Swiss Centre of Competence
for Deep Geothermal Energy
for power and heat production

GEO ENERGIE SUISSE

Overview of Seismicity during Injection Tests Bedretto borehole Welltec

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Introduction

- Motivation for the seismicity analysis
- Temporal sequence
- Analysis method of seismic events
- Seismic Monitoring System during tests
- Results
- Conclusion

Motivation for the seismicity analysis

- Could the packer expansion cause axial fractures along the packers and thus, a flow bypass?
- Could the injection into the closed casing (ballooning effect) cause new fractures?
- Could the injection into the open interval stimulate fractures?
- Did the ETH monitoring system detect seismic events during the packer expansion?
- Did the ETH monitoring system detect seismic events during the injections tests?

Temporal sequence

- Drilling of Welltec borehole (12-16.04.2021)
- Casing and Packer installation (16-27.08.2021)
- Packer expansion (27.08.2021)
- Interval 1 at 62 m (22.10.2021). *Sliding Sleeve was not open due to wrong opening procedure*
- Interval 1 at 62 m (28-29.10.2021). *Sliding Sleeve was not open. Welltec is still investigating.*
- Interval 2 at 76 m (29-30.10.2021). *Sliding Sleeve was open*
- Interval 1 at 62 m (01-15.11.2021). *Sliding Sleeve was not open. Welltec is still investigating.*

Analysis method of seismic events

1. Identification of different types of detected events on sensors in MB7 on 27.08.2021 and 22.10 – 16.11.2021

2. Day by Day analysis of:
    1. Different types of detected events on sensors in MB7 with various activities in the laboratory (what was injected, what was observed, is there a correlation?)
    2. Recurring signals on sensors in MB7 (Frac-Events and Seismic events detected at a single sensor) with pumping activity in the borehole (day by day)

Seismic Monitoring System

- 27.08.2021: the ETH monitoring system was not running
- 22.10.2021 – 16.11.2021: Signals are observed on acoustic emission sensors (AE) handled by ETH
- No total time coverage of the recorded events because too many data to be extracted by ETH
- Thus, concentration on specific injection phases (see table)

Timings asked to ETH	Timings received
22/10 -> 12:20 – 14:40	22/10 -> 12:21 – 15:38
28/10 -> 17:50 – 19:10	28/10 -> 17:51 – 19:59
29/10 -> 08:15 – 11:30	29/10 -> 08:17 – 11:59
30/10 -> 09:10 – 13:20	30/10 -> 09:10 – 13:59
01/11 -> 16:50 – 18:00	01/11 -> 16:51 – 18:59
02/11 -> 09:00 – 17:40	02/11 -> 09:00 – 10:23

- MB7 is the closest borehole to the Welltec borehole. Thus focusing mostly on sensors in MB7.
- 22.10.2021 – 02.11.2021: Most of events recorded on MB7_1_AE2

	Depth	X	Y	Z	Distance to injection at 62.6 m	Distance to injection at 76.4 m
MB7_1_AE2	64.619	-64.750258	-16.143989	1458.99759	18.5	19.2
MB7_1_AE3	31.107	-35.542745	-6.3496702	1472.18797	28.2	36.2

Analysis Results of seismic events

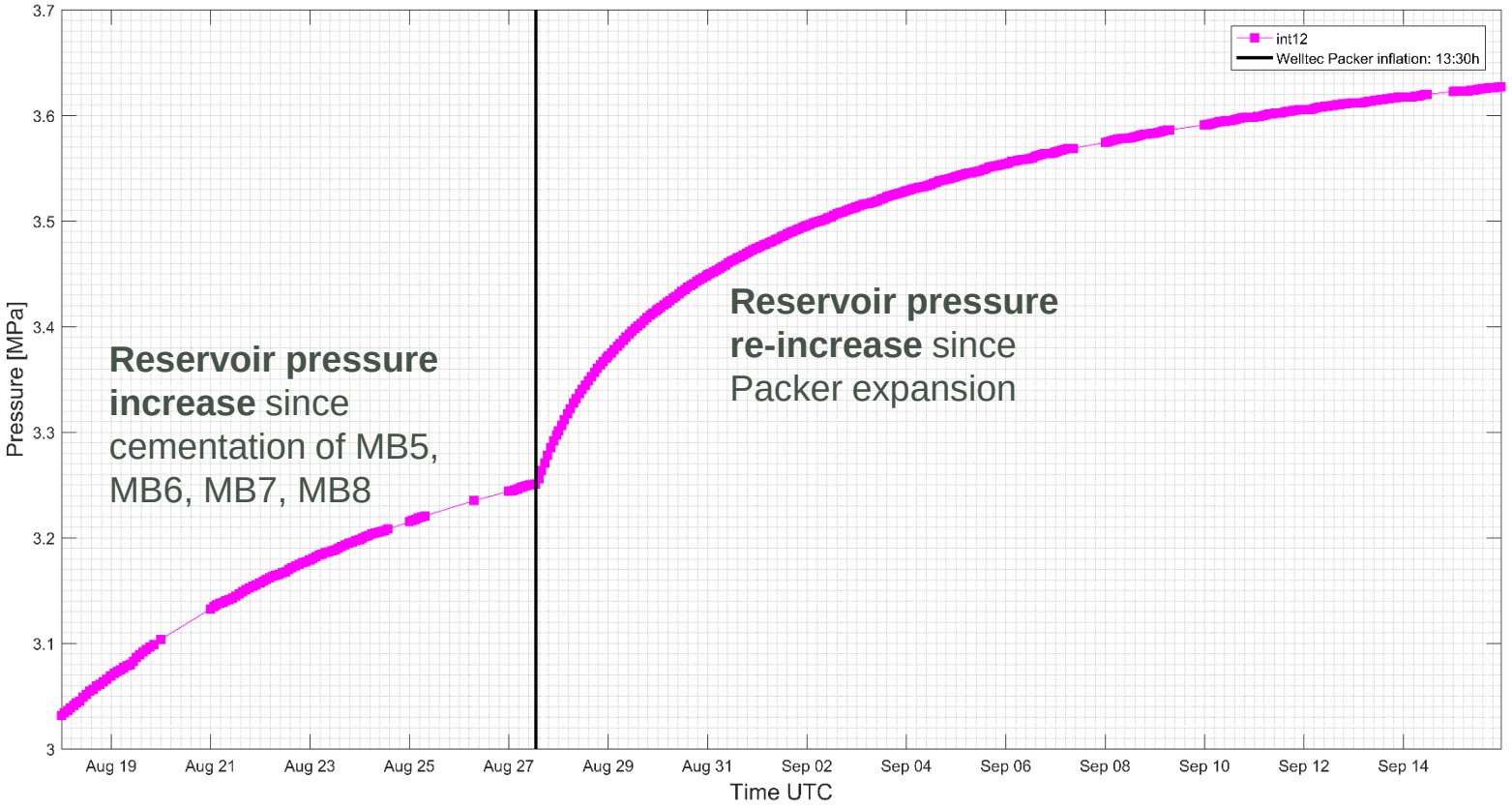
1. Identification of different types of detected events on sensors in MB7 on 27.08.2021 and 22.10 – 16.11.2021

2. Day by Day analysis of:
    1. Different types of detected events on sensors in MB7 with various activities in the laboratory (what was injected, what was observed, is there a correlation?)
    2. Recurring signals on sensors in MB7 (Frac-Events and Seismic events detected at a single sensor) with pumping activity in the borehole (day by day)

1. Events during Packer setting 27.08.2021

- After borehole drilling: Welltec BH outflow = 2.5 l/min
- After Cementation of monitoring boreholes: Welltec BH outflow = 4.3 l/min
- After packer expansion: Welltec annulus outflow = 2.5 l/min (and not 0 l/min)
- **No ETH seismicity monitoring at that moment**

Reaction in borehole ST1 interval 12



1. Events during Packer setting 27.08.2021

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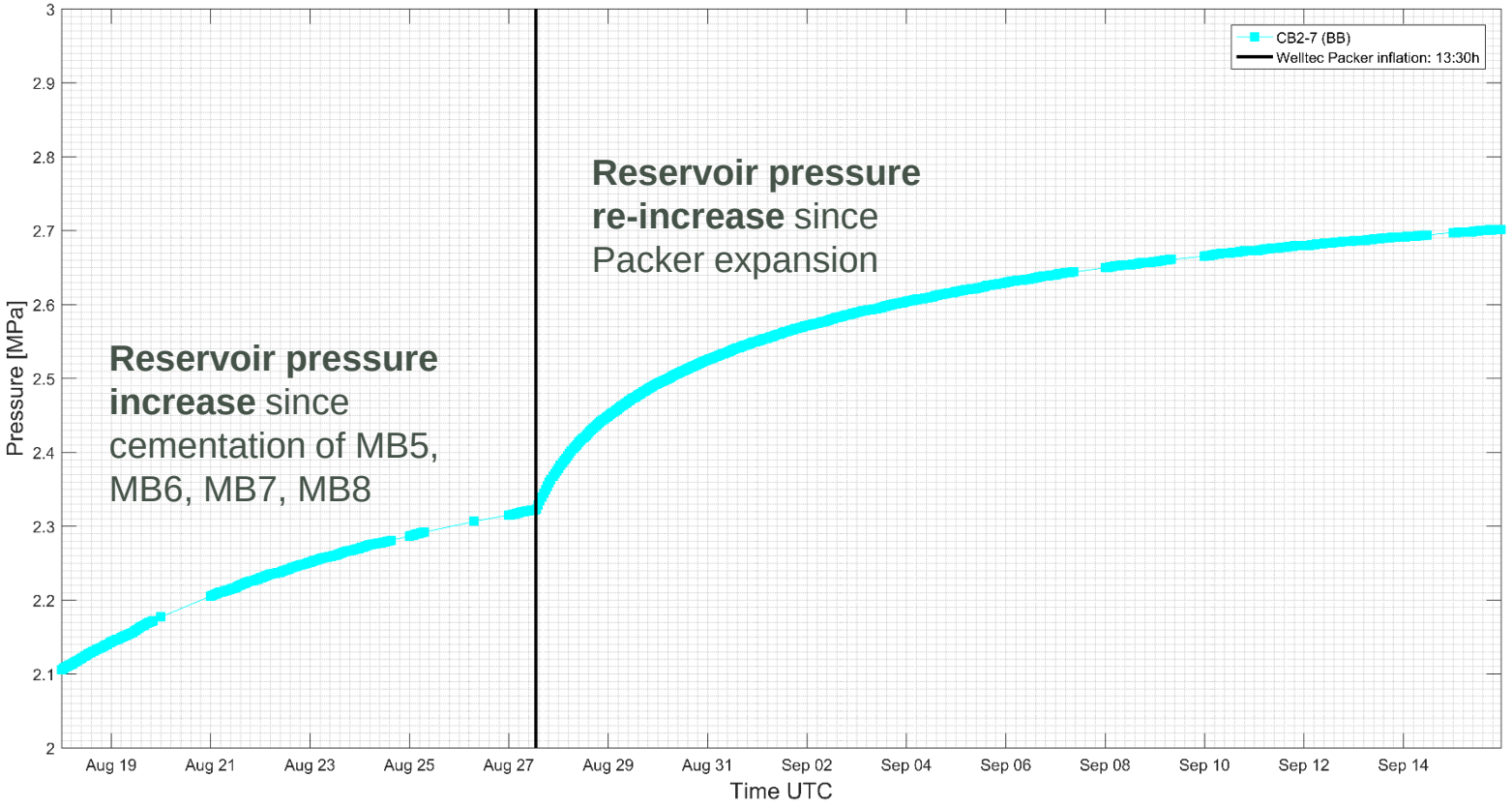
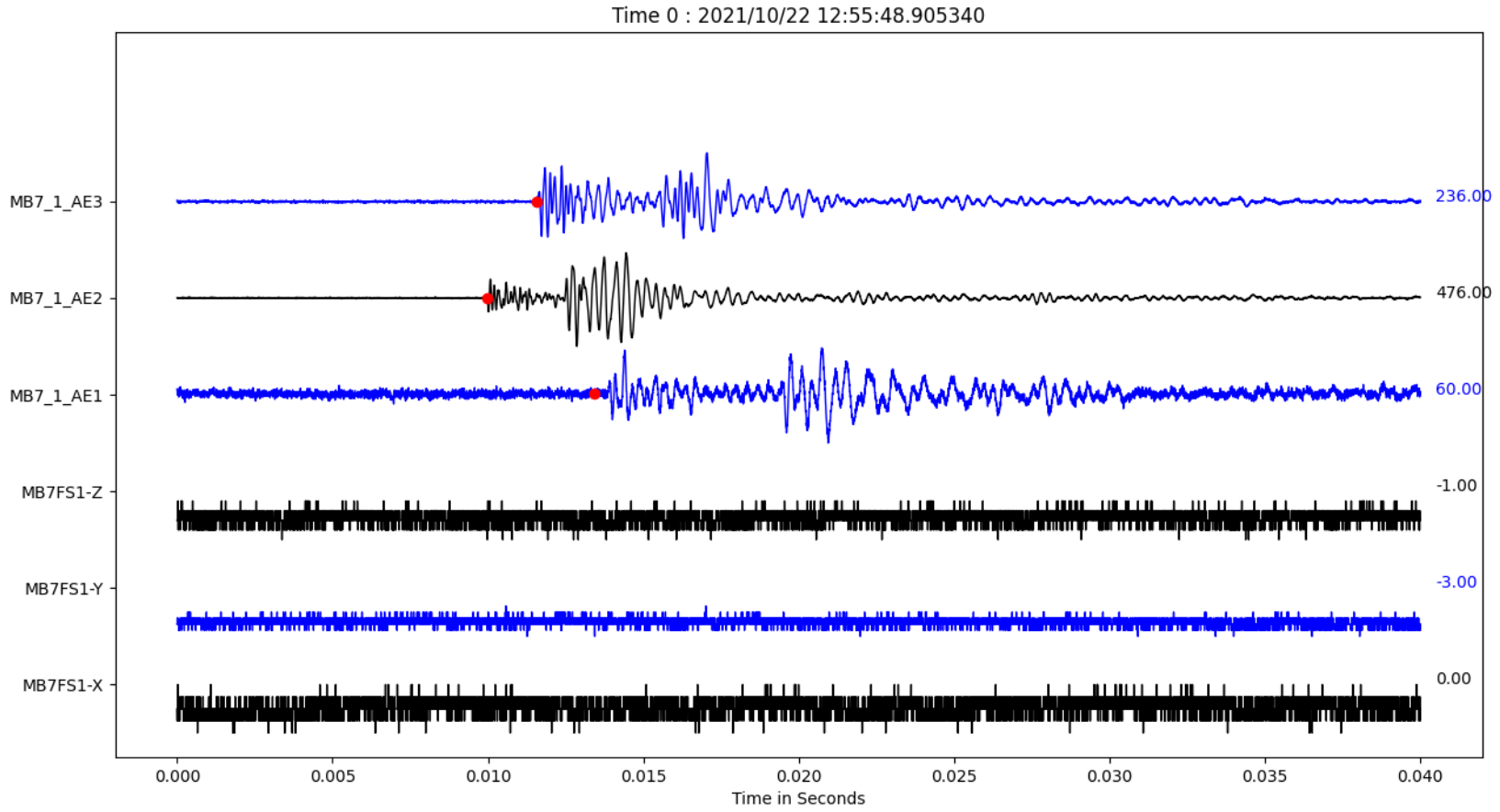
- **No ETH seismicity monitoring at that moment**

