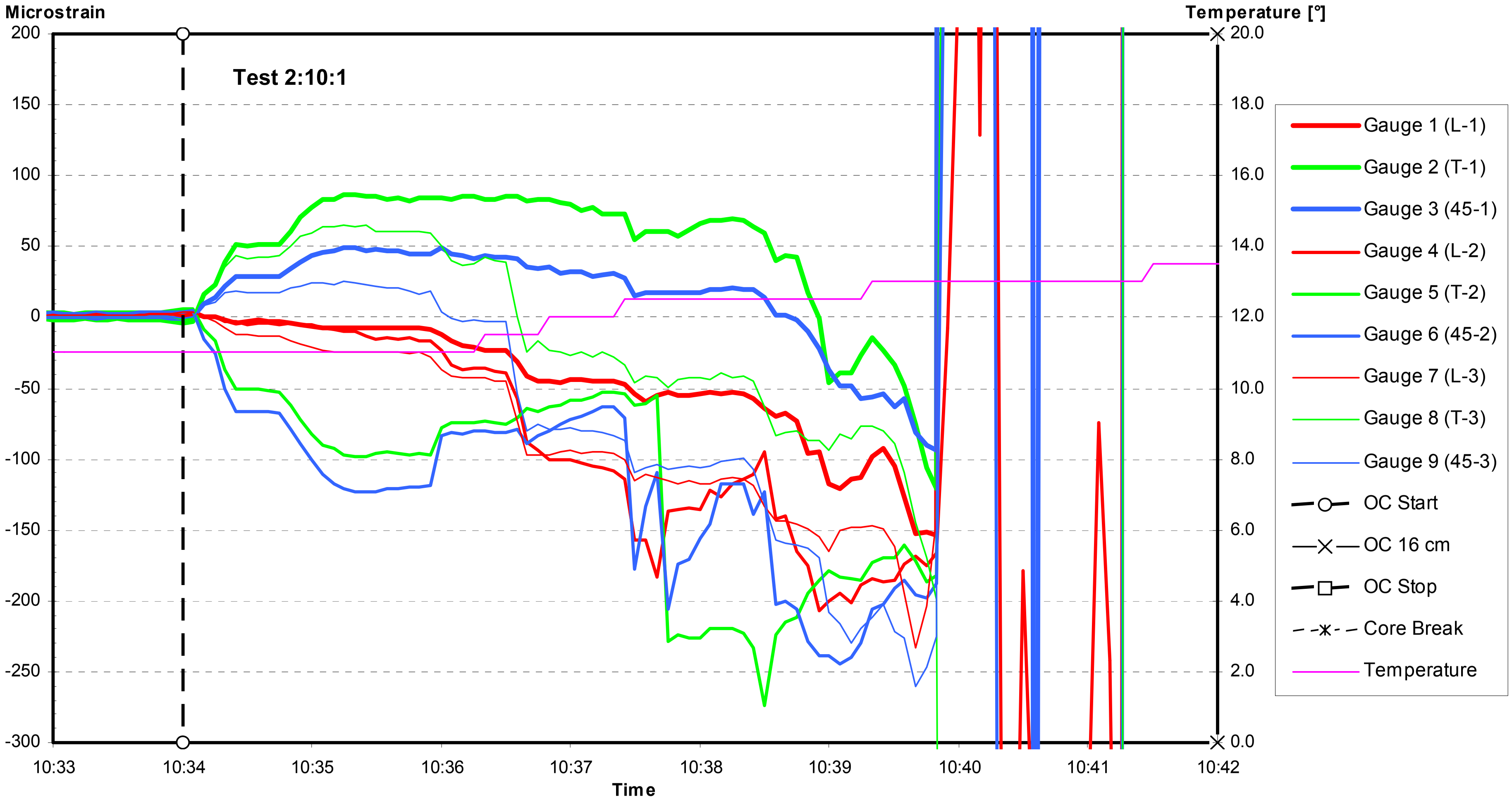


Figure B27. *Recorded strain data and temperature during overcoring (from start to approximately 16 cm drill bit position) for test no. 2:10:1, 474.25 m borehole length. Strain values reset to zero at 10:30.*

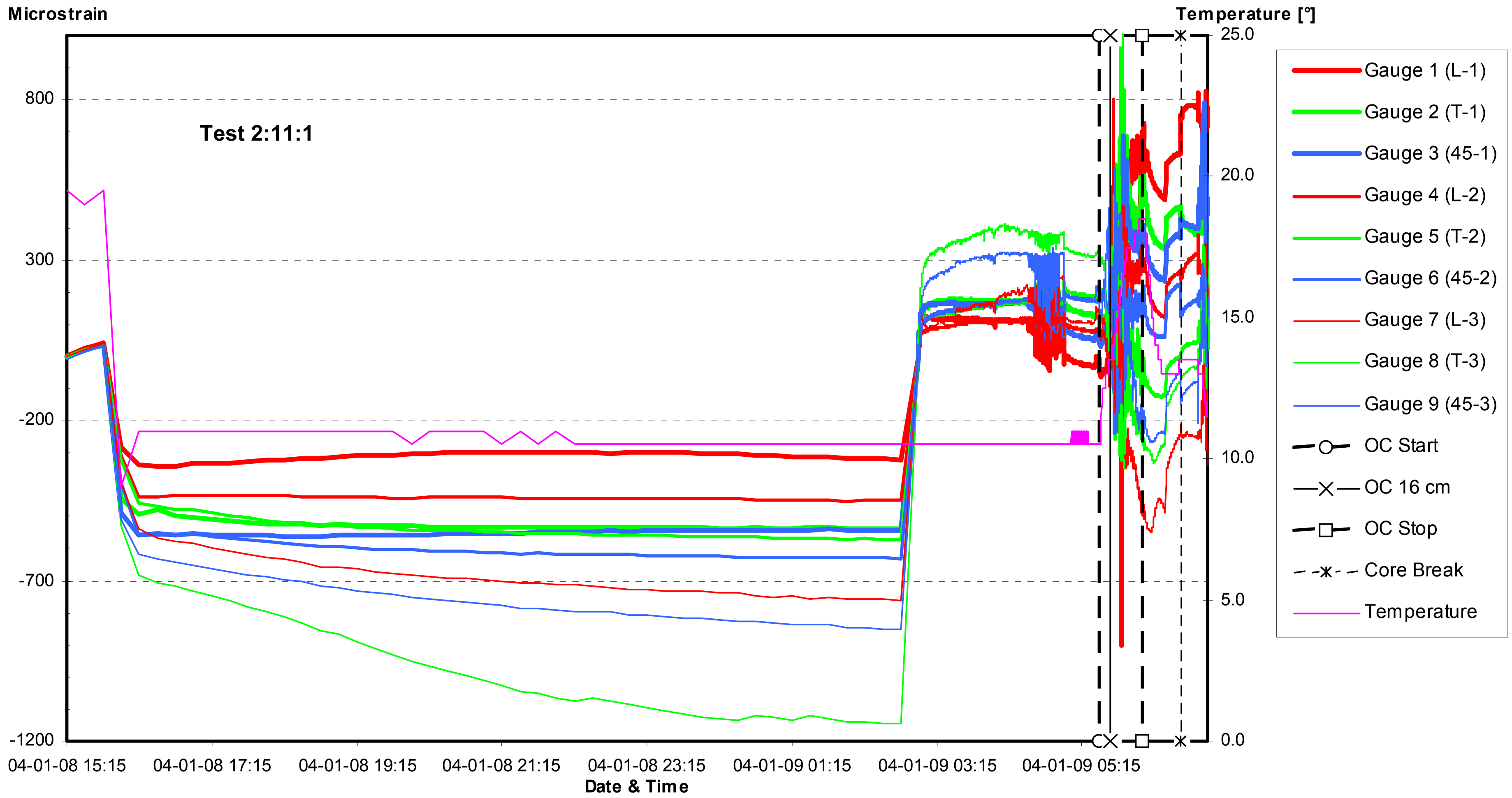


Figure B28. *All recorded strain data and temperature from activation of probe to recovery from borehole for test no. 2:11:1, 475.34 m borehole length.*

