International
Progress Report

IPR-02-04

Äspö Hard Rock Laboratory

Canister retireval test

Sensors data report
(Period: 001026-011101)
Report no: 3

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November 2001

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Report no.	No.
IPR-02-04	F69K
Author	Date
Goudarzi, Börgesson Röshoff, Feng	01-11-30
Checked by	Date
Approved	Date
Christer Svemar	02-02-22

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Keywords: Buffer, bentonite, rock, temperature, stress, strain, test, measurements, swelling, full scale, in situ

Abstract

This report presents data from the measurements in the Canister Retrieval Test from 001026 to 011101.

The following measurements are made in the bentonite: Temperature is measured in 32 points, total pressure in 27 points, pore water pressure in 14 points and relative humidity in 55 points. Temperature is also measured by all relative humidity gauges. The positions of the measuring points in the bentonite are related to a coordinate system in the deposition hole.

The following measurements are made in the rock: Temperature is measured in 40 points, stresses are measured in 8 points and strain is measured in 9 points. Stresses and strains are also measured in the rock around the empty deposition hole located 6 m south of the test hole.

The following measurements are made in the canister: Temperature is measured every meter along two fiber optic cables and strain is measured in 76 points on the surface of the copper envelop. Temperature is measured in the steel insert in 18 points.

The following measurements are made on the plug: Force is measured in 3 of the 9 anchors and vertical displacement is measured in three points.

The water inflow to the filter mats on the rock surface is also measured.

The general conclusion is that the measuring systems and transducers seem to work well but the following problems have been noted: The strain measurements in the canister are not reported due to question marks regarding the relevance of the results. Some Vaisala relative humidity transducers, the most located in ring 5, have failed due to water saturation. Four Kulite total pressure transducers out of six seem to yield erroneous results.

Sammanfattning

I denna rapport presenteras data från mätningar i Återtag under perioden 001026-011101.

Följande mätningar görs i bentoniten: Temperaturen mäts i 32 punkter, totaltryck i 27 punkter, porvattentryck i 14 punkter och relativa fuktigheten i 55 punkter. Temperaturen mäts även i alla relativa fuktighetsmätare. Varje mätpunkt relateras till ett koordinatsystem i deponeringshålet.

Följande mätningar görs i berget: Temperaturen mäts i 40 punkter, bergspänningar mäts i 8 punkter och töjningar i 9 punkter. Bergspänningar och töjningar mäts också i berget runt det tomma deponerinshålet 6 m söder om försökshålet.

Följande mätningar görs på ytan i kapselns kopparhölje: Temperaturen mäts varje meter längs två fiberoptiska kablar och töjning mäts i 76 punkter. Temperaturen mäts i stålinsatsen i kanistern i 18 punkter.

Följande mätningar görs på pluggen: Kraften mäts i 3 av de 9 stagen och vertikala förskjutningen mäts i tre punkter.

Vatteninflödet till filtermattorna mäts också.

En generell slutsats är att mätsystemen och givarna tycks fungera bra, men följande problem har noterats:Töjningsmätningarna i kapseln har inte redovisats p. g. a frågetecken beträffande mätresultatens relevans. Några av Visalas relativa fuktighetsmätare, de flesta belägna i ring 10 , har slutat fungera p. g. a. vattenmättnad. Fyra Kulite totaltrycksgivare av totalt sex tycks ge felaktiga resultat.

Contents

1 Introduction

The installation of the Canister Retieval Test was made during autumn 2000. In general the data in this report are presented in diagrams covering the time period 2000-10-26 to 2001-11-01. The time axis in the diagrams represents days from 2000-10-26. The diagrams are attached in Appendix A. The stress and strain measurements in the rock are reported separately in Appendix B.

A test overview with the positions of the measuring points and a brief description of the instruments is also presented in this report (chapters 3 and 4).

General comments concerning the collected data are given in chapter 2.

The main report is produced by Clay Technology while Appendix B, containing the stress and strain measurements in the rock, is produced by BBK.

2 Comments

2.1 General

In this chapter short comments on general trends in the measurements are given. Sensors that are not delivering reliable data or no data at all are noted and comments on the data in general are given.

The slot between rock and bentonite block was filled with bentonite pellets and water at 001026. This date is also marked as start date.

1 m water head in the water supply tank was connected to the filters on 001102.

The heating of the canister started with an initially applied constant power of 700 W at 001027 that is one day after test start. The power was raised to 1700 W on 001113. The power was further raised to 2600 W on 010213

The second report covered the period up to 010501.This report is the third one and covers the results up to 011101.

2.2 Total pressure, Geocon (App. A pages 1-4)

The measured pressure range is from 0 to 5.1 MPa. The highest pressure is indicated from P105, P107, P109 and P114. The three first ones are placed in Cylinder 1 and all of them are placed at the same distance from the canister and near the bentonite block periphery. P114 is placed in Ring5 in the slot at the bentonite block periphery.
P112 and U106, placed near the bentonite block periphery in ring 5, have increased to 1.8 – 2.2 MPa. Remarkable is that P110, P115 and P113 placed close to the canister has increased to 1.1- 2.9 MPa while P116, placed close to the rock surface, has only increased to about 0.40 MPa. P111 placed half way between the rock and the canister in ring 5 has increased to 1.6 MPa under this period.

If each section is considered separately all Geocon total pressure sensors show logical increase in pressure with increased radial distance from the canister surface except for section C in ring 5, where P116 close to the rock yields 0.4 MPa and P115 close to the canister yield 2.3 MPa.

Sensor P126 placed in Cyl.3 seems to have failed during the last months. Sensor P104 was not installed.

U106 was originally intended to be a pore pressure sensor but was replaced by a total pressure sensor.

2.3 Total Pressure, Kulite (App. A page 5)

Six Kulite total pressure transducers are installed in the bentonite blocks. Three of them yielded questionable data rather early in the test: P222 stopped working properly after 125 days, P224 yields remarkably high and irregular values and P221 yields unreliable reading and it is not plotted in this report. P223 also seems to have problems with a strange jerk after 345 days .Two of the transducers placed above the center of the canister yield logically very low pressure.

2.4 Suction, Wescore Psychrometers (App. A pages 6-12)

Wescor psychrometers are only working at suction below 5000 kPa, which correspond to high relative humidity (above about 96%). Seven transducer W141, W147, W124, W130, W140, W146 and W149 started yielding values that could be interpreted in the two last report. During the last sex months another 5 transducers (W122, W123, W128, W129 and W109) have started yielding interpretable values. The first four of them are placed in Ring 5 while the other one (W109) is placed in Cylinder 1. In Ring 5 six out of eight transducers are indicating a high relative humidity and after about 250 days the water seems to have reached through the entire buffer in two directions. In ring 10 seven out of eight transducers indicated a high relative humidity already after 150 days.

2.5 Relative humidity, Vaisala (App. A pages 13-16)

App. pages 10-13 show relative humidity and temperature measured with Vaisala transducers. W112 was not installed. W102 and W125 were out of order from start and they are not plotted in this report. W103, W150, W138, W136, W137 and W144 stopped working during the first six months. During the last six months another 6 transducers have stopped working (W119, W120, W127, W101, W118 and W143). The three first transducers are placed in ring5, W101 and W118 are placed in Cylinder 1 in the center (W101) and near the bentonite block periphery (W118) and W143 is placed half way between the rock and the canister in ring10. It is probable that the malfunction can be explained by a high relative humidity for most transducers. The exceptions are W101, W102 and W103, which are all placed in the center of the bottom block (C1). The reason for the successive malfunction of these is not clear. It is interesting to note the drying indicated by transducers W134 and W135, which are placed just above the canister. All transducers between the rock and the canister in rings 5 and 10 except one indicate a high degree of saturation, which confirm the results of the Wescor psychrometers.

2.6 Pore water pressure, Geocon (App. A pages 17-18)

U108 and U110 yield a water pressure of 320 kPa and 220 kPa. They are placed in the periphery of Ring 5. U107 and U105 yield 170 kPa and 150 kPa. These sensors are placed in Ring 5 but not near the periphery of the bentonite block. The pressure measured by these transducers is most likely a pore gas pressure since the water pressure applied in the filters in the periphery is only 55 kPa at that level.
U106 is replaced by a total pressure sensor.

The remaining sensors of this type yield pressure close to zero.

2.7 Pore water pressure, Kulite (App. A page 19)

There are only one sensor of this type in Ring 10 and one in Cylinder 4. Both indicate pressure close to zero.

2.8 Water flow into the filters (App. A page 20)

Measurement of water inflow into the filters started on 001102. The total inflow to the filter has since that date been 245 liter. The inflow is slowly reduced with time and at present about 0.1 l/day.

2.9 Forces on the plug (App. A page 21)

The forces on the plug have been measured since 001106.The total force is about 4000 kN at 011101.

During the first about 50 days the plug was only fixed with 3 rods. When the total force exceeded 1500 kN the rest of the 9 rods were fixed in a prescribed manner. This procedure took place 12-14 December that is 46-48 days after test start. From that time only every third anchor is measured and the results should thus be multiplied with 3. The diagram shows both the actual measurements and after multiplication with 3.

2.10 Displacement of the plug (App. A page 22)

The three displacement gauges were placed and started to measure displacements from 001101. The tilting of the plug that could be observed in the beginning of the test has ceased and the displacement in the last three months period seems to be the same in all three points. The displacement is fairly linear with time with a rate of about 7 μm per day.

2.11 Canister power (App. A page 23)

The measurement of the power of the canister was erroneous during the first 20 days, which was the reason for that only 700 W were applied from start.

2.12 Temperature in the buffer (App. A pages 24-28)

The temperature ranges from no increase at all (in the periphery of the upper bentonite cylinder C4) to a total temperature of 86 degrees in the center close to the canister. The highest temperature gradient is 0.90 degrees/cm (ring 5). The measurements with thermocouples T124-T132 where erroneous during the last 50 days due to temporary malfunction of the data scanner.

2.13 Temperature in the rock (App. A pages 29-32)

The maximum temperature in the rock (64 degrees) is measured in the central section on the surface of the deposition hole. Almost complete axial symmetry of the temperature measured in the rock is observed.

2.14 Temperature on the canister surface, Optical fiber cables (App. A pages 33-34)

The first diagram shows the maximum temperature plotted as a function of time. The maximum temperature on the canister surface is 95 degrees. The second diagram shows the distribution of the temperature along the cables at 010917 and 011127. The length of the cable on the canister surface is only about 20 m and close to the entrances the temperature is affected by the lower surrounding temperatures.

Problems with the data collection system have yielded loss of measurements at long intervals.

2.15 Temperature inside the canister (App. A pages 36-37)

Very small changes of temperature inside the canister are recorded. The highest temperature, which is measured in the center of the canister (P15), has increased 2 degrees during the last 6 months to 103 degrees. In the same central section the temperature on the surface of the steel insert (P5) is about 8 degrees lower, which can be compared to the corresponding temperature on the copper surface, which is still a few degrees lower.

2.16 Strain in the canister

Continuous measurements have been made but so far no results have been produced due to evaluation problems.

2.16 Rock stresses and strains

Rock stresses and strains are reported in Appendix B.

3 Geometry

The test installation consists of a full-scale deposition hole, a copper canister equipped with electrical heaters and bentonite blocks (cylindrical and ring shaped). A plug of concrete and steel is anchored to the rock on top of the bentonite.

The saturation of the bentonite is attained artificially by vertical filter stripes. 16 stripes with a width of 0.1 meters and a length of 5.5 meters are applied on the surrounding rock.

Measurements are made in four vertical sections A, B, C and D according to Figure 3-1. Direction A-B is parallel to the tunnels axial with A headed almost against north.

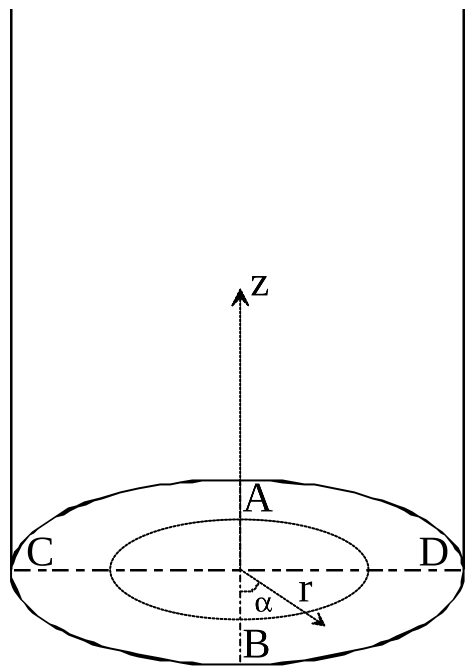


Figure 3-1. *Figure describing the instrument planes (A-D) and the coordinate system used when describing the instrument positions.*

4 Location of instruments

4.1 Brief description of the instruments

The different instruments that are used in the experiment are briefly described in this chapter.

Measurements of temperature

Buffer

Thermocouples from BICC have been installed for measuring temperature in the buffer. Measurements are done in 32 points in the test hole. In addition, temperature gauges are built in into the capacitive relative humidity sensors (29 sensors) as well as in the pressure gauges of vibrating wire type (13 gauges). Temperature is also measured in the psychrometers.

Canister

Temperature is measured inside the canister (on the insert) in 19 points with PT-100 gauges. In addition temperature is measured on the surface of the canister with optical fiber cables. An optical measuring system called FTR (Fiber Temperature Laser Radar) from BICC is used.

Rock

Temperature in the rock and on the rock surface of the hole is measured in 40 points with thermocouples from BICC.

Measurement of total pressure in the buffer

Total pressure is the sum of the swelling pressure and the pore water pressure. It is measured with the following instrument types:

- Geocon total pressure cells with vibrating wire transducers. 15 cells of this type have been installed.
- Kulite total pressure cells with piezo resistive transducers. 6 cells of this type have been installed.

Measurement of pore water pressure in the buffer

Pore water pressure is measured with the following instrument types:

- Geocon pore pressure cells with vibrating wire transducer. 13 cells of this type have been installed.
- Kulite pore pressure cells with piezo resistive transducer. 2 cells of this type have been installed.

Measurement of the water saturation process

The water saturation process is recorded by measuring the relative humidity in the pore system, which can be converted into water ratio or total suction (negative water pressure). The following techniques and devices are used:

- Vaisala relative humidity sensor of capacitive type. 29 cells of this type have been installed. The measuring range is 0-100 % RH.

- Wescor psychrometers model PST-55. The devices measure the relative humidity in the pore system. The measuring range is 95.5-99.6 % RH corresponding to the pore water pressure -0.5 to -6MPa. 26 cells of this type have been installed.

Measurements of strain in the Canister

These measurements are not reported.

Measurements of stresses and strain in the rock

These measurements are not reported.

Measurements of forces on the plug

The force on the plug caused by the swelling pressure of the bentonite is measured in 3 of the 9 anchors. The force transducers are of the type GLÖTZL.

Measurements of plug displacement

Due to straining of the anchors the swelling pressure of the bentonite will cause not only a force on the plug but also displacement of the plug. The displacement is measured in three points with transducers of the type LVDT with the range 0 – 50 mm.

Measurement of water flow into the permeable mats

Water is supplied to the bentonite with filter strips attached to the rock surface. The water flow into these mats is measured by measuring the water volume in the supply tank with a differential pressure transmitter that measures the difference in pressure between the nitrogen in the top of the tank and the water in the bottom of the tank.

4.2 Strategy for describing the position of each device

Every instrument is named with a short unique name consisting of 1-2 letters describing the type of measurement and 3 figures numbering the device. Every instrument position in the buffer and rock is described with three coordinates according to Figure 3-1.

The r-coordinate is the horizontal distance from the center of the hole and the z-coordinate is the height from the bottom of the hole (the block height is set to 500 mm). The α−coordinate is the angle from the vertical direction B (almost south).

The short description of the positions in the diagrams differs between the buffer and the rock.

Buffer: Three positions with the following meaning: (bentonite block or cylinder number counted from the bottom \ direction A, B, C, or D \ radius in mm from center line)

Rock: Three positions with the following meaning: (distance in meters from the bottom \ α according to Fig 3-1 \ distance in meters from the hole surface)

The bentonite blocks are called cylinders and rings. The cylinders are numbered C1-C4 and the rings R1-R10 respectively (Figure 4-1).

4.3 Position of each instrument in the bentonite

Measurements are done in four vertical sections A, B, C and D according to Figure 3-1. Direction A and B are placed in the tunnels axial direction.

An overview of the positions of the instruments is shown in Fig 4-1. Exact positions are described in Tables 4-1 to 4-4.

The instruments are located in two main levels in the blocks, 50 mm and 160 mm, from the upper surface. The thermocouples have mostly placed in the 50mm level and the other gauges in the 160 mm level.

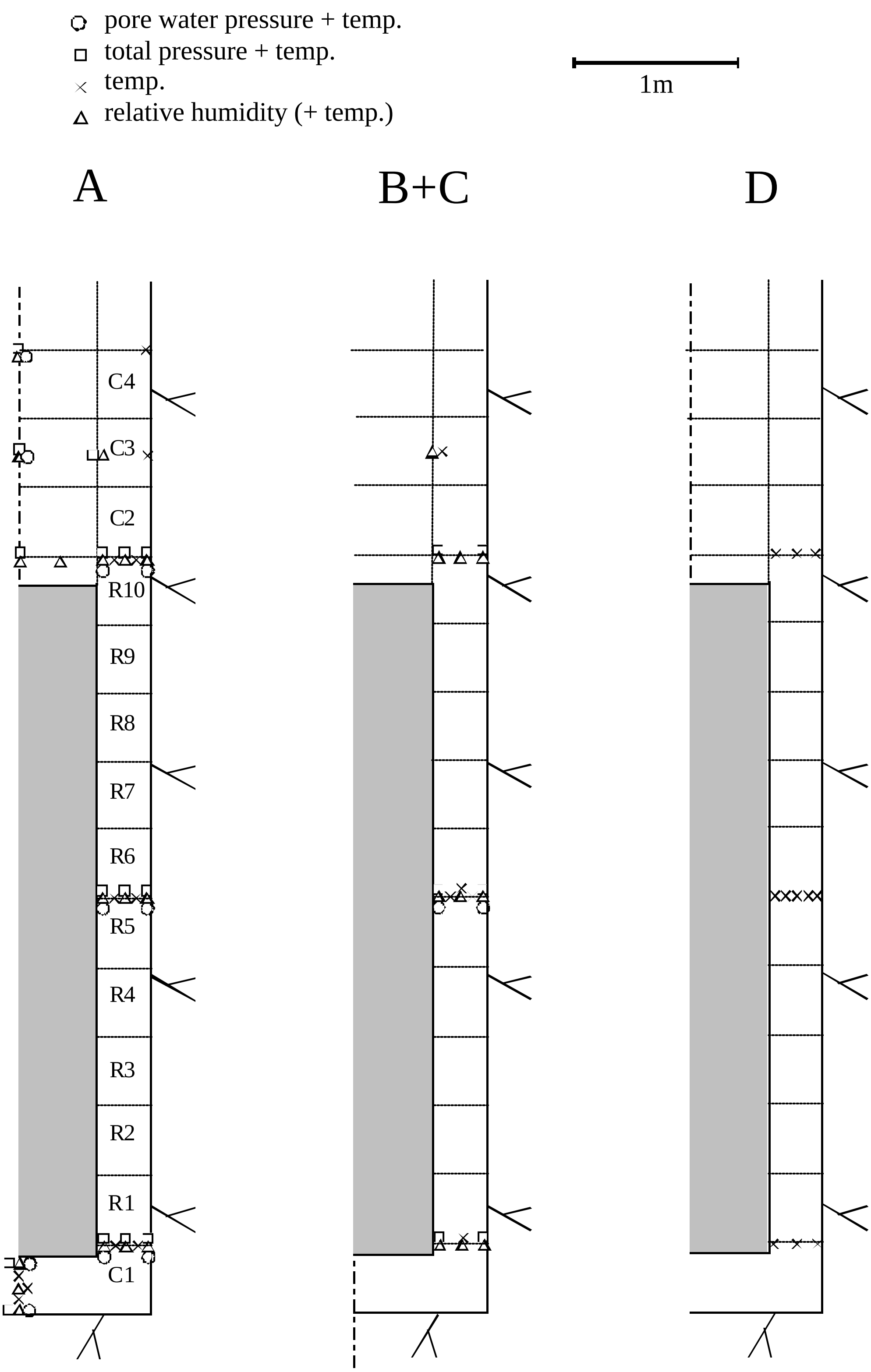


Figure 4-1 *Schematic view over the instruments in four vertical sections and the block designation.*

Table 4-1 Numbering and position of instruments for measuring temperature (T)

		Instrument position in block				Cable pos.		
Type and number	Block	Direction	α	r	Z	α	Fabricate	Remark
T101	Cyl. 1	Center	90	50	50	242	BICC	
T102	Cyl. 1	Center	90	50	250	238	BICC	
T103	Cyl. 1	Center	90	50	450	230	BICC	
T104	Cyl. 1	A	180	635	450	206	BICC	
T105	Cyl. 1	A	180	735	450	202	BICC	
T106	Cyl. 1	B	365	685	450	38	BICC	
T107	Cyl. 1	C	275	685	450	274	BICC	
T108	Cyl. 1	D	90	585	450	96	BICC	
T109	Cyl. 1	D	90	685	450	94	BICC	
T110	Cyl. 1	D	90	785	450	92	BICC	
T111	Ring 5	A	180	635	2950	224	BICC	
T112	Ring 5	A	180	735	2950	218	BICC	
T113	Ring 5	B	360	610	2950	318	BICC	
T114	Ring 5	B	360	685	2950	322	BICC	
T115	Ring 5	B	360	735	2950	324	BICC	
T116	Ring 5	C	270	610	2950	258	BICC	
T117	Ring 5	C	270	685	2950	260	BICC	
T118	Ring 5	C	270	735	2950	262	BICC	
T119	Ring 5	D	90	585	2950	44	BICC	
T120	Ring 5	D	90	635	2950	46	BICC	
T121	Ring 5	D	90	685	2950	48	BICC	
T122	Ring 5	D	90	735	2950	50	BICC	
T123	Ring 5	D	90	785	2950	52	BICC	
T124	Ring 10	A	180	635	5450	200	BICC	
T125	Ring 10	A	180	735	5450	194	BICC	
T126	Ring 10	D	90	585	5450	54	BICC	
T127	Ring 10	D	90	685	5450	56	BICC	
T128	Ring 10	D	90	785	5450	58	BICC	
T129	Cyl. 3	A	180	785	6250	166	BICC	
T130	Cyl. 3	B	365	585	6250	358	BICC	
T131	Cyl. 3	C	275	585	6250	280	BICC	
T132	Cyl. 4	A	180	785	6950	66	BICC	

Table 4-2 Numbering and position of instruments for measuring total pressure (P)

		Instrument position in block				Cable pos.		
Type and number	Block	Direction	α	r	z	α	Fabricate	Remark
P101	Cyl. 1	Center	180	50	50	244	Geocon	
P102	Cyl. 1	Center	180	50	250	232	Geocon	
P103	Cyl. 1	A	185	585	250	208	Geocon	
P104	Cyl. 1	A	185	685	250	204	Geocon	
P105	Cyl. 1	A	185	785	250	186	Geocon	
P106	Cyl. 1	B	365	585	250	40	Geocon	
P107	Cyl. 1	B	365	785	250	2	Geocon	
P108	Cyl. 1	C	275	585	250	278	Geocon	
P109	Cyl. 1	C	275	785	250	270	Geocon	
P110	Ring 5	A	185	585	2750	228	Geocon	
P111	Ring 5	A	185	685	2750	222	Geocon	
P112	Ring 5	A	185	785	2750	188	Geocon	
P113	Ring 5	B	365	535	2750	36	Geocon	
P114	Ring 5	B	365	825	2750	16	Geocon	
P115	Ring 5	C	275	585	2750	296	Geocon	
P116	Ring 5	C	275	785	2750	290	Geocon	
P117	Ring 10	Center	180	50	5250	24	Kulite	
P118	Ring 10	A	180	585	5250	216	Geocon	
P119	Ring 10	A	180	685	5250	198	Geocon	
P120	Ring 10	A	180	785	5250	192	Geocon	
P121	Ring 10	B	365	585	5250	20	Kulite	
P122	Ring 10	B	365	785	5250	18	Kulite	
P123	Ring 10	C	275	585	5250	286	Kulite	
P124	Ring 10	C	275	785	5250	284	Kulite	
P125	Cyl. 3	Center	180	50	6250	158	Geocon	
P126	Cyl. 3	A	180	585	6250	162	Geocon	
P127	Cyl. 4	Center	180	50	6750	64	Kulite	

Table 4-3 Numbering and position of instruments for measuring pore water pressure (U)

		Instrument position in block				Cable pos.		
Type and number	Block	Direction	α	r	z	α	Fabricate	Remark
U101	Cyl. 1	Center	270	50	50	246	Geocon	
U102	Cyl. 1	Center	270	50	250	236	Geocon	Horizontal
U103	Cyl. 1	A	175	585	250	126	Geocon	
U104	Cyl. 1	A	175	785	250	178	Geocon	
U105	Ring 5	A	175	585	2750	138	Geocon	
U106	Ring 5	A	175	785	2750	180	Geocon	
U107	Ring 5	B	355	535	2750	314	Geocon	
U108	Ring 5	B	355	825	2750	348	Geocon	
U109	Ring 5	C	265	585	2750	256	Geocon	In the slot
U110	Ring 5	C	265	825	2750	264	Geocon	In the slot
U111	Ring 10	A	175	585	5250	146	Geocon	
U112	Ring 10	A	175	785	5250	152	Geocon	
U113	Cyl. 3	Center	270	50	6250	156	Geocon	
U114	Cyl. 4	Center	270	50	6950	62	Kulite	

Table 4-4 Numbering and position of instruments for measuring water content (W)

		Instrument position in block				Cable pos.		
Type and number	Block	Direction	α	r	Z	α	Fabricate	Remark
W101	Cyl. 1	Center	360	50	50	248	Vaisala	
W102	Cyl. 1	Center	360	400	160	240	Vaisala	
W103	Cyl. 1	Center	360	50	450	234	Vaisala	Horizontal
W104	Cyl. 1	A	180	585	340	128	Vaisala	
W105	Cyl. 1	A	180	685	340	132	Vaisala	
W106	Cyl. 1	A	180	785	340	184	Vaisala	
W107	Cyl. 1	A	170	585	340	124	Wescor	
W108	Cyl. 1	A	170	685	340	130	Wescor	
W109	Cyl. 1	A	170	785	340	134	Wescor	
W110	Cyl. 1	B	360	585	340	304	Vaisala	
W111	Cyl. 1	B	360	785	340	360	Vaisala	
W112	Cyl. 1	B	360	685	340	308	Vaisala	
W113	Cyl. 1	B	355	585	340	302	Wescor	
W114	Cyl. 1	B	355	685	340	306	Wescor	
W115	Cyl. 1	B	355	785	340	310	Wescor	
W116	Cyl. 1	C	270	585	340	250	Wescor	
W117	Cyl. 1	C	270	685	340	252	Wescor	
W118	Cyl. 1	C	270	785	340	254	Vaisala	
W119	Ring 5	A	180	585	2840	226	Vaisala	
W120	Ring 5	A	180	685	2840	220	Vaisala	
W121	Ring 5	A	180	785	2840	182	Vaisala	
W122	Ring 5	A	170	585	2840	136	Wescor	
W123	Ring 5	A	170	685	2840	140	Wescor	
W124	Ring 5	A	170	785	2840	142	Wescor	
W125	Ring 5	B	360	535	2840	316	Vaisala	In the slot
W126	Ring 5	B	360	685	2840	34	Vaisala	
W127	Ring 5	B	360	785	2840	350	Vaisala	
W128	Ring 5	B	350	535	2840	312	Wescor	In the slot
W129	Ring 5	B	350	685	2840	320	Wescor	
W130	Ring 5	B	350	785	2840	346	Wescor	
W131	Ring 5	C	270	585	2840	294	Wescor	In the slot
W132	Ring 5	C	275	685	2840	292	Wescor	
W133	Ring 5	C	270	785	2840	288	Wescor	
W134	Ring 10	Center	360	50	5340	22	Vaisala	
W135	Ring 10	A	180	262	5340	26	Vaisala	
W136	Ring 10	A	180	585	5340	214	Vaisala	
W137	Ring 10	A	180	685	5340	196	Vaisala	
W138	Ring 10	A	180	785	5340	190	Vaisala	
W139	Ring 10	A	170	585	5340	144	Wescor	
W140	Ring 10	A	170	685	5340	148	Wescor	
W141	Ring 10	A	170	785	5340	150	Wescor	
W142	Ring 10	B	360	585	5340	328	Vaisala	
W143	Ring 10	B	360	685	5340	332	Vaisala	
W144	Ring 10	B	360	785	5340	336	Vaisala	
W145	Ring 10	B	355	585	5340	326	Wescor	
W146	Ring 10	B	355	685	5340	330	Wescor	
W147	Ring 10	B	355	785	5340	334	Wescor	
W148	Ring 10	C	270	585	5340	266	Wescor	
W149	Ring 10	C	270	685	5340	268	Wescor	
W150	Ring 10	C	270	785	5340	272	Vaisala	
W151	Cyl. 3	Center	360	50	6250	154	Vaisala	
W152	Cyl. 3	A	180	585	6250	160	Vaisala	
W153	Cyl. 3	B	360	585	6250	356	Vaisala	
W154	Cyl. 3	C	270	585	6250	276	Wescor	
W155	Cyl. 4	Center	360	50	6840	60	Vaisala	

4.4 Instruments in the rock

Temperature measurements

40 thermocouples are placed in the rock and on the rock surface of the deposition hole. Holes have been bored in three directions on three levels and one additional hole has been bored in the bottom of the deposition hole i.e. totally 10 holes. They are led from the rock, over the gap between rock and bentonite and up along the bentonite block periphery. The position of the thermocouples in the rock is shown in Table 4-5.

Table 4-5 Numbering and positions of thermocouples in the rock

Type and number	Level	Direction	Distance from rock surface	Cable pos. α	Fabricate	Remark
TR101	0	Center	0.000	70°-90°	BICC	
TR102	0	Center	0.375	70°-90°	BICC	
TR103	0	Center	0.750	70°-90°	BICC	
TR104	0	Center	1.500	70°-90°	BICC	
TR105	0.61	10°	0.000	4°-14°	BICC	
TR106	0.61	10°	0.375	4°-14°	BICC	
TR107	0.61	10°	0.750	4°-14°	BICC	
TR108	0.61	10°	1.500	4°-14°	BICC	
TR109	0.61	80°	0.000	70°-90°	BICC	
TR110	0.61	80°	0.375	70°-90°	BICC	
TR111	0.61	80°	0.750	70°-90°	BICC	
TR112	0.61	80°	1.500	70°-90°	BICC	
TR113	0.61	170°	0.000	168°-176°	BICC	
TR114	0.61	170°	0.375	168°-176°	BICC	
TR115	0.61	170°	0.750	168°-176°	BICC	
TR116	0.61	170°	1.500	168°-176°	BICC	
TR117	3.01	10°	0.000	4°-14°	BICC	
TR118	3.01	10°	0.375	4°-14°	BICC	
TR119	3.01	10°	0.750	4°-14°	BICC	
TR120	3.01	10°	1.500	4°-14°	BICC	
TR121	3.01	80°	0.000	70°-90°	BICC	
TR122	3.01	80°	0.375	70°-90°	BICC	
TR123	3.01	80°	0.750	70°-90°	BICC	
TR124	3.01	80°	1.500	70°-90°	BICC	
TR125	3.01	170°	0.000	168°-176°	BICC	
TR126	3.01	170°	0.375	168°-176°	BICC	
TR127	3.01	170°	0.750	168°-176°	BICC	
TR128	3.01	170°	1.500	168°-176°	BICC	
TR129	5.41	10°	0.000	4°-14°	BICC	
TR130	5.41	10°	0.375	4°-14°	BICC	
TR131	5.41	10°	0.750	4°-14°	BICC	
TR132	5.41	10°	1.500	4°-14°	BICC	
TR133	5.41	80°	0.000	70°-90°	BICC	
TR134	5.41	80°	0.375	70°-90°	BICC	
TR135	5.41	80°	0.750	70°-90°	BICC	
TR136	5.41	80°	1.500	70°-90°	BICC	
TR137	5.41	170°	0.000	168°-176°	BICC	
TR138	5.41	170°	0.375	168°-176°	BICC	
TR139	5.41	170°	0.750	168°-176°	BICC	
TR140	5.41	170°	1.500	168°-176°	BICC	

Stress and strain measurements

See Appendix B.

4.5 Instruments in the canister

The canister is instrumented with optical fiber cables on the copper surface, thermocouples in the steel insert and strain gauges on the inner and outer surface of the copper envelop in canister.

Optical fiber cables

Figure 4-2 shows how the two optical fiber cables are placed on the canister surface. Both ends of a cable are used for measurements. This means that the two cables are used as four measuring channels as described in Table 4-6.

With this laying the cable will enter and exit the surface at almost the same position. Curvatures are shaped as a quarter circle with a radius of 20 cm. The cable is placed in a milled out channel on the surface. The channel has a width and a depth of just above 2 mm

Table 4-6. Combination of cables and channels

Channel 1	Outlet of cable 1
Channel 2	Inlet of cable 1
Channel 3	Outlet of cable 2
Channel 4	Inlet of cable 2

Figure 4-3 shows the location of the thermocouples on the steel insert inside the canister.