Reaction in borehole CB2 Interval 7 (Fracture Bad Boy)



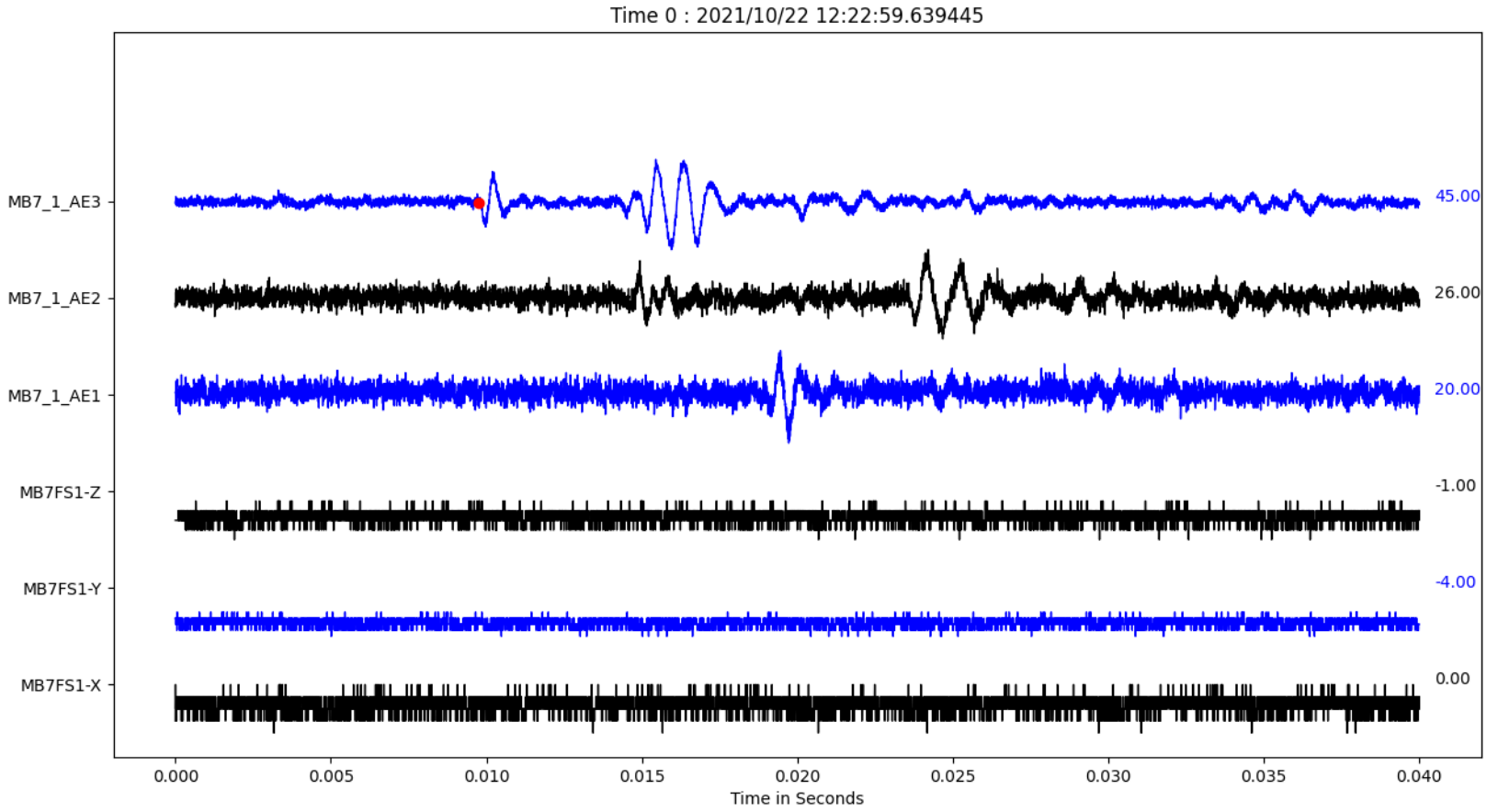
1.a Types of events 22.10-02.11.21

- 1 seismic event detected on several channels and different boreholes.
- Detected first at MB7_1_AE2 and then on MB7_1_AE3 and MB7_1_AE1



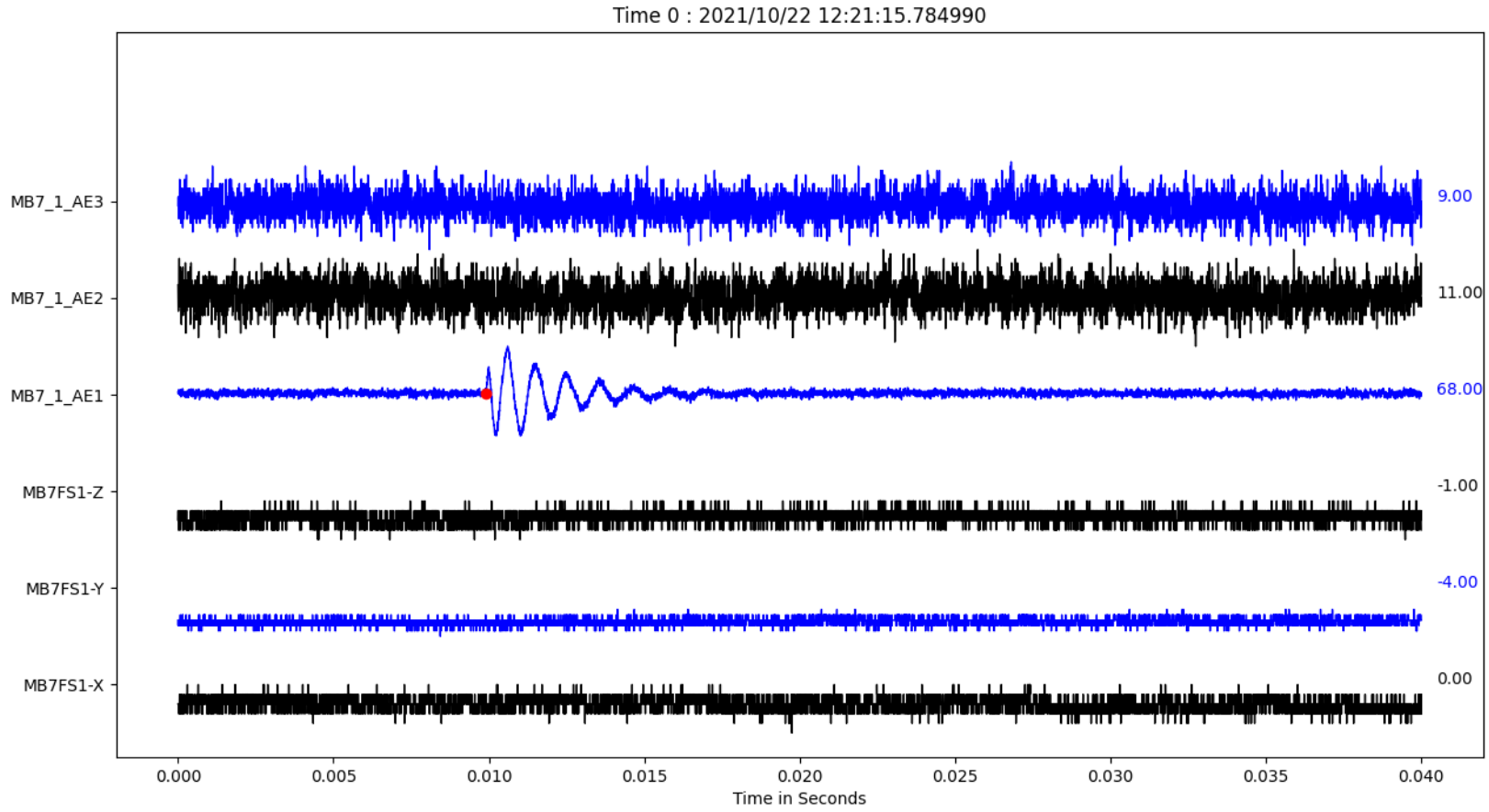
1.b Types of events 22.10-02.11.21

- Seismic events, coming from another place than injection point in Welltec borehole (from tunnel?)
- First arrival at AE3 (depth 31.107m, distance from injection point 30m)
- Second arrival at AE2 (depth 64.619m, distance from injection point 19m)