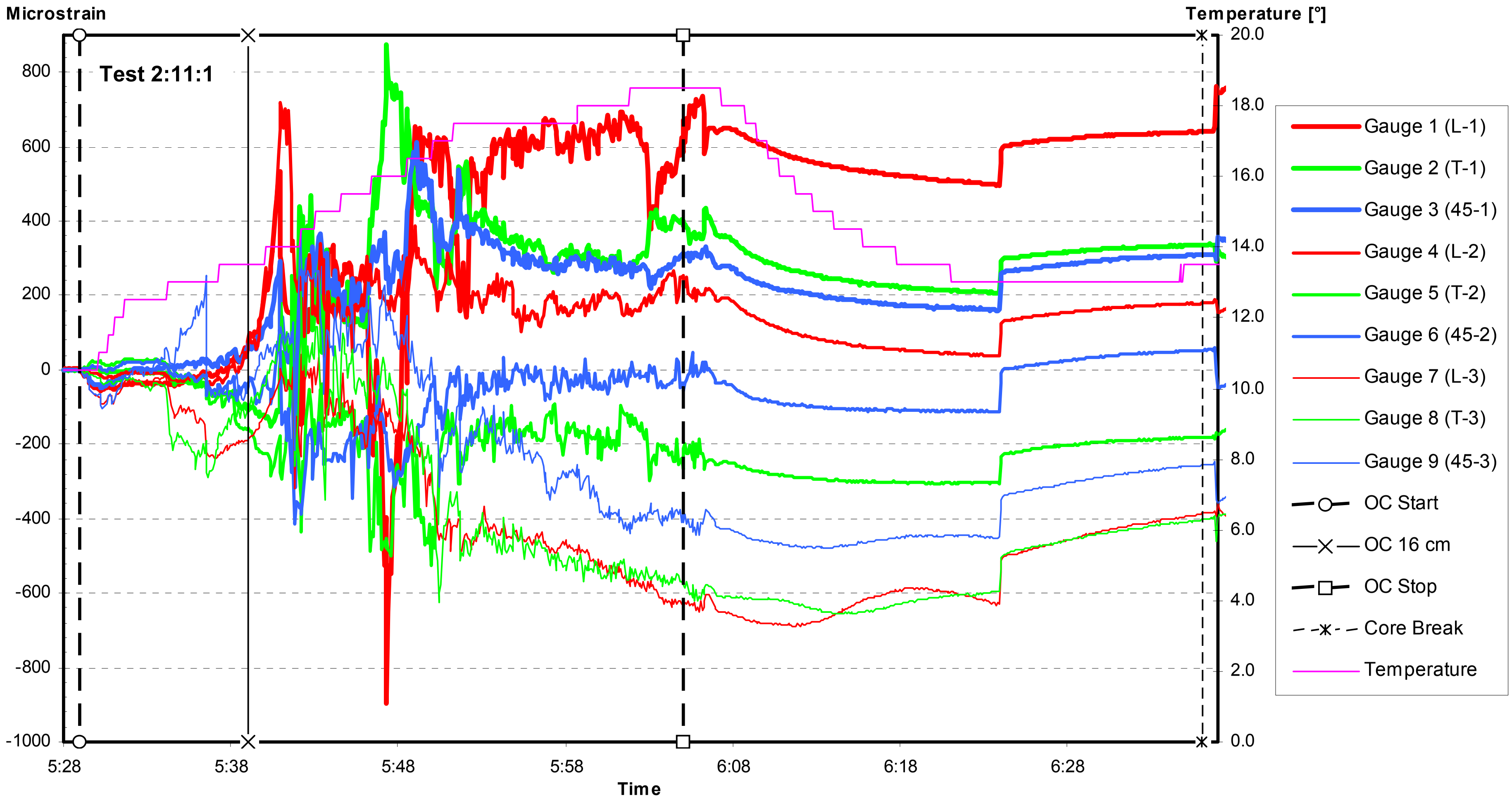


Figure B29. *Recorded strain data and temperature during overcoring (from start to core break) for test no. 2:11:1, 475.34 m borehole length. Strain values reset to zero at 05:28.*

Appendix C

Biaxial test data

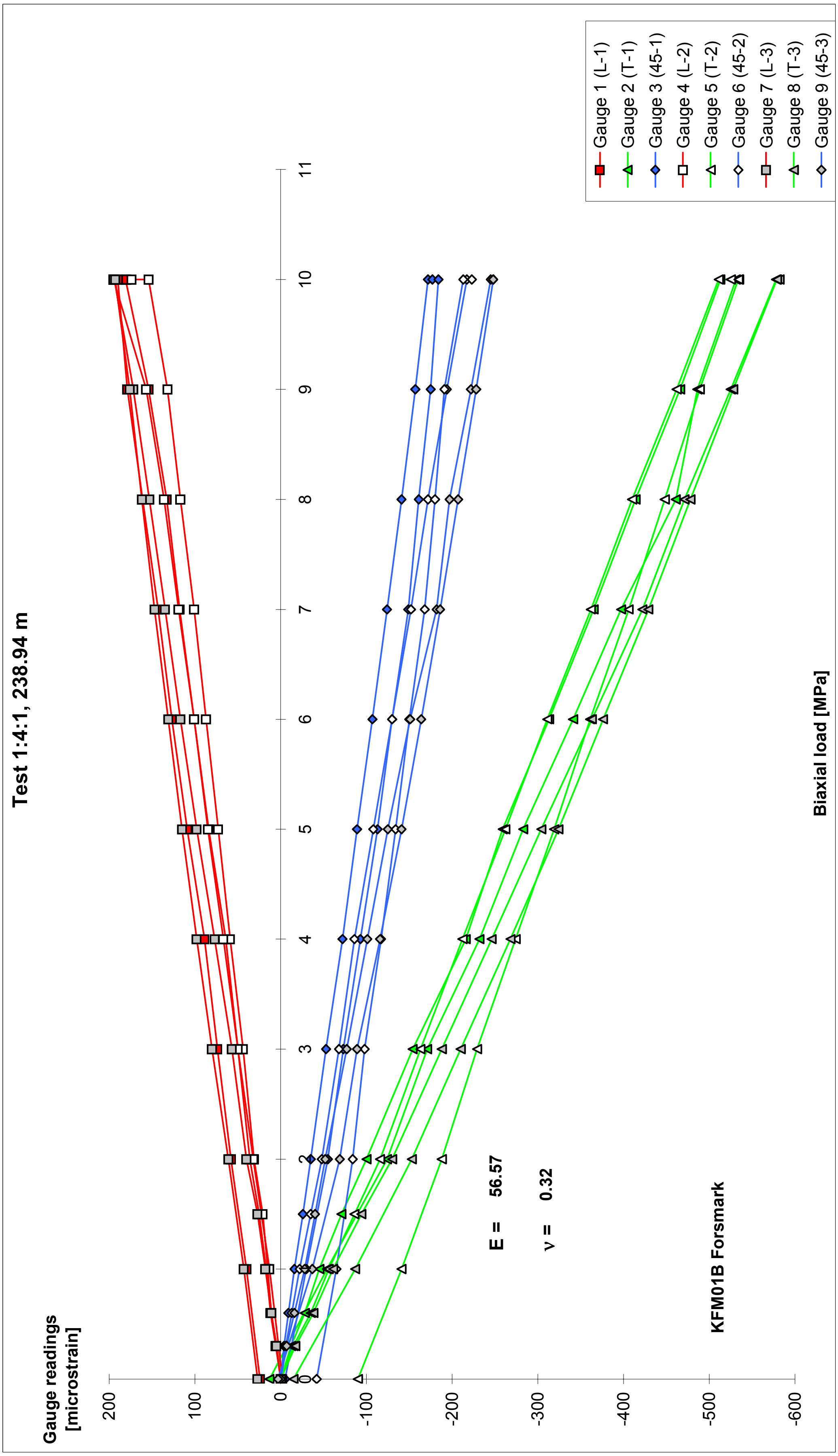


Figure C1. *Results from biaxial testing of test no. 1:4:1, 238.94 m borehole length.*