Thermocouple, PT100

Temperature in the steel insert measured at 18 point of measuring with. thermocouple of type PT100. Figure 4-4 shows how these thermocouple are placed

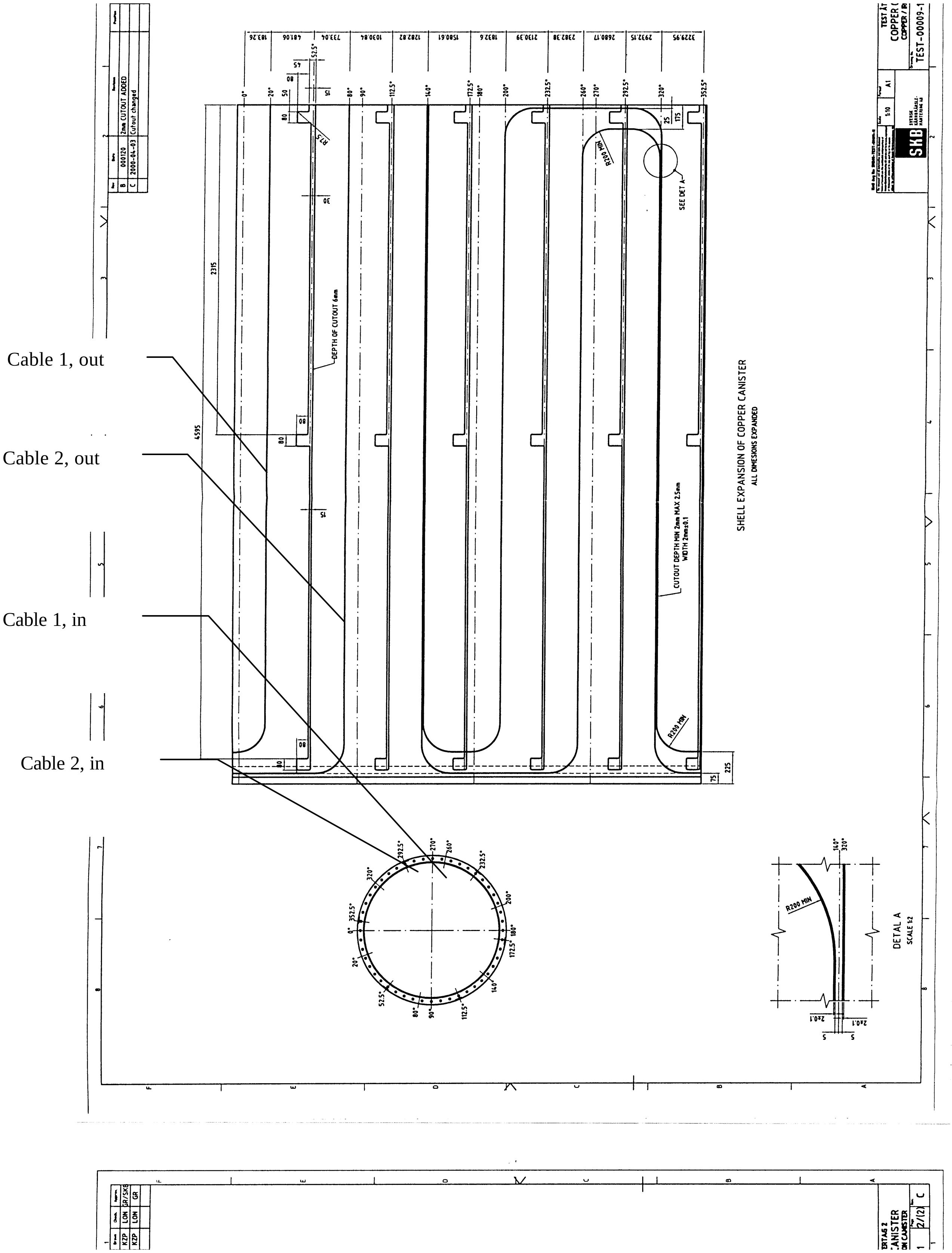
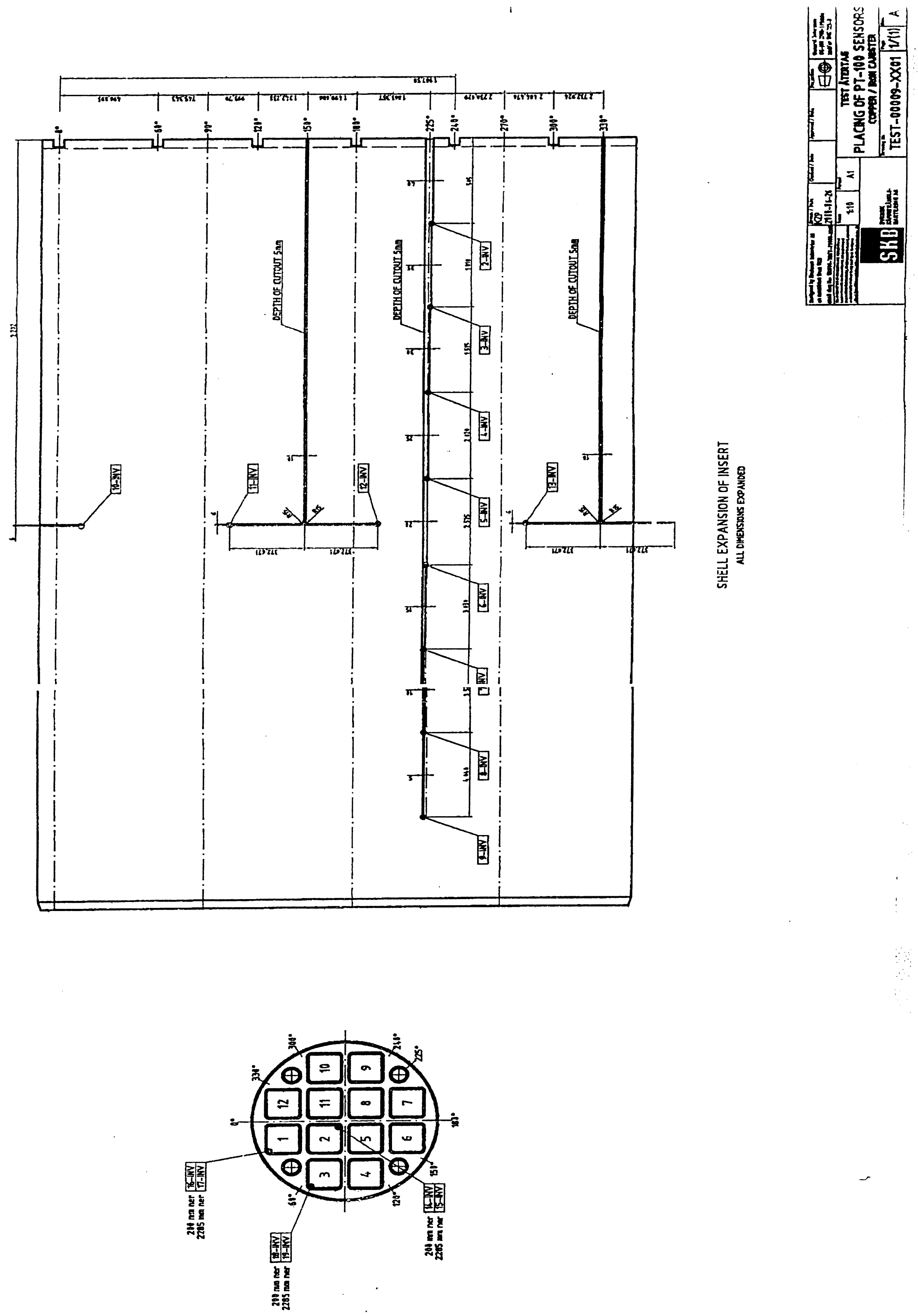


Figure 4-2. *Laying of two optical fibre cables with protection tube of Inconel 625 (outer diameter 2 mm) for measurement of the canister surface temperature (surface unfolded).*



Figur 4-3. *Location of thermocouples inside the canister*

4.6 Instruments at the plug

Three force transducers and three displacement transducers have been placed on the plug to measure the force of the anchors and the displacement of the plug. The location of these transducers can be described in relation to Fig 4-4, which shows a schematic view of the plug with the slots, rods and cables.

The rods are numbered 1-9 anti-clockwise and number 1 is assumed to be the northern rod in direction A. The force transducers are placed on rods 3, 6, and 9. The displacement transducers are placed between the rods 5 cm from the rock surface of the hole and according to Table 4-6. They are fixed on the rock surface and measure thus the displacement relative the rock.

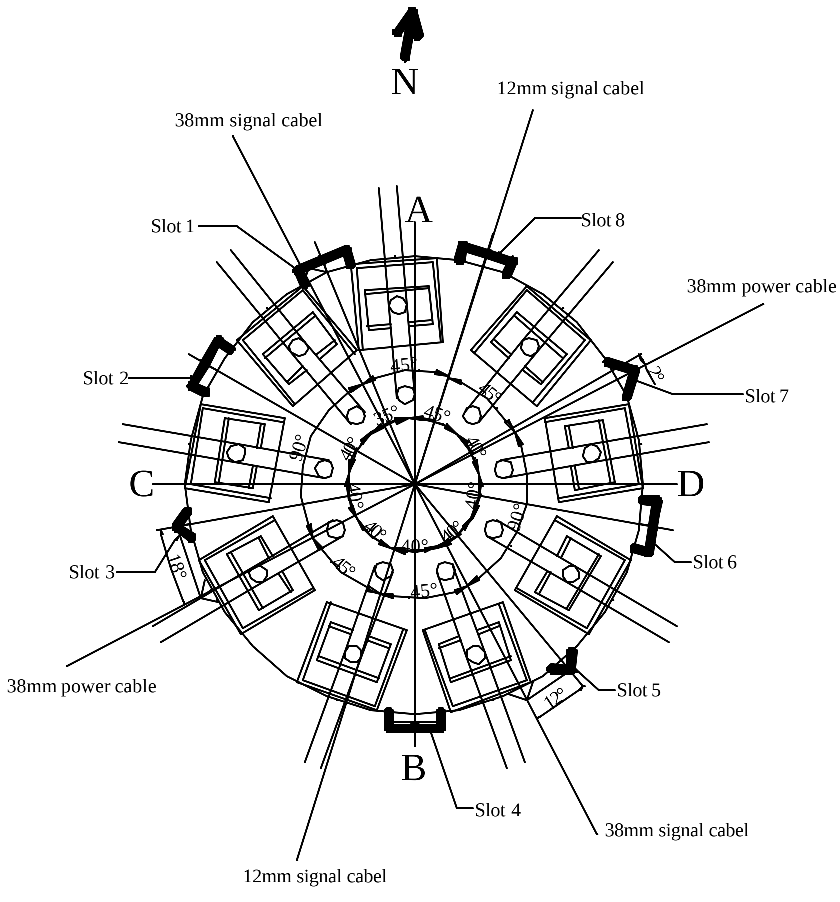


Figure 4-4. *Schematic view of the deposition hole, showing the position of the slots, the rods and the cables from the canister.*

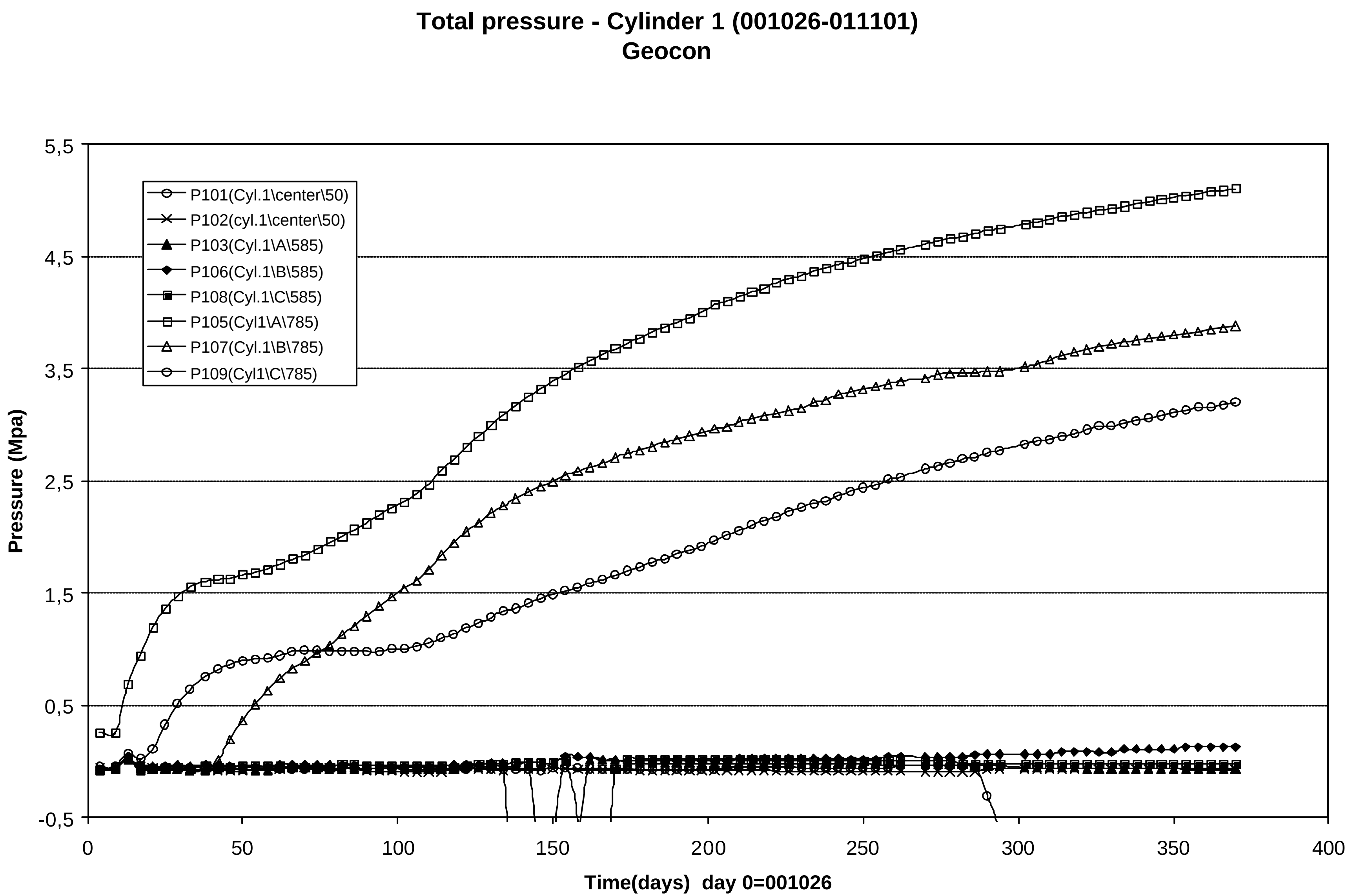
Table 4-6. Location of displacement transducers

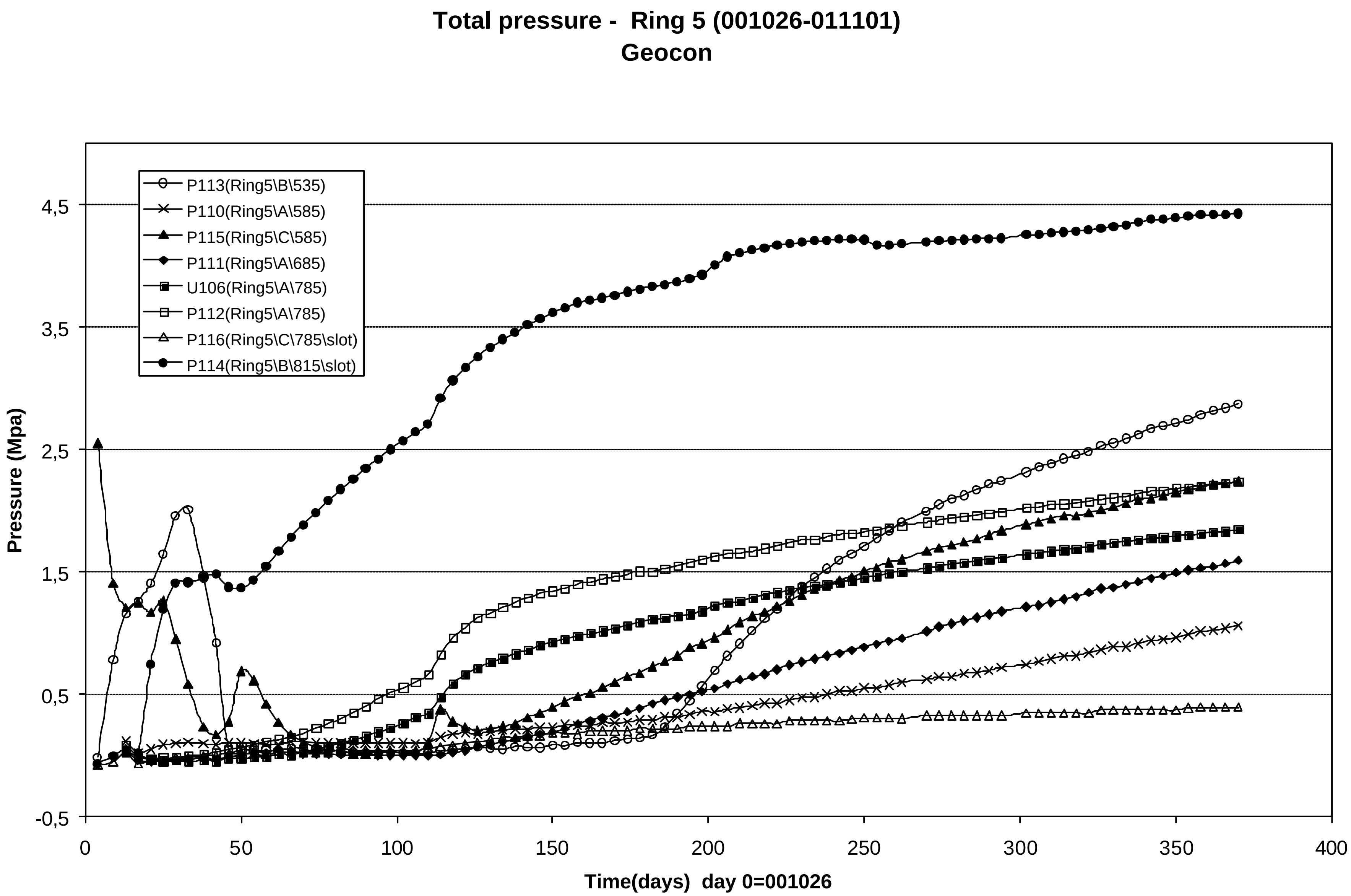
Transducer No.	Located between rods No.
1	4 and 5
2	7 and 8
3	1 and 2

References

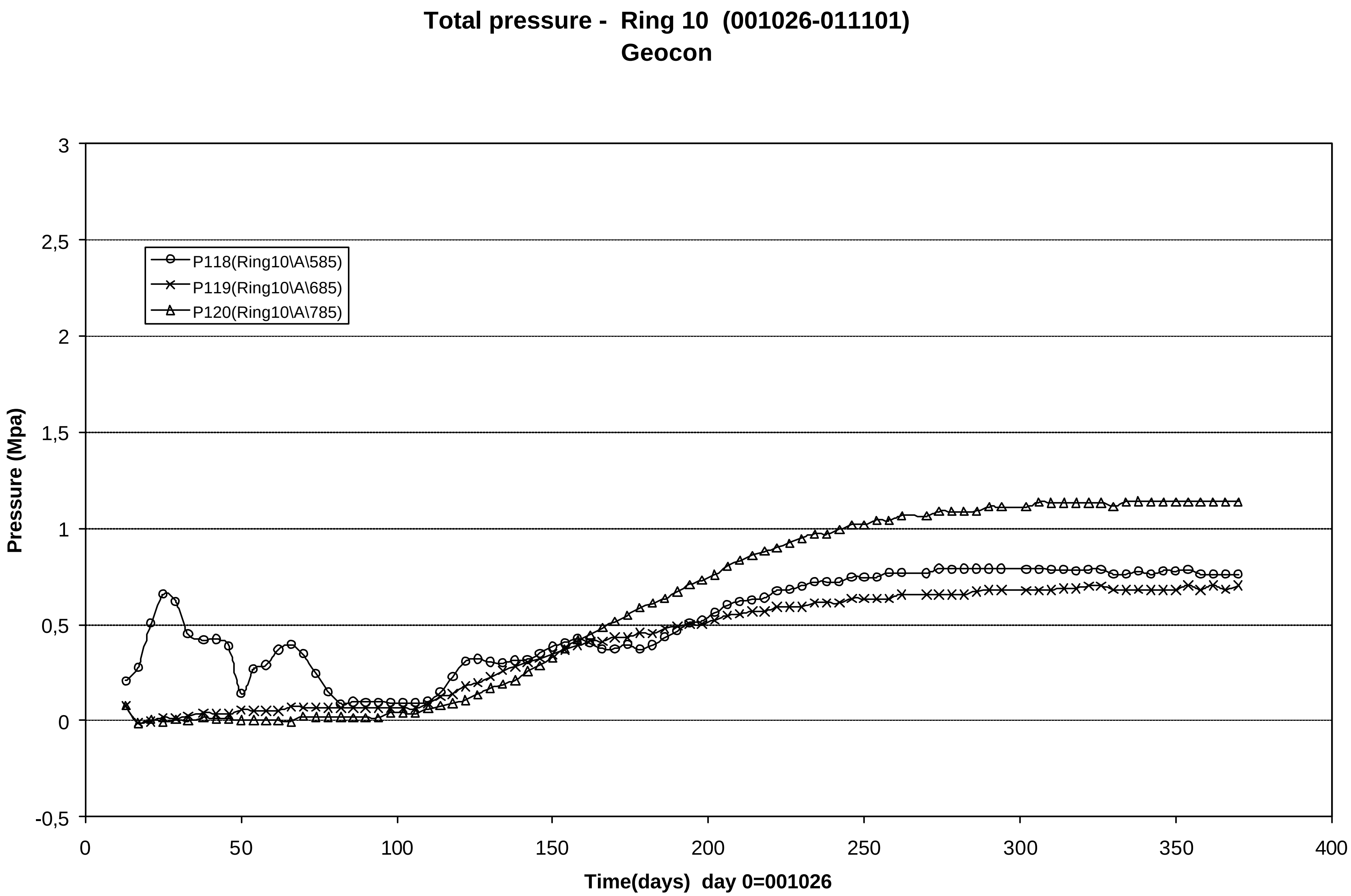
/1-1/ Sanden T, Börgesson L. Report on instrument positions and preparation of bentonite blocks for instruments and cables May 2000. SKB IPR-00-14

Appendix A

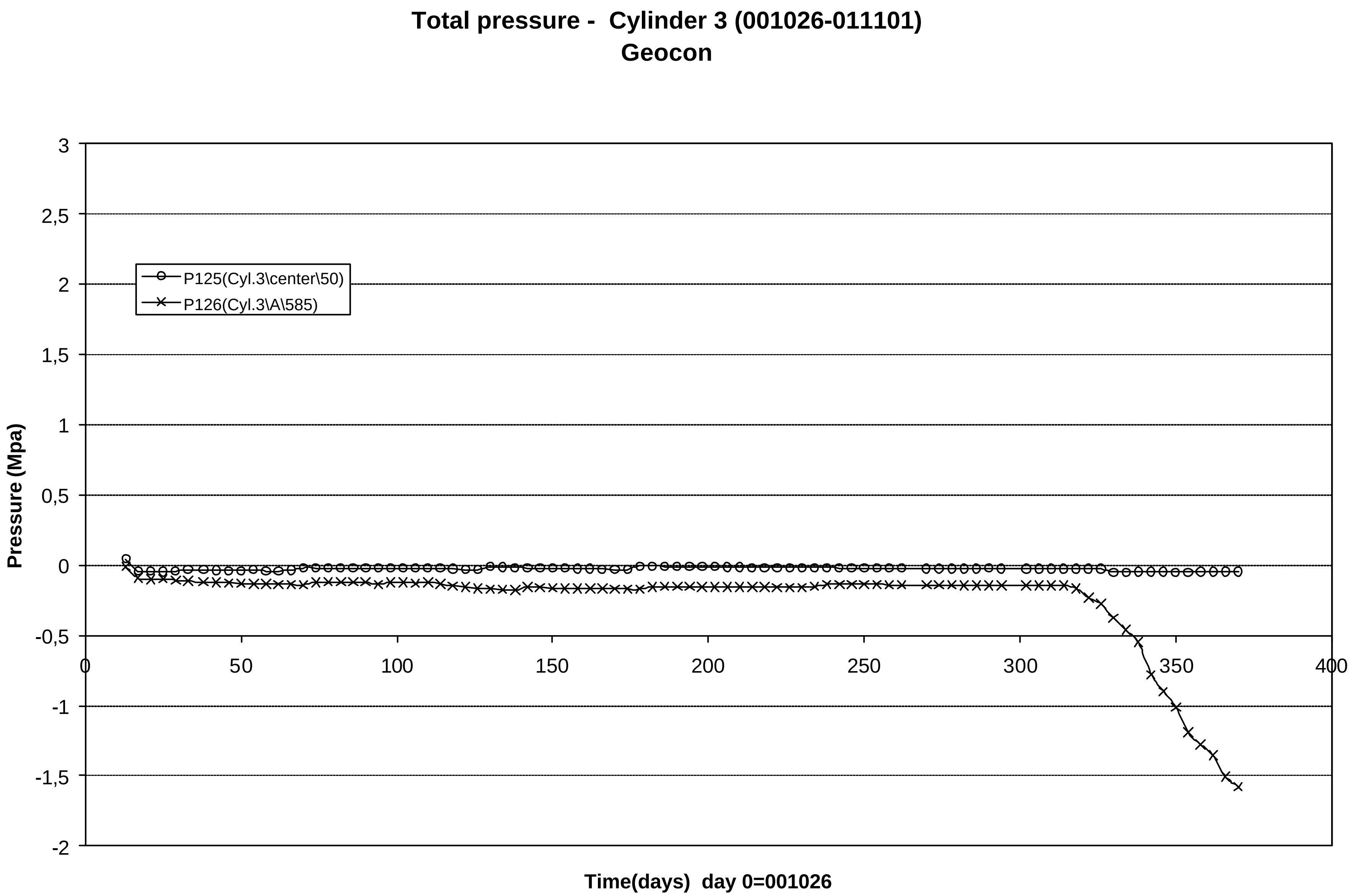

Total pressure - Cylinder 1 (001026-011101)
Geocon
P101(Cyl.1\center\50)
P102(cyl.1\center\50)
P103(Cyl.1\A\585)
P106(Cyl.1\B\585)
P108(Cyl.1\C\585)
P105(Cyl1\A\785)
P107(Cyl.1\B\785)
P109(Cyl1\C\785)
Pressure (Mpa)
5,5
4,5
3,5
2,5
1,5
0,5
-0,5
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026

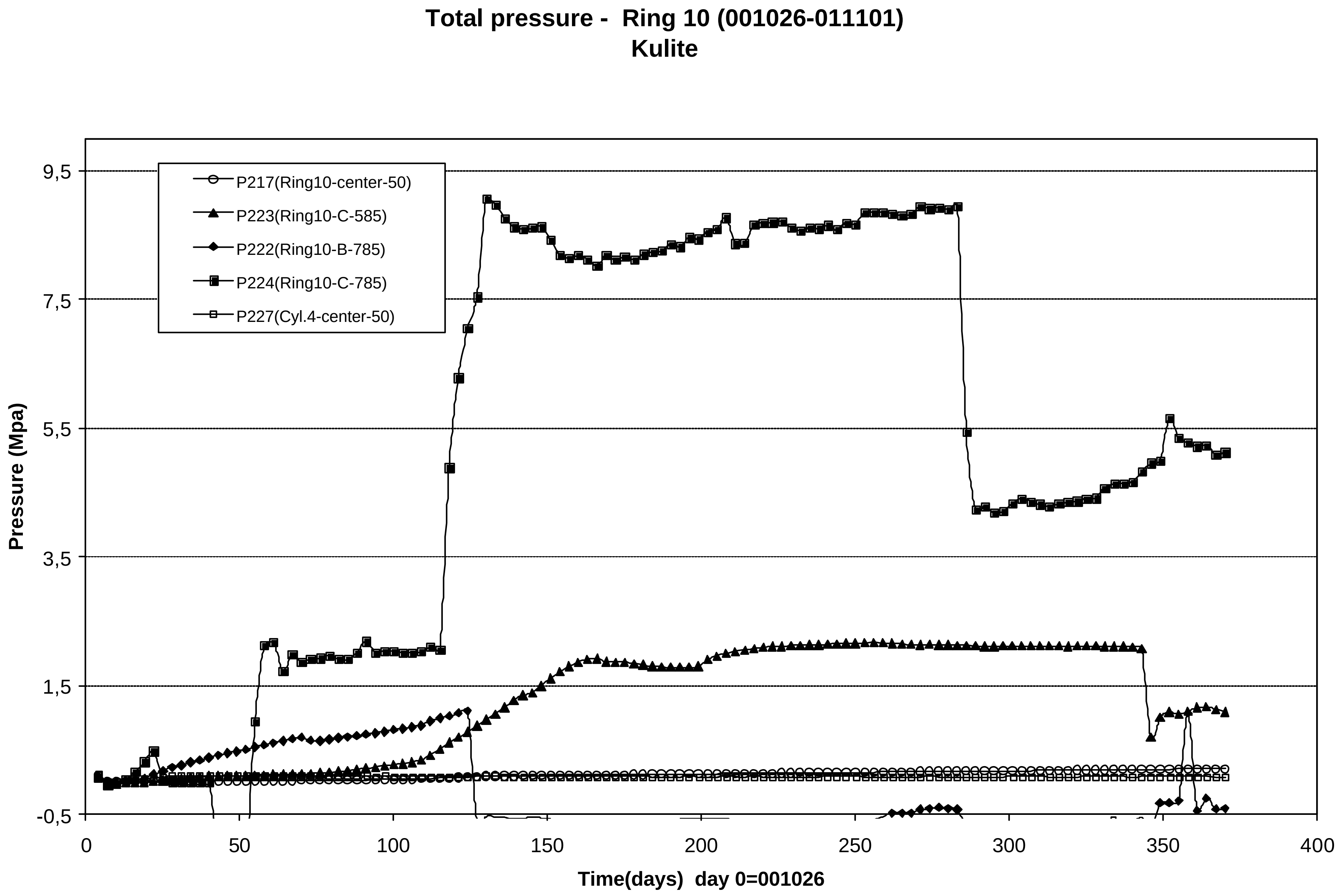


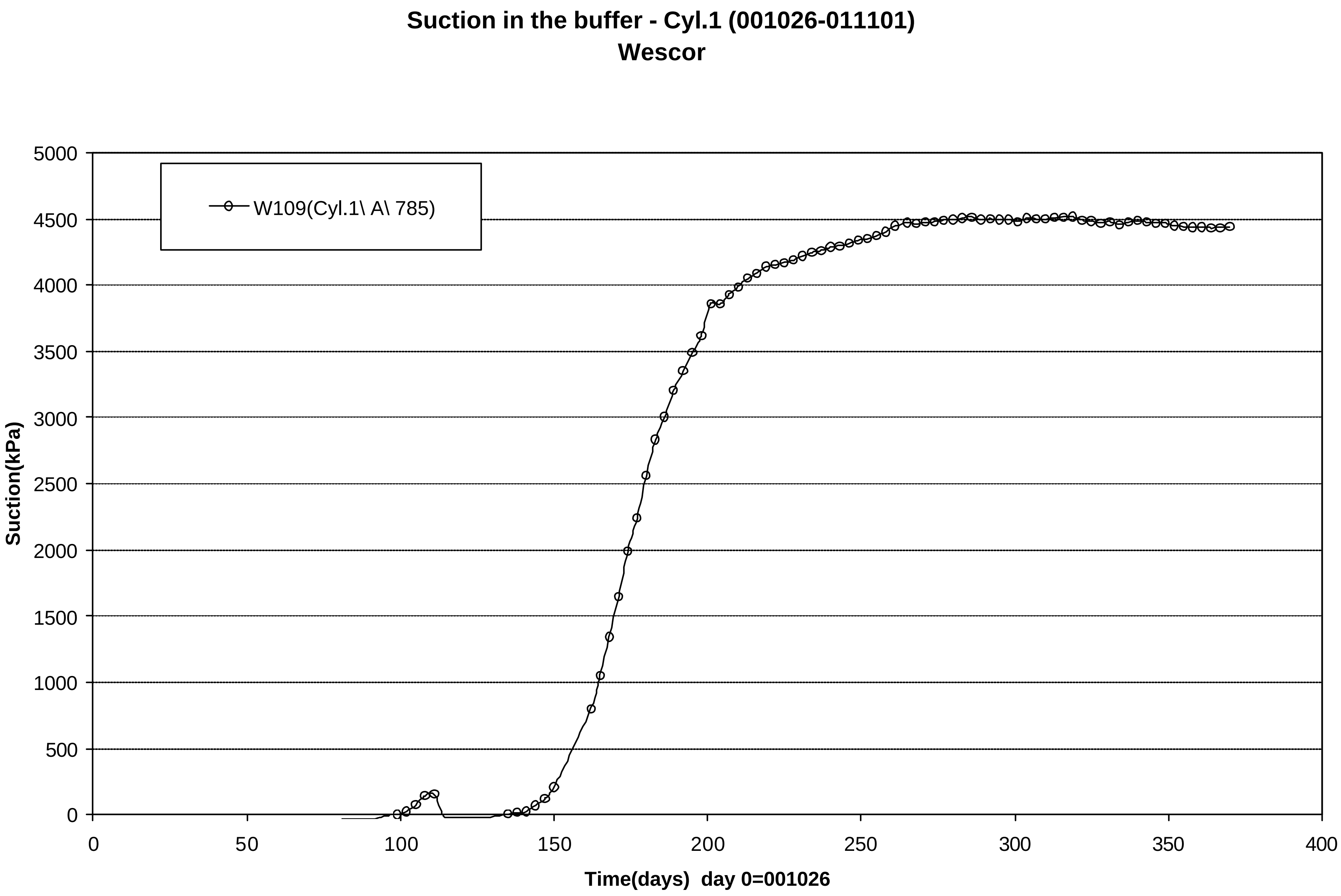
Total pressure - Ring 5 (001026-011101)
Geocon
P113(Ring5\B\535)
P110(Ring5\A\585)
P115(Ring5\C\585)
P111(Ring5\A\685)
U106(Ring5\A\785)
P112(Ring5\A\785)
P116(Ring5\C\785\slot)
P114(Ring5\B\815\slot)
Pressure (Mpa)
4,5
3,5
2,5
1,5
0,5
-0,5
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026