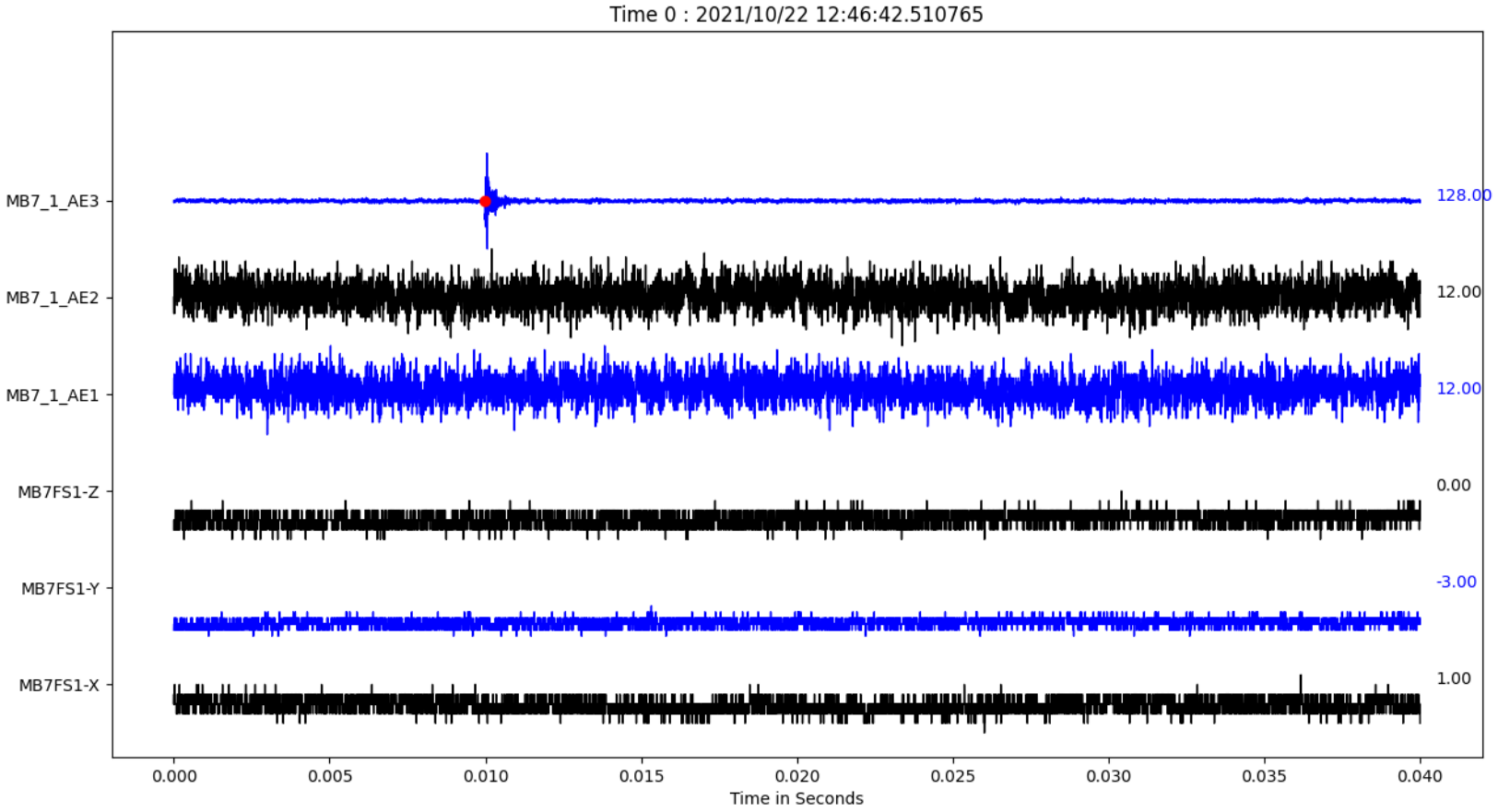
1.c Types of events 22.10-02.11.21

- Recurring signal, detected at a single sensor. We call it “Frac-event”.
- The frequency distingues it from the following Seismic event, detected at a single sensor



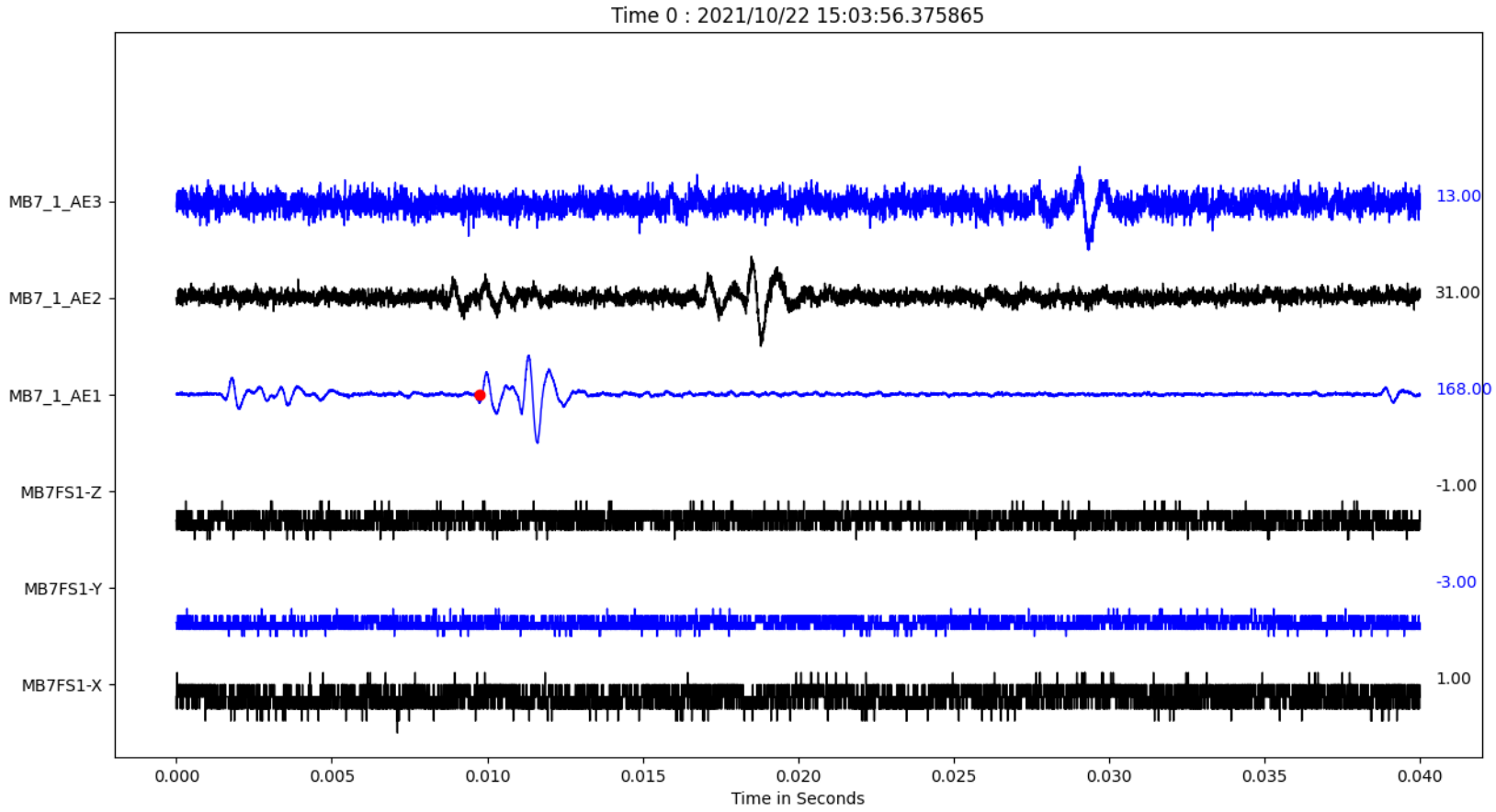
1.d Types of events 22.10-02.11.21

- Recurring signal, detected at a single sensor. We call it “Seismic events, detected at a single sensor”
- The frequency distingues it from the previous Frac-events



1.e Types of events 22.10-02.11.21

- 1 type of event appears only on 22.10, when taking out the hydrochain out of ST2



Analysis Results of seismic events

1. Identification of different types of detected events on sensors in MB7 on 27.08.2021 and 22.10 – 16.11.2021

2. Day by Day analysis of:
    1. Different types of detected events on sensors in MB7 with various activities in the laboratory (what was injected, what was observed, is there a correlation?)
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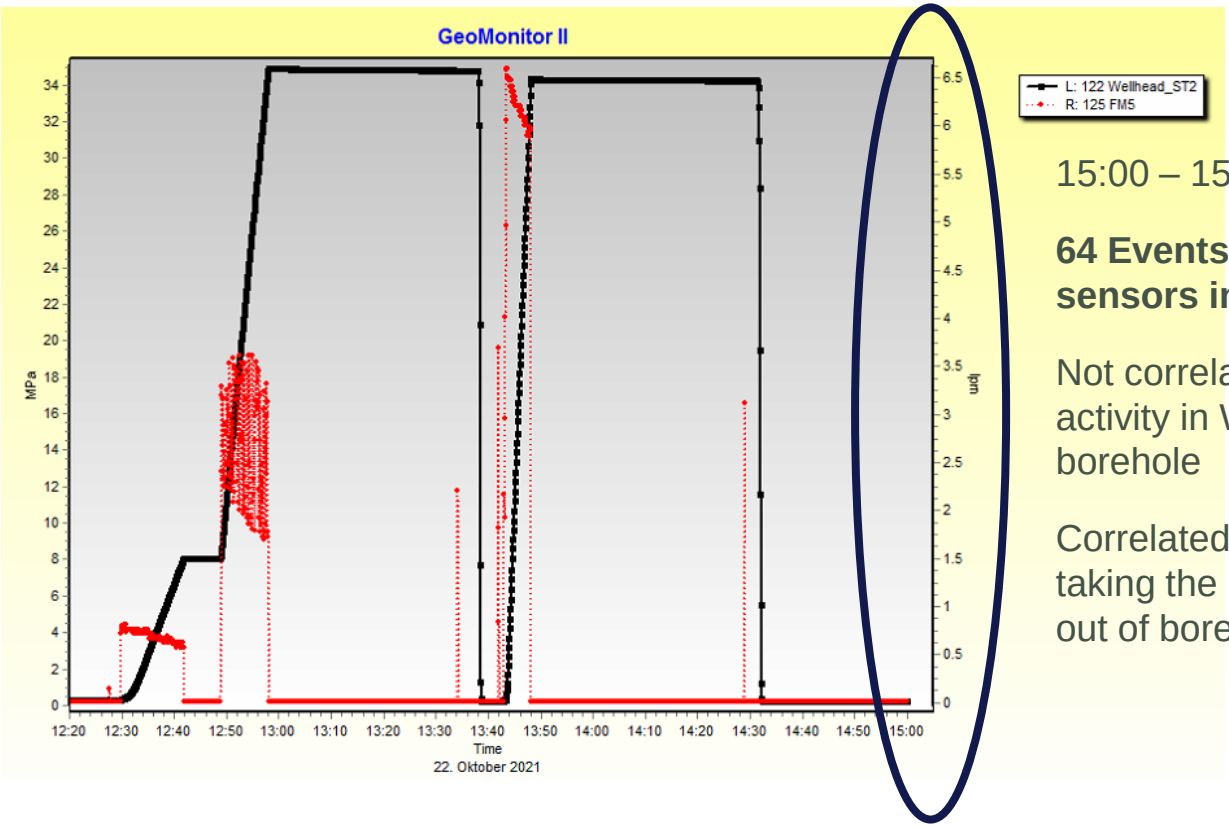
2.1 Interval 1 Hydrotest 22.10.2021