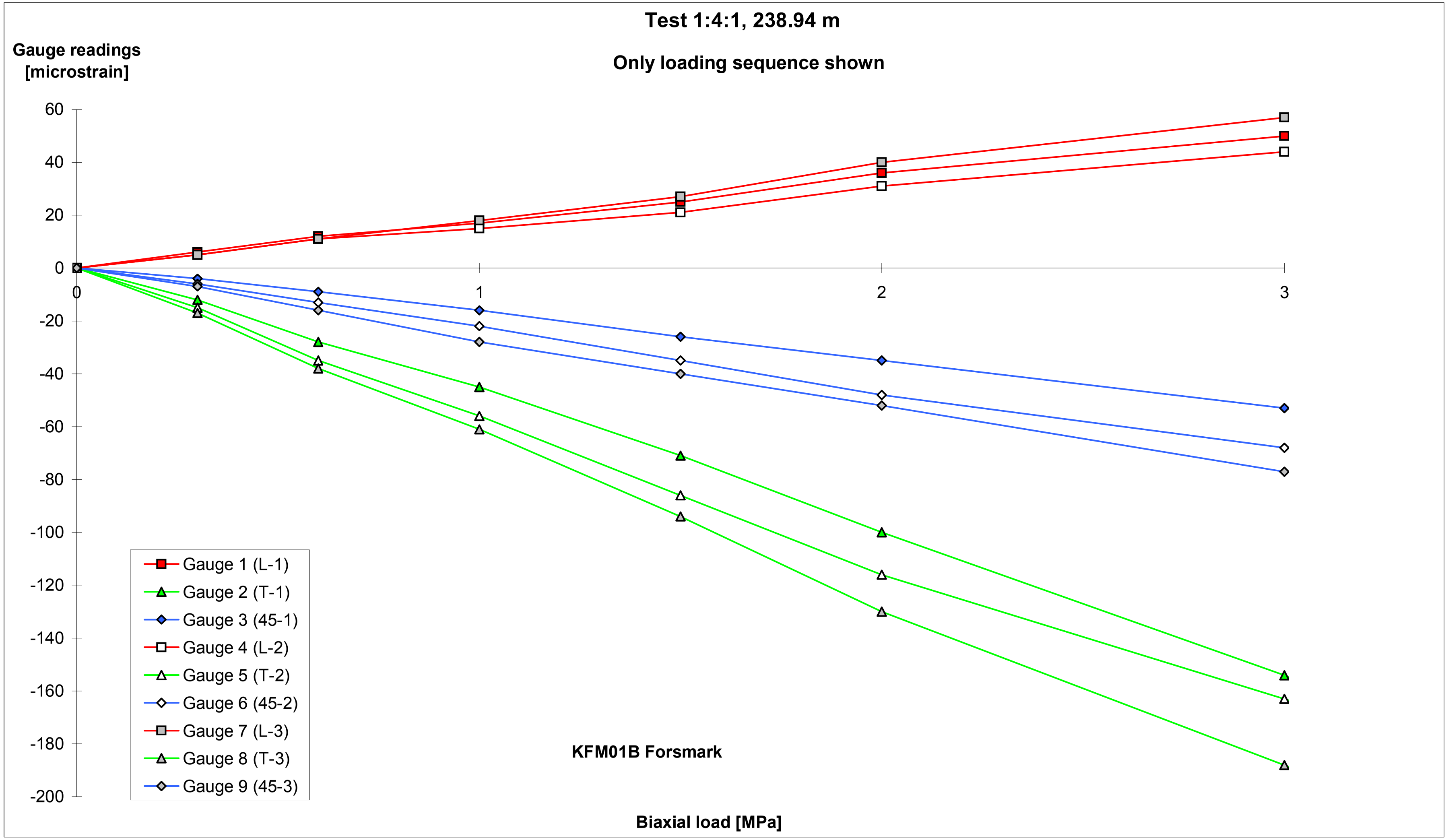


Figure C2. *Results from biaxial testing of test no. 1:4:1, 238.94 m borehole length, showing loading sequence up to 3 MPa applied load.*

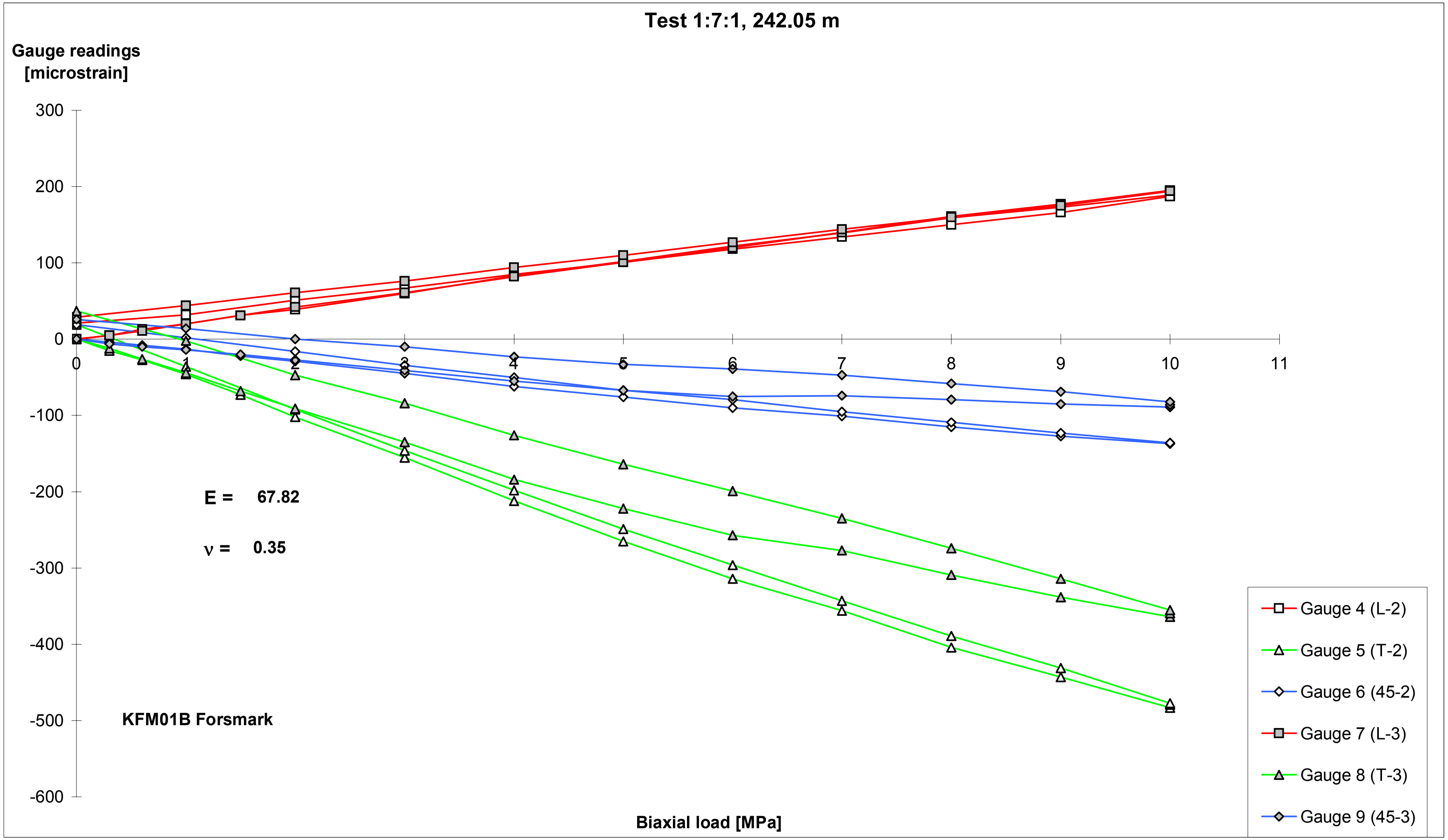


Figure C3. *Results from biaxial testing of test no. 1:7:1, 242.05 m borehole length.*