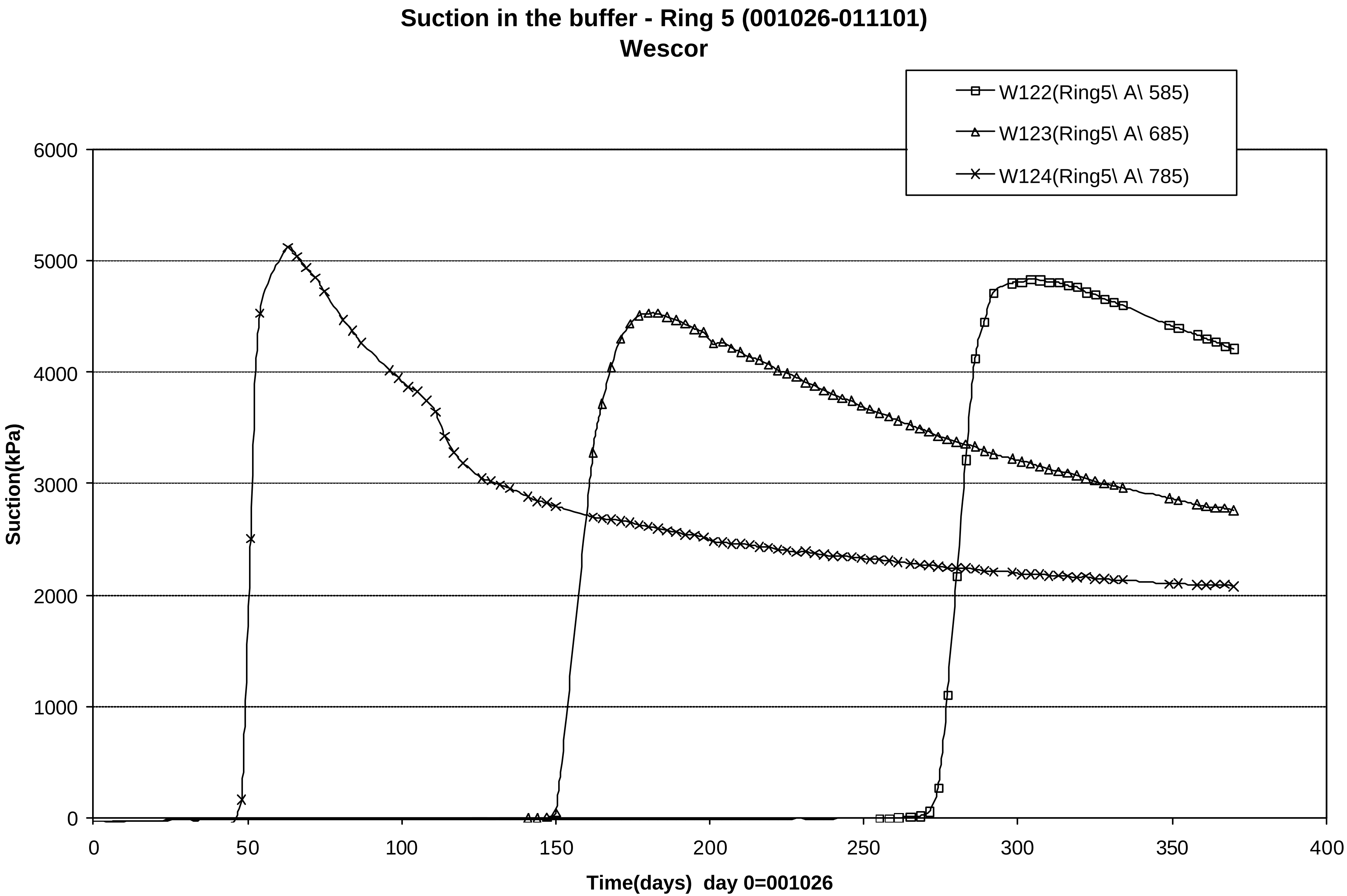
Total pressure - Ring 10 (001026-011101)
Geocon
Pressure (Mpa)
3
2,5
2
1,5
1
0,5
0
-0,5
P118(Ring10\A\585)
P119(Ring10\A\685)
P120(Ring10\A\785)
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026


Total pressure - Cylinder 3 (001026-011101)
Geocon
P125(Cyl.3\center\50)
P126(Cyl.3\A\585)
Pressure (Mpa)
3
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
-2
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026

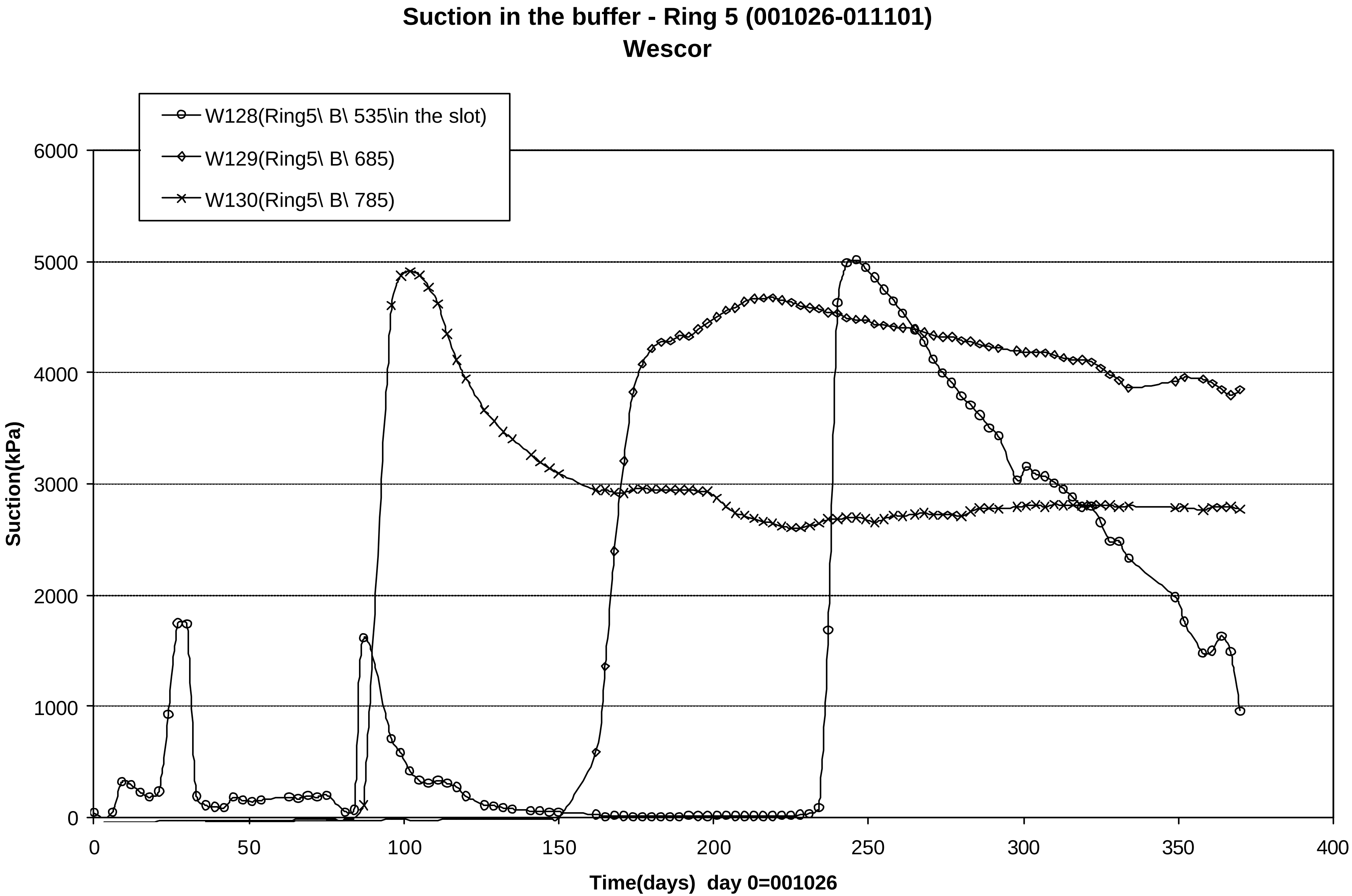

Total pressure - Ring 10 (001026-011101)
Kulite
P217(Ring10-center-50)
P223(Ring10-C-585)
P222(Ring10-B-785)
P224(Ring10-C-785)
P227(Cyl.4-center-50)
Pressure (Mpa)
9,5
7,5
5,5
3,5
1,5
-0,5
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026



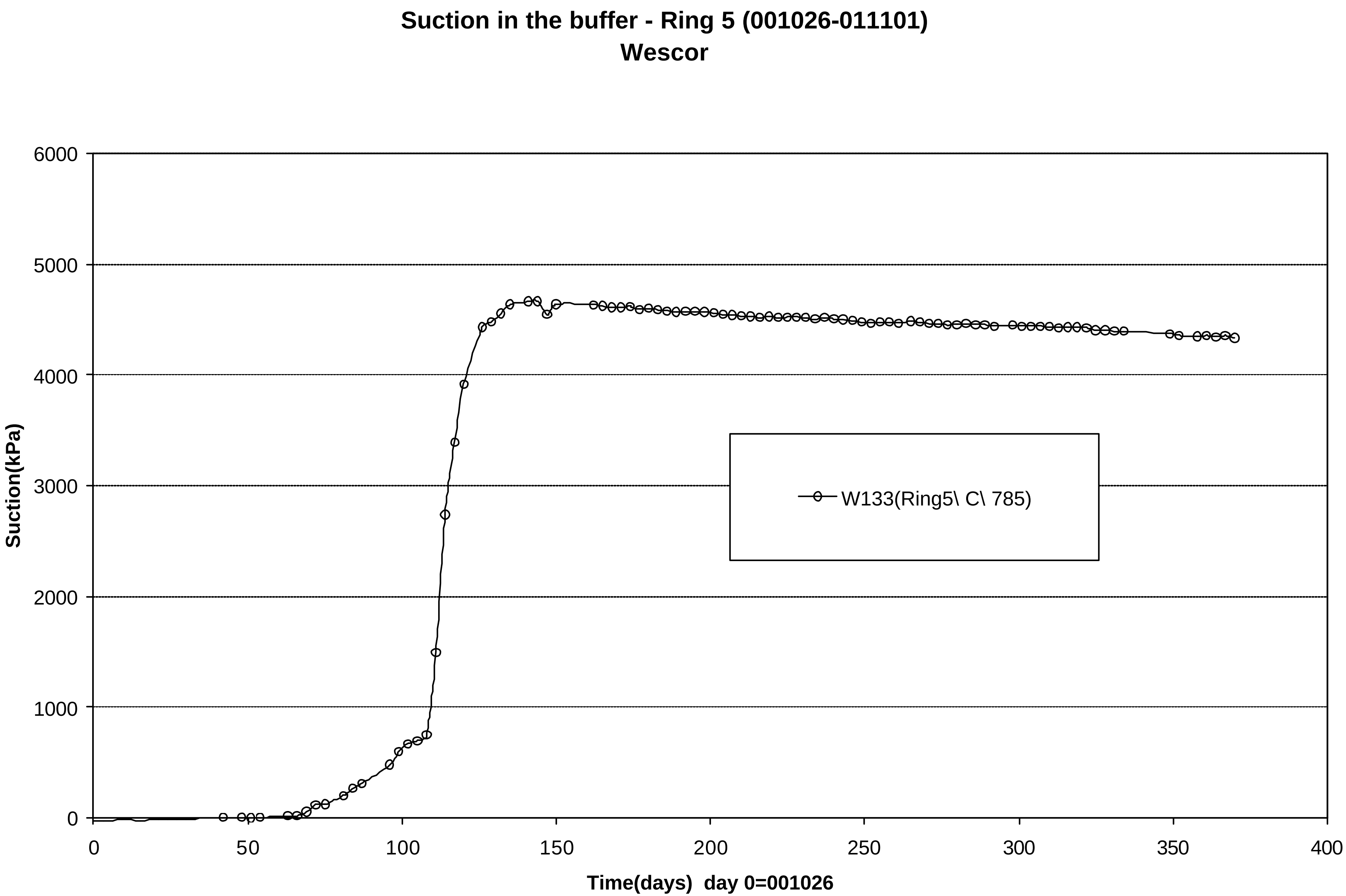
Suction in the buffer - Cyl.1 (001026-011101)
Wescor
W109(Cyl.1\ A\ 785)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Suction(kPa)
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026

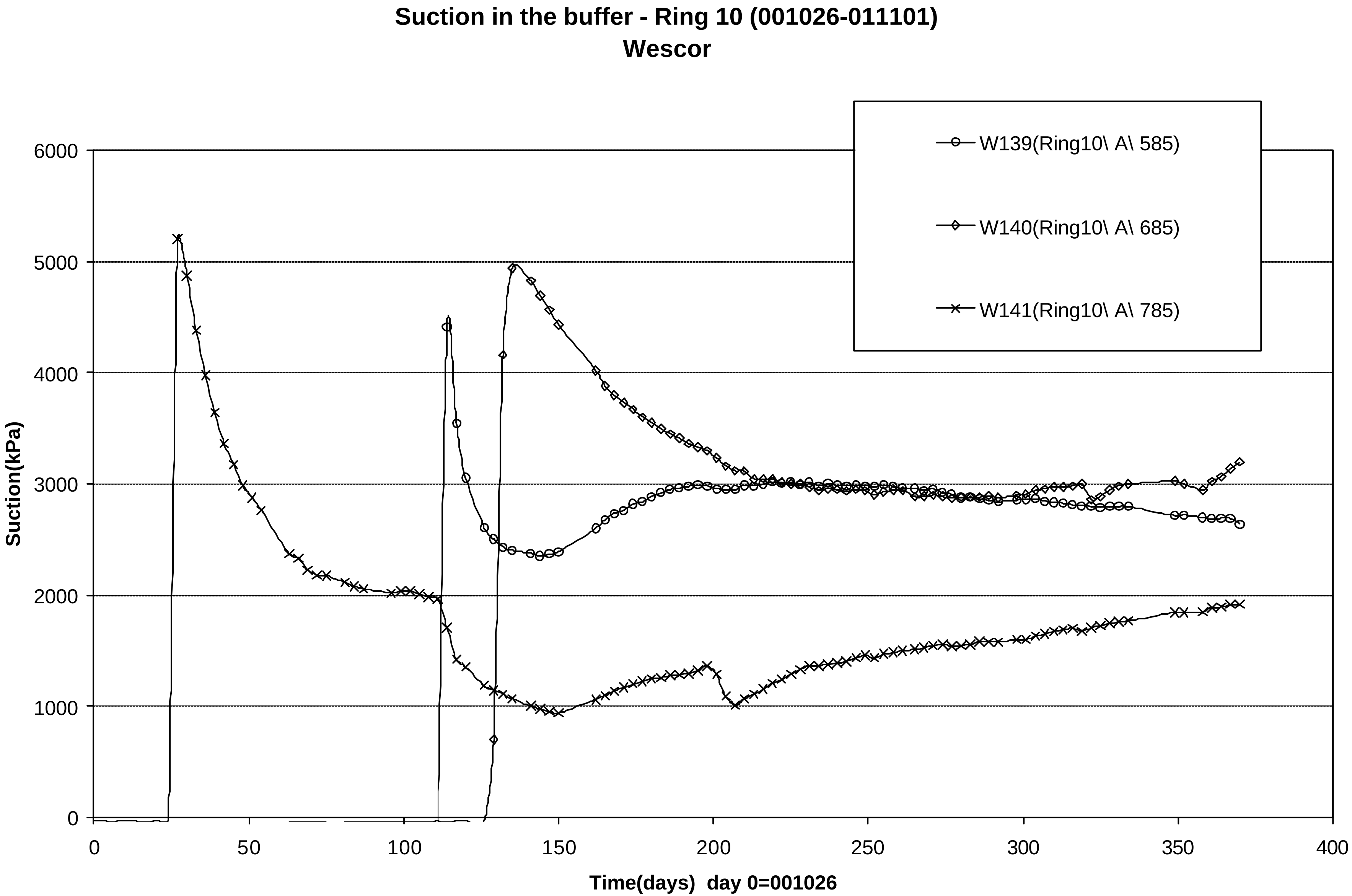


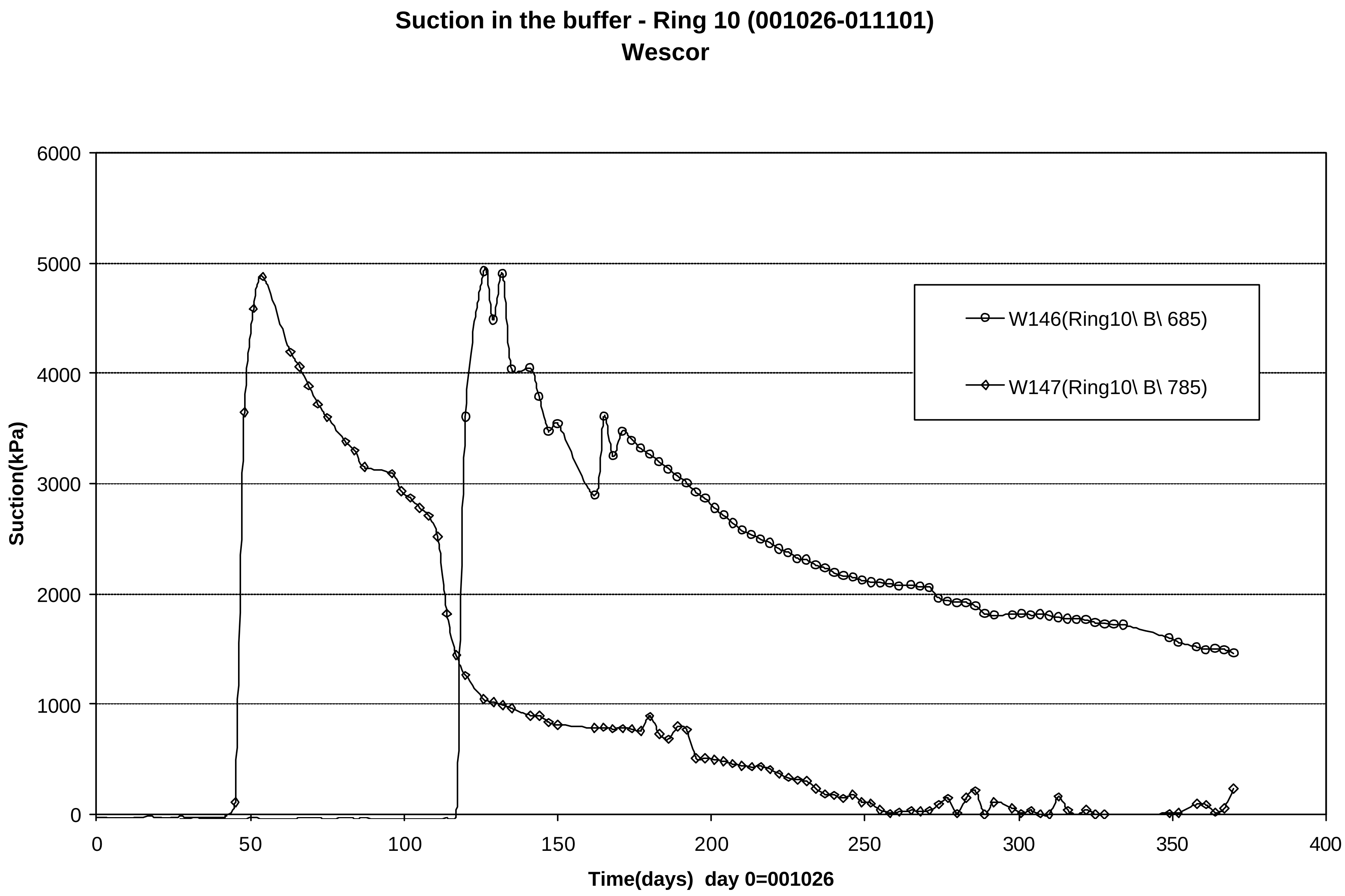
Suction in the buffer - Ring 5 (001026-011101)
Wescor
W122(Ring5\ A\ 585)
W123(Ring5\ A\ 685)
W124(Ring5\ A\ 785)
Suction(kPa)
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026



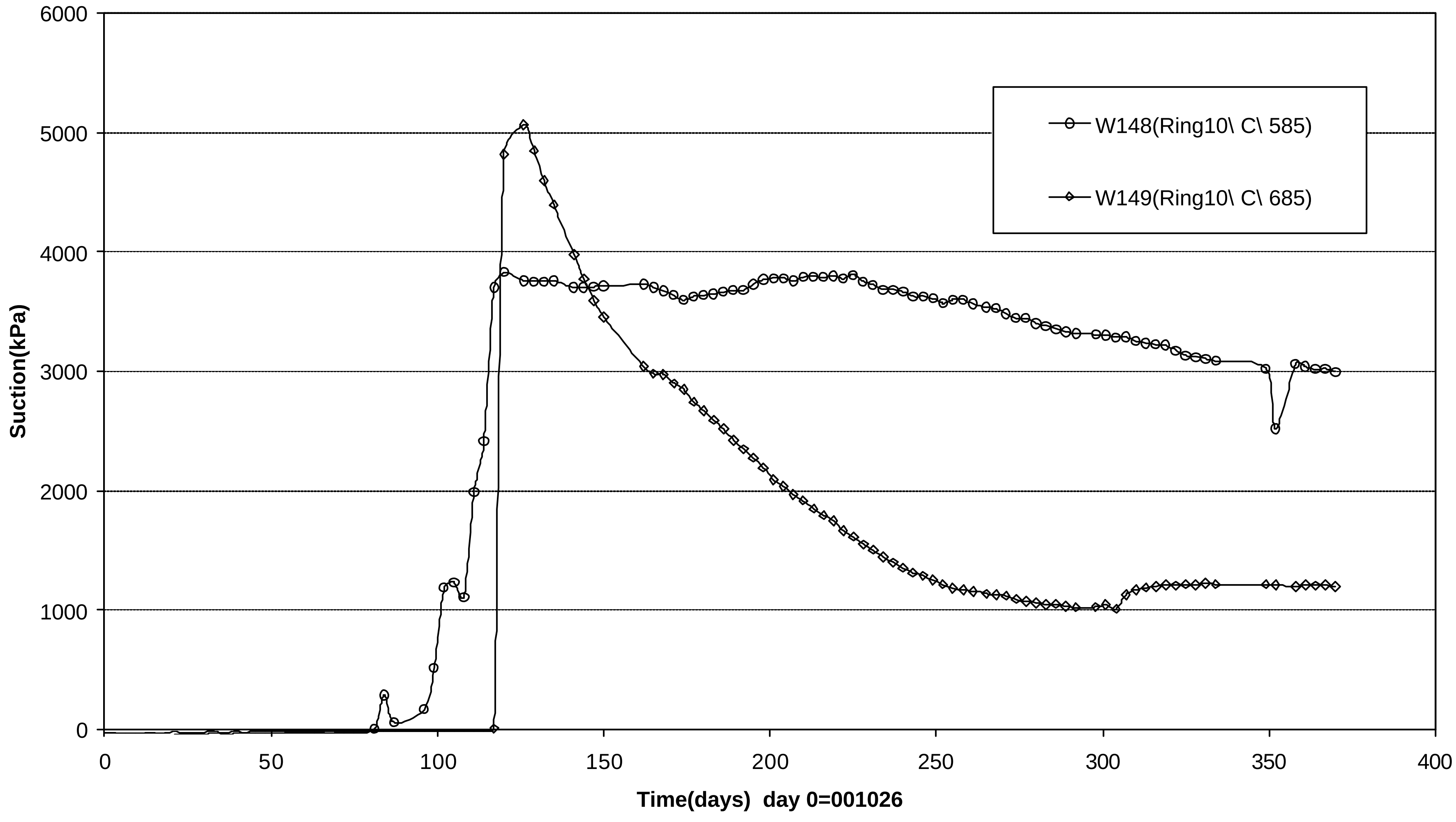
Suction in the buffer - Ring 5 (001026-011101)
Wescor
W128(Ring5\ B\ 535\in the slot)
W129(Ring5\ B\ 685)
W130(Ring5\ B\ 785)
Suction(kPa)
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026

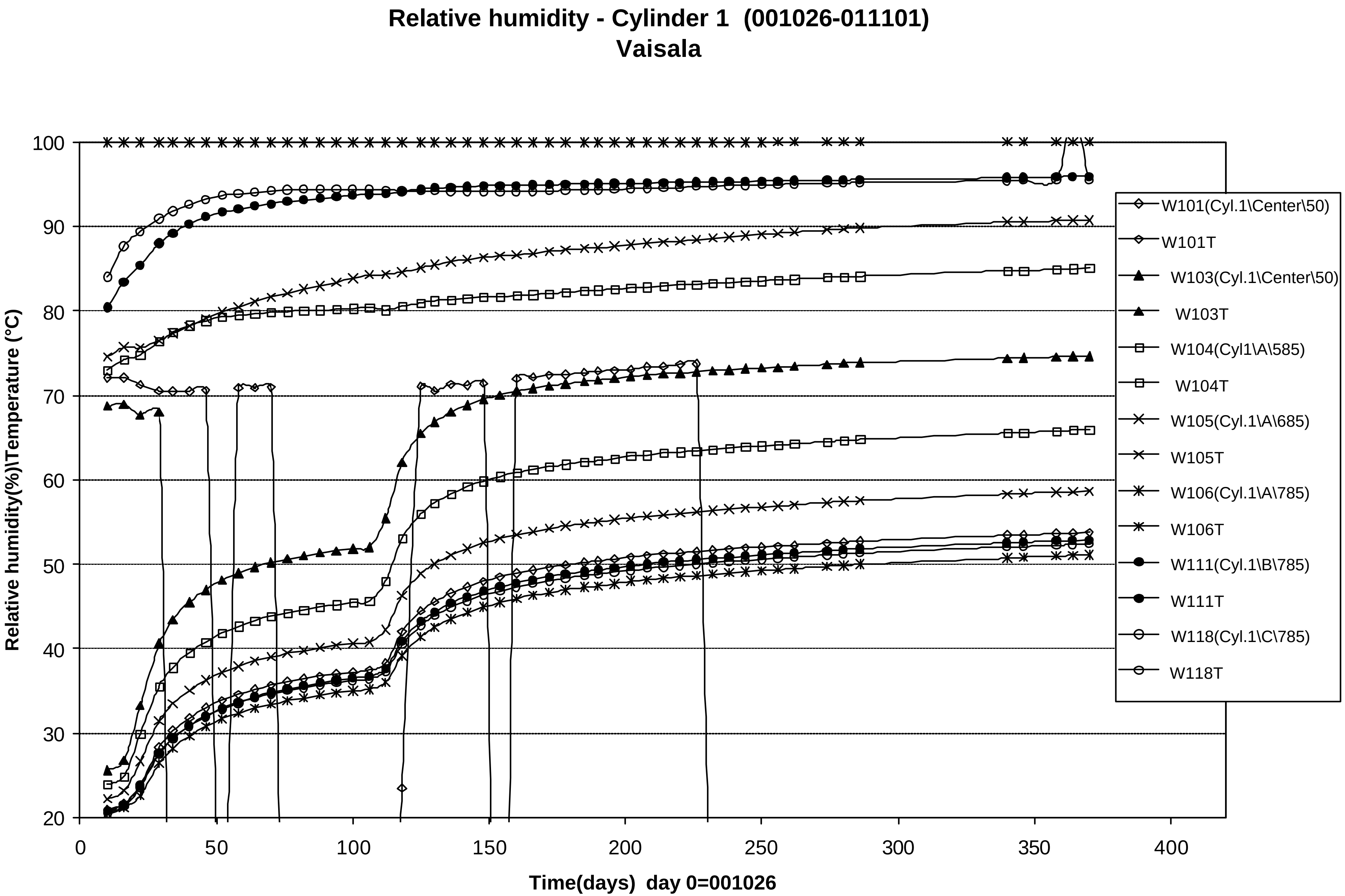

Suction in the buffer - Ring 5 (001026-011101)
Wescor
Suction(kPa)
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026
W133(Ring5\ C\ 785)


Suction in the buffer - Ring 10 (001026-011101)
Wescor
W139(Ring10\ A\ 585)
W140(Ring10\ A\ 685)
W141(Ring10\ A\ 785)
Suction(kPa)
0
1000
2000
3000
4000
5000
6000
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026

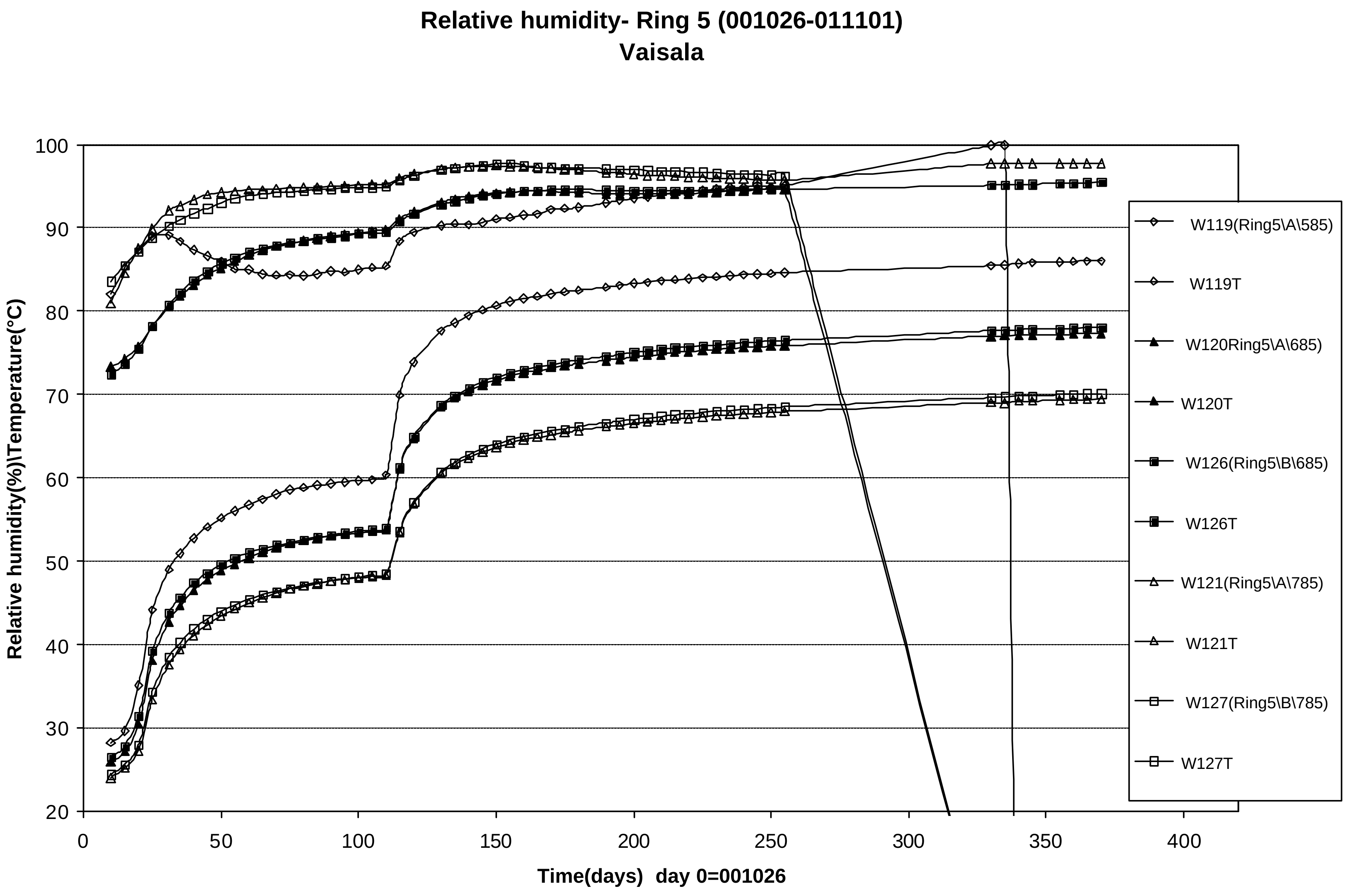

Suction in the buffer - Ring 10 (001026-011101)
Wescor
Suction(kPa)
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026
W146(Ring10\ B\ 685)
W147(Ring10\ B\ 785)