15:00 – 15:08

64 Events on sensors in MB7

Not correlated with activity in Welltec borehole

Correlated with taking the hydrochain out of borehole ST2

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

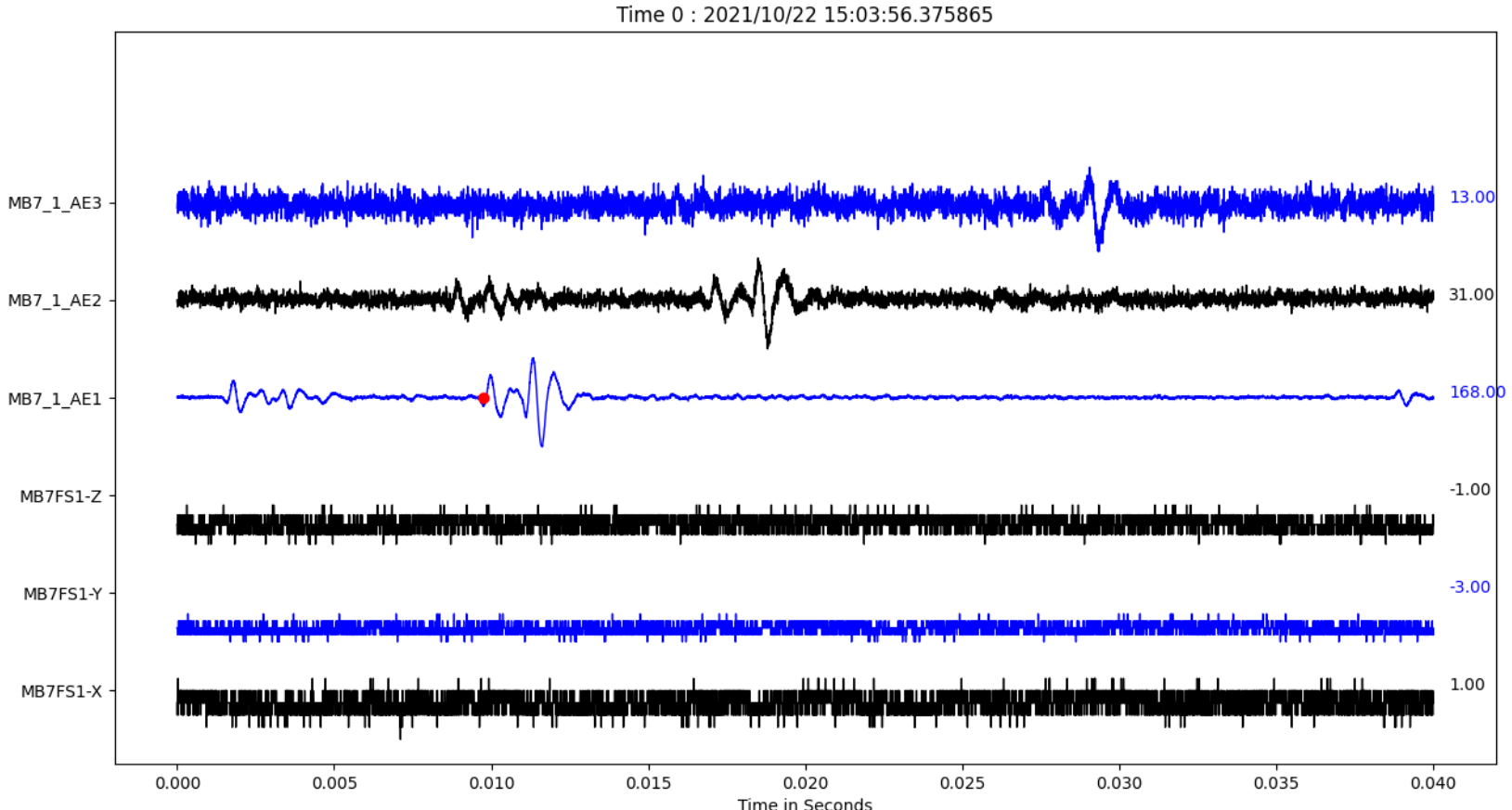
Injection: 12:29 – 12:41 Shut-in: 12:41 – 12:48

Injection: 12:48 – 12:58 Shut-in: 12:58 – 13:38

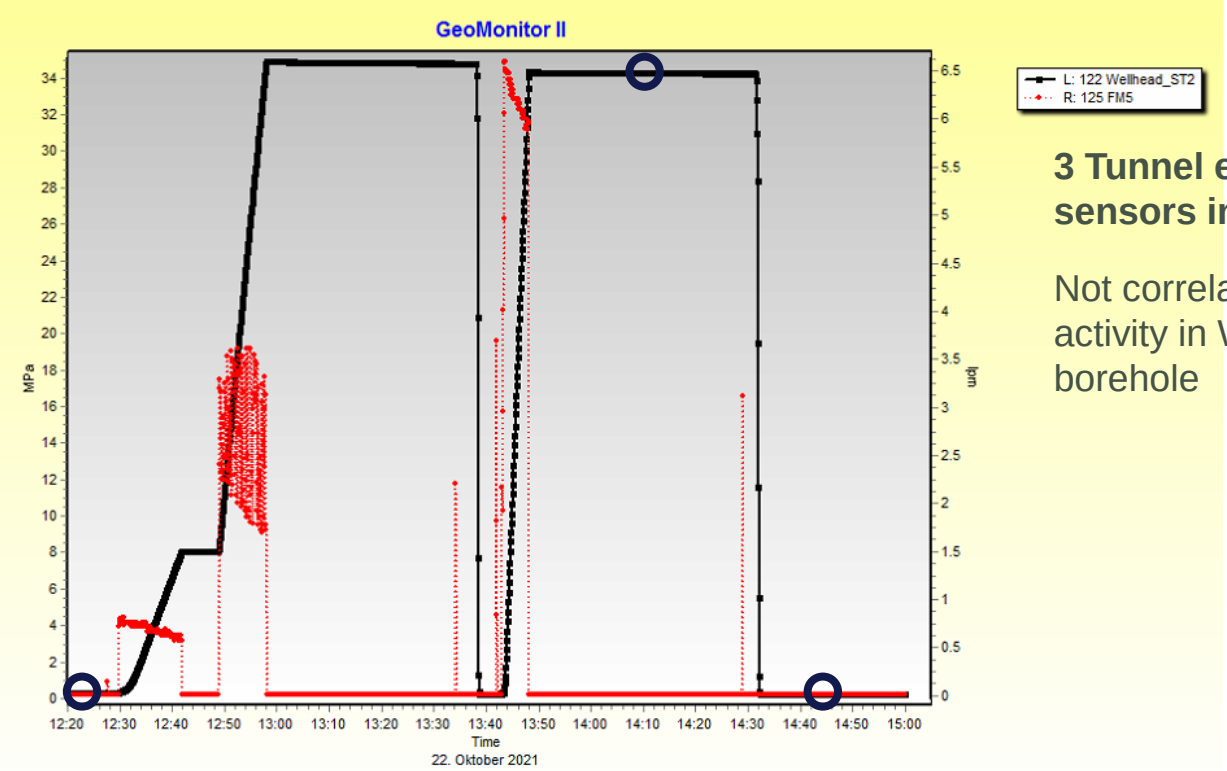
Injection: 13:43 – 13:48 Shut-in: 13:48 – 14:31

2.1 Interval 1 Hydrotest 22.10.2021

- 15:00 – 15:08 64 events detected on sensors in MB7, also detected in MB1, MB3, MB5, MB8
- During this time interval, the first signal is detected at different sensors. We see the signal moving upwards with time
- Not correlated with activity in Welltec borehole but correlated with taking the hydrochain out of ST2



2.1 Interval 1 Hydrotest 22.10.2021



3 Tunnel events on sensors in MB7

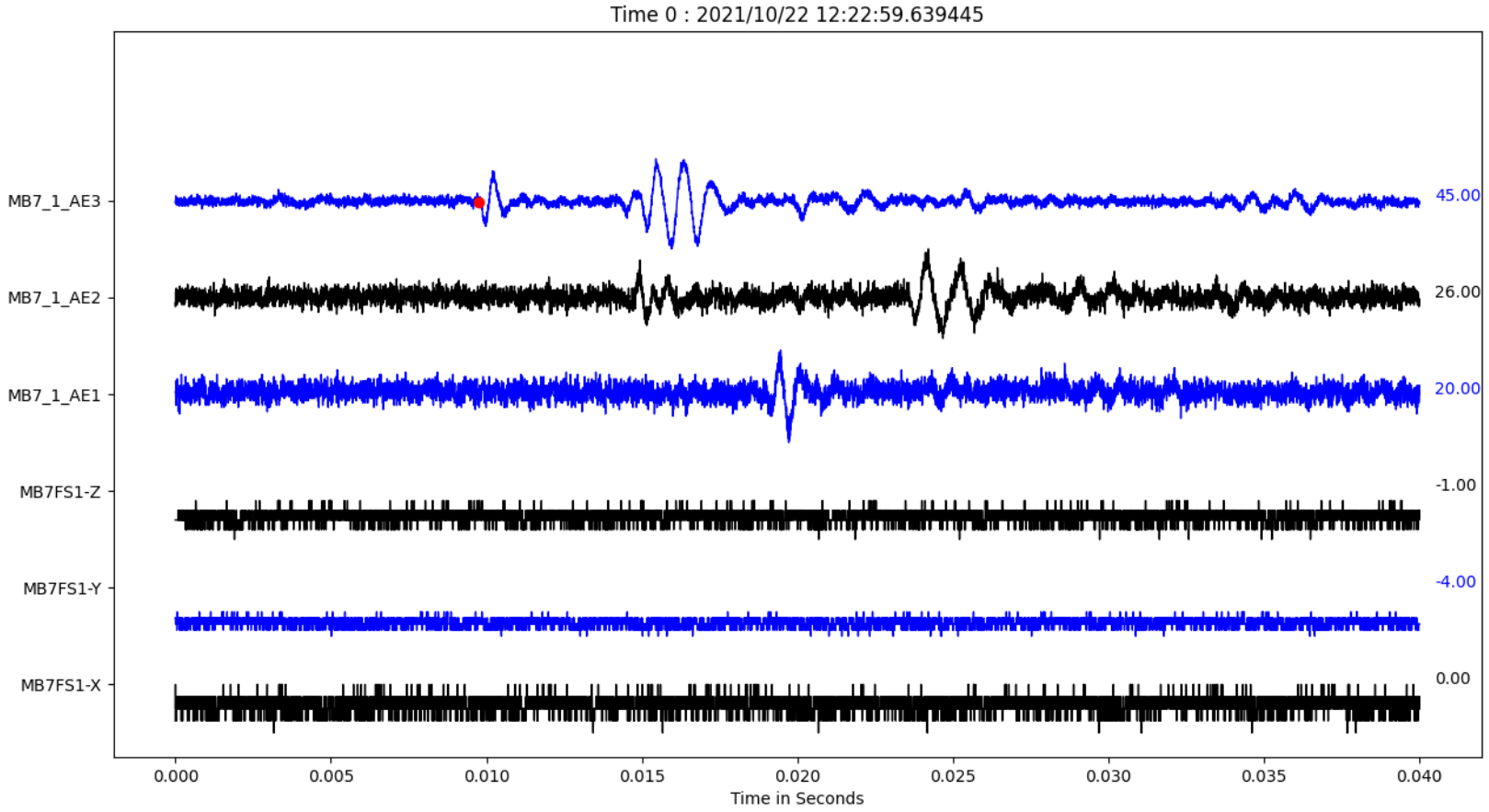
Not correlated with activity in Welltec borehole