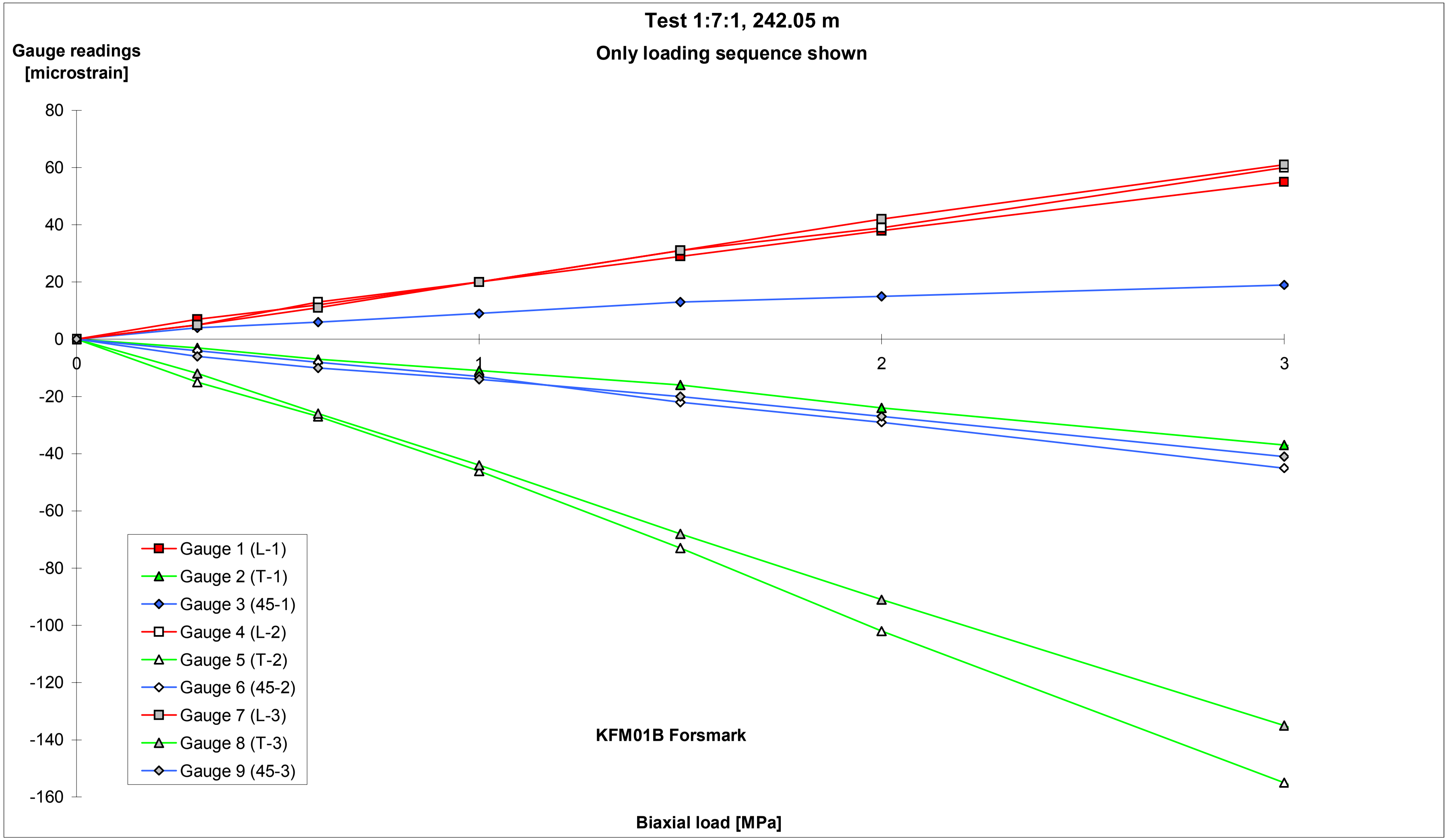


Figure C4. *Results from biaxial testing of test no. 1:7:1, 242.05 m borehole length, showing loading sequence up to 3 MPa applied load.*

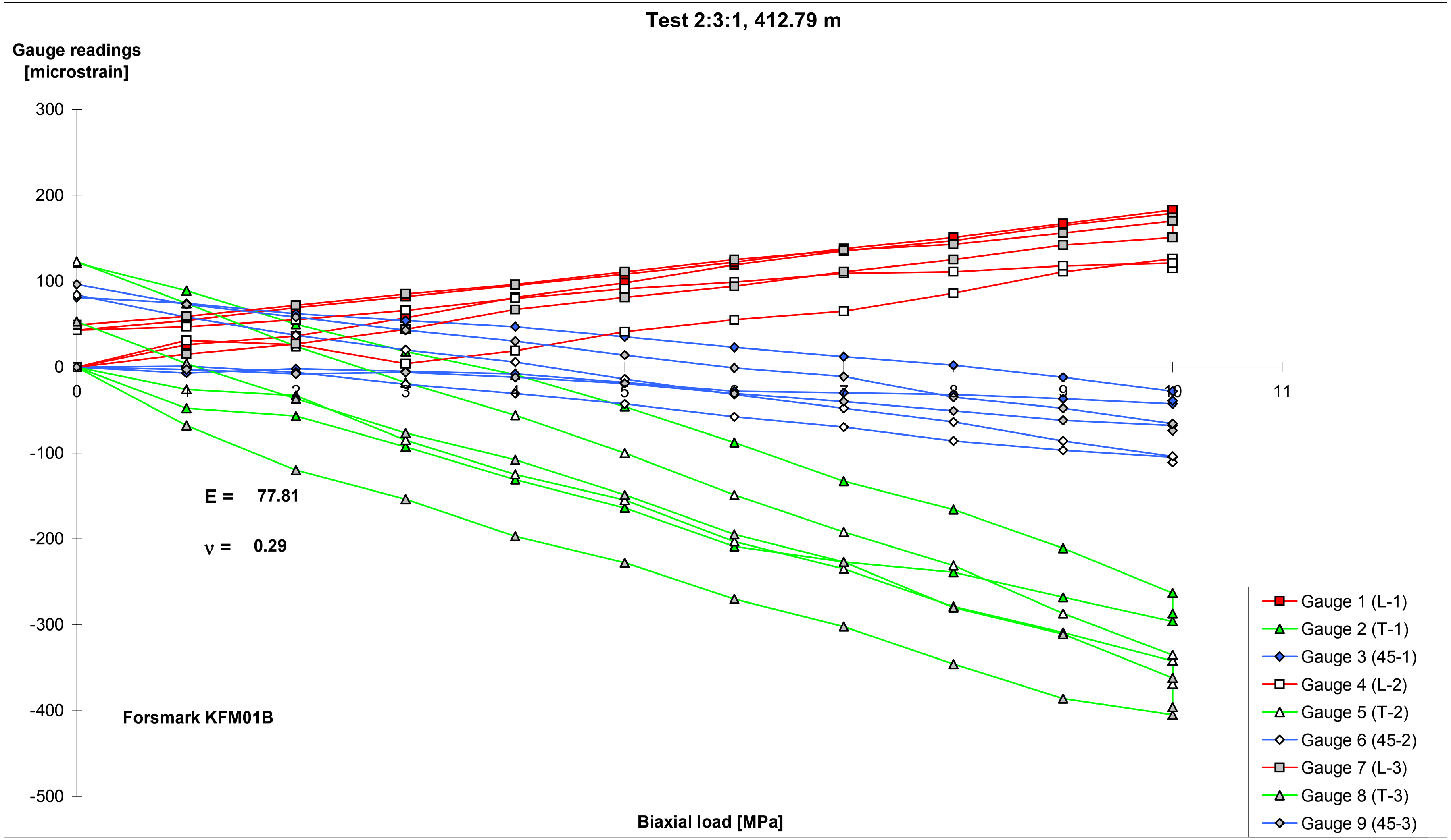


Figure C5. *Results from biaxial testing of test no. 2:3:1, 412.79 m borehole length.*