Suction in the buffer - Ring 10 (001026-011101)
Wescor



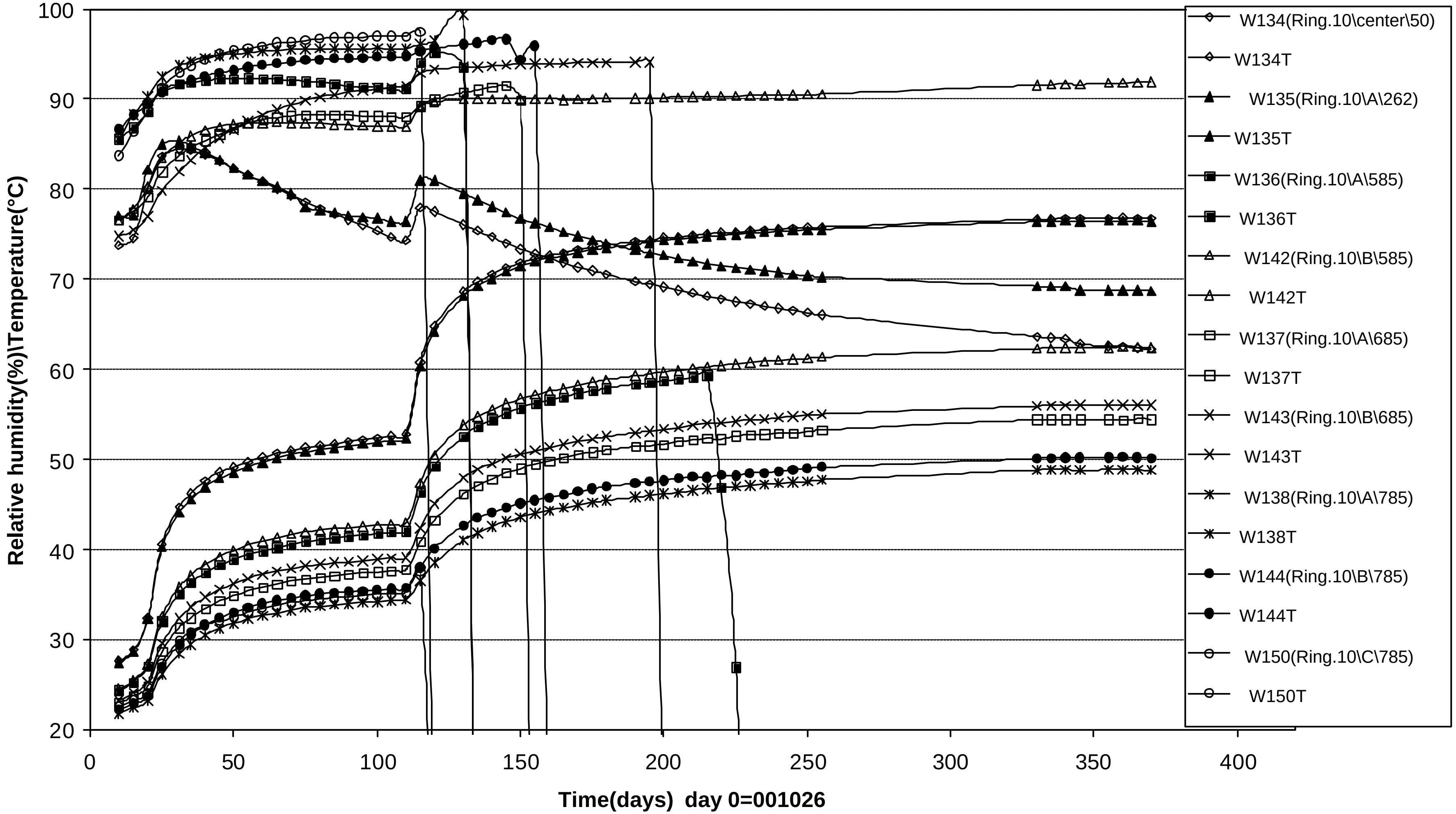


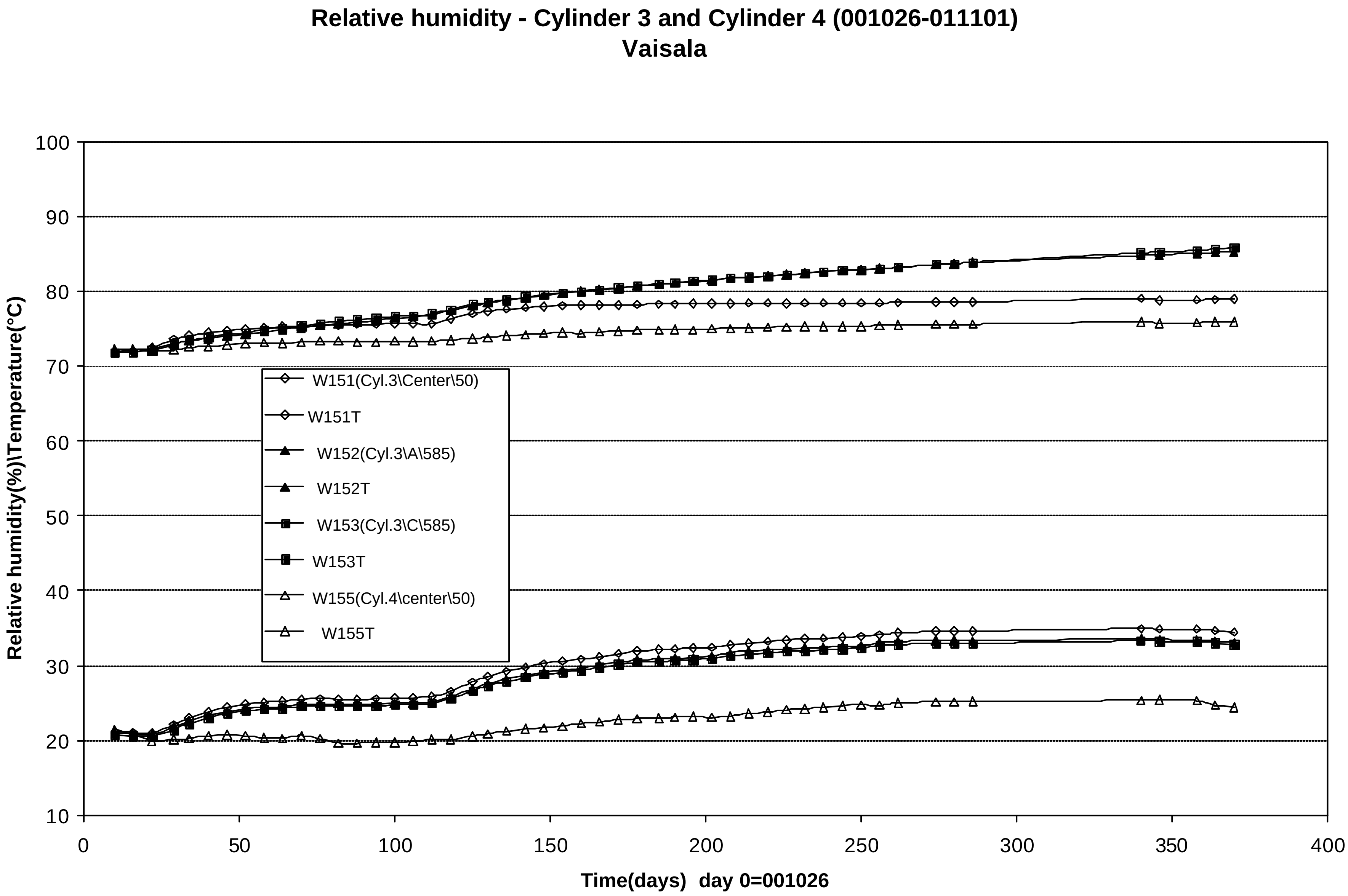
Relative humidity - Cylinder 1 (001026-011101)
Vaisala
Relative humidity(%)\Temperature (°C)
Time(days) day 0=001026
100
90
80
70
60
50
40
30
20
0
50
100
150
200
250
300
350
400
W101(Cyl.1\Center\50)
W101T
W103(Cyl.1\Center\50)
W103T
W104(Cyl1\A\585)
W104T
W105(Cyl.1\A\685)
W105T
W106(Cyl.1\A\785)
W106T
W111(Cyl.1\B\785)
W111T
W118(Cyl.1\C\785)
W118T

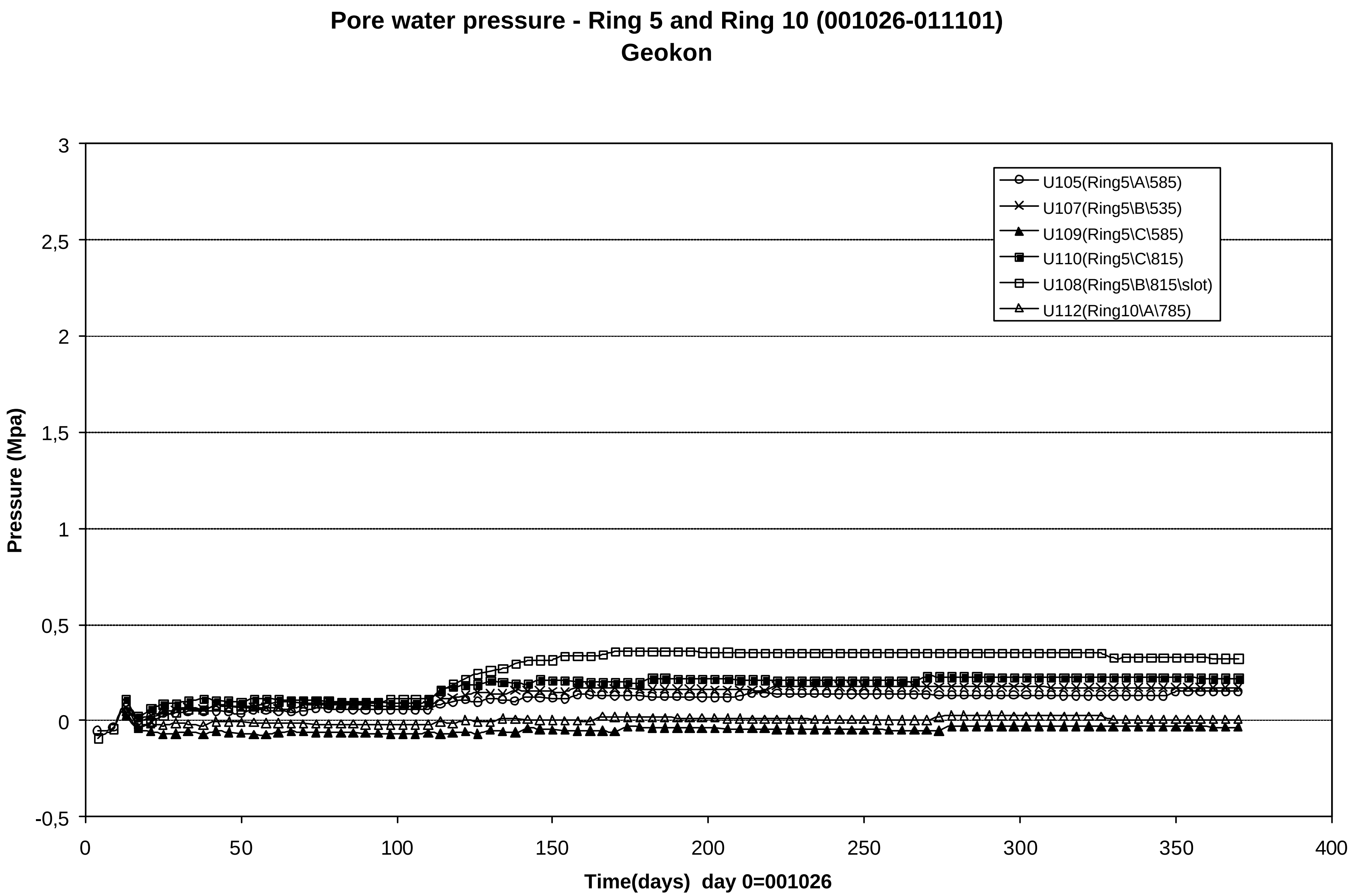


Relative humidity- Ring 5 (001026-011101)
Vaisala
Relative humidity(%)\Temperature(°C)
Time(days) day 0=001026
100
90
80
70
60
50
40
30
20
0
50
100
150
200
250
300
350
400
W119(Ring5\A\585)
W119T
W120Ring5\A\685)
W120T
W126(Ring5\B\685)
W126T
W121(Ring5\A\785)
W121T
W127(Ring5\B\785)
W127T

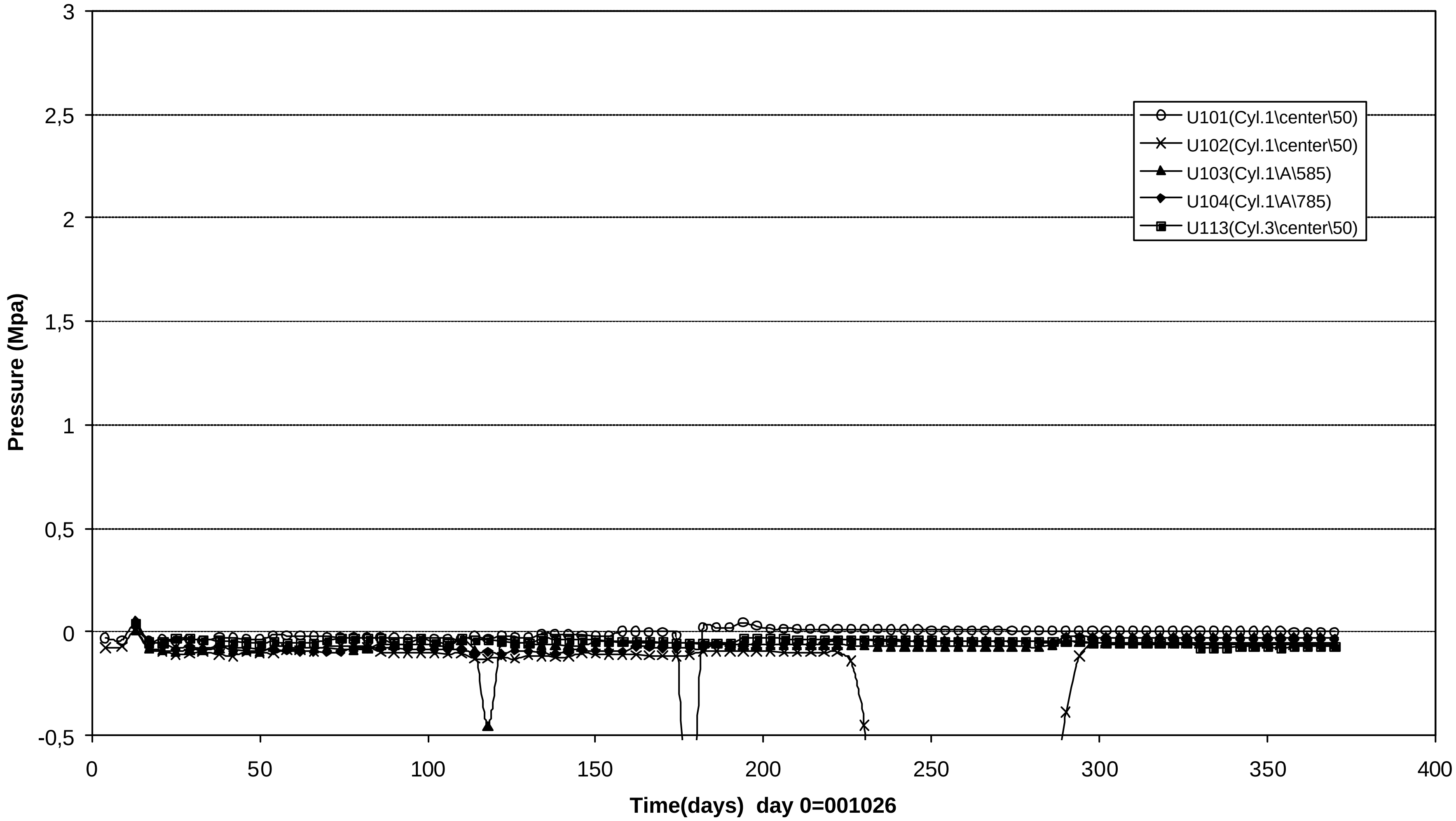
Relative humidity - Ring 10 (001026-011101)
Vaisala



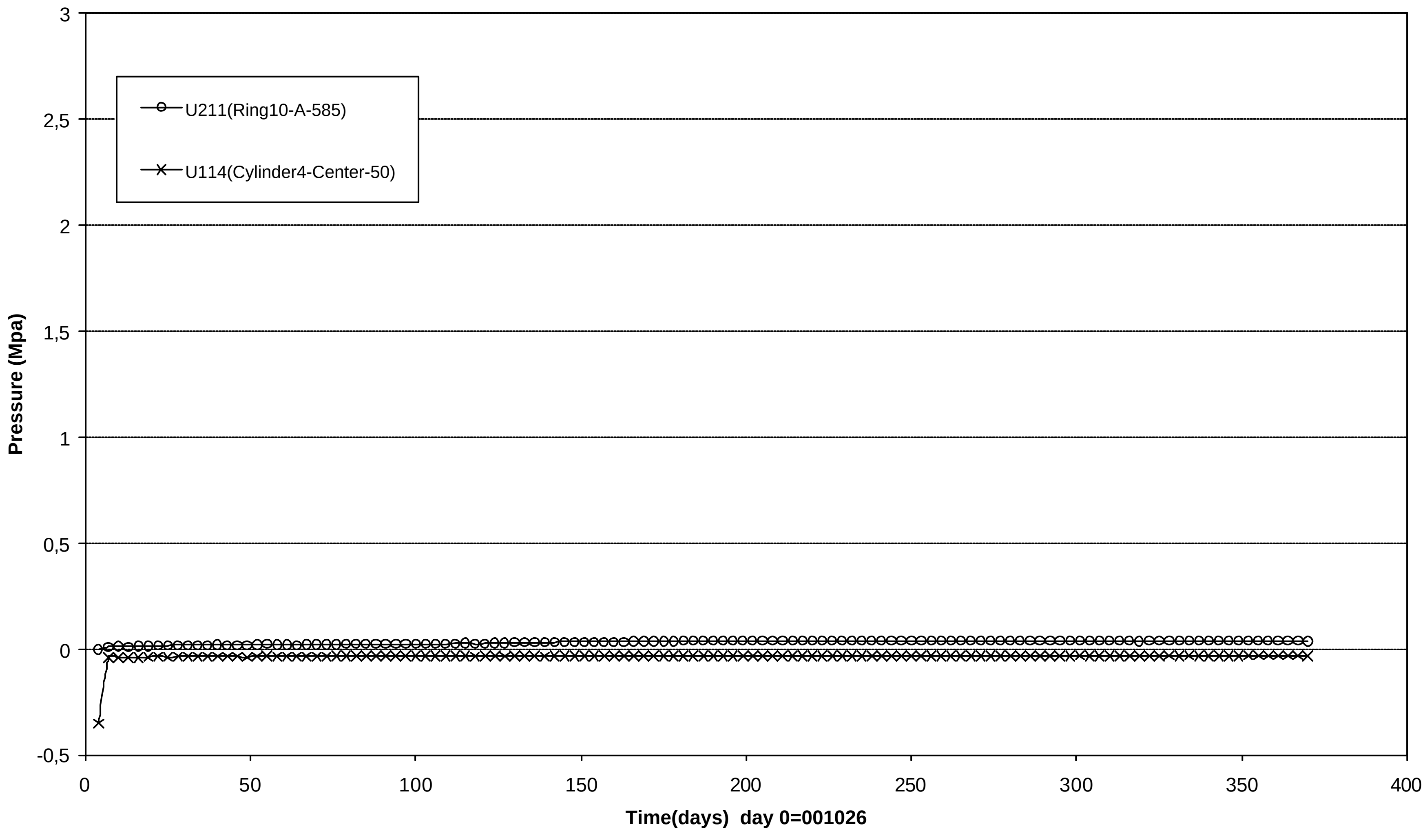

Relative humidity - Cylinder 3 and Cylinder 4 (001026-011101)
Vaisala
Relative humidity(%)\Temperature(°C)
100
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026
W151(Cyl.3\Center\50)
W151T
W152(Cyl.3\A\585)
W152T
W153(Cyl.3\C\585)
W153T
W155(Cyl.4\center\50)
W155T

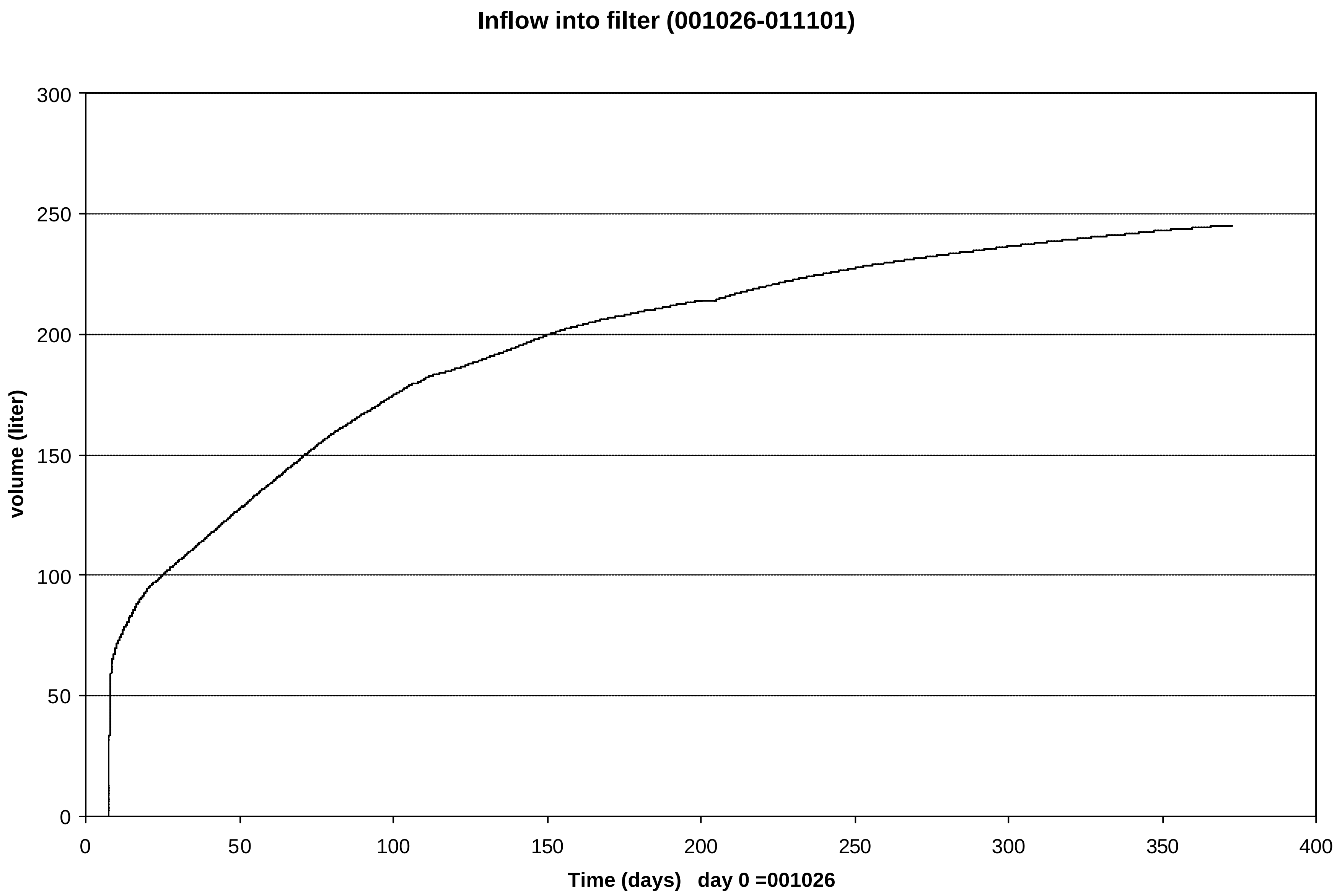

Pore water pressure - Ring 5 and Ring 10 (001026-011101)
Geokon
Pressure (Mpa)
3
2,5
2
1,5
1
0,5
0
-0,5
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026
U105(Ring5\A\585)
U107(Ring5\B\535)
U109(Ring5\C\585)
U110(Ring5\C\815)
U108(Ring5\B\815\slot)
U112(Ring10\A\785)

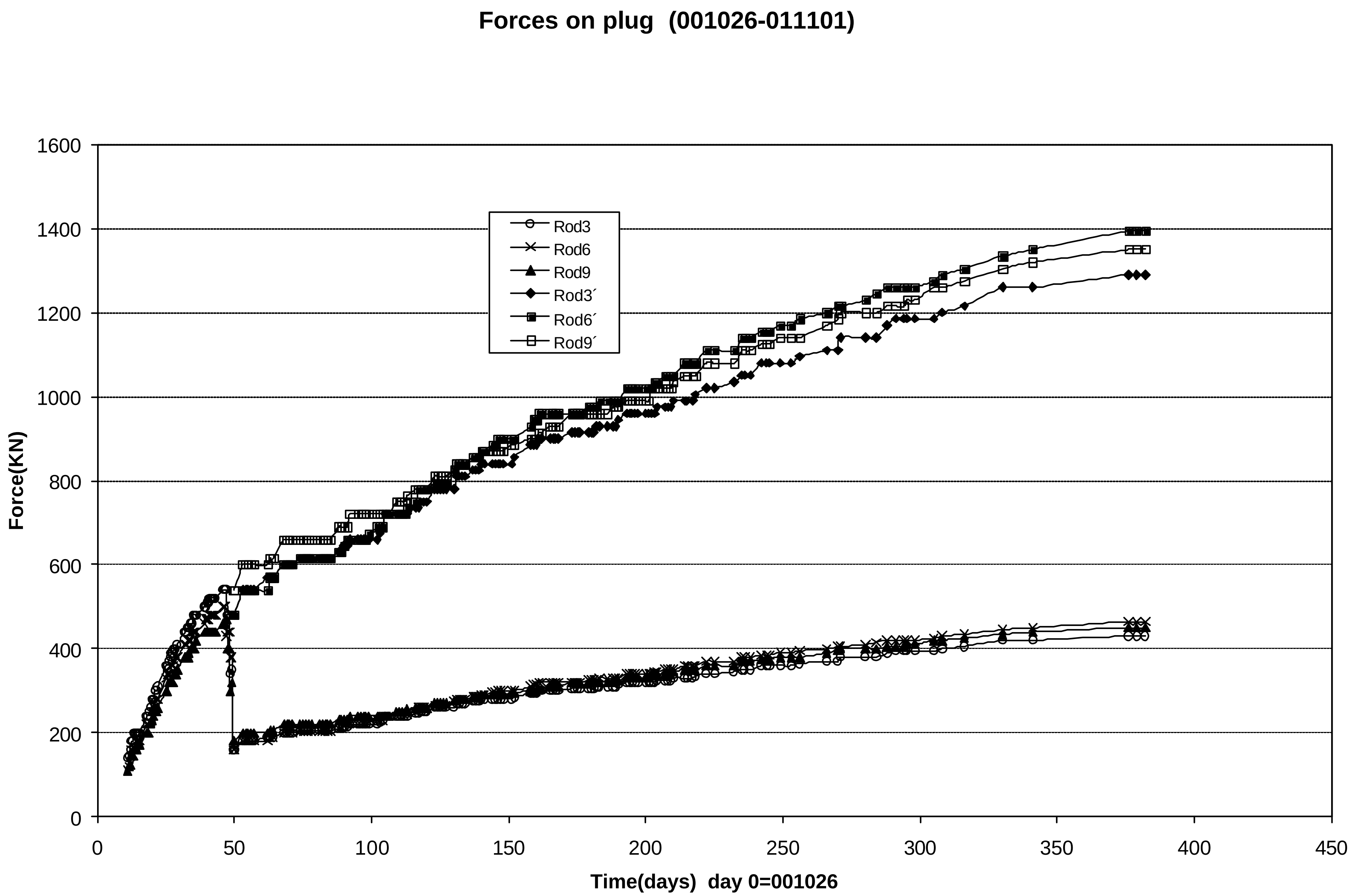
Pore water pressure - Cylinder 1 and Cylinder 3 (001026-011101)
Geokon



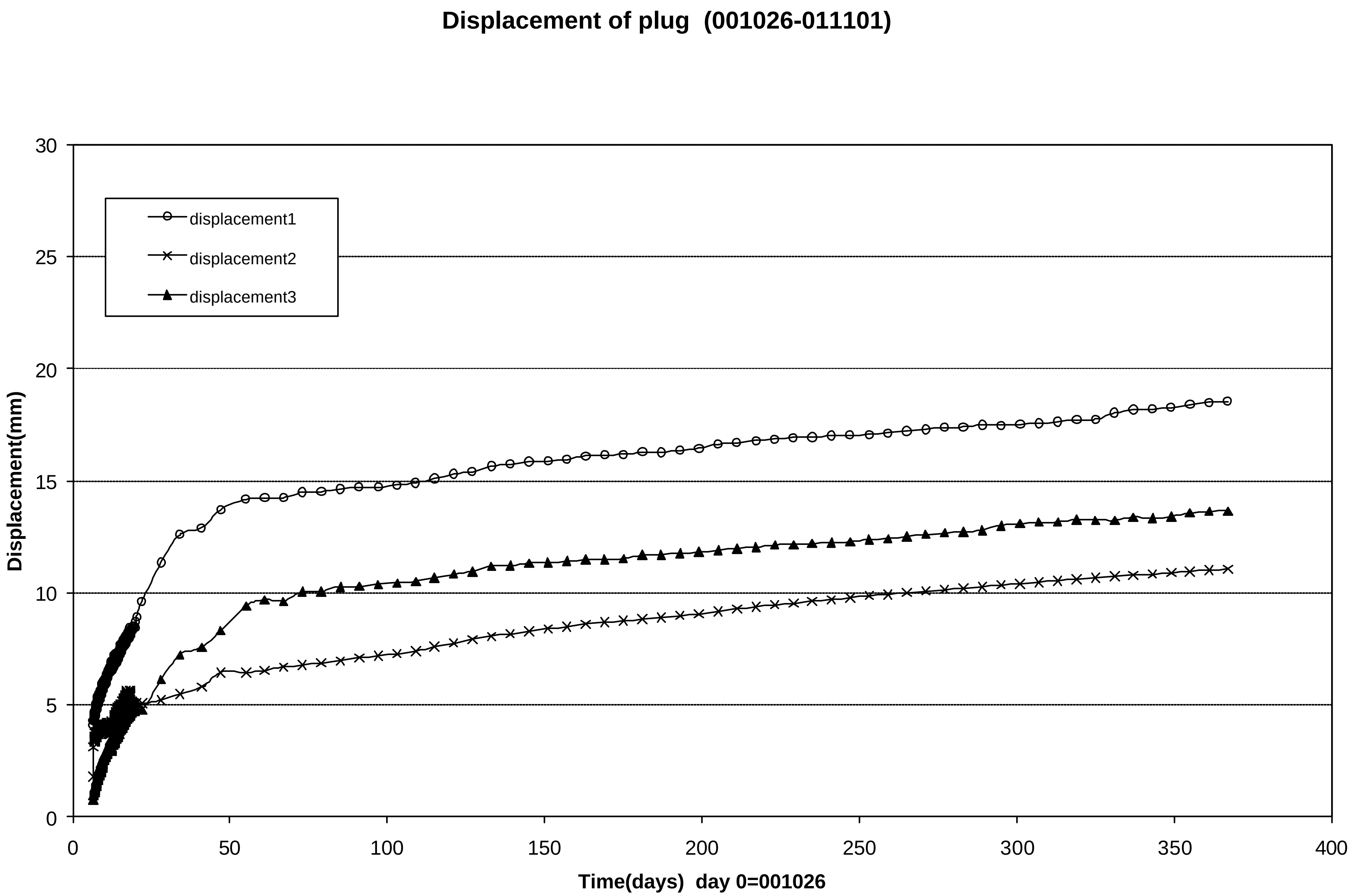
Pore water pressure - Ring 10 & Cylinder 4 (001026-011101)
Kulite



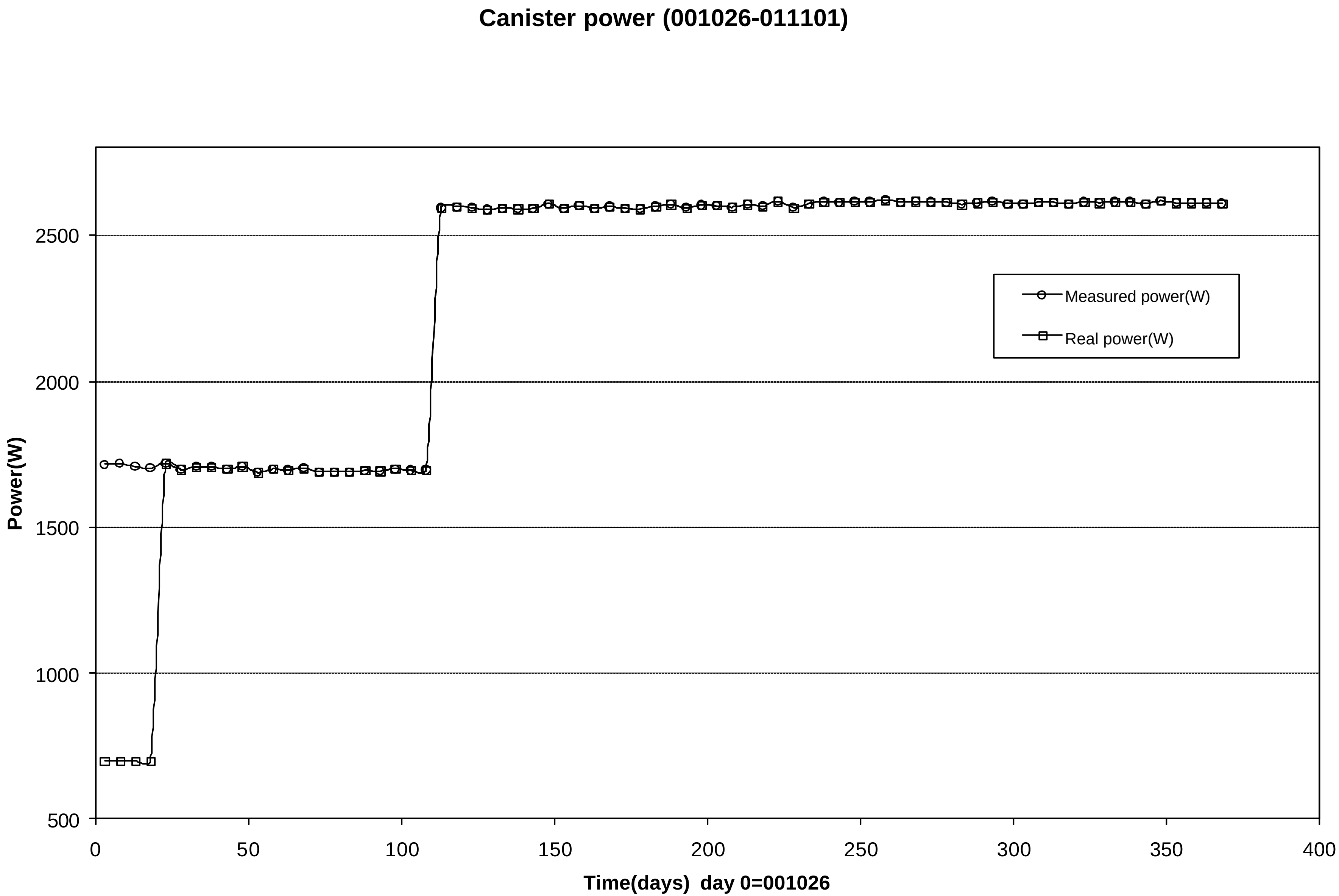

Inflow into filter (001026-011101)
volume (liter)
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
Time (days) day 0 =001026