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

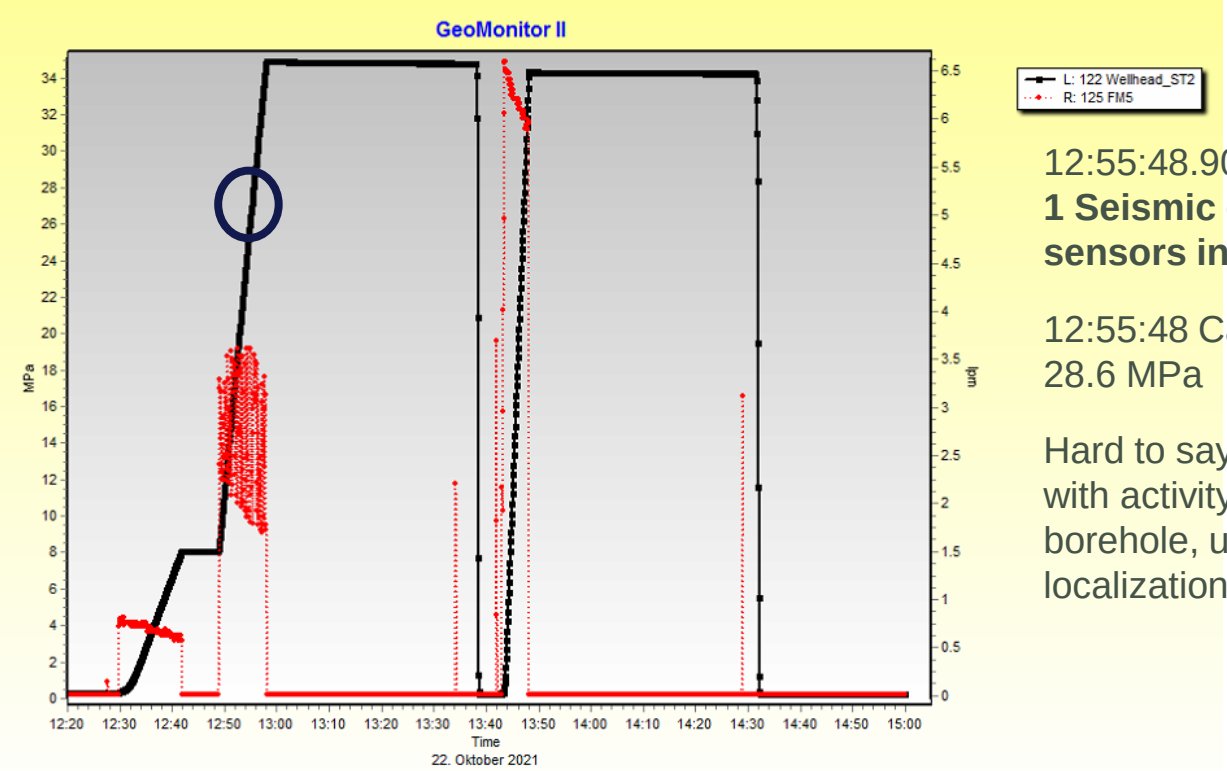
Injection: 12:29 – 12:41	Shut-in: 12:41 – 12:48
Injection: 12:48 – 12:58	Shut-in: 12:58 – 13:38
Injection: 13:43 – 13:48	Shut-in: 13:48 – 14:31

2.1 Interval 1 Hydrotest 22.10.2021

- 3 events detected on sensors in MB7, also detected in MB3, MB5, MB8
- First arrival at AE3, Second arrival at AE2. Thus probably coming from another place than injection point in Welltec borehole (from tunnel?)



2.1 Interval 1 Hydrotest 22.10.2021



12:55:48.905340
1 Seismic event on sensors in MB7

12:55:48 Casing pressure 28.6 MPa

Hard to say if correlated with activity in Welltec borehole, unless its localization is known

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

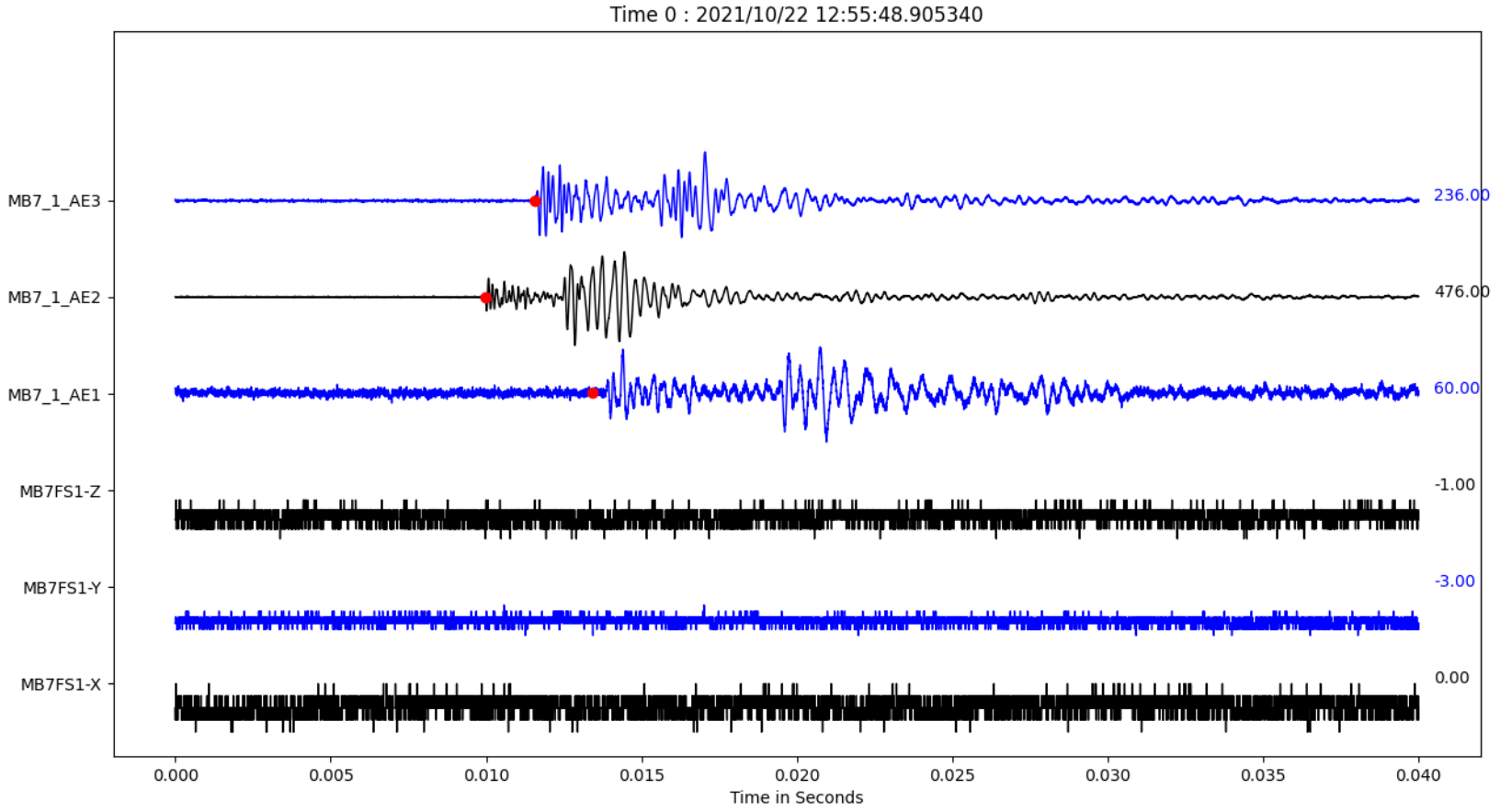
Injection: 12:29 – 12:41 Shut-in: 12:41 – 12:48

Injection: 12:48 – 12:58 Shut-in: 12:58 – 13:38

Injection: 13:43 – 13:48 Shut-in: 13:48 – 14:31

2.1 Interval 1 Hydrotest 22.10.2021

- 12:55:48.905340 1 Seismic event detected on sensors in MB7
- 12:55:48 Casing pressure 28.6 MPa
- Hard to say if correlated with activity in Welltec borehole, unless its localization is known



2.2 Interval 1 Hydrotest 22.10.2021

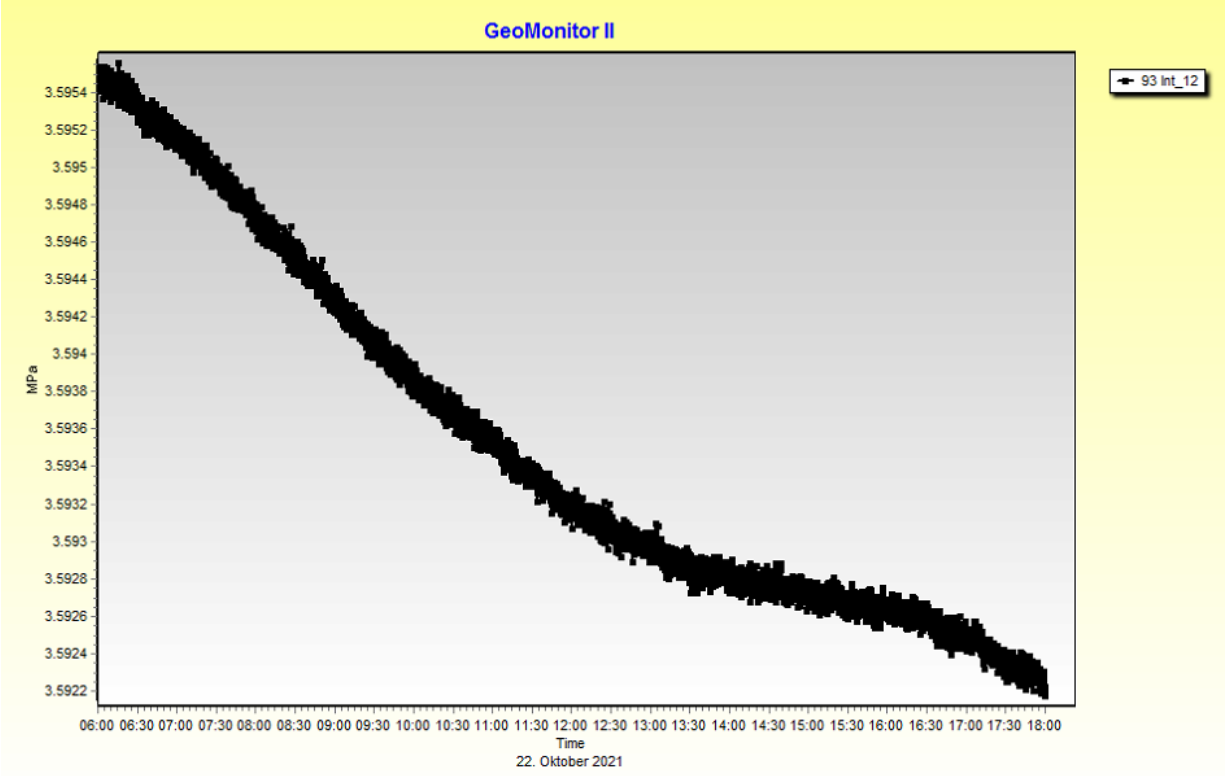
Welltec interval	Activity	Date Time	Duration (min)	Number of "Frac-events"	"Frac-events" rate per min	Seismic Events at single sensor	"Single Sensor Seismic-events" rate per min	Inflow Interval (Injection) (l/min)	Interval uphole pressure (Mpa)	Welltec annulus outflow (l/min)
1	Shut-in	22.10.2021 12:21	8.00	7	0.87	0	0.00		0.29	2.59
1	Injection-test	22.10.2021 12:29	12.00	7	0.58	1	0.08	0.65	8.01	No meas.
1	Shut-in	22.10.2021 12:41	7.00	4	0.57	1	0.14		8.02	No meas.
1	Injection-test	22.10.2021 12:48	10.00	4	0.40	2	0.20	2.5	34.9	No meas.
1	Shut-in	22.10.2021 12:58	40.15	18	0.45	5	0.12		34.78	2.5
1	Opening Shut-in valve	22.10.2021 13:38	3.68	0	0.00	0	0.00		0.21	No meas.
1	Shut-in	22.10.2021 13:41	1.17	0	0.00	0	0.00		0.22	No meas.
1	Injection-test	22.10.2021 13:43	5.22	2	0.38	0	0.00	6.5	34.31	No meas.
1	Shut-in	22.10.2021 13:48	43.30	24	0.55	4	0.09		34.23	2.49
1	Opening Shut-in valve	22.10.2021 14:31	66.48	26	0.39	5	0.08		0.23	2.49
	End events observation	22.10.2021 15:38								