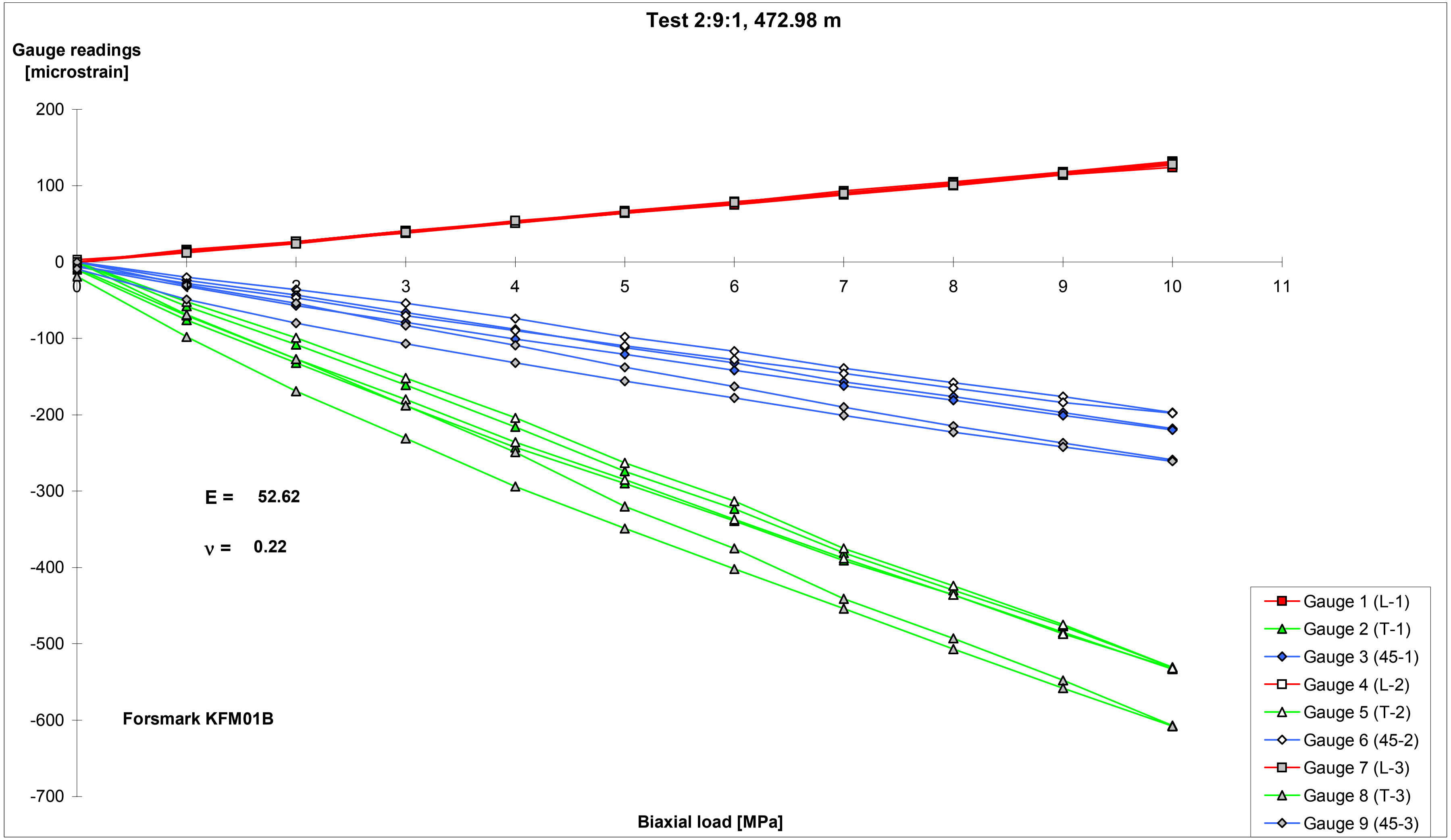


Figure C6. *Results from biaxial testing of test no. 2:9:1, 472.98 m borehole length.*

Stress calculation input data and results

Table D1. Measured and average in situ stresses for borehole KFM01B, Level 1, test nos. 1:4:1, 1:5:1, and 1:7:1.

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description : Forsmark KFM01B
Measurement Level : 1
Date : 2004-02-10

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

Input Data

Depth [m]	Hole dip [°]	Hole bearing [°]	Bearing (ball) - X [°]	Young's modulus [GPa]	Poisson's ratio	Overcoring Time [hh:mm:ss]	Overcoring Time [hh:mm:ss]
238.94	74.3	268.2	325	56.6	0.32	Start=08:40:00	Stop=09:07:00
240.01	74.3	268.2	185	56.6	0.32	Start=09:12:00	Stop=09:21:00
242.05	74.3	268.2	212	67.8	0.35	Start=09:15:00	Stop=09:28:45

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]
238.94	165	1046	1001	189	1642	729	254	825	507
240.01	81	1196	1098	-3	841	294	81	488	70
242.05	58	1029	820	-3	801	489	-6	704	58

Calculated Principal Stresses

Depth [m]	σ_1 [MPa]	σ_1 - Dip [°]	σ_1 - Bearing [°]	σ_2 [MPa]	σ_2 - Dip [°]	σ_2 - Bearing [°]	σ_3 [MPa]	σ_3 - Dip [°]	σ_3 - Bearing [°]
238.94	50.5	42.4	101.6	37.4	38.9	324.0	29.6	22.8	214.2
240.01	38.7	12.4	281.7	22.3	18.9	187.3	15.6	67.1	43.1
242.05	40.2	12.1	288.6	32.4	16.9	194.9	19.0	69.0	52.7
Average	*40.3*	*1.8*	*288.7*	*28.6*	*28.6*	*197.7*	*26.4*	*61.4*	*22.1*

Calculated Horizontal and Vertical Stresses

Depth [m]	Major stress σ_A [MPa]	σ_A - Bearing [°]	Minor stress σ_B [MPa]	σ_B - Bearing [°]	Vertical stress σ_z [MPa]	Error (sum of squares)	Strains re-calculated?
238.94	44.1	112.5	31.3	22.5	42.2	11163.4	No
240.01	37.7	103.3	21.6	13.3	17.4	7904.0	No
242.05	39.4	114.2	31.1	24.2	21.1	3875.4	No
Average	*40.3*	*108.9*	*28.1*	*18.9*	*26.9*		

Table D2. Measured and average in situ stresses for borehole KFM01B, Level 2, test nos. 2:3:1 and 2:8:2.

SwedPower

OVERCORING STRESS MEASUREMENTS

Project Description : Forsmark KFM01B
Measurement Level : 2
Date : 2004-02-12

(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	Overcoring Time [hh:mm:ss]	Overcoring Time [hh:mm:ss]
412.79	72	269.7	140	77.8	0.29	Start=13:14:30	Stop=13:48:15
471.69	71.6	270.6	175	77.8	0.29	Start=09:22:00	Stop=09:47:00

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]
412.79	-22	326	-38	-68	943	780	-53	958	366
471.69	7	137	-87	-83	1420	1011	12	397	118

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]
412.79	42.3	28.0	140.7	25.2	33.7	30.0	10.3	43.4	260.9
471.69	46.8	23.4	155.9	14.5	62.2	11.0	10.0	14.3	252.2
Average	*44.1*	*24.5*	*150.5*	*19.7*	*42.8*	*35.5*	*10.7*	*37.2*	*260.8*

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?
412.79	37.2	151.6	18.6	61.6	21.9	2068.7	No
471.69	41.7	156.8	10.4	66.8	19.3	7807.6	No
Average	*39.4*	*154.8*	*14.5*	*64.8*	*20.6*		

Table D3. Calculated in situ stresses for test no. 2:1:3, 406.92 m borehole length.

SwedPower **OVERCORING STRESS MEASUREMENTS**

Project Description : Forsmark KFM01B
Date : 2003-10-30
Borehole Dip : 72
Borehole Bearing : 269.7
Measurement Depth : 406.92 m

Input Data

Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	Overcoring Time [hh:mm:ss]	Overcoring Time [hh:mm:ss]
120	67.8	0.35	Start=10:16:30	Stop=10:35:00

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

Strains

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]
450	1236	1238	202	873	475	308	225	-342

Principal Stresses

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]
56.0	35.4	222.0	36.5	50.0	74.3	15.7	16.2	323.9

Horizontal and Vertical Stresses

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?
49.1	49.1	17.7	139.1	41.4	47896.0	No

Table D4. Calculated in situ stresses for test no. 2:9:1, 472.98 m borehole length.

SwedPower **OVERCORING STRESS MEASUREMENTS**

Project Description :	Forsmark KFM01B
Date :	2003-12-16
Borehole Dip :	71.6
Borehole Bearing :	270.6
Measurement Depth :	472.98 m

Input Data

Bearing (ball) - X [º]	Young's modulus [GPa]	Poisson's ratio	(values for gauge and resistance factor are always 2 and 1, respectively)	Overcoring Time [hh:mm:ss]	Overcoring Time [hh:mm:ss]
165	52.6	0.22		Start=11:05:00	Stop=11:25:00

Strains

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]
-69	203	-63	-115	1056	427	-180	7	6

Principal Stresses

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]
19.5	13.7	132.0	2.6	34.4	32.4	-3.1	52.2	240.4

Horizontal and Vertical Stresses

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?
18.4	134.1	0.7	44.1	0.0	7678.7	No

Appendix E

Transient strain analysis results

Table E1. Results from transient strain analysis of overcoring measurements in borehole KFM01B.