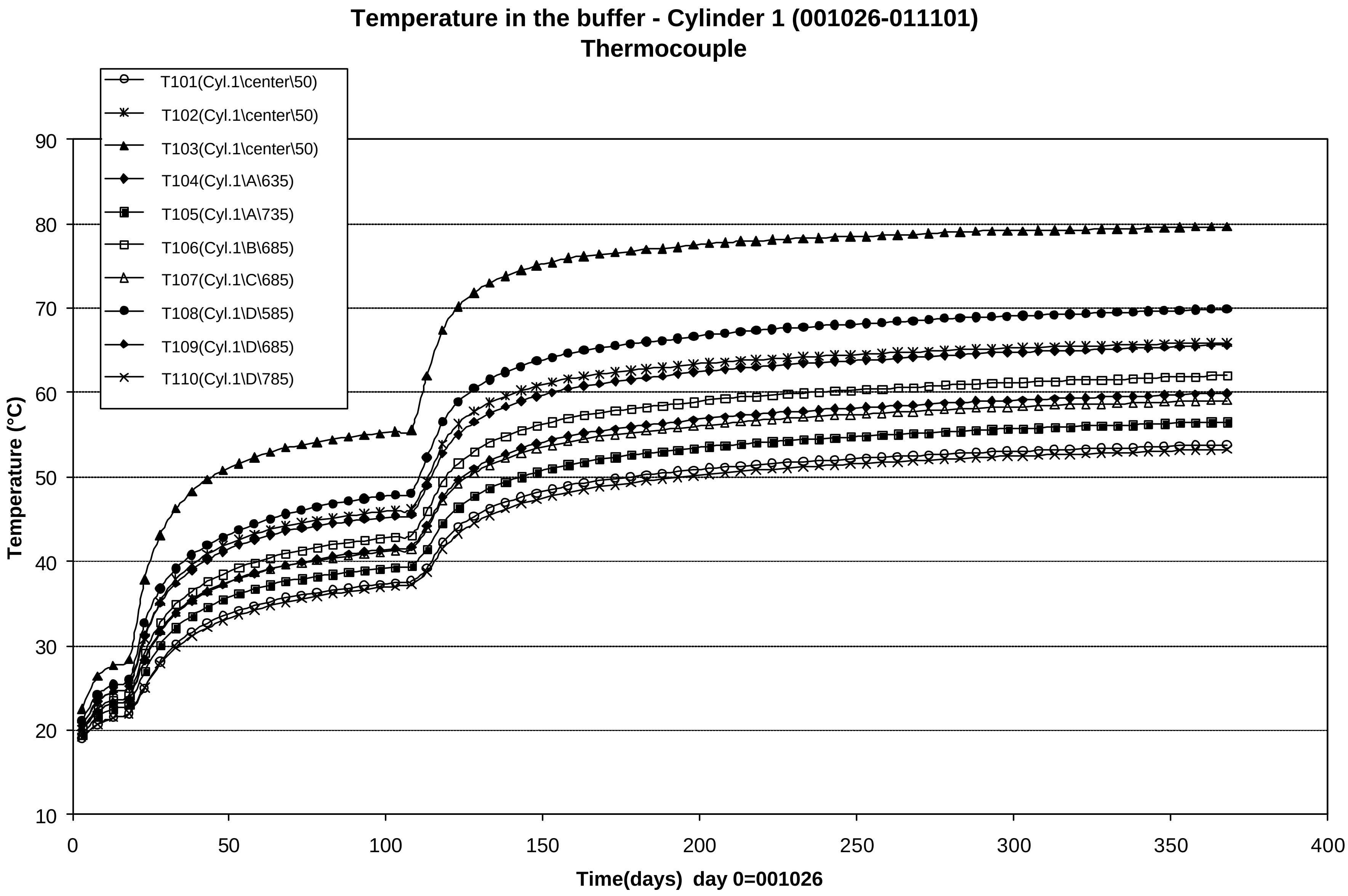
Forces on plug (001026-011101)
Force(KN)
Time(days) day 0=001026
0
200
400
600
800
1000
1200
1400
1600
0
50
100
150
200
250
300
350
400
450
Rod3
Rod6
Rod9
Rod3´
Rod6´
Rod9´

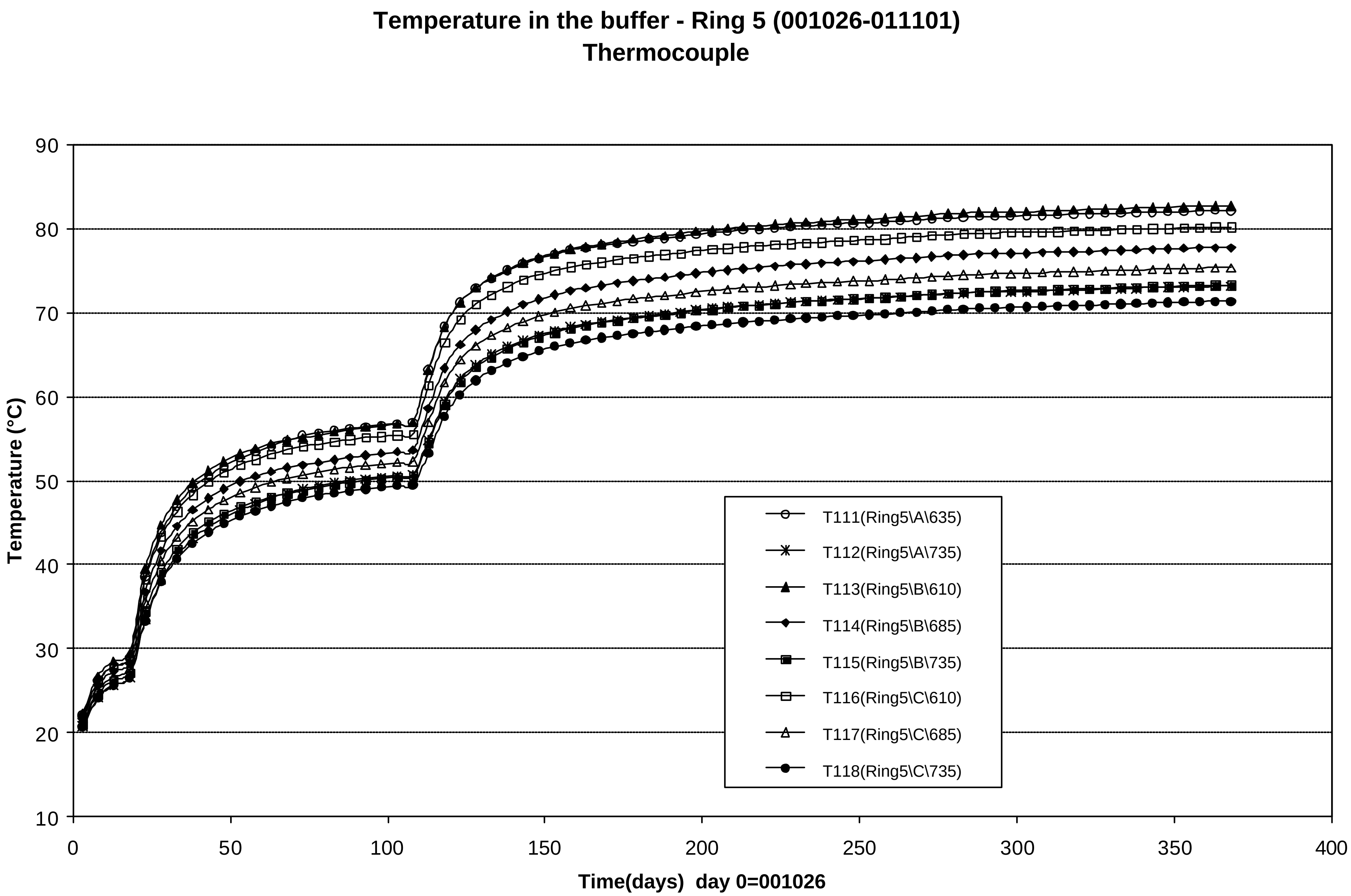


Displacement of plug (001026-011101)
displacement1
displacement2
displacement3
Displacement(mm)
30
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026

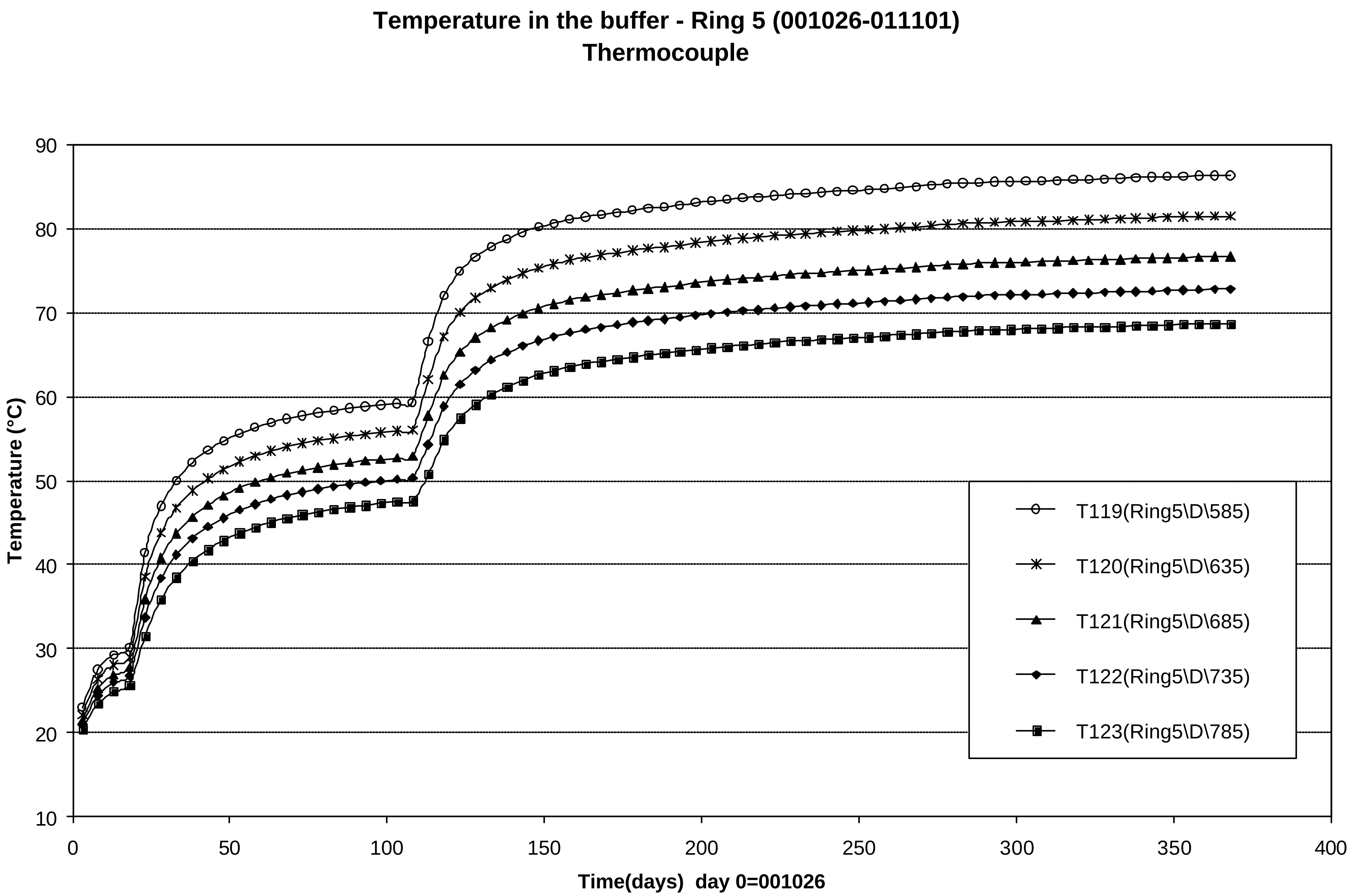


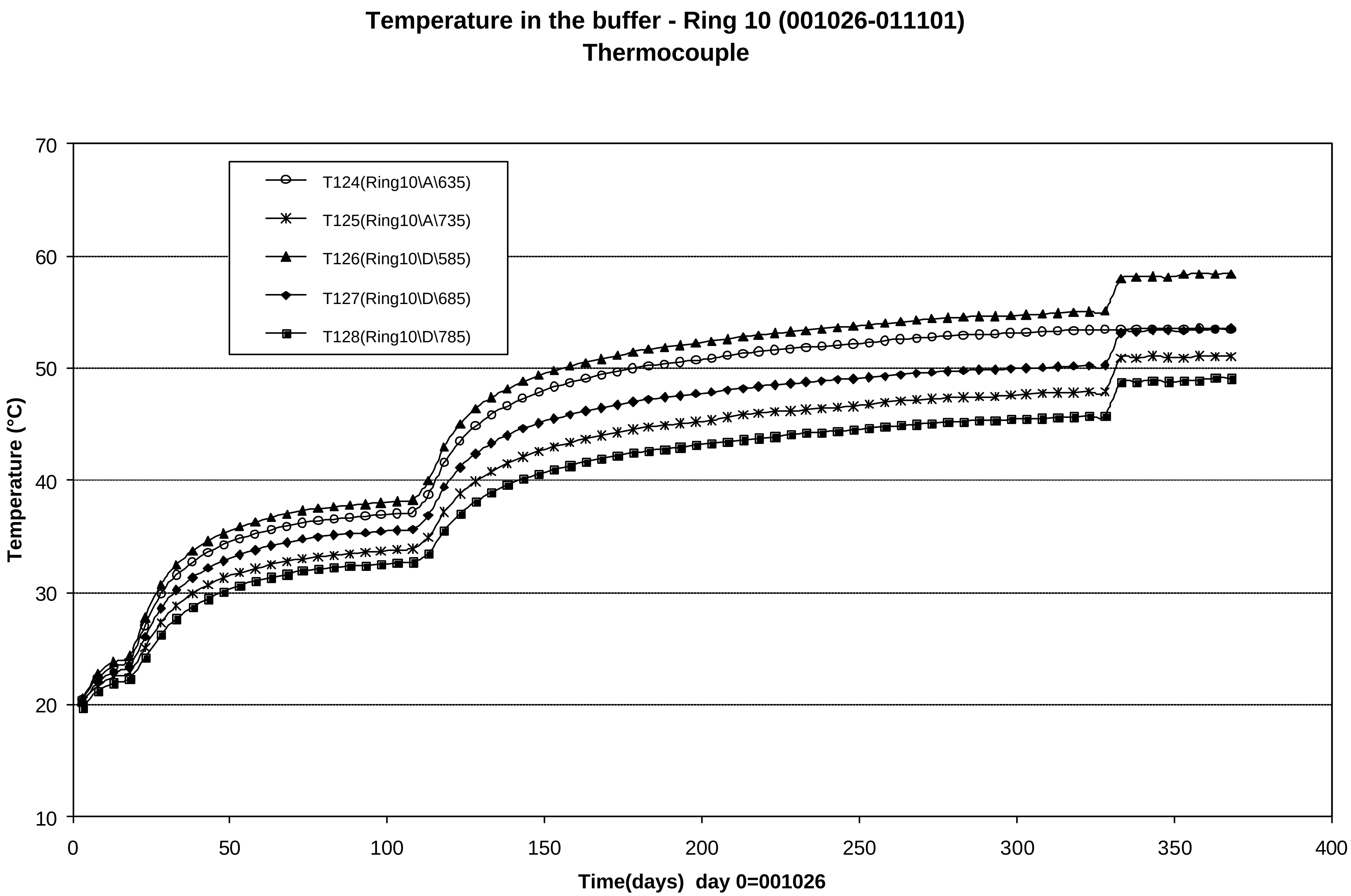
Canister power (001026-011101)
Measured power(W)
Real power(W)
Power(W)
2500
2000
1500
1000
500
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026


Temperature in the buffer - Cylinder 1 (001026-011101)
Thermocouple
T101(Cyl.1\center\50)
T102(Cyl.1\center\50)
T103(Cyl.1\center\50)
T104(Cyl.1\A\635)
T105(Cyl.1\A\735)
T106(Cyl.1\B\685)
T107(Cyl.1\C\685)
T108(Cyl.1\D\585)
T109(Cyl.1\D\685)
T110(Cyl.1\D\785)
Temperature (°C)
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026

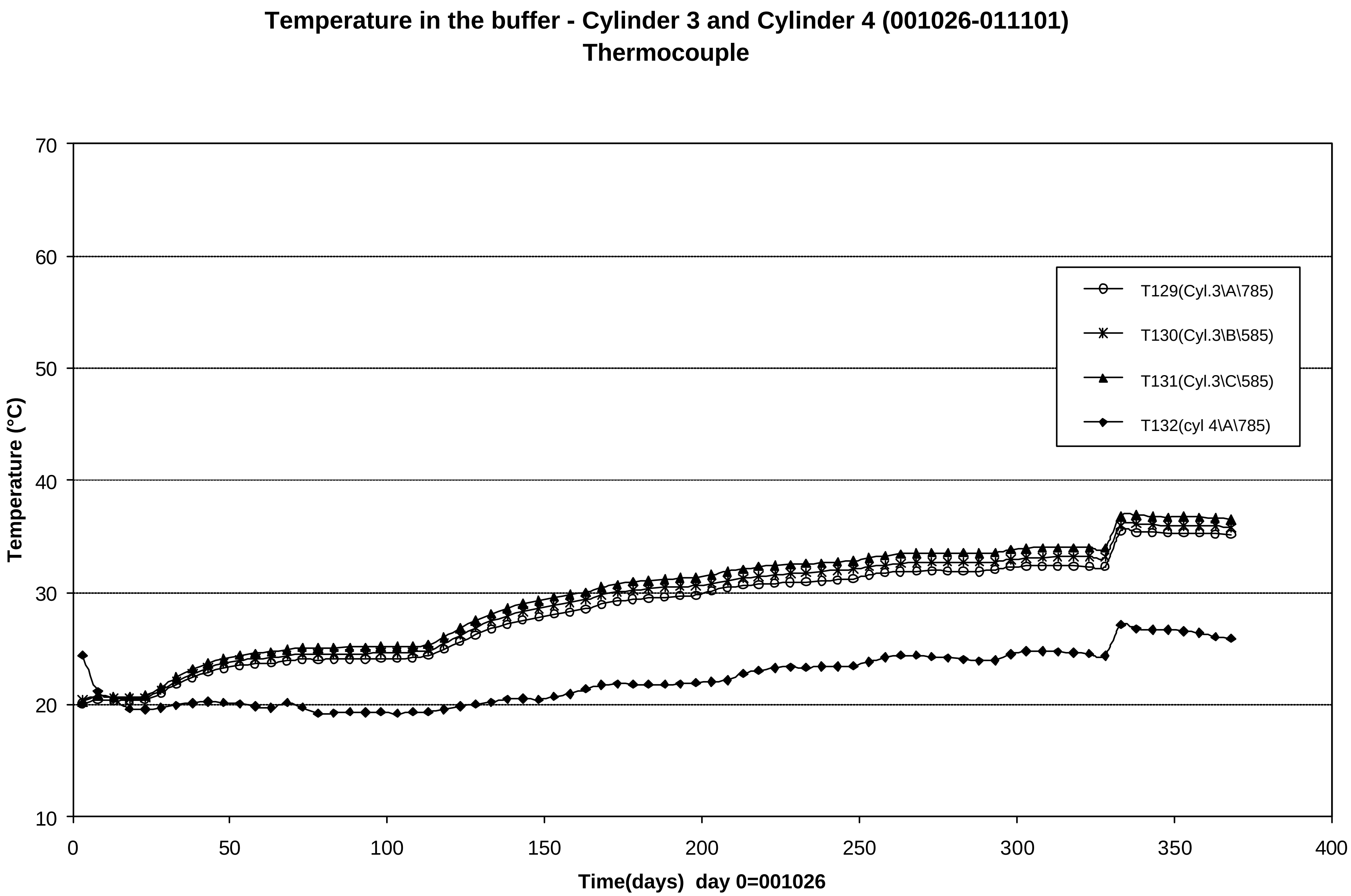


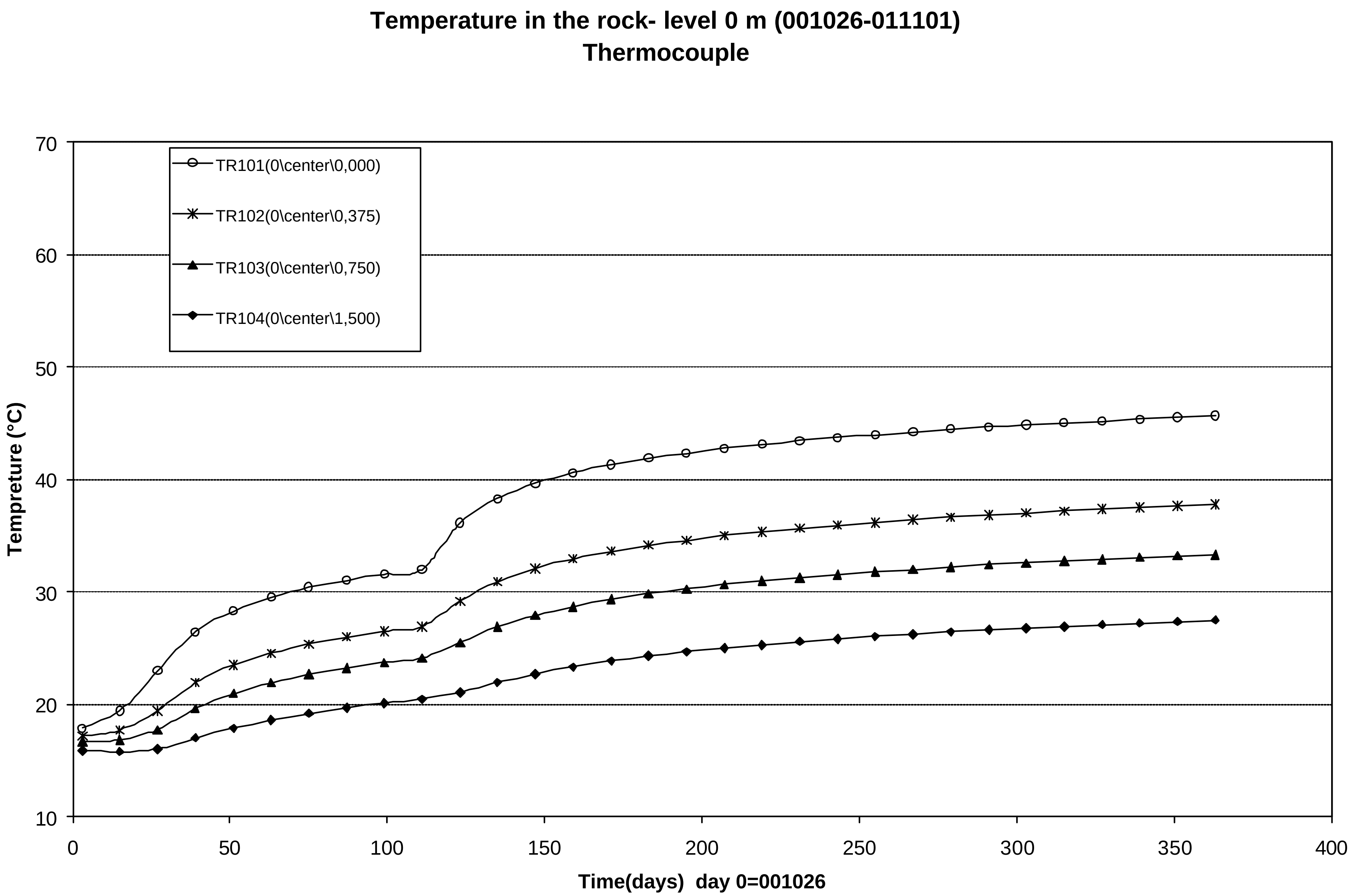
Temperature in the buffer - Ring 5 (001026-011101)
Thermocouple
Temperature (°C)
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026
T111(Ring5\A\635)
T112(Ring5\A\735)
T113(Ring5\B\610)
T114(Ring5\B\685)
T115(Ring5\B\735)
T116(Ring5\C\610)
T117(Ring5\C\685)
T118(Ring5\C\735)

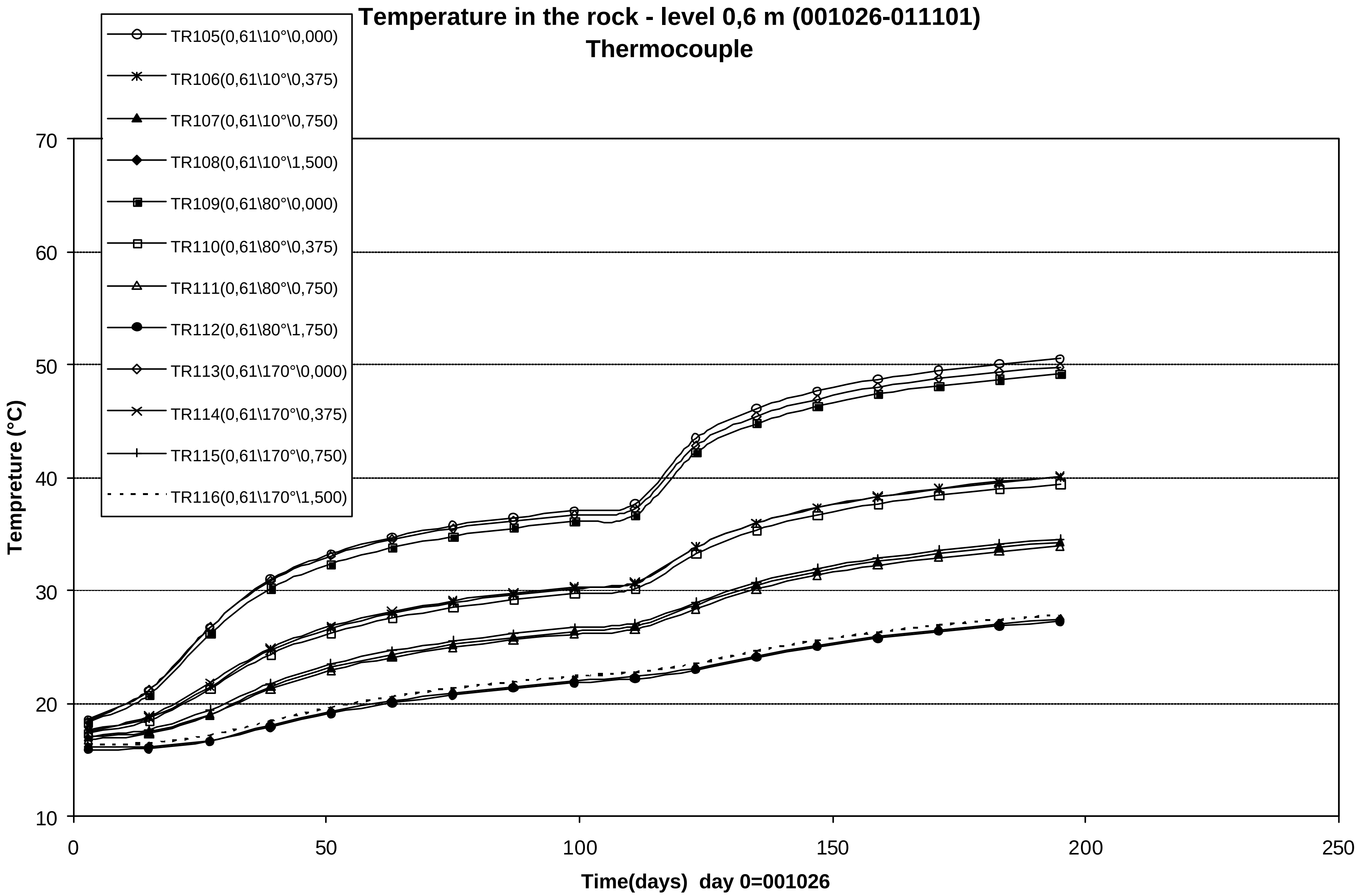

Temperature in the buffer - Ring 5 (001026-011101)
Thermocouple
Temperature (°C)
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026
T119(Ring5\D\585)
T120(Ring5\D\635)
T121(Ring5\D\685)
T122(Ring5\D\735)
T123(Ring5\D\785)

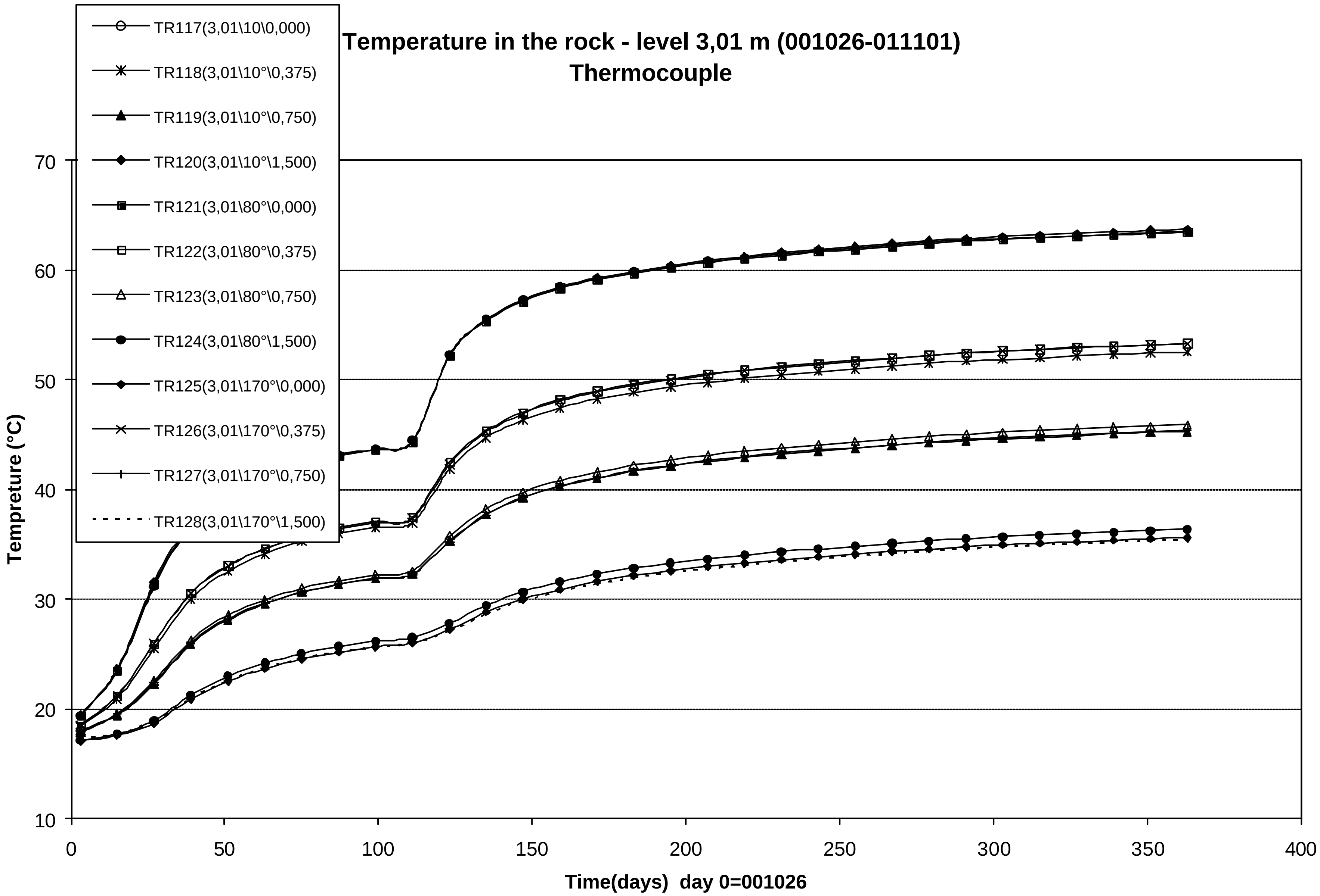


Temperature in the buffer - Ring 10 (001026-011101)
Thermocouple
T124(Ring10\A\635)
T125(Ring10\A\735)
T126(Ring10\D\585)
T127(Ring10\D\685)
T128(Ring10\D\785)
Temperature (°C)
Time(days) day 0=001026
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400