- Red = higher than Standard-deviation, Blue = lower than Standard-deviation
- “Frac-events”: no visible correlation with Activity
- “Single Sensor Seismic-events”: no visible correlation with Activity

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

Statistics "Frac-events"	Statistics "Single Sensor Seismic-events"
Mean	Mean
0.42	0.07
Standard-dev	Standard-dev
0.25	0.07

2.2 Interval 1 Reaction ST1 Interval 12



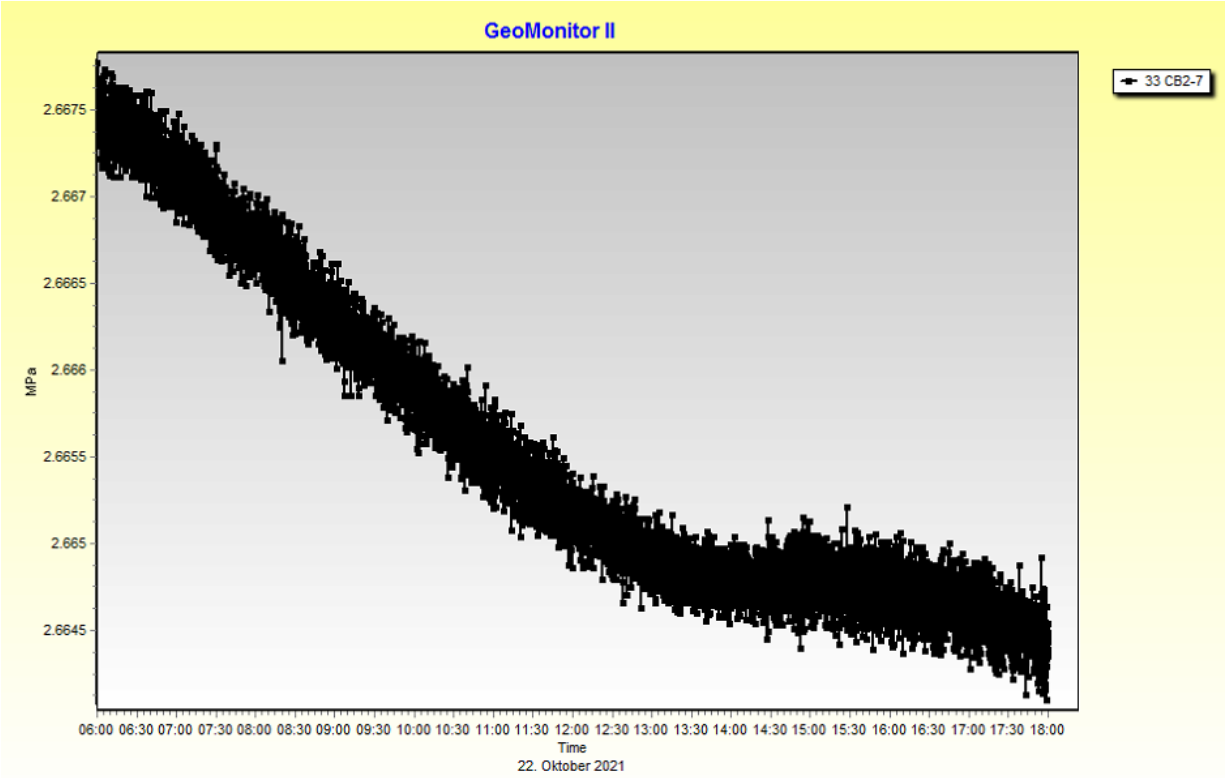
Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

Injection: 12:29 – 12:41 Shut-in: 12:41 – 12:48

Injection: 12:48 – 12:58 Shut-in: 12:58 – 13:38

Injection: 13:43 – 13:48 Shut-in: 13:48 – 14:31

2.2 Interval 1 Reaction CB2 Interval 7



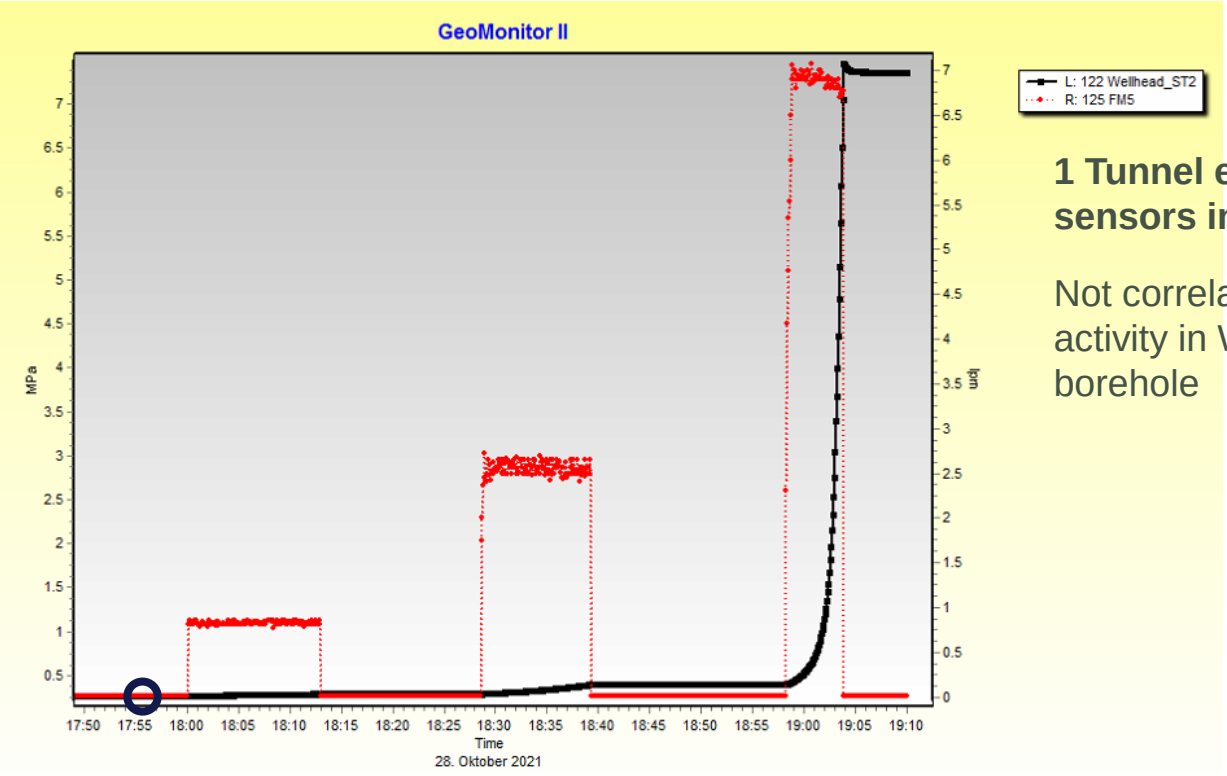
Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

Injection: 12:29 – 12:41 Shut-in: 12:41 – 12:48

Injection: 12:48 – 12:58 Shut-in: 12:58 – 13:38

Injection: 13:43 – 13:48 Shut-in: 13:48 – 14:31

2.1 Interval 1 Hydrotest 28.10.2021



1 Tunnel event on sensors in MB7

Not correlated with activity in Welltec borehole

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

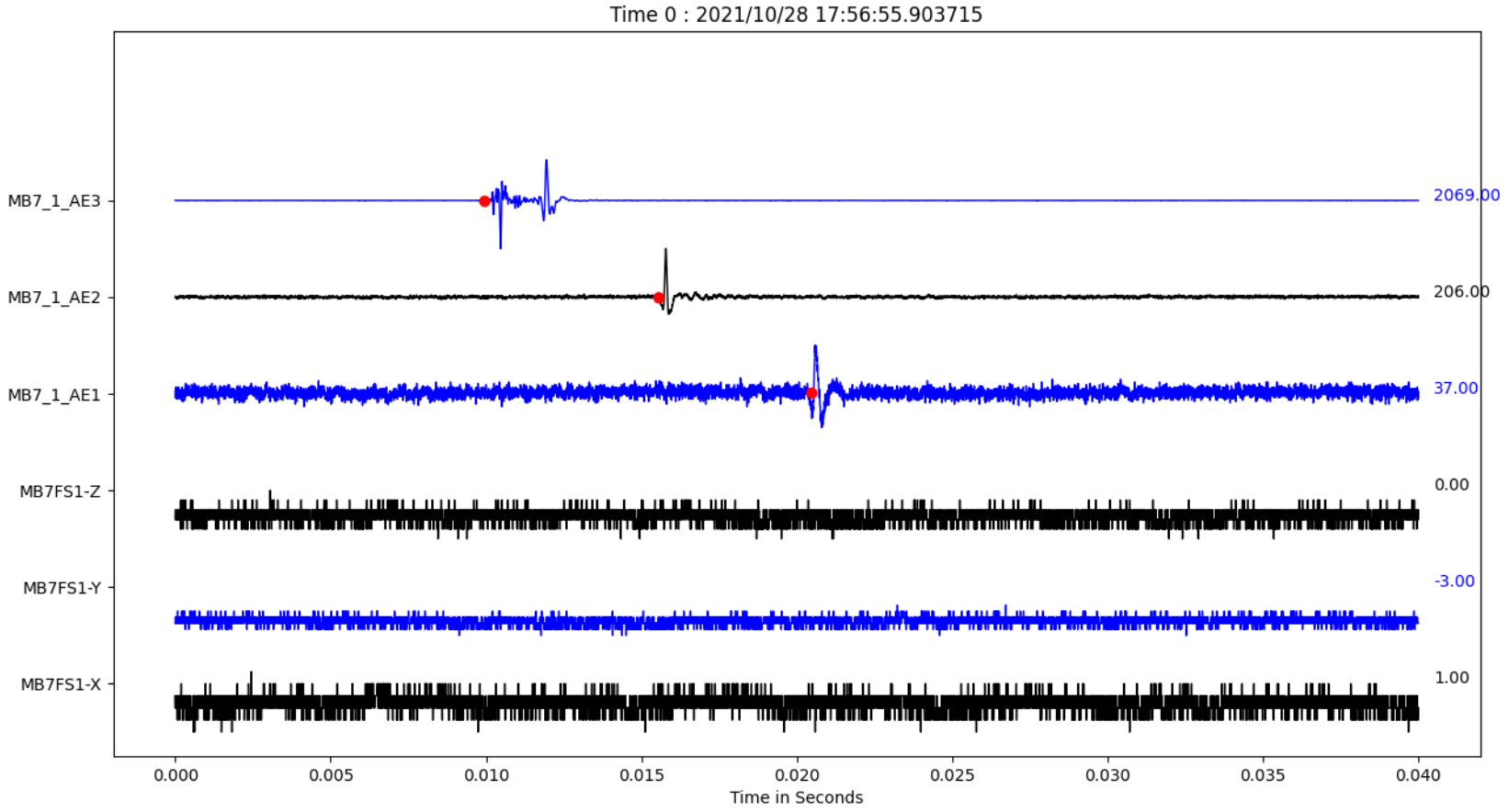
Injection: 18:00 – 18:12 Shut-in: 18:12 – 18:28

Injection: 18:28 – 18:39 Shut-in: 18:39 – 18:58

Injection: 18:58 – 19:03 Shut-in: 19:03 – 08:21

2.1 Interval 1 Hydrotest 28.10.2021

- 1 event detected detected on sensors in MB7, also detected MB3, MB5, MB8
- First arrival at AE3, Second arrival at AE2. Thus probably coming from another place than injection point in Welltec borehole (from tunnel?)