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
1:4:1	238.94	Max strain amplitude [μstrain]	859	1293	1017	911	1899	701	706	1112	478	5	33	Tangential gauges (2, 5, 8) in good agreement with measured strains. Axial gauges (1, 4, 7) show largest discrepancy.
		Max strain difference [%]	34	9	26	44	4	38	62	24	36			
1:5:1	240.01	Max strain amplitude [μstrain]	618	1380	1121	747	1017	268	486	690	107	8	32	Fair agreement for tangential gauges (2, 5, 8). Larger deviations for axial and inclined gauges.
		Max strain difference [%]	36	21	15	63	18	87	81	22	136			
1:7:1	242.05	Max strain amplitude [μstrain]	577	1184	836	758	979	488	591	878	121	5	30	Fair agreeement for tangential gauges, but overall larger deviations from measured strains compared to 1:4:1 and 1:5:1.
		Max strain difference [%]	51	37	37	68	40	50	67	40	144			
2:1:3	406.92	Max strain amplitude [μstrain]	549	1368	1336	863	1030	547	493	492	388	11	41	Large deviation for all strain gagues, except gauge nos. 3 and 5.
		Max strain difference [%]	72	17	9	63	18	64	64	34	124			
2:3:1	412.79	Max strain amplitude [μstrain]	459	499	145	537	1063	818	655	1102	364	6	39	Tangential gauge nos. 5 and 8 in good agreement with measured strains. Larger deviations for all other gauges.
		Max strain difference [%]	54	40	39	20	13	25	35	4	41			
2:5:1	415.16	Max strain amplitude [μstrain]	-	-	-	-	-	-	-	-	-	-	-	No comparison with theoretical values possible; only inverse solution used.
		Max strain difference [%]	-	-	-	-	-	-	-	-	-			

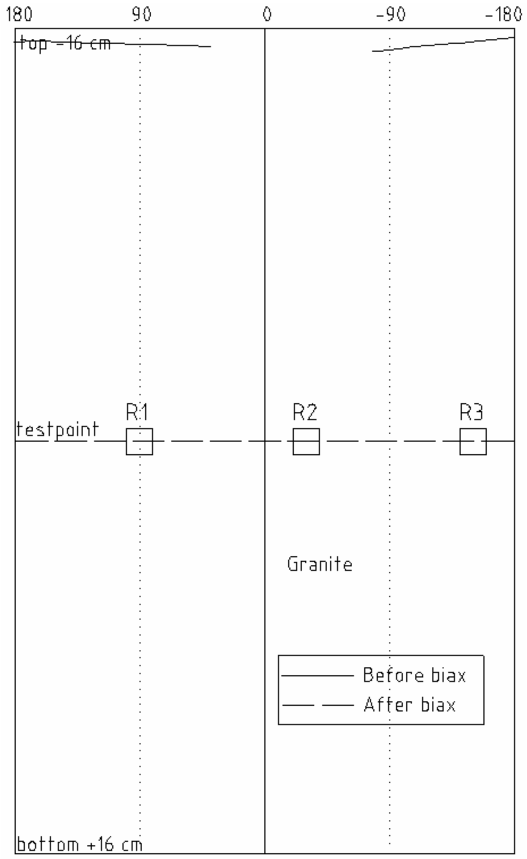
Table E1. (concluded.)

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
2:7:3	465.05	Max strain amplitude [μstrain]	-	-	-	-	-	-	-	-	-	-	-	No comparison with theoretical values possible; only inverse solution used.
		Max strain difference [%]	-	-	-	-	-	-	-	-	-			
2:8:2	471.69	Max strain amplitude [μstrain]	391	348	210	491	1598	1040	566	546	290	20	46	Poor agreement for nearly all gauges, in particular the axial and inclined ones.
		Max strain difference [%]	105	36	126	44	28	31	25	24	111			
2:9:1	472.98	Max strain amplitude [μstrain]	341	274	138	300	1151	488	336	135	160	12	20	Poor agreement for nearly all gauges. Gauge nos. 5 and 6 are in fair agreement with theoretical strains.
		Max strain difference [%]	57	57	187	95	20	22	66	152	52			
2:10:1	474.25	Max strain amplitude [μstrain]	-	-	-	-	-	-	-	-	-	-	-	No comparison with theoretical values possible; only inverse solution used.
		Max strain difference [%]	-	-	-	-	-	-	-	-	-			
2:11:1	475.34	Max strain amplitude [μstrain]	-	-	-	-	-	-	-	-	-	-	-	No comparison with theoretical values possible; only inverse solution used.
		Max strain difference [%]	-	-	-	-	-	-	-	-	-			

Overcore logging sheets

OVERCORE SAMPLE LOG

Borehole no., test no., depth : KFM01B, Test no. 1:4:1, 238.94 m depth



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

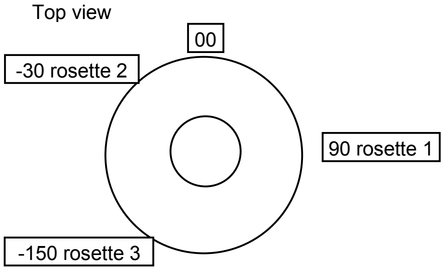
GEOLOGY

STRUCTURES (JOINTS)

No joints observed. Core discing at the bottom end of the overcore sample.

Mark any observed fractures

Top view

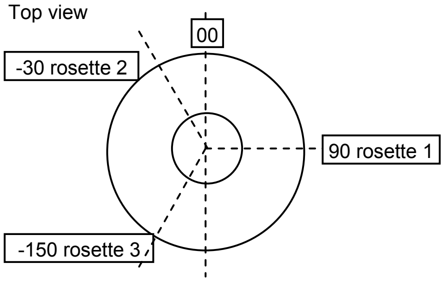


COMMENTS

Strain gauge orientation OK.

Control of strain gauge orientation

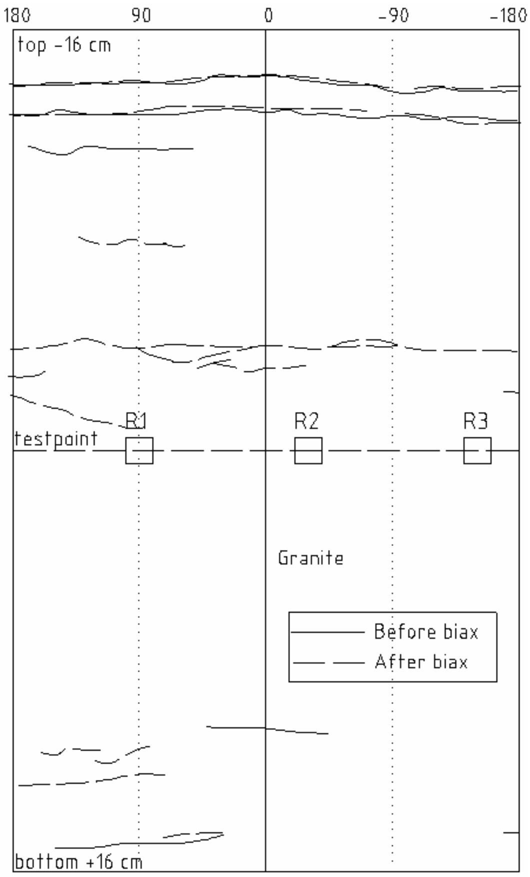
Top view



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 : KFM01B, Test no. 1:5:1, 240.01 m depth



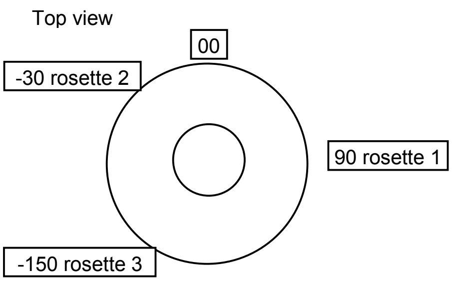
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

STRUCTURES (JOINTS)

Sub-horizontal fractures at top of sample. Core discing at the bottom end of the overcore sample.
Several new fractures formed perpendicular to core axis after biaxial testing, as the sample failed.

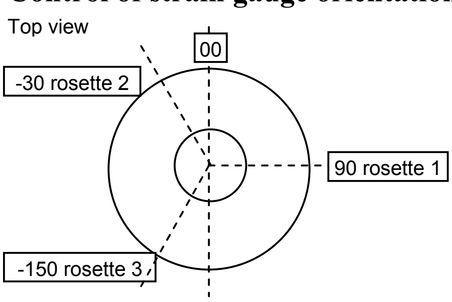
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

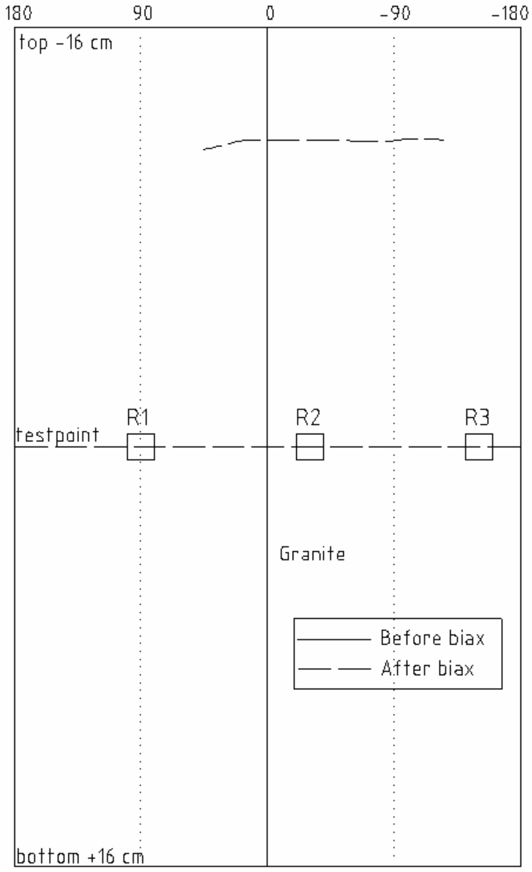
Control of strain gauge orientation



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 : **KFM01B, Test no. 1:7:1, 242.05 m depth**



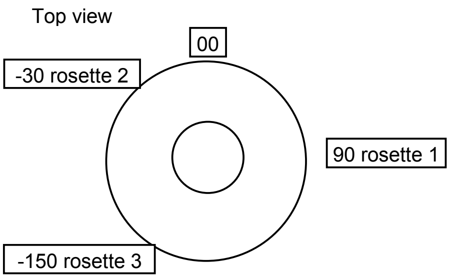
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

STRUCTURES (JOINTS)

No joints observed. Core discing at the bottom end of the overcore sample.