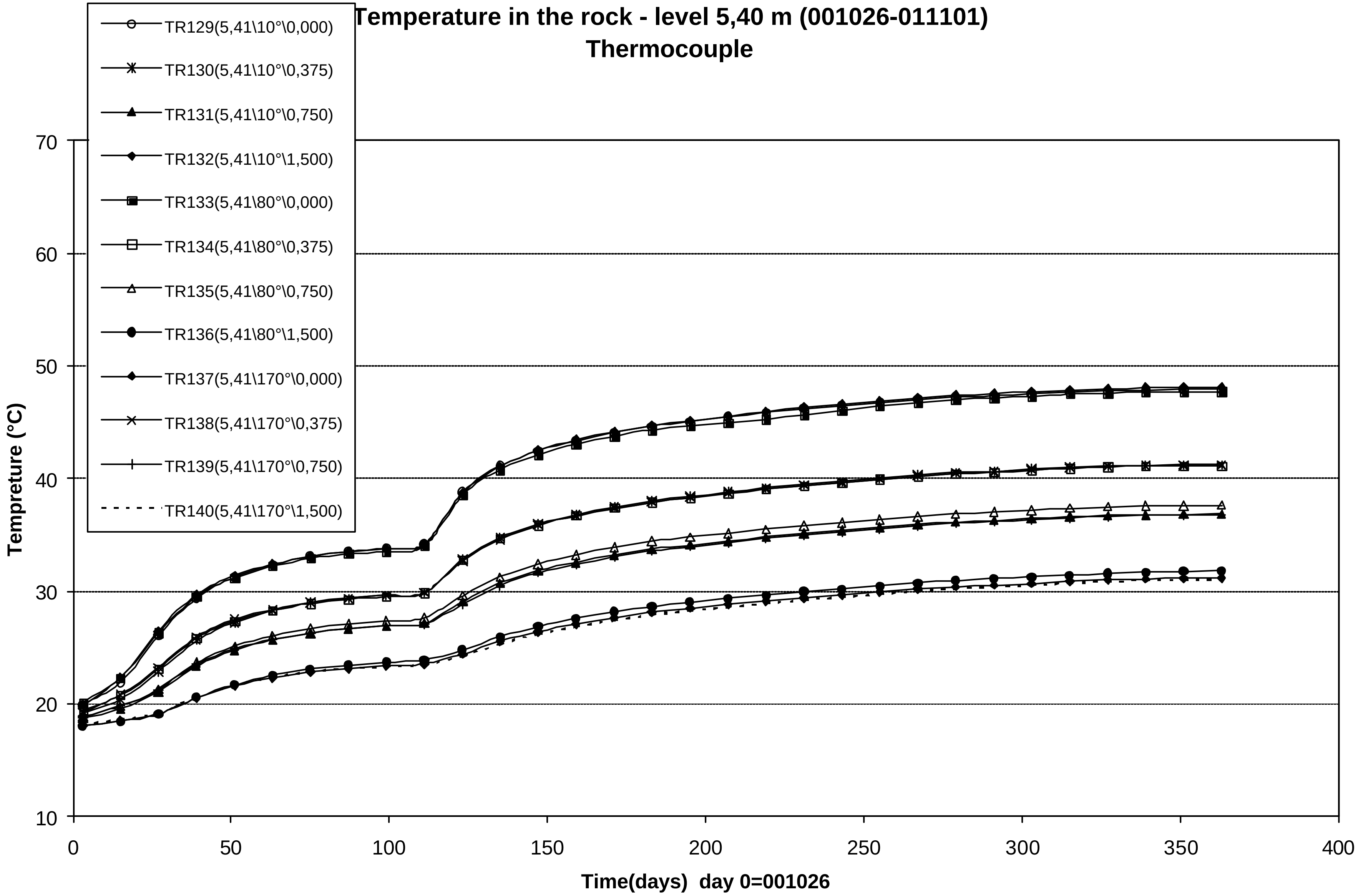

Temperature in the buffer - Cylinder 3 and Cylinder 4 (001026-011101)
Thermocouple
Temperature (°C)
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026
T129(Cyl.3\A\785)
T130(Cyl.3\B\585)
T131(Cyl.3\C\585)
T132(cyl 4\A\785)

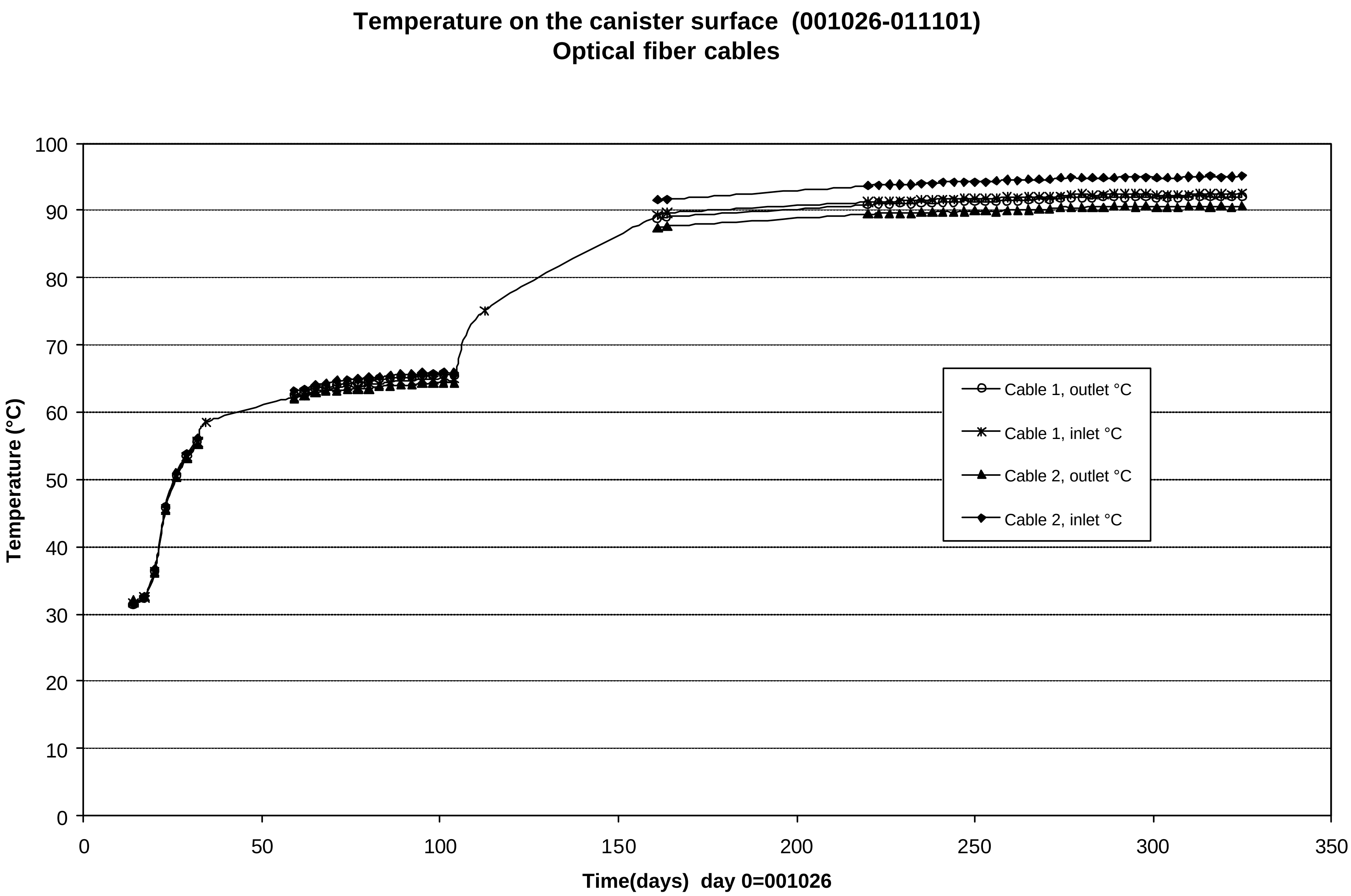

Temperature in the rock- level 0 m (001026-011101)
Thermocouple
TR101(0\center\0,000)
TR102(0\center\0,375)
TR103(0\center\0,750)
TR104(0\center\1,500)
Tempreture (°C)
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026


Temperature in the rock - level 0,6 m (001026-011101)
Thermocouple
TR105(0,61\10°\0,000)
TR106(0,61\10°\0,375)
TR107(0,61\10°\0,750)
TR108(0,61\10°\1,500)
TR109(0,61\80°\0,000)
TR110(0,61\80°\0,375)
TR111(0,61\80°\0,750)
TR112(0,61\80°\1,750)
TR113(0,61\170°\0,000)
TR114(0,61\170°\0,375)
TR115(0,61\170°\0,750)
TR116(0,61\170°\1,500)
Tempreture (°C)
Time(days) day 0=001026
0
50
100
150
200
250
10
20
30
40
50
60
70

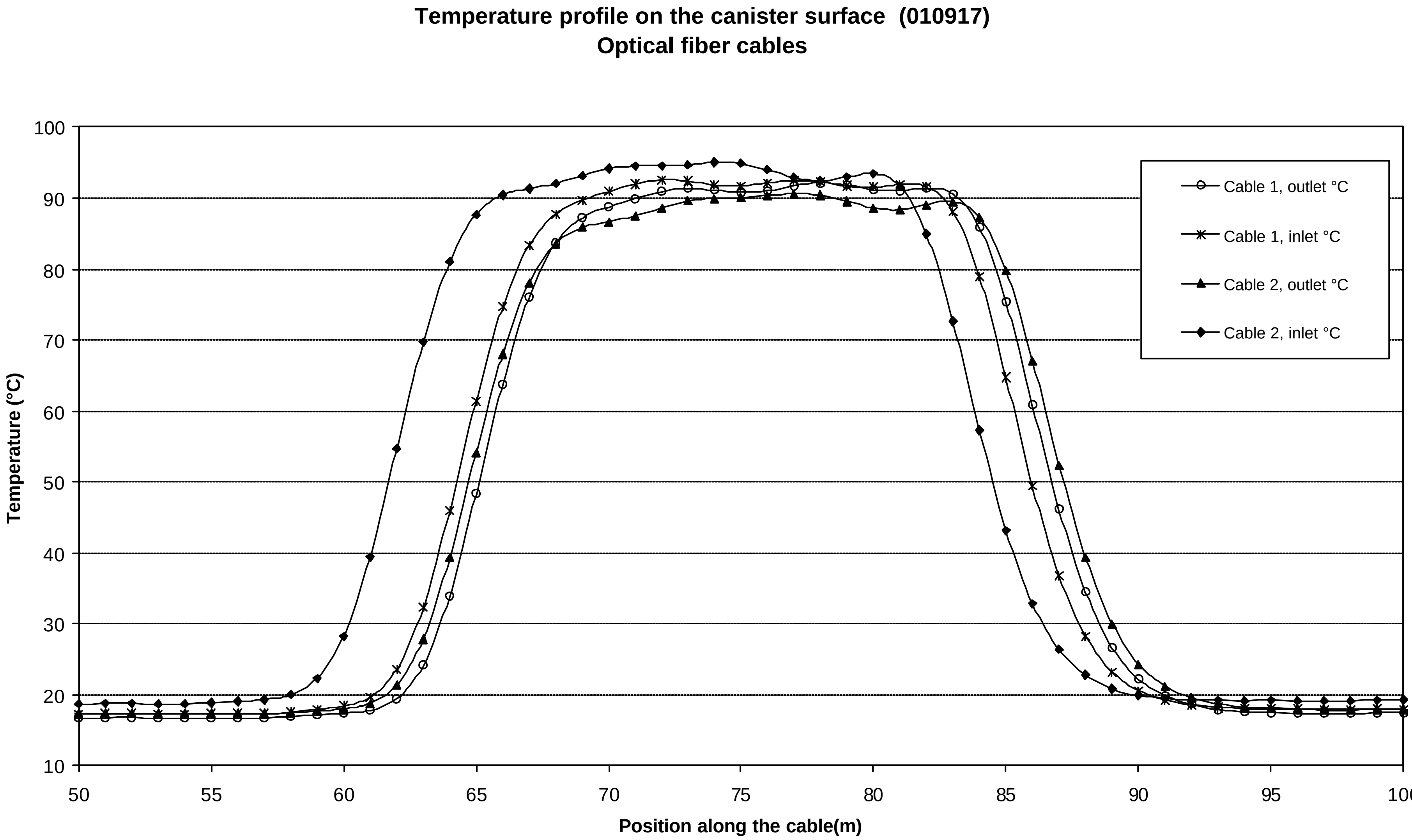


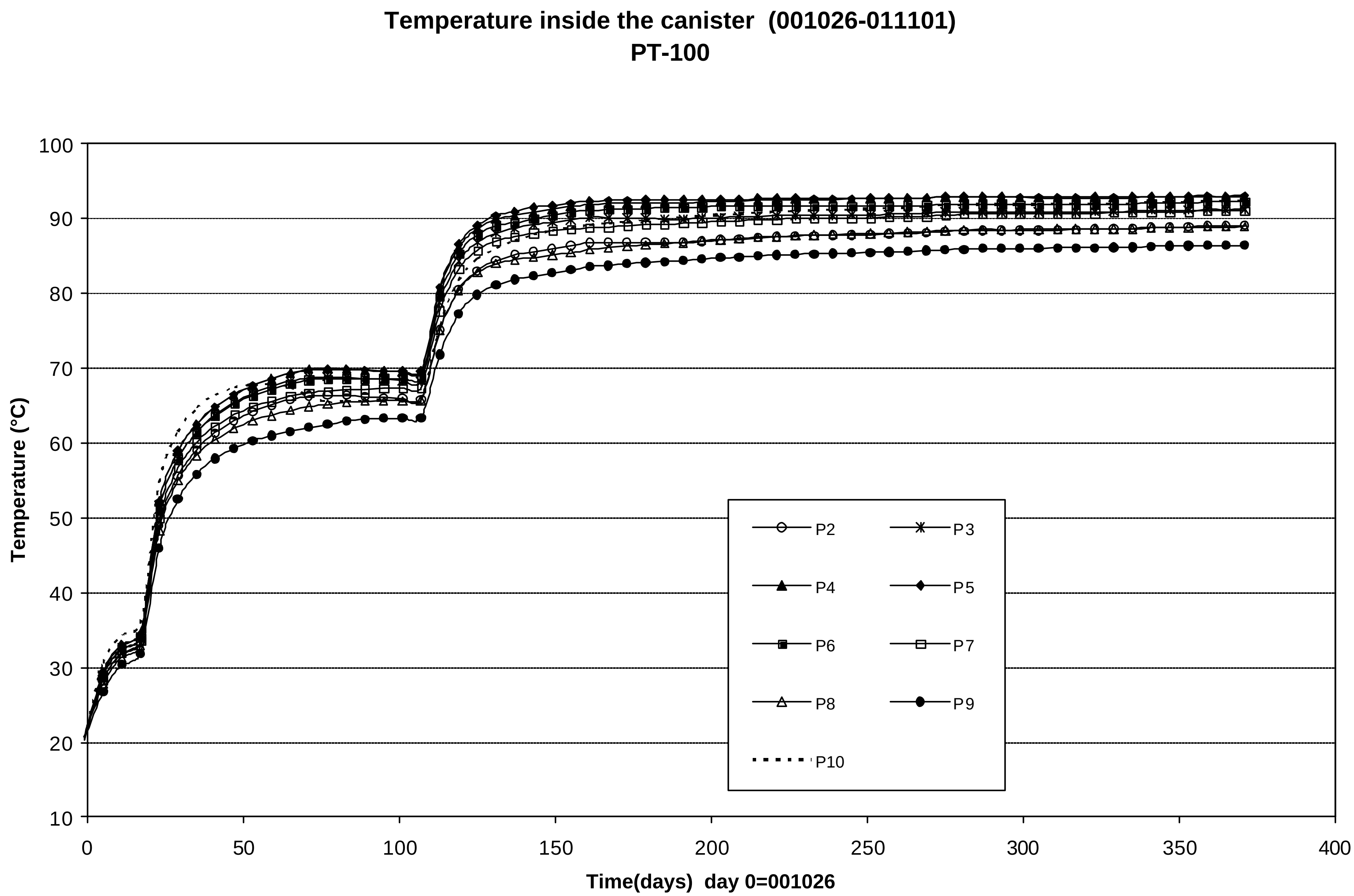
Temperature in the rock - level 3,01 m (001026-011101)
Thermocouple
TR117(3,01\10\0,000)
TR118(3,01\10°\0,375)
TR119(3,01\10°\0,750)
TR120(3,01\10°\1,500)
TR121(3,01\80°\0,000)
TR122(3,01\80°\0,375)
TR123(3,01\80°\0,750)
TR124(3,01\80°\1,500)
TR125(3,01\170°\0,000)
TR126(3,01\170°\0,375)
TR127(3,01\170°\0,750)
TR128(3,01\170°\1,500)
Tempreture (°C)
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026


Temperature in the rock - level 5,40 m (001026-011101)
Thermocouple
TR129(5,41\10°\0,000)
TR130(5,41\10°\0,375)
TR131(5,41\10°\0,750)
TR132(5,41\10°\1,500)
TR133(5,41\80°\0,000)
TR134(5,41\80°\0,375)
TR135(5,41\80°\0,750)
TR136(5,41\80°\1,500)
TR137(5,41\170°\0,000)
TR138(5,41\170°\0,375)
TR139(5,41\170°\0,750)
TR140(5,41\170°\1,500)
Tempreture (°C)
Time(days) day 0=001026
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400

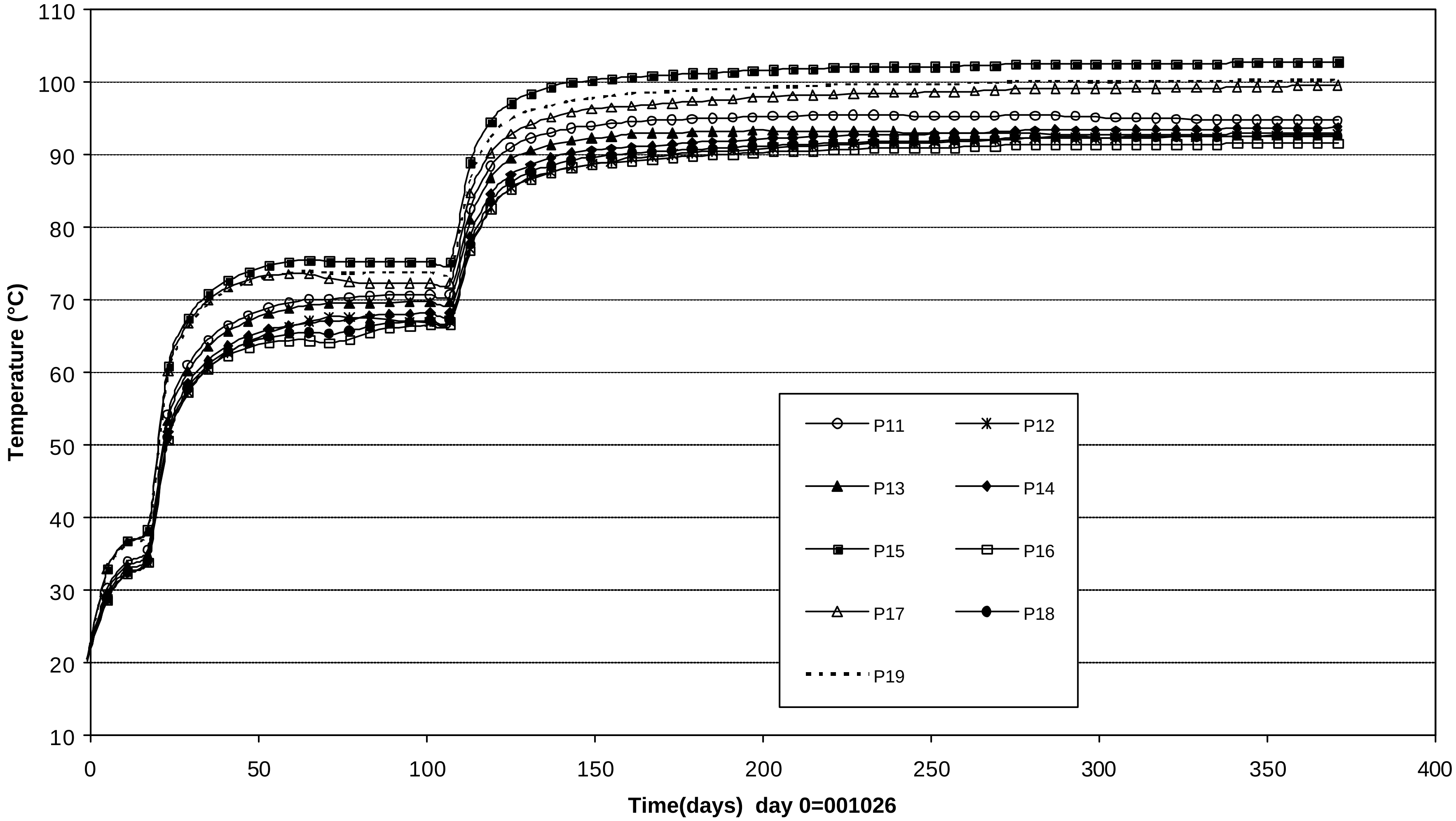


Temperature on the canister surface (001026-011101)
Optical fiber cables
Temperature (°C)
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
350
Time(days) day 0=001026
Cable 1, outlet °C
Cable 1, inlet °C
Cable 2, outlet °C
Cable 2, inlet °C


Temperature profile on the canister surface (010917)
Optical fiber cables
Temperature (°C)
Position along the cable(m)
Cable 1, outlet °C
Cable 1, inlet °C
Cable 2, outlet °C
Cable 2, inlet °C
100
90
80
70
60
50
40
30
20
10
50
55
60
65
70
75
80
85
90
95
100


Temperature inside the canister (001026-011101)
PT-100
Temperature (°C)
100
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
Time(days) day 0=001026
P2
P3
P4
P5
P6
P7
P8
P9
P10

Temperature inside the canister (001026-011101)
PT-100



Appendix B

STRESS AND STRAIN MEASUREMENT OF THE ROCK MASS RETRIEVAL TEST AT ÄSPÖ

Measuring period

2000-10-01 – 2001-11-30

Kennert Röshoff

Quanhong Feng

BBK

2001-12-12

Contents

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1 EXTENT

BBK AB and NCC Teknik have, on commission of SKB, ÄSPÖ hard rock laboratory, performed rock mechanical measurements in Repository tunnel at Äspö. The measurement program comprises of registration of the stress and the strain response around the two canister holes during drilling and heating of the rock mass.

In the first phase, the response of the rock mass was monitored during the drilling of the two canister holes (QPTD F69-00-21). This second phase includes the response registered during a heating phase. Hole 2, showing in Figure 3.1 and Figure 3.2, has a heating source while hole 1 is open and not heated. The heating experiment started on 2000-10-27 and will continue for about five years.

The aim of the instrumentation is to monitor the stress changes due to heating of the rock mass in a canister hole. The strain meter is used to monitor the relative changes of strain of the intact rock and across fractures.

The commission extends over field measurement and evaluation.

BBK AB is responsible for measuring equipment, the mobilization, field measurement, the computer processing. BBK AB and NCC Teknik are responsible for the interpretation and report of the measurements.

This report presents the measurement results in the test period from 2000-10-01 to 2001-11-30.

2 TECHNICAL BACKGROUND

2.1 The vibrating wire embedment biaxial stressmeter

The biaxial stressmeter, Geokon model is designed to measure compressive stress changes in rock, salt, concrete or ice. Principal stress changes are measured in the plane perpendicular to the borehole axes. The stressmeter consists of a high-strength steel cylinder that is grouted into a 60 mm borehole. Stress changes in the host material cause the cylinder to deform. Specification for the biaxial stressmeter is according to Appendix 1.

The radial deformation of the cylinder is measured by means of three pair of vibrating wire sensors spaced 60° intervals. Changes of stress produce corresponding changes in the resonant frequency of the sensors. These changes of frequency can be related to stress changes using factory-supplied calibrations. Longitudinal strain sensors and temperature sensors are also included in the stressmeter.

2.2 Embedded strain meters

The vibrating wire strain gages are designed for direct embedment in concrete. The strainmeter is 15 cm long and commonly used for strain measurement in foundations, piles, bridges, dams, tunnel liners etc. Specification for the strainmeter is according to Appendix 2.

The strain is measured using the vibrating wire principle. A length of a steel wire is tensioned between two end blocks that are embedded directly in concrete. Deformation (i.e. strain changes) of the concrete mass will cause the two end blocks to move relative to one another, thus altering the tension in the steel wire. The tension is measured by excitation of the wire and measuring its resonant frequency of vibration using an electro magnetic coil.

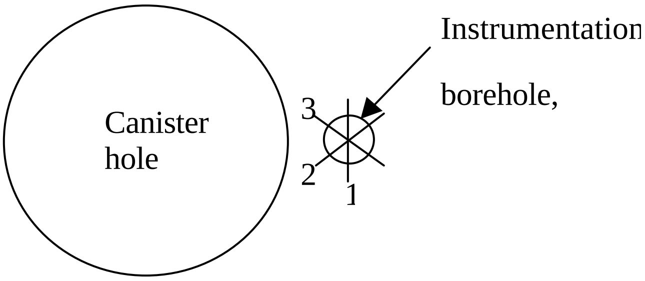
2.3 Cement

Special expansive grout was used to insure that the gage is in complete contact with the surrounding rock. The instruments are grouted in special cement from Denmark named Densitop T2. This cement is chosen to have as similar properties as the rock as possible. The compression strength is 150 MPa. The coefficient of expansion is approximate 8.5 microstrain/C° that is similar to hard rock as granite and as 85 % of common concrete.

3 FIELD MEASUREMENT

3.1 Installation work

Installation of the stressmeter gage is accomplished by inserting the gage into a grout-filled borehole using a setting tool and self-aligning setting rod.



The stress cell is orientated so that the first vibrating wire is orientated tangentially to the canister hole. The second string is orientated 60° from tangential direction and the third string is orientated 120° from tangential direction.

The strainmeter were fixed to a 6 mm glasfiber rod and pushed into the grout after the stress cell was installed.

3.2 Location of instruments

See figure 3.1 and figure 3.2.

3.3 Registration

The measurements, recording every one hour during the period of 2000-10-01 to 2001-01-01, and then recording every six hours during the period of 2001-01-03 to 2001-11-30, have been captured by a datalogger type Campbell CR10X.

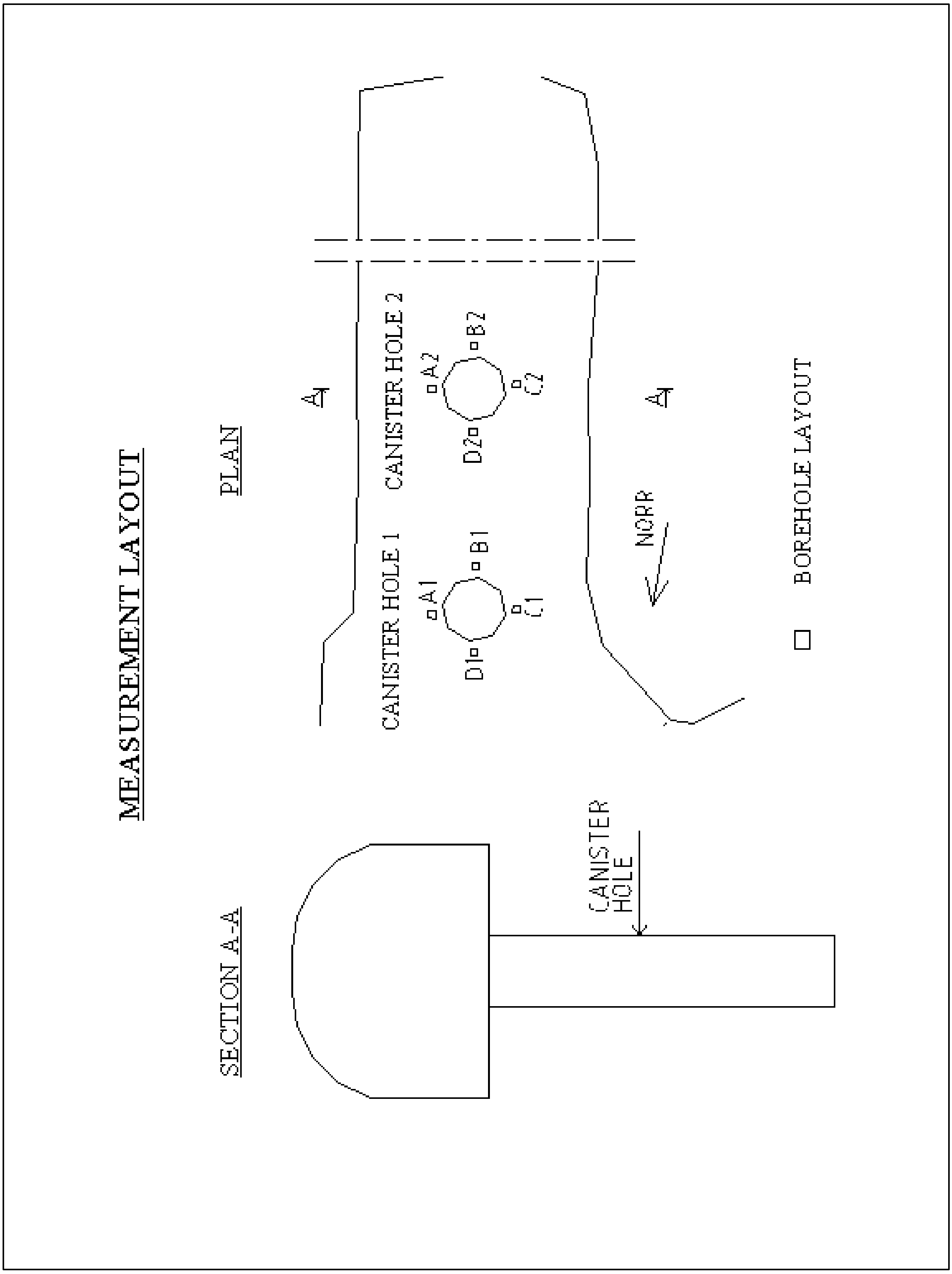


Figure 3.1 Measurement Layout

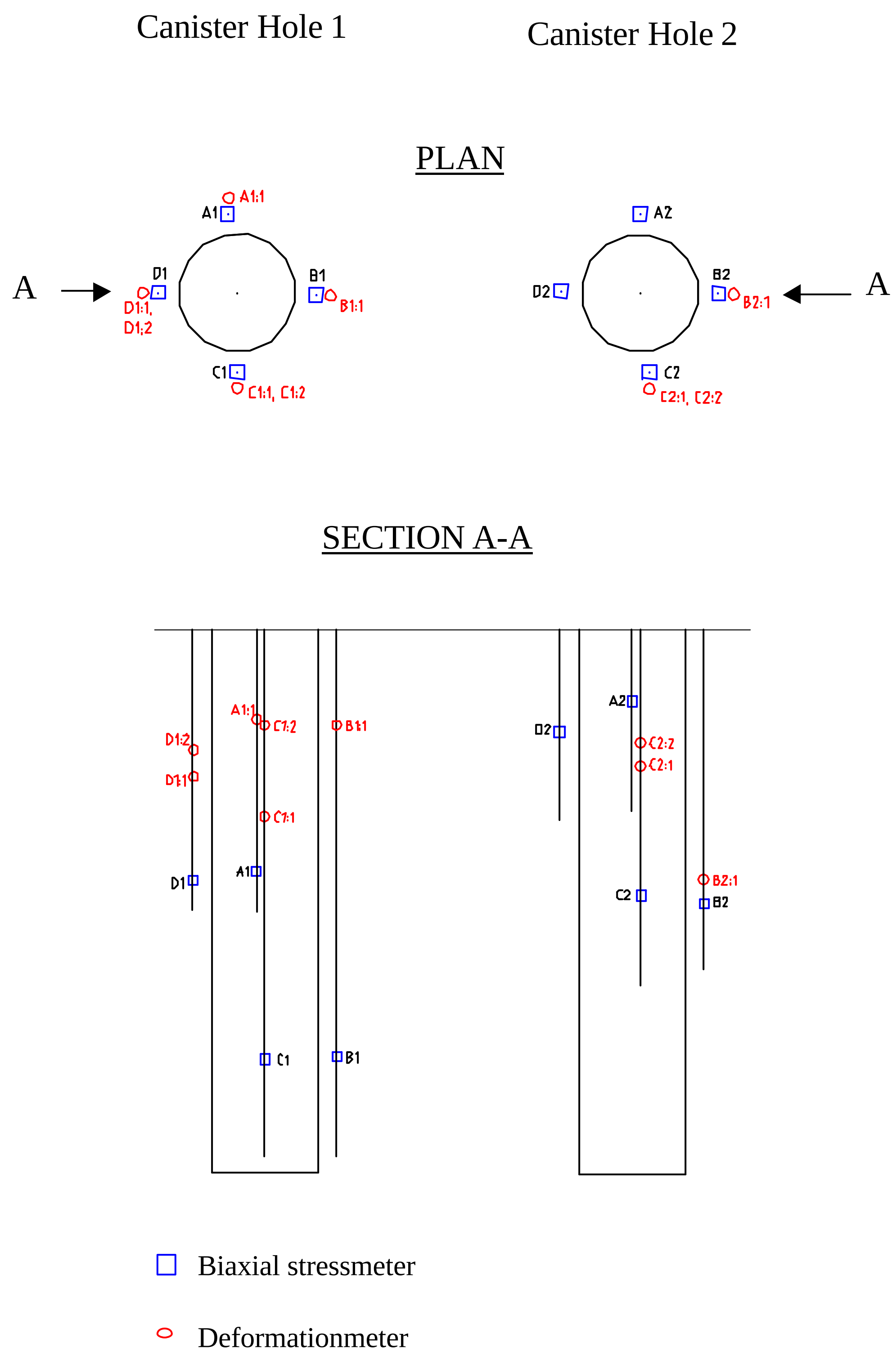


Figure 3.2 Location of instruments

4 COMPUTER PROCESSING OF FIELD DATA

4.1 Evaluation of stresses

The stress changes are evaluated from the measured deformations registered by the vibrating wires.