2.2 Interval 1 Hydrotest 28.10.2021

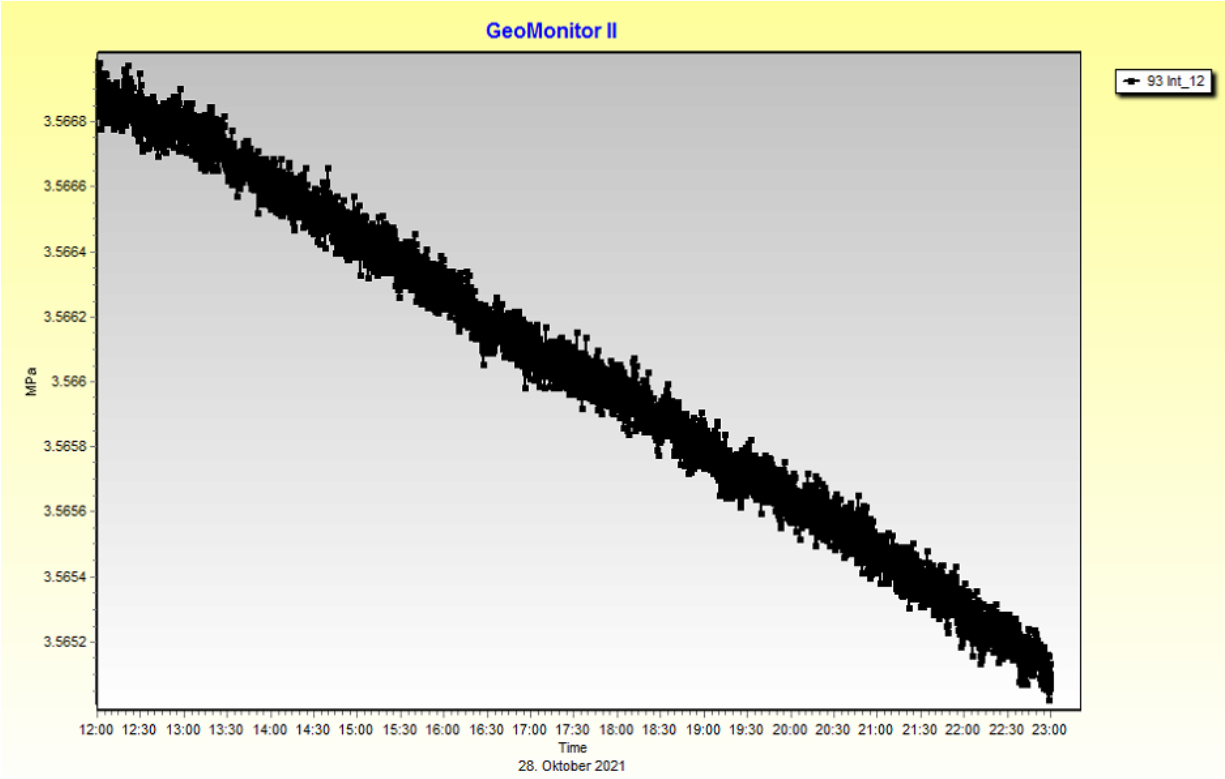
Welltec interval	Activity	Date Time	Duration (min)	Number of "Frac-events"	"Frac-events" rate per min	Seismic Events at single sensor	"Single Sensor Seismic-events" rate per min	Inflow Interval (Injection) (l/min)	Interval uphole pressure (Mpa)	Welltec annulus outflow (l/min)
1	Shut-in	28.10.2021 17:51	9.07	5	0.55	1	0.11		0.27	2.32
1	Injection-test	28.10.2021 18:00	12.87	5	0.39	1	0.08	0.83	0.29	2.42
1	Shut-in	28.10.2021 18:12	15.62	7	0.45	3	0.19		0.29	2.5
1	Injection-test	28.10.2021 18:28	10.68	4	0.37	2	0.19	2.6	0.39	2.46
1	Shut-in	28.10.2021 18:39	18.97	14	0.74	0	0.00		0.39	2.51
1	Injection-test	28.10.2021 18:58	5.68	2	0.35	0	0.00	7	7.46	2.99
1	Shut-in	28.10.2021 19:03	55.12	38	0.69	7	0.13		7.6	2.5
	End events observation	28.10.2021 19:59								

- Red = higher than Standard-deviation, Blue = lower than Standard-deviation
- “Frac-events”: higher rate per min during shut-in
- “Single Sensor Seismic-events”: no visible correlation with Activity
- Lower rates of “Frac-events” and “Single Sensor Seismic-events” when the annulus outflow is high (2.99 l/min)

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

Statistics "Frac-events"	Statistics "Single Sensor Seismic-events"
Mean	Mean
0.51	0.10
Standard-dev	Standard-dev
0.15	0.07

2.2 Interval 1 Reaction ST1 Interval 12



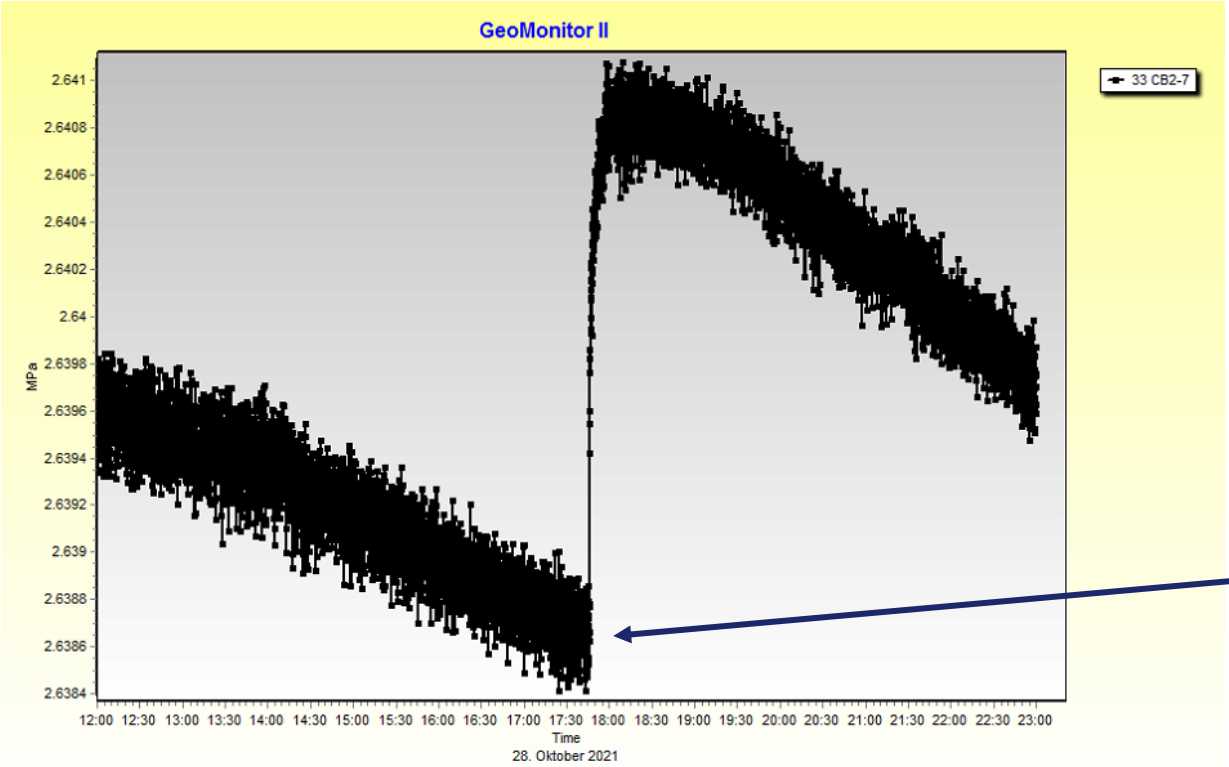
Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

Injection: 18:00 – 18:12 Shut-in: 18:12 – 18:28

Injection: 18:28 – 18:39 Shut-in: 18:39 – 18:58

Injection: 18:58 – 19:03 Shut-in: 19:03 – 08:21

2.2 Interval 1 Reaction CB2 Interval 7



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Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

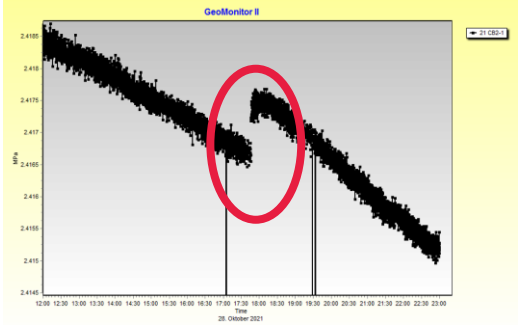
Injection: 18:00 – 18:12 Shut-in: 18:12 – 18:28

Injection: 18:28 – 18:39 Shut-in: 18:39 – 18:58

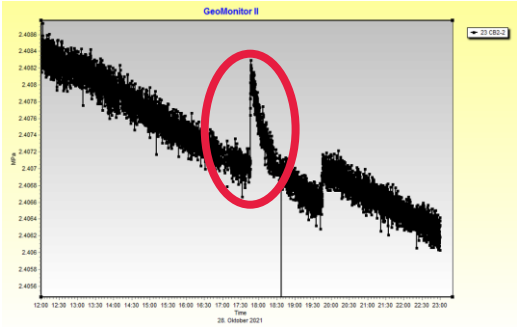
Injection: 18:58 – 19:03 Shut-in: 19:03 – 08:21