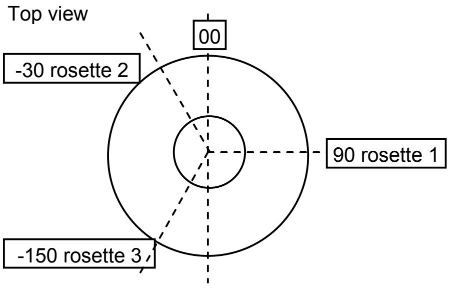
Mark any observed fractures



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 : KFM01B, Test no. 2:1:3, 406.92 m depth

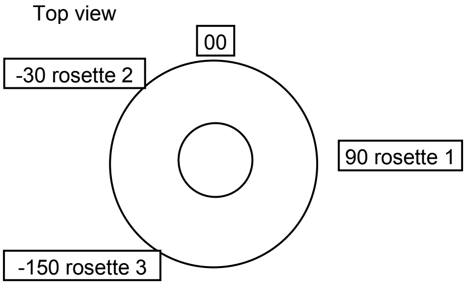
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

STRUCTURES (JOINTS)

Core discing of almost entire sample made core logging difficult. No biaxial testing conducted.

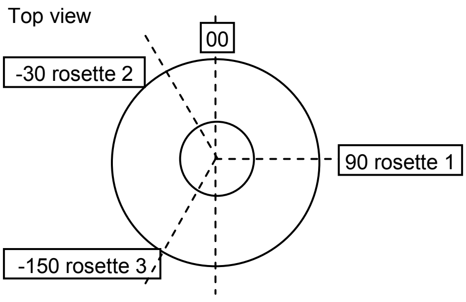
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

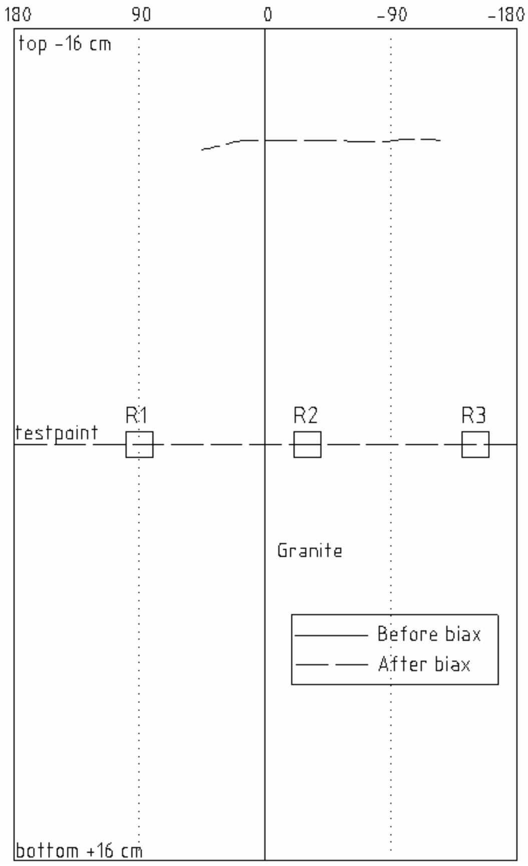
Control of strain gauge orientation



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 : KFM01B, Test no. 2:3:1, 412.79 m depth



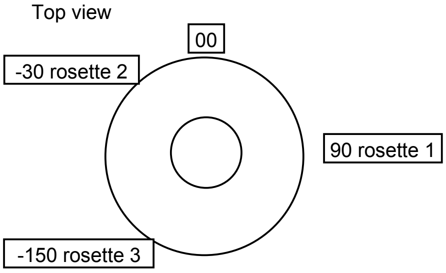
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

STRUCTURES (JOINTS)

No joints observed. Core discing at the bottom end of the overcore sample.
Signs of additional fractures formed after biaxial testing.

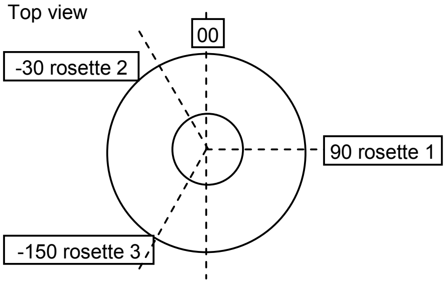
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

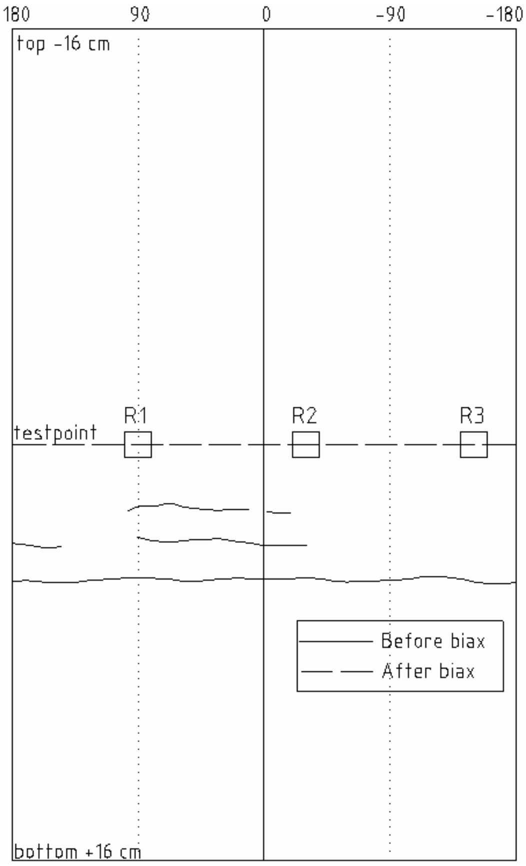
Control of strain gauge orientation



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 : KFM01B, Test no. 2:8:2, 471.69 m depth



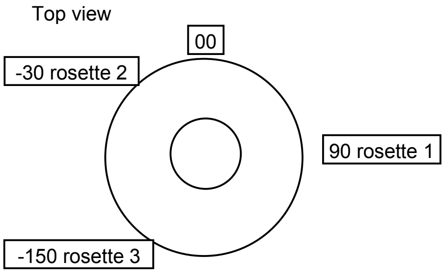
Angle clockwise in borehole direction
rosette 1 =+90 degrees
rosette 2 =-30 degrees
rosette 3 =-150 degrees

GEOLOGY

STRUCTURES (JOINTS)

Core discing observed, starting at approximately 20 cm position, and continuing for the rest of the overcore (not logged).

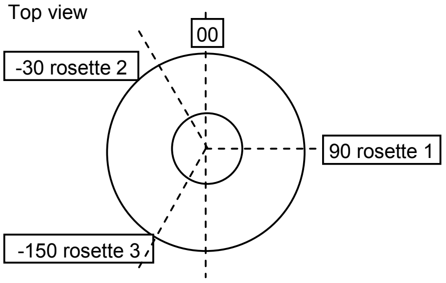
Mark any observed fractures



COMMENTS

Strain gauge orientation OK.