4.1.1 Radial deformations

Radial deformation for each of the strings are calculated with the equation:

$V_r = (R_1 - R_0)$* Gagefactor (inc. or mm)

V_r = Radial deformation for each of the strings

R_1= Deformation reading in digits (= frequency ^{2} / 1000)

R_0= Deformation zero reading in digits (= frequency ^{2} / 1000)

The body of the stressmeter is restrained so it is assumed that the body will not expand even if the temperature changes. Temperature correction is made for thermal expansion of the wire. The coefficient for thermal expansion of wire is 12.2 microstrain per degree C. Temperature correction is added in the equation for radial deformation according to:

$$\mathrm{Vr} = (\mathrm{R}_0 - \mathrm{R}_1) * \mathrm{G} * 25.4 + (0.0000122) * 25.4 * (((\mathrm{T}_1 + \mathrm{T}_2)/2) - ((\mathrm{T}_{0_1} + \mathrm{T}_{0_2})/2))$$

G = Gage factor

T_{01} = Temperature of thermal zero expansion for string 1

T_{02} = Temperature of thermal zero expansion for string 2

T_1, T_2 = Temperatures for string 1 and string 2

4.1.2 Calculation of deformation to stresses

The magnitude and the direction of the stress changes are determined from the measured radial deformation of the sensor in three directions.

The equations below give the magnitude and the direction of the maximum stress increase and reduction in a plane perpendicular to the borehole axes:

<u>Maximal stress increase</u>

$$p = \frac{1}{2}\left[\frac{1}{3B}\left(\left(2V_{r_1} - V_{r_2} - V_{r_3}\right)^2 + 3\left(V_{r_2} - V_{r_3}\right)^2\right)^{1/2} + \frac{1}{3A}\left(V_{r_1} + V_{r_2} + V_{r_3}\right)\right]$$

V_{r_1} = Radial deformation for string 1

V_{r_2} = Radial deformation for string 2

V_{r_3} = Radial deformation for string 3

A , B = Coefficients depending on the sensor geometry and the material properties

<u>Maximal stress reduction</u>

$$q = \left[\frac{1}{3A} \left(V_{r_1} + V_{r_2} + V_{r_3} \right) - p \right]$$

<u>Longitudinal stress correction:</u>

$$ue_{lT} E = u * (R_0 - R_T) G + (T_T - T_0) C$$

υ = Poisson´s ratio of the rock
E_i = Youngs´s Modulus of the rock
ε_{lT} = longitudinal strain

<u>The angle of the maximal stress increase</u>

The angle in the plane perpendicular to the borehole axes is measured clockwise from the tangential direction of the canister hole.

$$q = \frac{1}{2} \cos^{-1} \left[\frac{V_{r_1} - A(p+q)}{B(p-q)} \right]$$

4.1.3 Vertical stress change

The changes of stresses in vertical direction has been calculated and evaluated from the longitudinal deformation in the borehole direction. Two vibrating wires monitored the vertical stress change along the borehole.

Calculation of stresses according to position 4.1.2.

4.2 Evaluation of strain

Nine strain gages were installed in the same boreholes as the biaxial stressmeters.

4.2.1 Calculation of strain

Strain measurement were calculated as temperature compensated load related strain with the following equation:

$$m_{true} = (R_1 - R_0) * B + (T_1 - T_0)(C_1 - C_2)$$

m_{true} = temperature compensated microstrain

R_1 and R_0 =Digits reading

B = batch calibration factor

C_1 and C_2 are the coefficients of expansion of steel and concrete, 12.2 microstrian/ C° and 8.5 microstrain/C°.

4.3 Material parameters

Material parameters used in the calculations are as the following:

- Young's modulus of intact rock 69 Gpa
- Poisson's ratio of intact rock 0.25
- Coefficients of expansion of steel 12.2 microstrain/ C°
- Coefficients of expansion of concrete 8.5 microstrain/C°

4.4 Processing

The raw data registered have been processed in Microsoft Excel software. The calculation and evaluation gathered from the deformations in the plane perpendicular to the borehole axes are presented as:

Temperature

Radial deformation of the three pairs of wires in plane perpendicular to borehole axes

Maximal stress increases and stress reduction in plane perpendicular to borehole axes

Orientation of maximal stress increase in plane perpendicular to borehole axes

Vertical stress changes

Stress correction in plane due to vertical stress changes

Strain measurement

5 RESULTS

A summary of the results for the stress changes are presented in Table 1 and Figure 5.1 for total changes of stress magnitudes and stress orientation in phase2 (heating), covering the period from 2000-10-01 up to 2001-11-30. The results are not compensated for temperature changes.

Although the measurements of stressmeters are affected by temperature, the temperature compensated results of stressmeters are not presented in this report because we need to make a further detailed study of the relationship between temperature and stressmeter measurements. Results of the biaxial stressmeter without temperature compensated and the strainmeter with temperature compensated from each borehole for the measuring period 2000-10-01 to 2001-11-30 are summarized on the diagrams in section 5.1 and 5.2 for the whole period.

The diagrams in section 5.1 and 5.2 for each borehole displays:

- Maximal stress increases and stress reductions in plane perpendicular to borehole axes.
- Orientation of maximal stress increase in plane perpendicular to borehole axes.
- Strain measurements presented in diagrams are temperature-compensated with the unit of microstrain. Positive value is representing elongation.

The registration so far indicates that

- The temperature is inhomogeneous around the canister hole. In borehole B2 and C2, the temperature has a maximum of about 57°C while borehole A2 and D2 have only reached about 26°C.
- The stress changes are inhomogeneous around the canister hole.
- The new stress field shows a maximum increase of stresses up to 31.1 MPa and a maximum reduction of –10.9 MPa, compared to the old stress field.
- The orientation of the new stress field, as measured clockwise from the tangent to the deposition hole, shows up to 38° deviation to the previous tangential stress orientation.

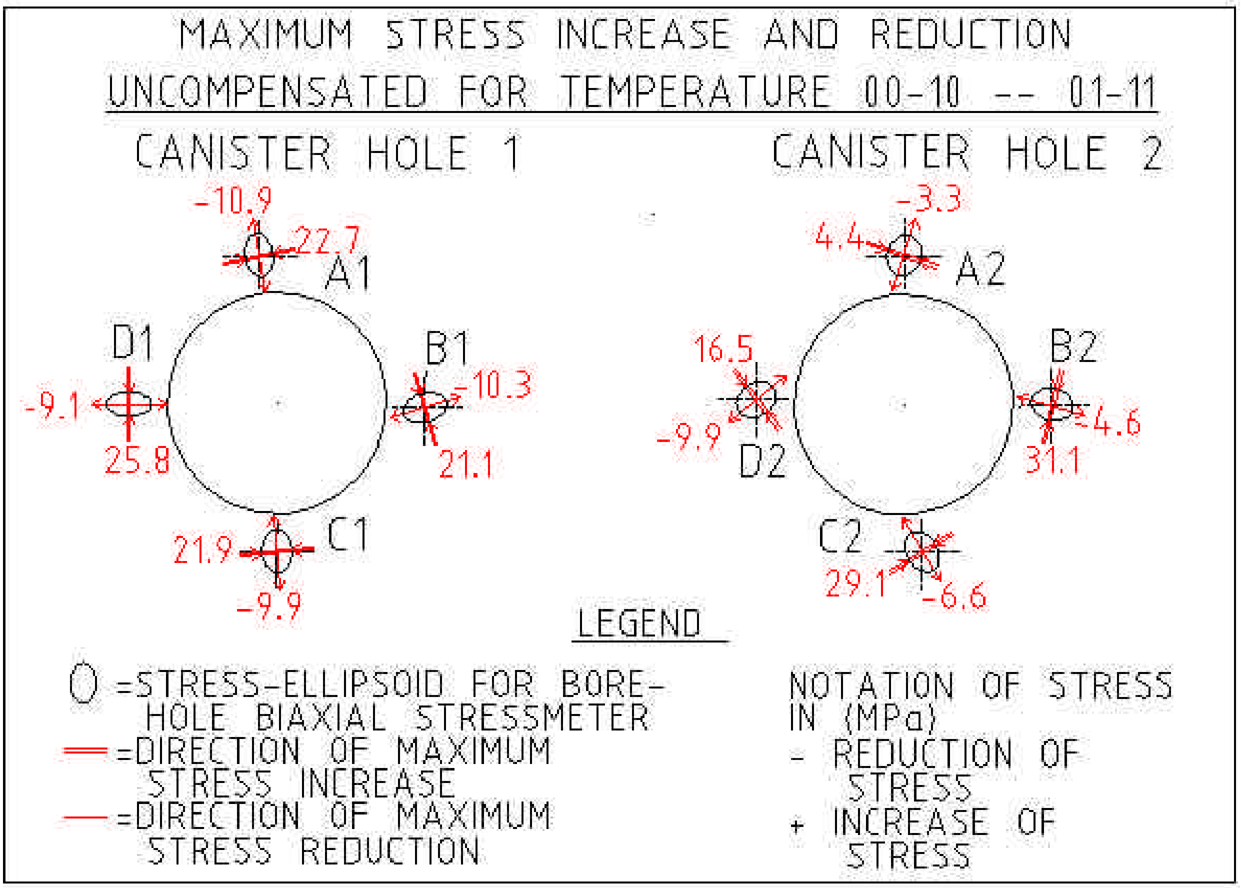


Figure 5.1 Maximum stress changes uncompensated for temperature

Table 1. Summary of results for stress measurements

- Results uncompensated for temperature:

Stress-meter	Measuring period					
	Phase 1: Drilling			Phase 2: Heating Period: 2000-10-01 – 2001-11-30		
	Max. stress increase (MPa)	Max. stress reduction (MPa)	Orientation of max. stress increase (degree)	Max. stress increase (MPa)	Max. stress reduction (MPa)	Orientation ofmax. stress increase (degree)
A1	17.0	-10.0	11.5	22.7	-10.9	10.3
B1	15.0	-11.0	17.0	21.1	-10.3	16.8
C1	12.0	-7.4	0	21.9	-9.9	5.4
D1	22.0	-11.0	0	25.8	-9.1	0
A2	5.0	-4.0	-11.0	4.4	-3.3	-18.3
B2	11.0	-7.3	-7.5	31.1	-4.6	-14.1
C2	11.0	-7.7	29.5	29.1	-6.6	31.2
D2	9.3	-7.2	38.5	16.5	-9.9	38.7

Notes: Positive value of stress measurement indicates compression; Negative value of stress measurement indicates extension.

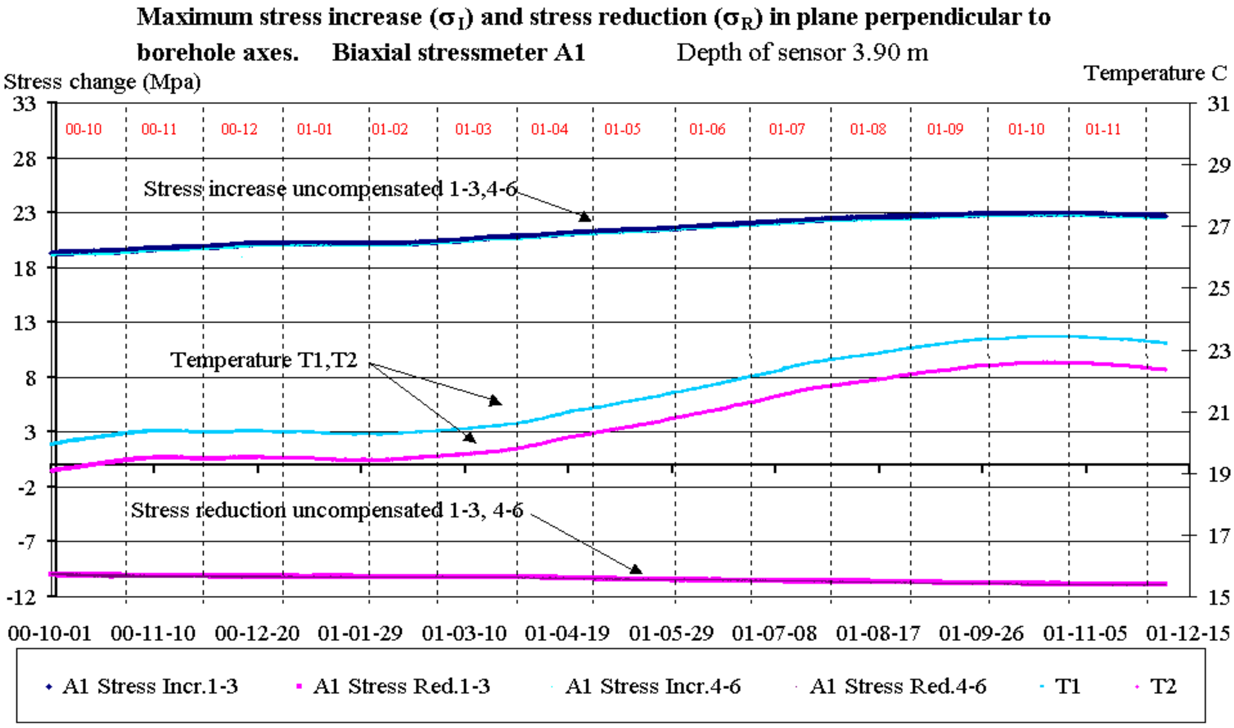
Positive value of orientation indicates anti-clockwise rotation; Negative value of orientation indicates clockwise rotation.

5.1 Results of canister hole 1

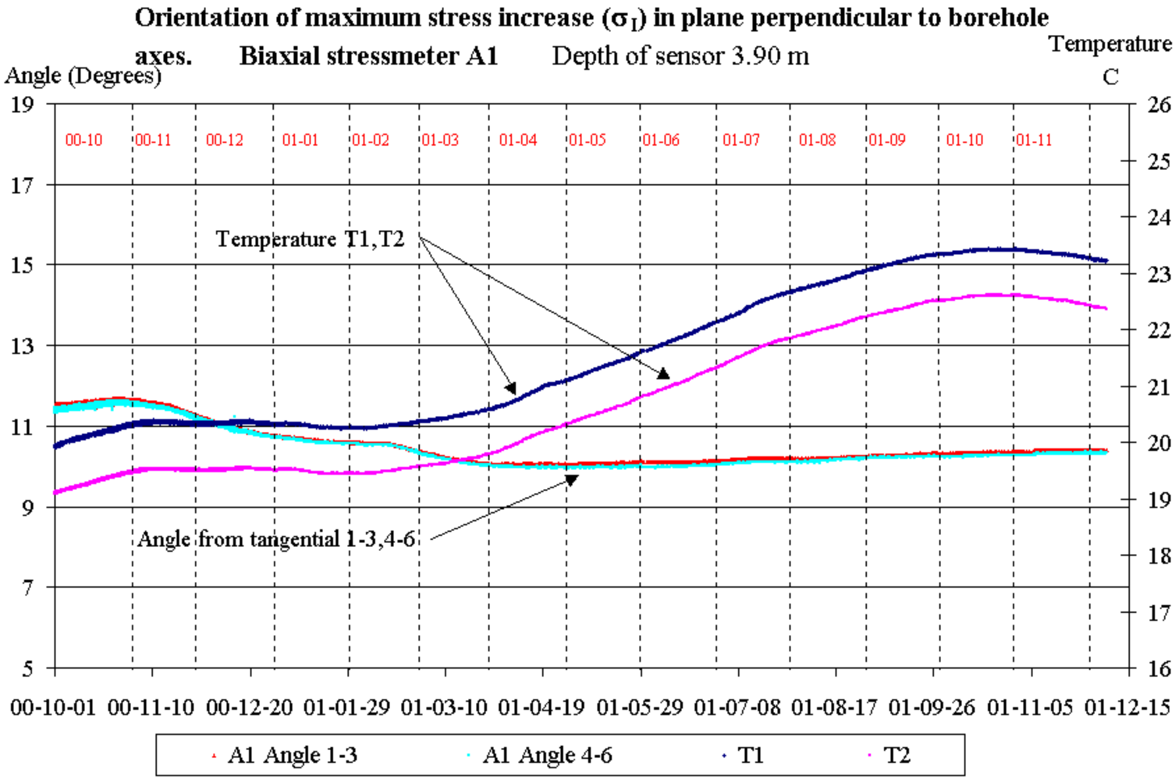
5.1.1 Stress change for each biaxial stressmeter

Biaxial stressmeter A1 uncompensated for temperature:

Maximum stress increase and reduction

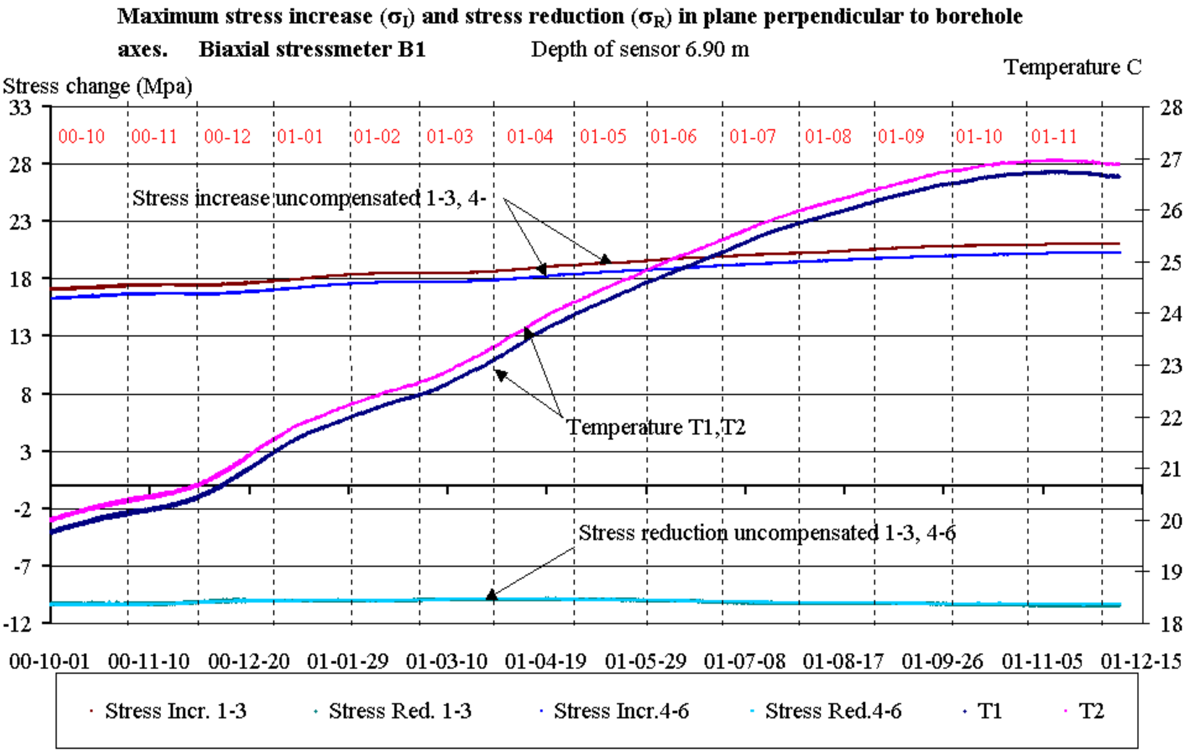


Orientation

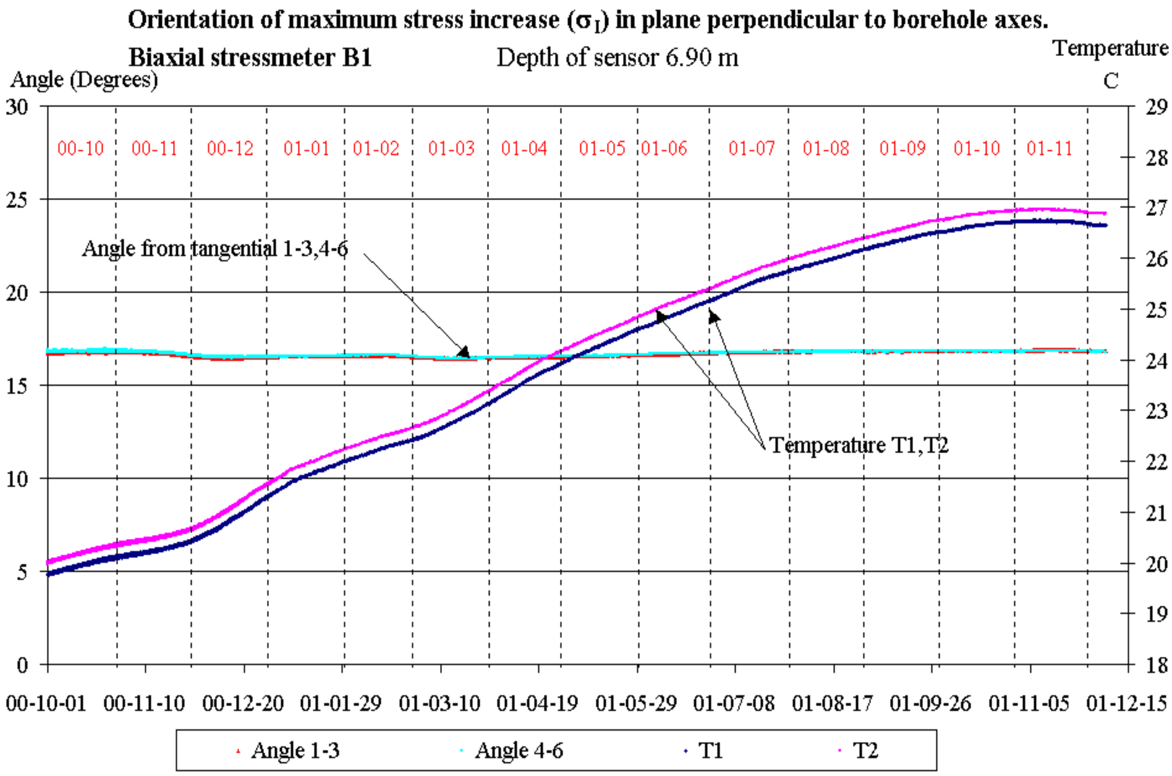


Biaxial stressmeter B1 uncompensated for temperature:

Maximum stress increase and reduction

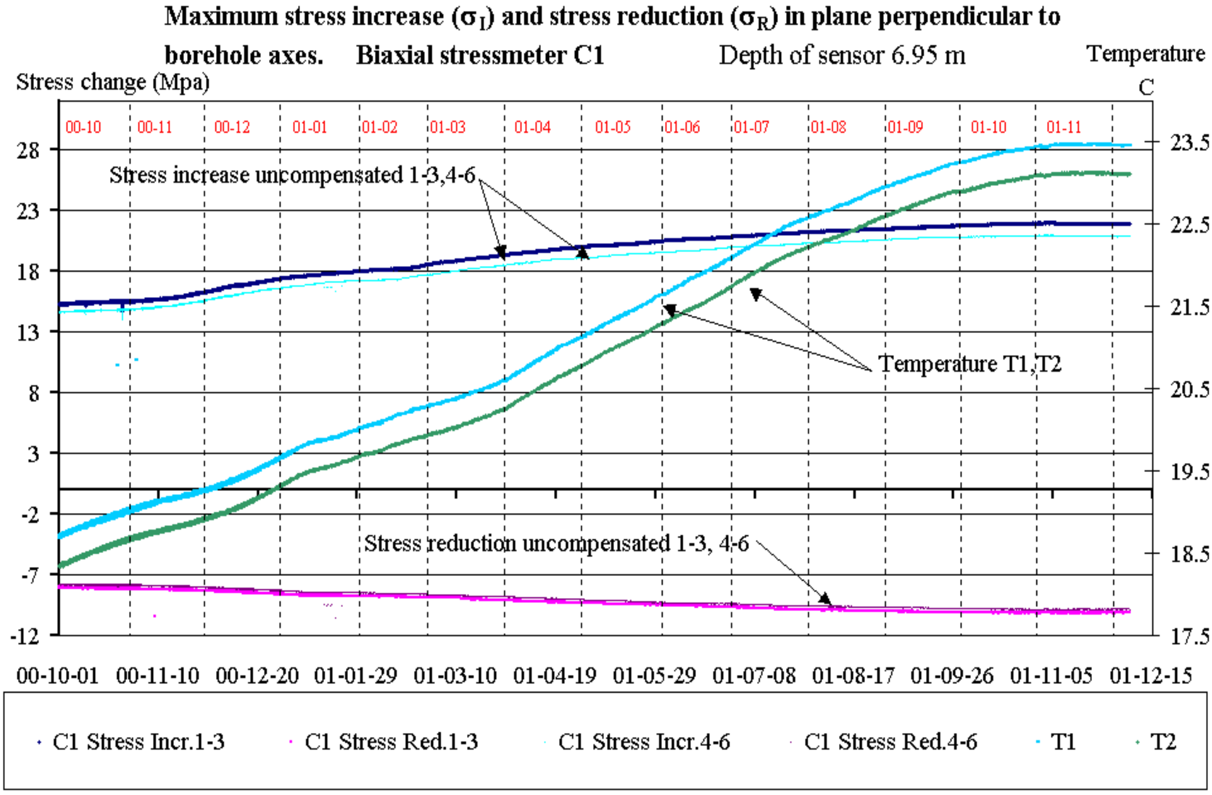


Orientation

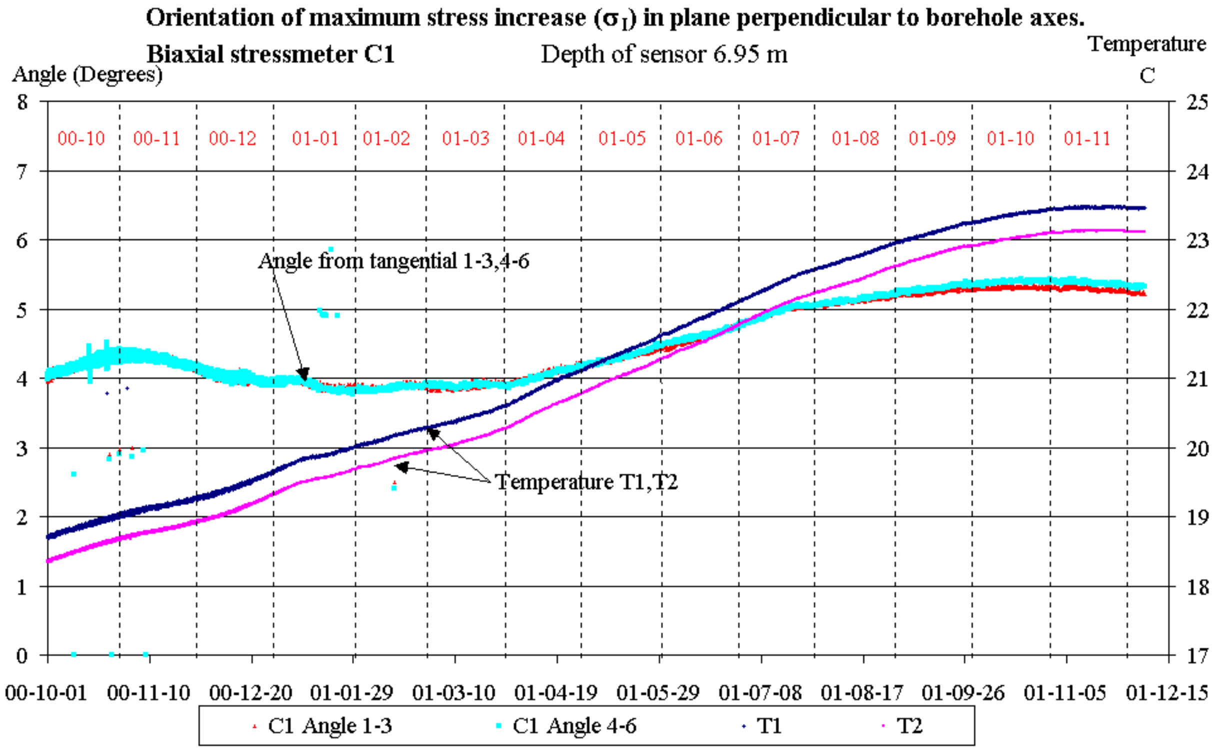


Biaxial stressmeter C1 uncompensated for temperature:

Maximum stress increase and reduction

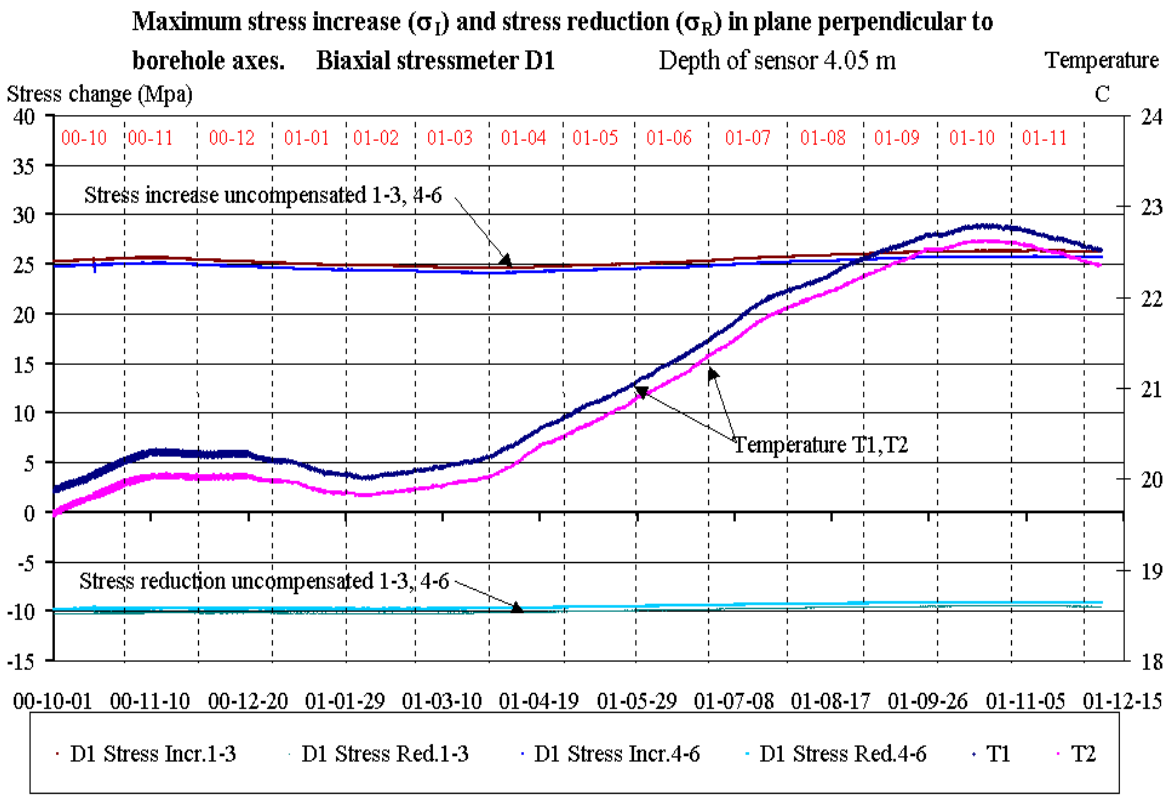


Orientation:

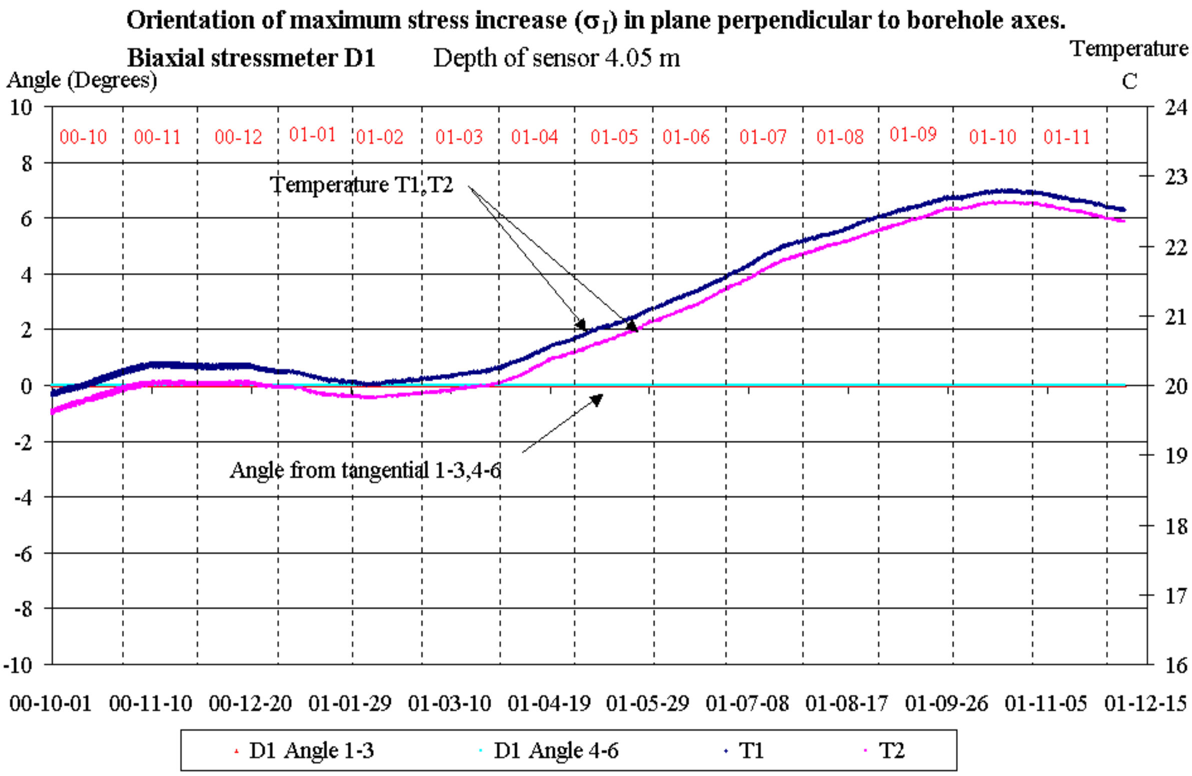


Biaxial stressmeter D1 uncompensated for temperature:

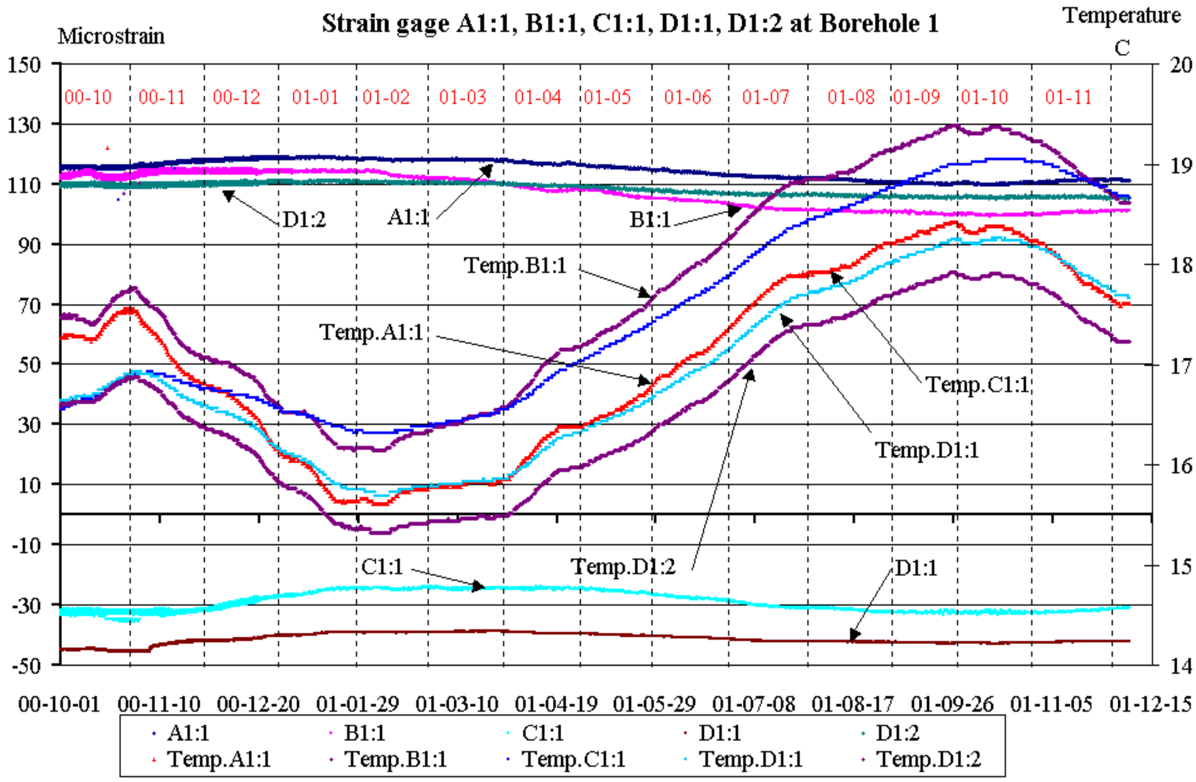
Maximum stress increase and reduction



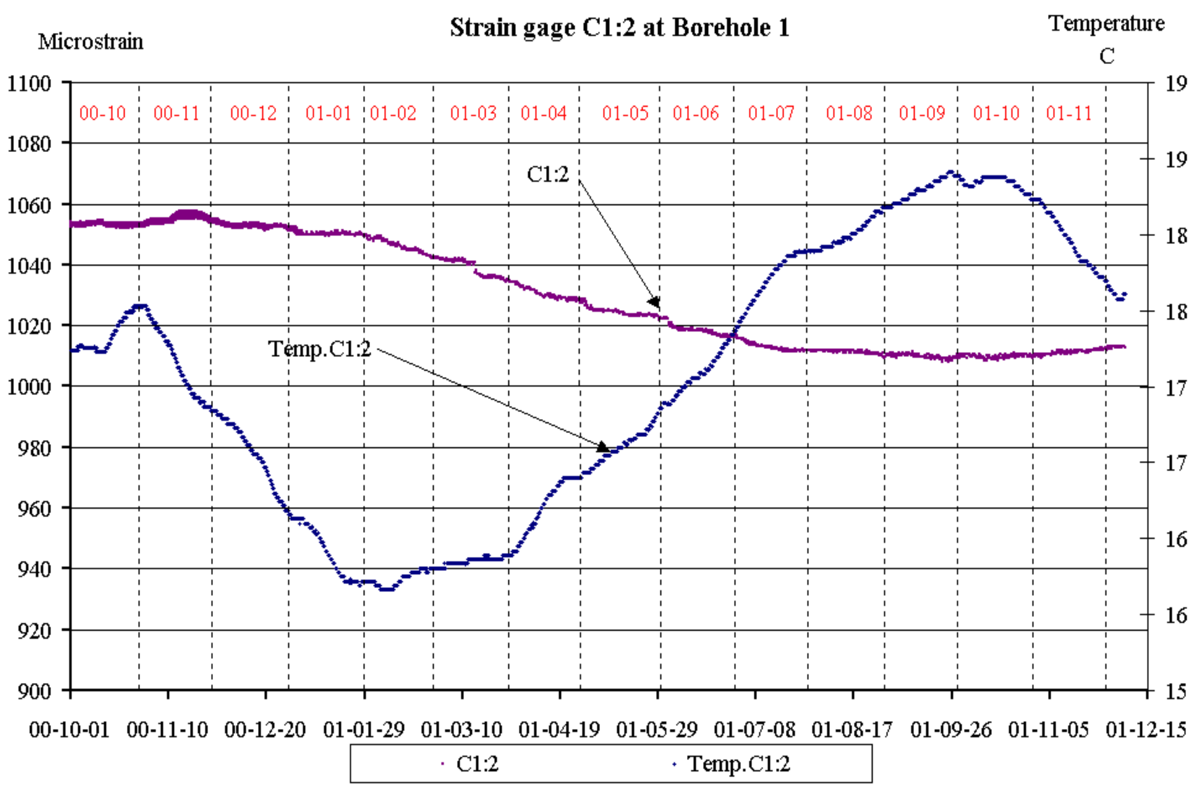
Orientation:



5.1.2 Strainmeter A1:1, B1:1, C1:1, D1:1, D1:2 (temperature compensated)



5.1.3 Strainmeter C1:2 (temperature compensated)

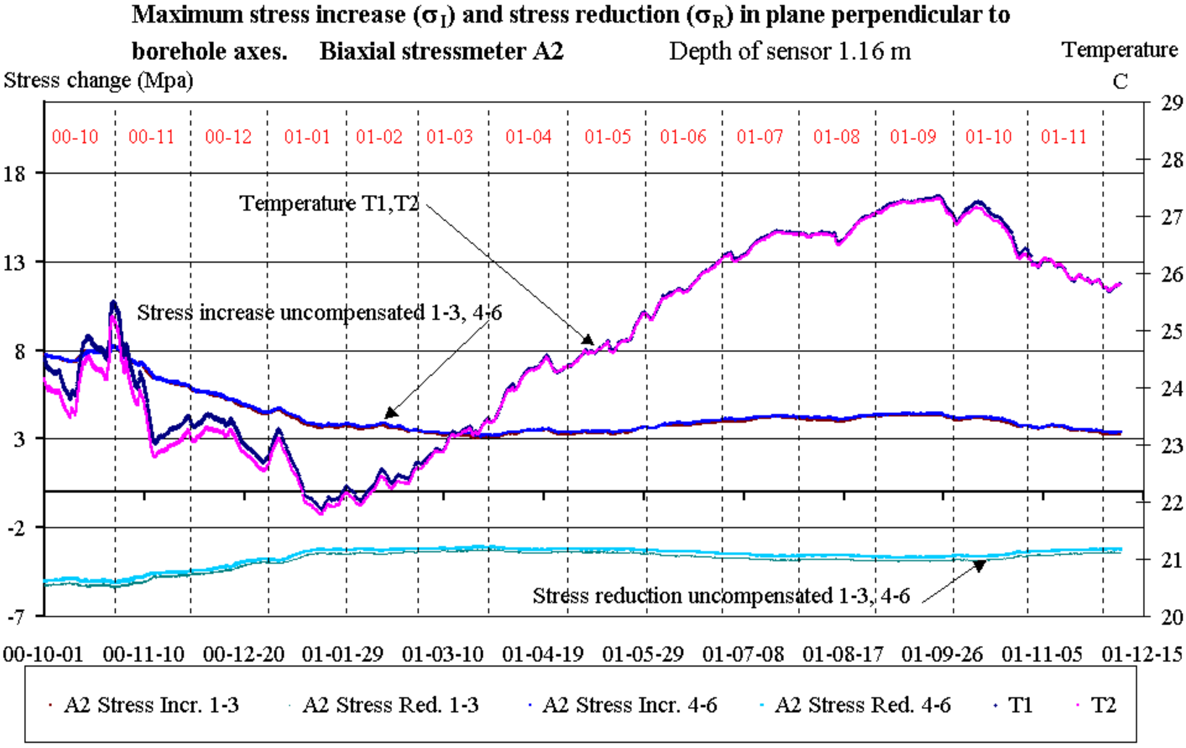


5.2 Results of canister hole 2

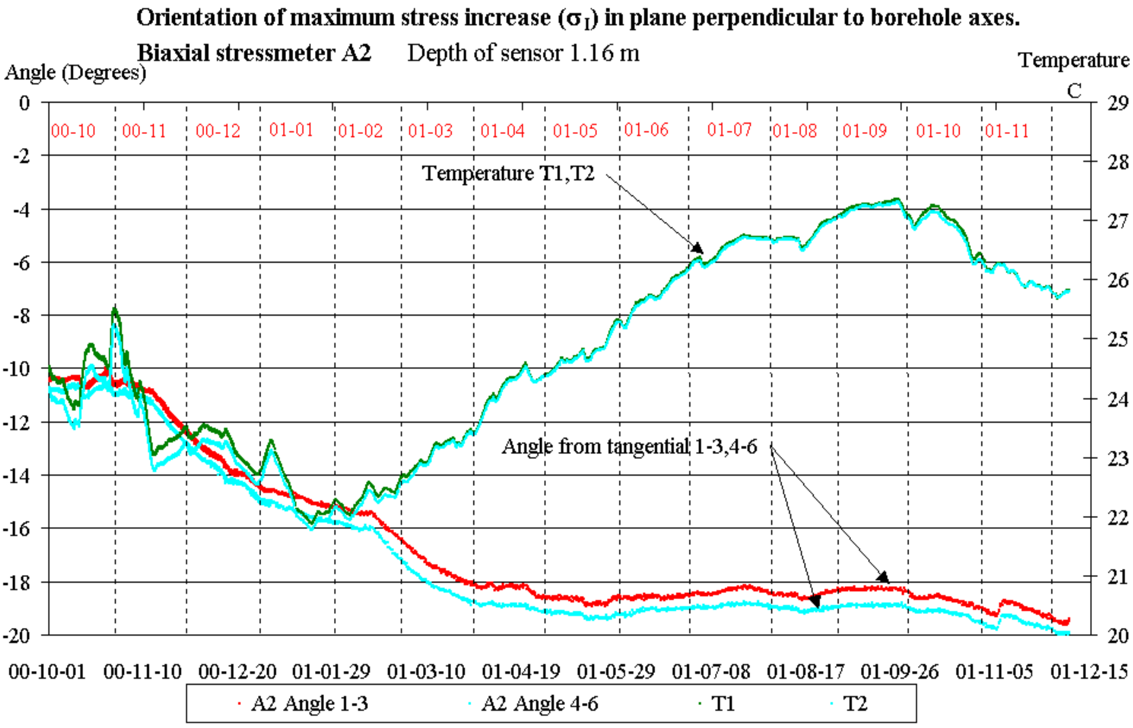
5.2.1 Stress change for each biaxial stressmeter

Biaxial stressmeter A2 uncompensated for temperature:

Maximum stress increase and reduction

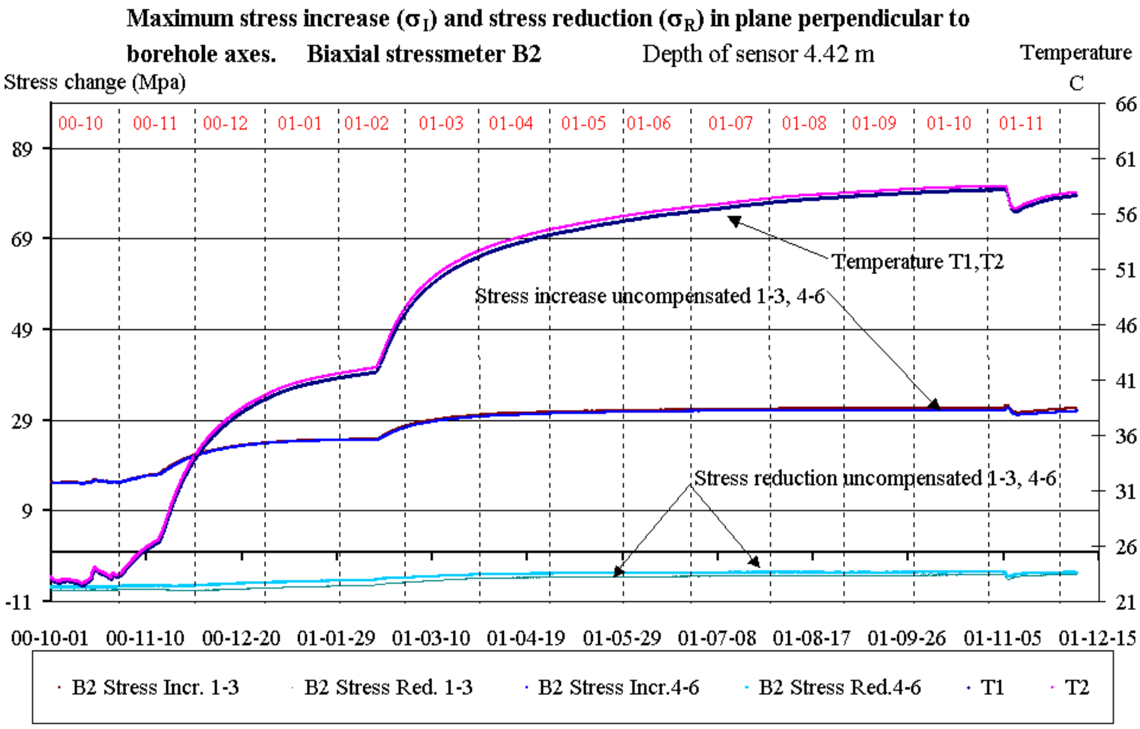


Orientation:

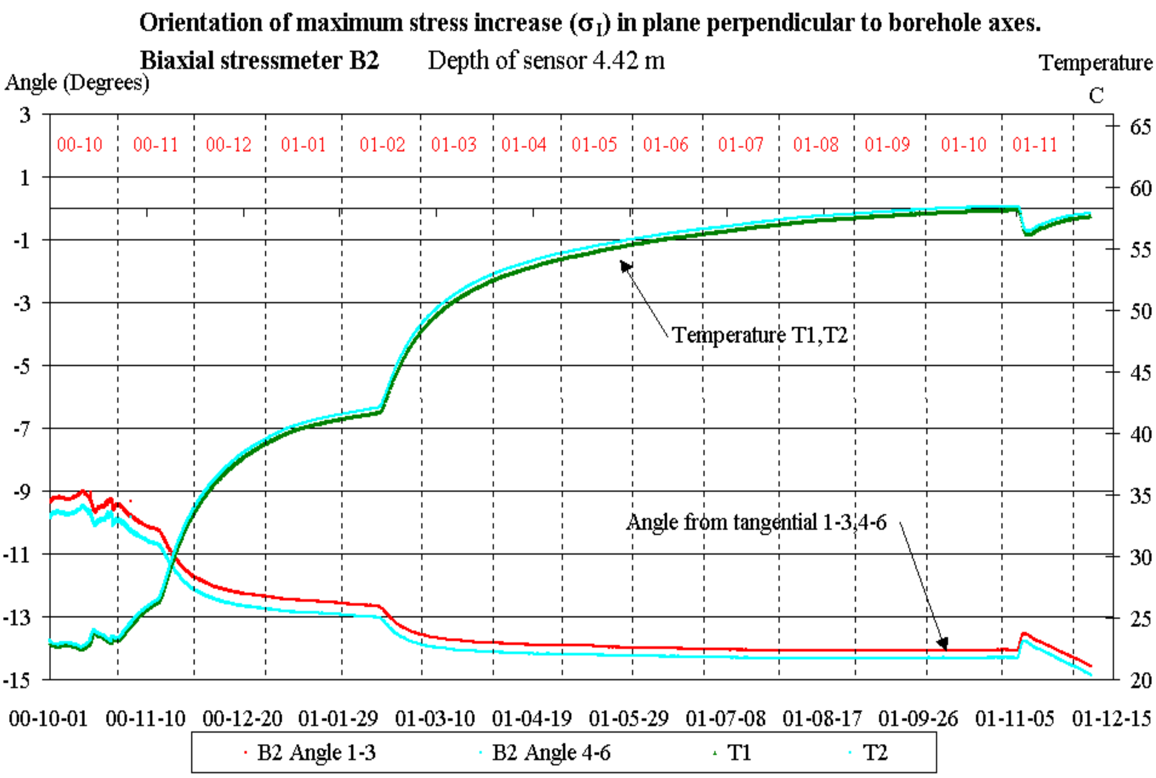


Biaxial stressmeter B2 uncompensated for temperature:

Maximum stress increase and reduction

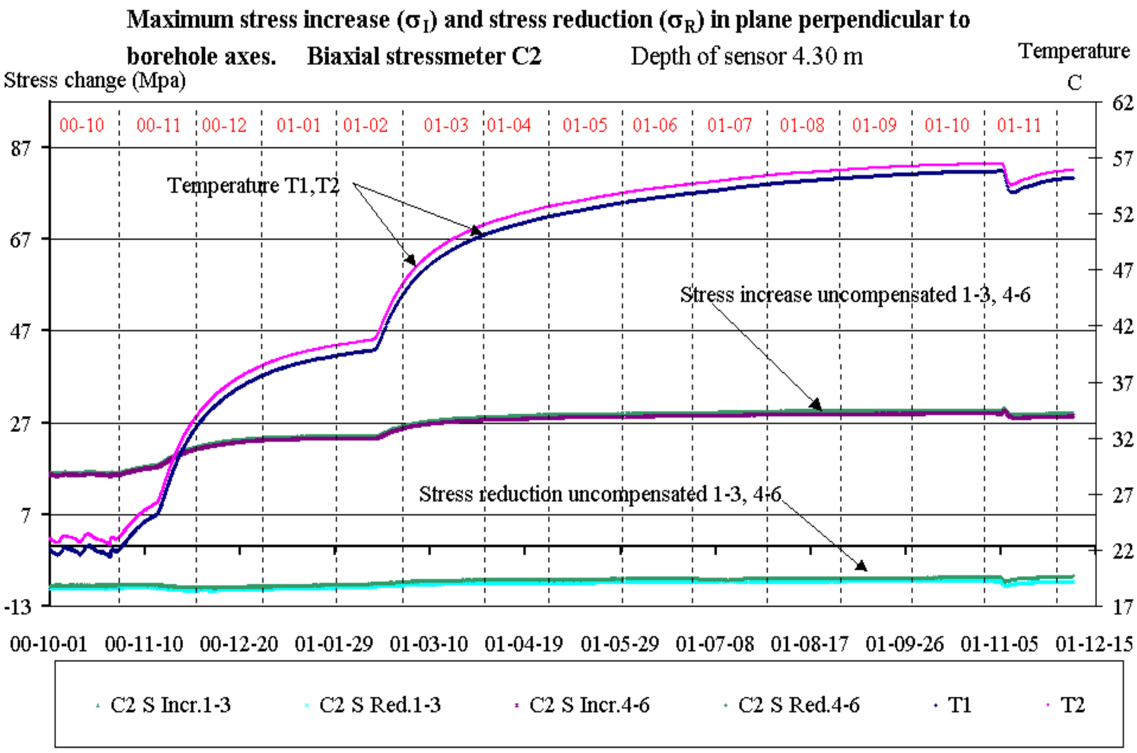


Orientation:

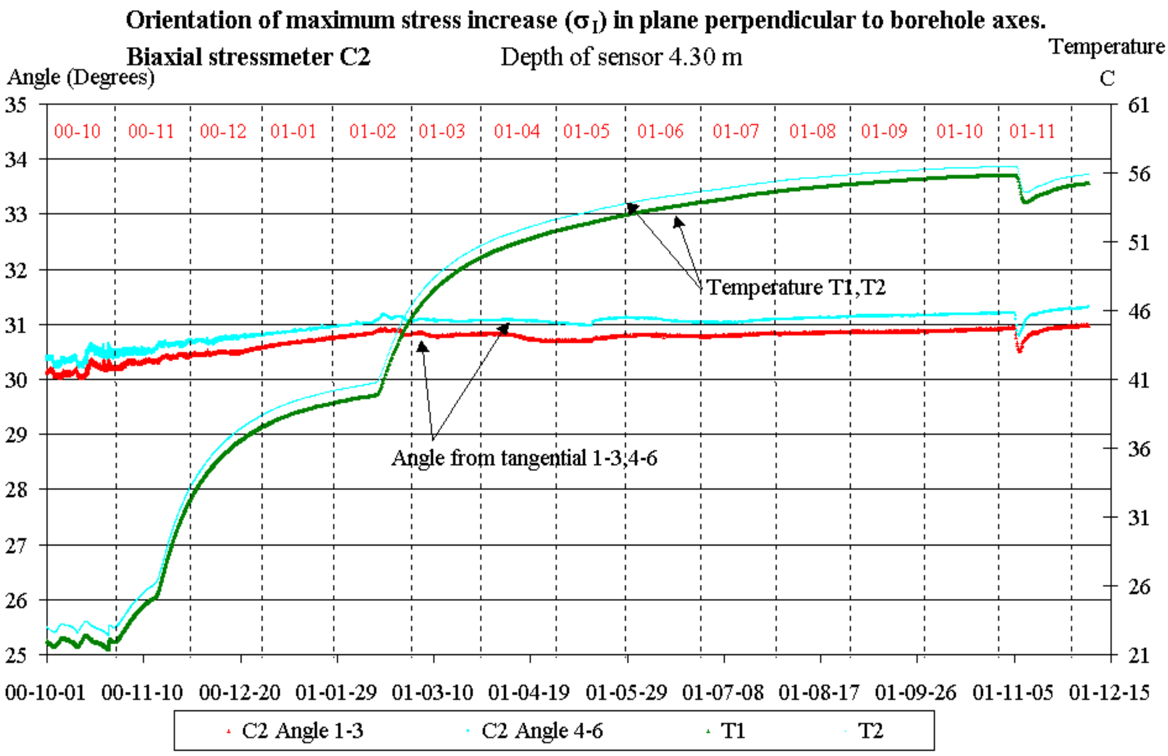


Biaxial stressmeter C2 uncompensated for temperature:

Maximum stress increase and reduction

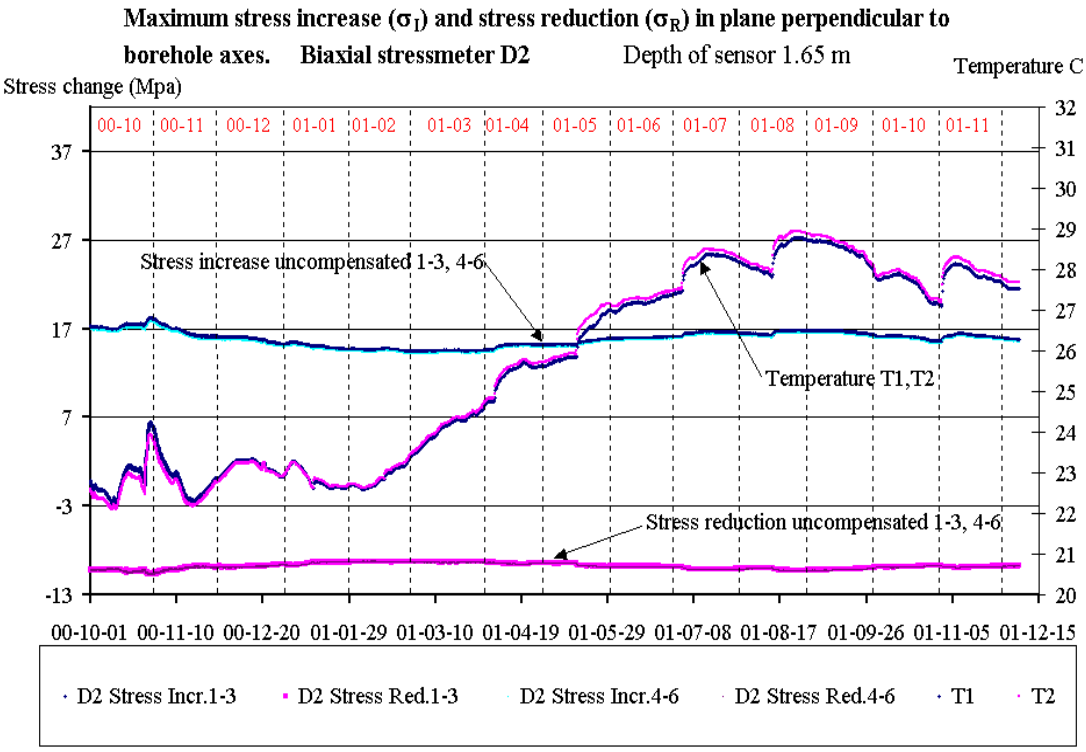


Orientation:

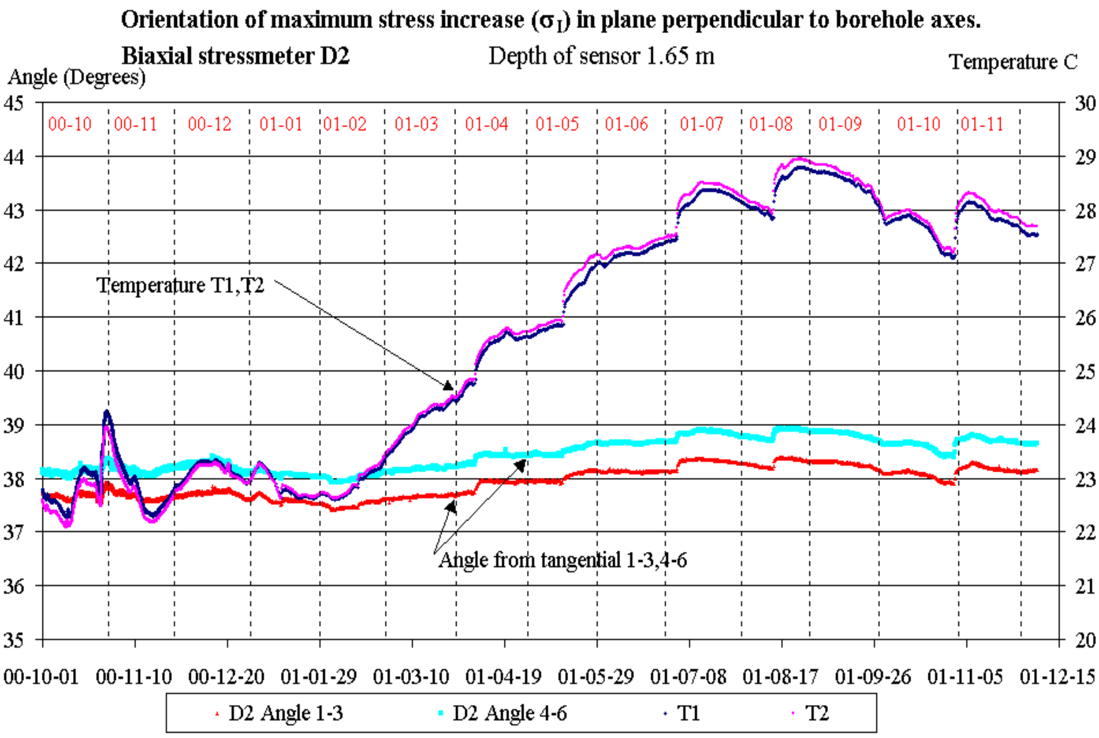


Biaxial stressmeter D2 uncompensated for temperature:

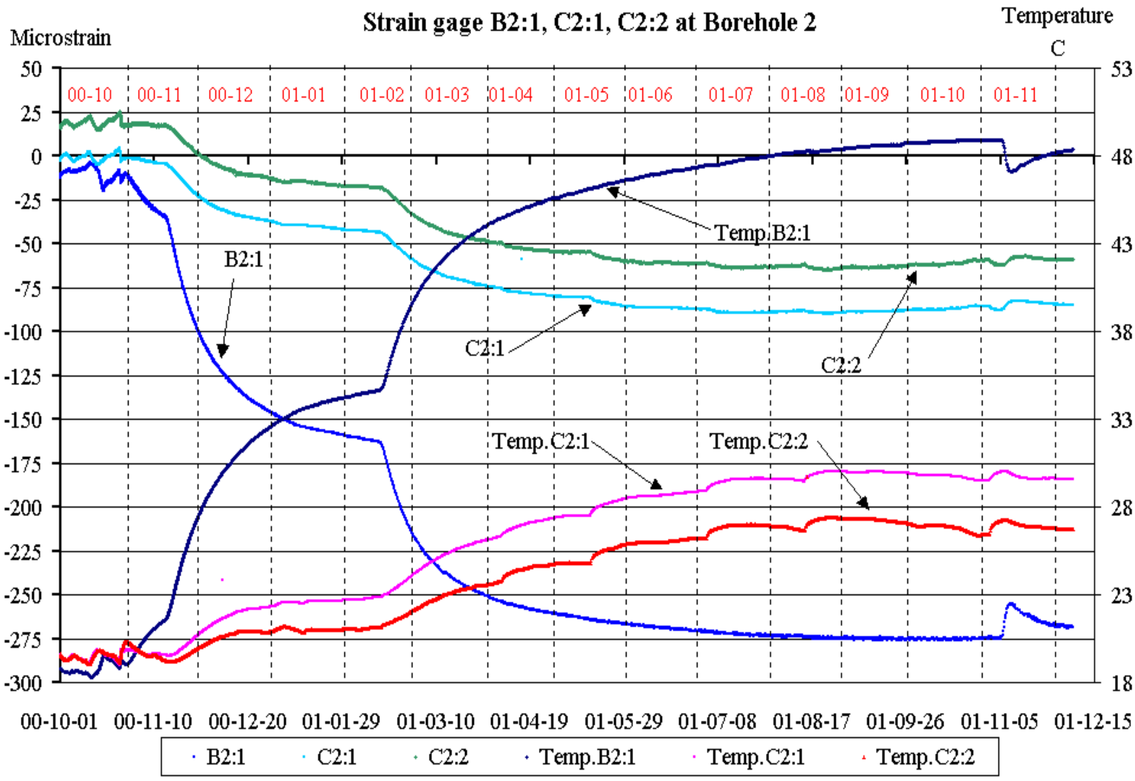
Maximum stress increase and reduction



Orientation:



5.2.2 Strainmeter B2:1, C2:1, C2:2 (temperature compensated)



Appendix 1

Model 4350 VW Biaxial Stressmeter

The Model 4350 VW Biaxial Stressmeter is designed to measure compressive stress changes in rock, salt, concrete or ice. Three or six VW sensors oriented at 60° intervals allow the principal stress changes to be measured in the plane perpendicular to the stressmeter axis. The stressmeter consists of a high strength steel cylinder which is grouted (or frozen, in the case of ice) into a BX (60mm (2.36in.)) size borehole

Specifications	
Standard Range	70 MPa (10,000psi)
Sensitivity[1]	14 to 70 KPa (2 to 10psi)
Accuracy	±0.1% F.S.
Temperature Range[2]	–20°C to +80°C
Borehole Diameter	BX (60mm (2.36in.))

[1]Depends on rock modulus
[2]High temperature versions (up to 200°C) available on request

Appendix 2

MODEL VCE-4200/4210/4202 CONCRETE EMBEDMENT TYPE

These Strain Gages are designed for direct embedment in concrete. The VCE-4200 (standard model) has a I 53mm (6in.) gage length and 1 me sensitivity and is commonly used for strain measurements in foundations, piles, bridges, dams, tunnel linings, etc. It is also available as a high temperature version (up to 200°C). The VCE-4210 has the same range as the Model 4200 but has a 250mm (10in.) gage length making it particularly suitable for use in large aggregate concrete. The 4202, with a 51mm (2in.) gage length, is designed for laboratory use and/or where there are space limitations.

SPECIFICATIONS	4200	4210	4202
Standard Range	3000µe	3000µe	3000µe
Sensitivity	1.0µe	0.4µe	0.4µe
Accuracy	±1.0% F.S.	±1.0% F.S.	±1.0% F.S.
Nonlinearity	<0.5%	<0.5%	<0.5%
Temperature Range	-20°C to +80°C		
Active Gage Length	150mm (5.875in.)	250mm (10in.)	51mm (2in.)