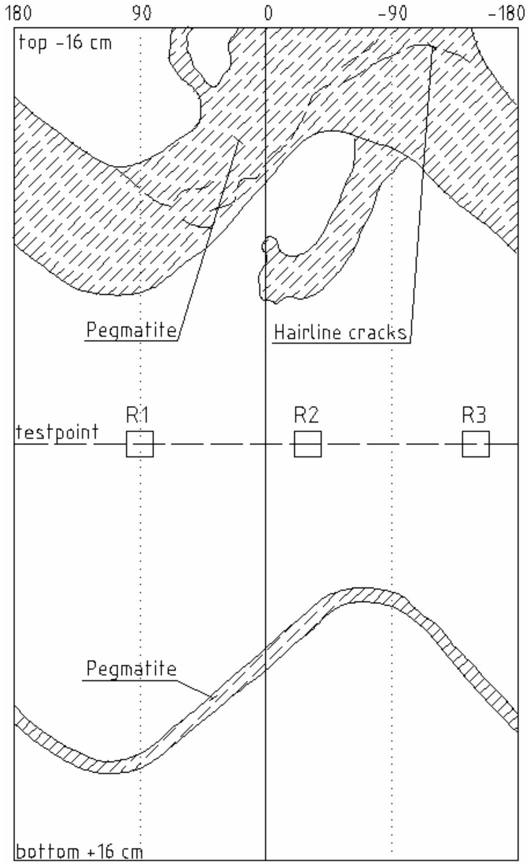
Control of strain gauge orientation



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 : KFM01B, Test no. 2:9:1, 472.98 m depth



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

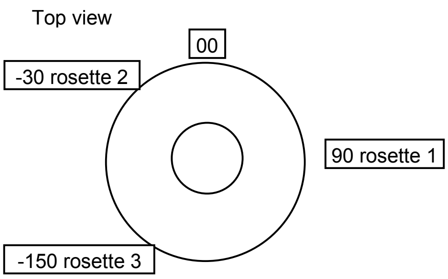
GEOLOGY

Pegmatite dominating in upper portion of sample. Pegmatite bands occurring also in lower portion of overcore sample.

STRUCTURES (JOINTS)

Hairline cracks occurring in pegmatite zone in upper portion of sample.

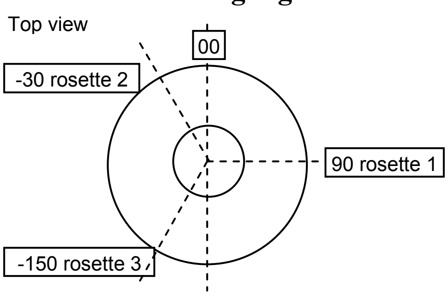
Mark any observed fractures



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.

Appendix G

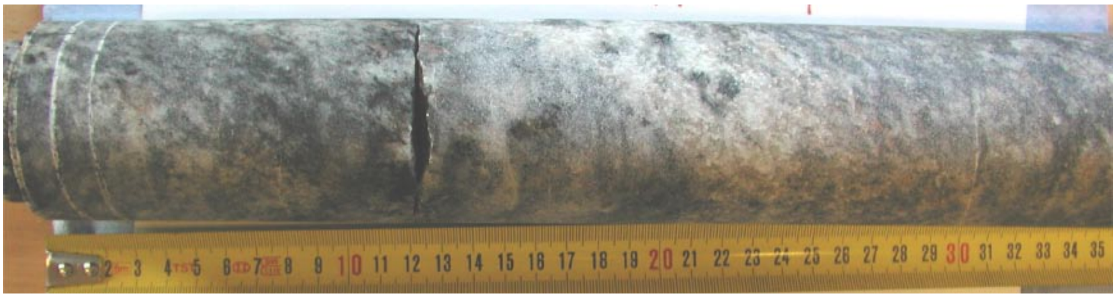
Photos of core samples

1:4:1, 238.94 m — pilot core

1:4:1, 238.94 m — overcore sample

1:5:1, 240.01 m — pilot core

1:5:1, 240.01 m — overcore sample



1:7:1, 242.05 m — pilot core

1:7:1, 242.05 m — overcore sample

Figure G1. *Photos of pilot core and overcore sample for borehole KFM01B, Level 1.*

2:1:3, 406.92 m — pilot core

2:1:3, 406.92 m — overcore sample: 0 – 19 cm

19 – 60 cm

60 – 100 cm

2:3:1, 412.79 m — pilot core

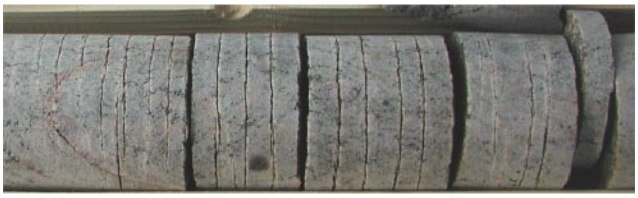
2:3:1, 412.79 m — overcore sample

Figure G2. *Photos of pilot core and overcore sample for borehole KFM01B, Level 2.*

2:5:1, 415.16 m — pilot core

2:5:1, 415.16 m — overcore sample: 0 – 40 cm

40 – 60 cm



60 – 85 cm

2:7:3, 465.05 m — pilot core

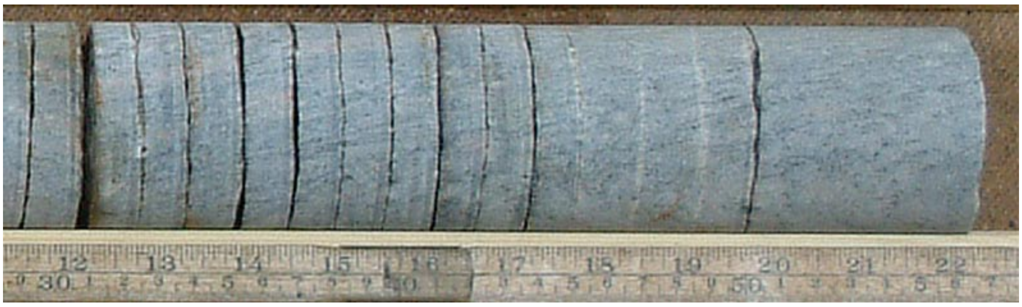
2:7:3, 465.05 m — overcore sample

Figure G2. (continued.)

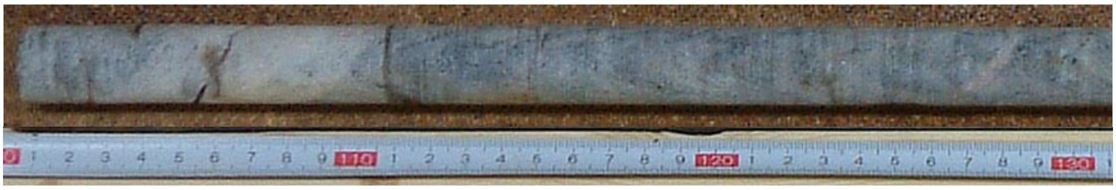
2:8:2, 471.69 m — pilot core

2:8:2, 471.69 m — overcore sample: 0 – 30 cm

30 – 60 cm



2:9:1, 472.98 m — pilot core



2:9:1, 472.98 m — overcore sample: 0 – 30 cm

30 – 65 cm

Figure G2. (continued.)

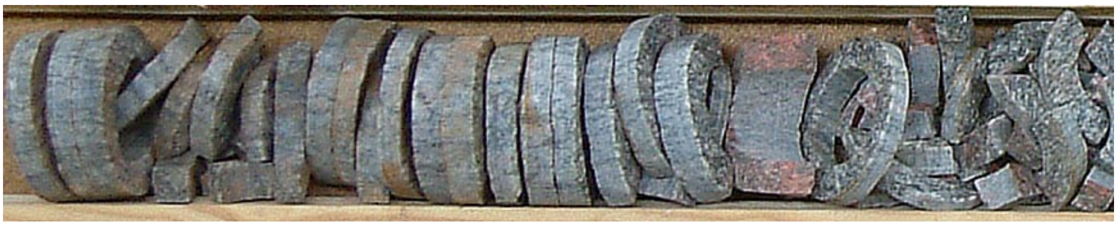
2:10:1, 474.25 m — pilot core

2:10:1, 474.25 m — overcore sample: 0 – 30 cm

30 – 65 cm

2:11:1, 475.34 m — pilot core

2:11:1, 475.34 m — overcore sample: 0 – 40 cm



40 – 80 cm

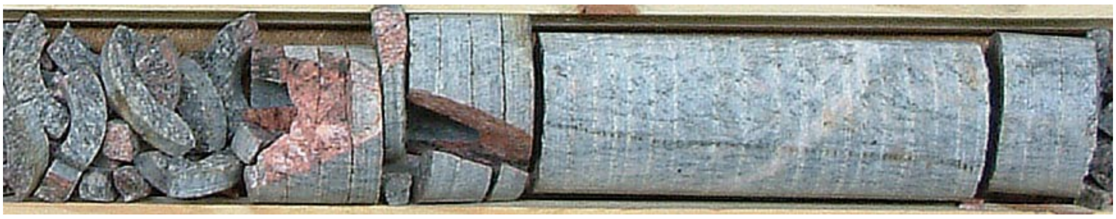


Figure G2. (concluded.)