2.2 Interval 1 Reaction CB2 other Intervals

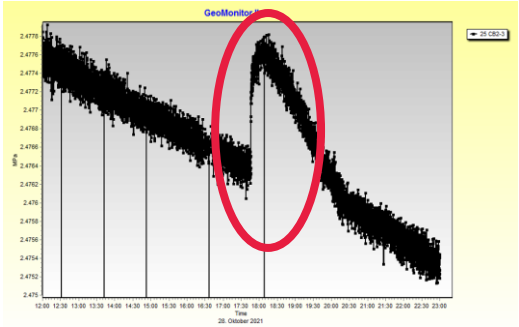
CB2-1



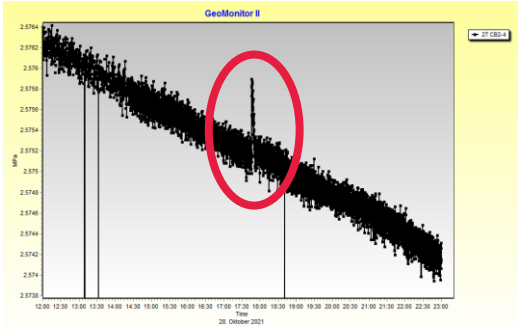
CB2-2



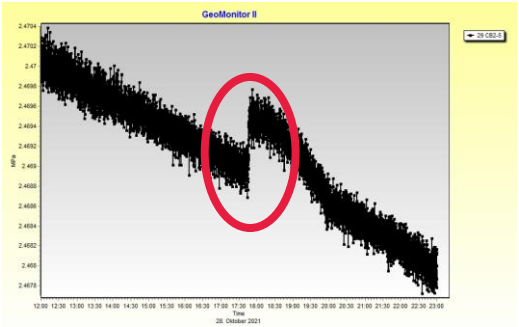
CB2-3



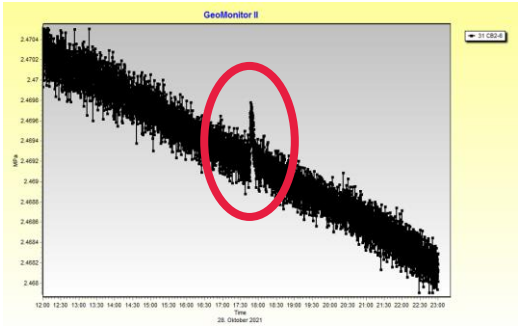
CB2-4



CB2-5

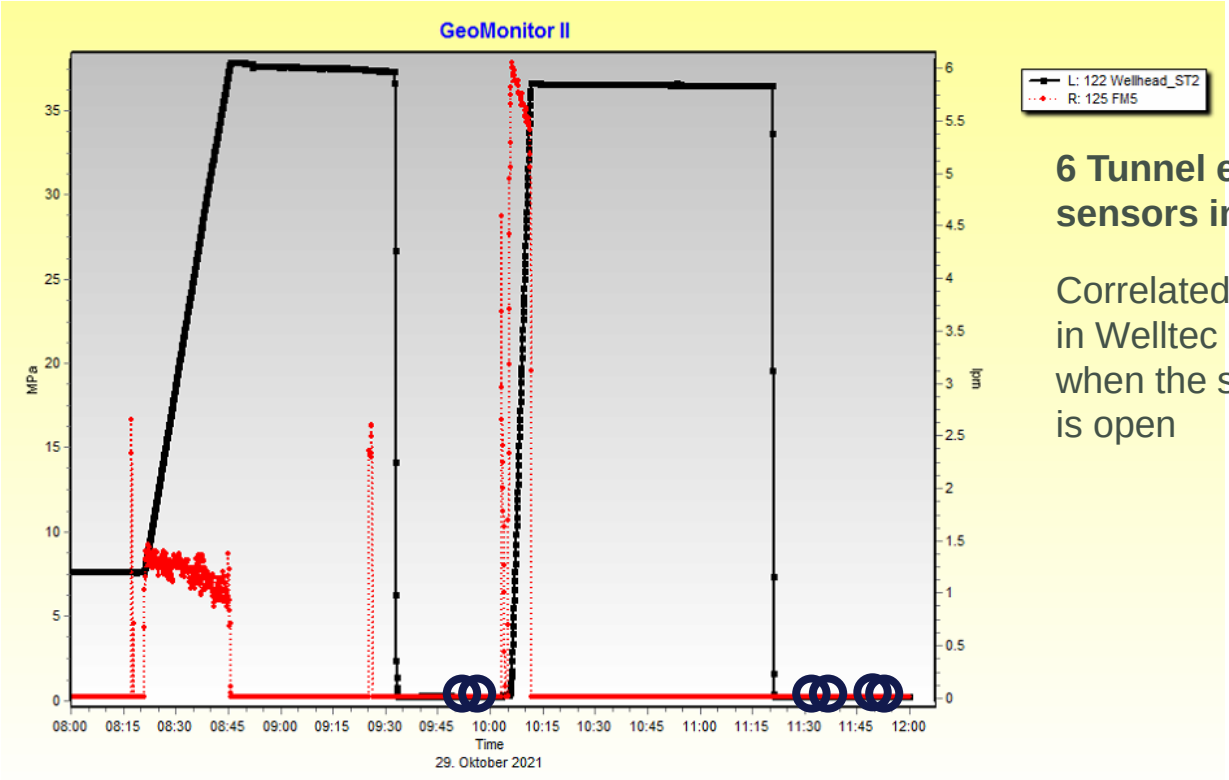


CB2-6



- What happened on 28.10.2021 around 17:46?
  - Installation of pressure sensor at wellhead Welltec borehole
  - Other possibilities??

2.1 Interval 1 Frac 29.10.2021



6 Tunnel events on sensors in MB7

Correlated with activity in Welltec borehole, when the shut-in valve is open

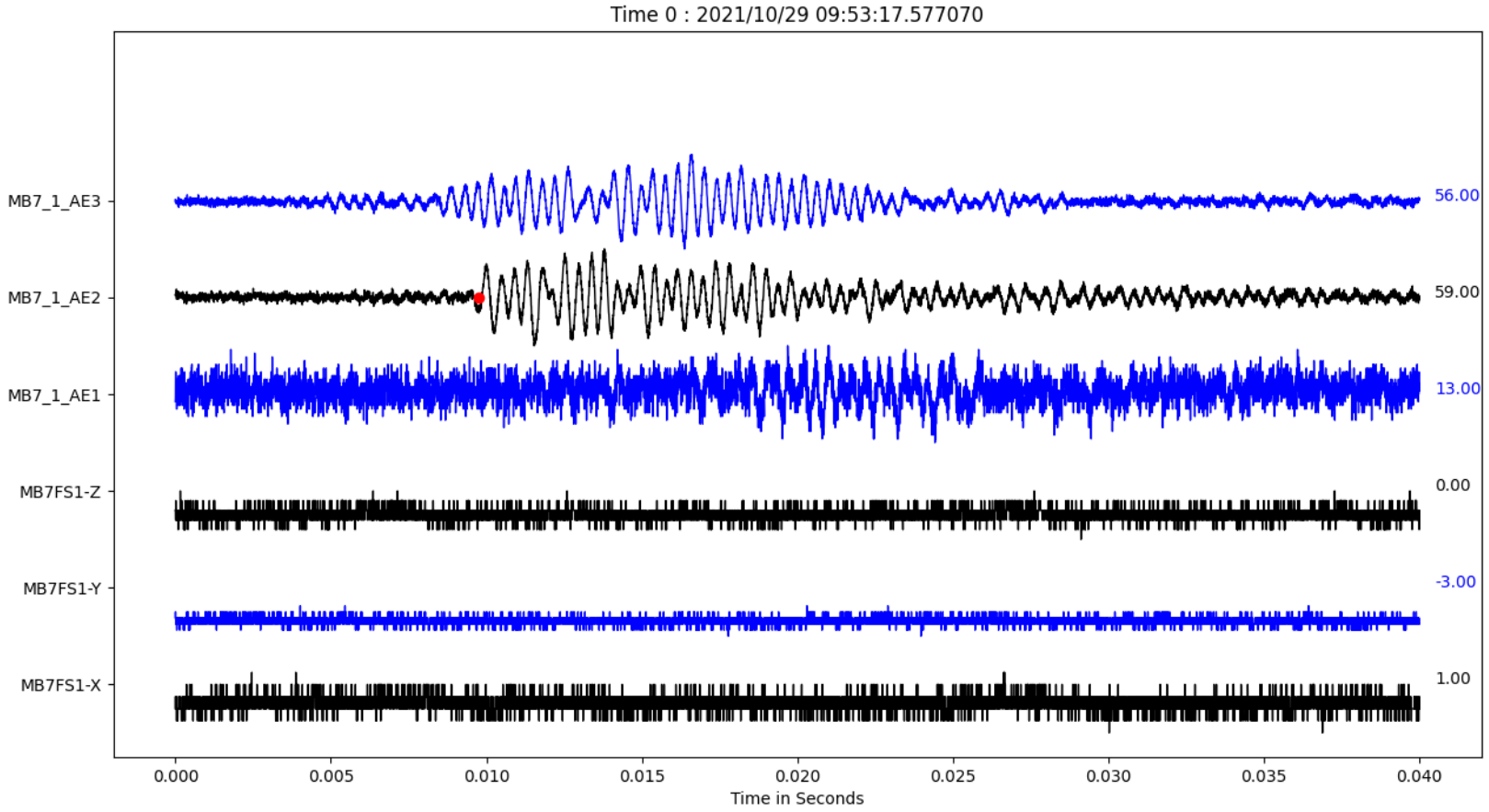
Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

Injection: 08:21 – 08:45 Shut-in: 08:45 – 09:32

Injection: 10:05 – 10:11 Shut-in: 10:11 – 11:20

2.1 Interval 1 Frac 29.10.2021

- 6 events detected detected on sensors in MB7, also detected in MB3, MB5, MB8
- First arrival at AE3, Second arrival at AE2. Thus probably coming from another place than injection point in Welltec borehole (from tunnel?)



2.2 Interval 1 Frac 29.10.2021

Welltec interval	Activity	Date Time	Duration (min)	Number of "Frac-events"	"Frac-events" rate per min	Seismic Events at single sensor	"Single Sensor Seismic-events" rate per min	Inflow Interval (Injection) (l/min)	Interval uphole pressure (Mpa)	Welltec annulus outflow (l/min)
1	Shut-in	29.10.2021 08:17	4.67	2	0.43	2	0.43		7.6	2.52
1	Frac-cycle 1	29.10.2021 08:21	23.95	6	0.25	1	0.04	1.3	37.81	2.58
1	Shut-in	29.10.2021 08:45	46.85	25	0.53	7	0.15		37.27	2.34
1	Opening Shut-in valve	29.10.2021 09:32	31.52	9	0.29	3	0.10		0.23	2.5
1	Shut-in	29.10.2021 10:03	1.33	0	0.00	0	0.00		0.27	No meas.
1	Frac-cycle 2	29.10.2021 10:05	6.15	5	0.81	1	0.16	5.9	36.61	3.03
1	Shut-in	29.10.2021 10:11	69.38	38	0.55	13	0.19		36.47	2.3
1	Opening Shut-in valve	29.10.2021 11:20	37.15	19	0.51	4	0.11		0.22	2.42
	End events observation	29.10.2021 11:58								

- Red = higher than Standard-deviation, Blue = lower than Standard-deviation
- “Frac-events”: higher rates correlated with more outflow from annulus
- “Single Sensor Seismic-events”: no visible correlation

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

- Less outflow through annulus when shut-in, more outflow when injecting
  - Pressure increase inside casing causes a ballooning of the casing, pushing against borehole wall/fractures

Statistics "Frac-events"	Statistics "Single Sensor Seismic-events"
Mean	Mean
0.42	0.15
Standard-dev	Standard-dev
0.23	0.12

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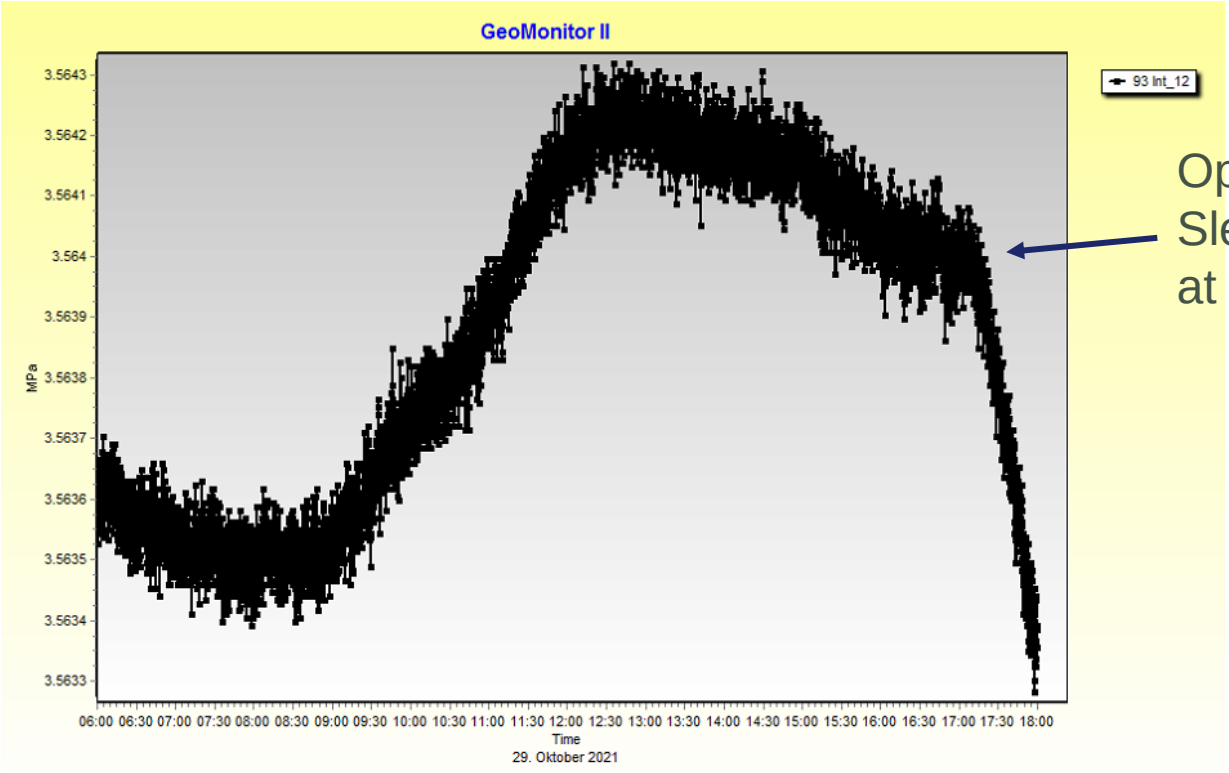
2.2 Interval 1 Reaction ST1 Interval 12



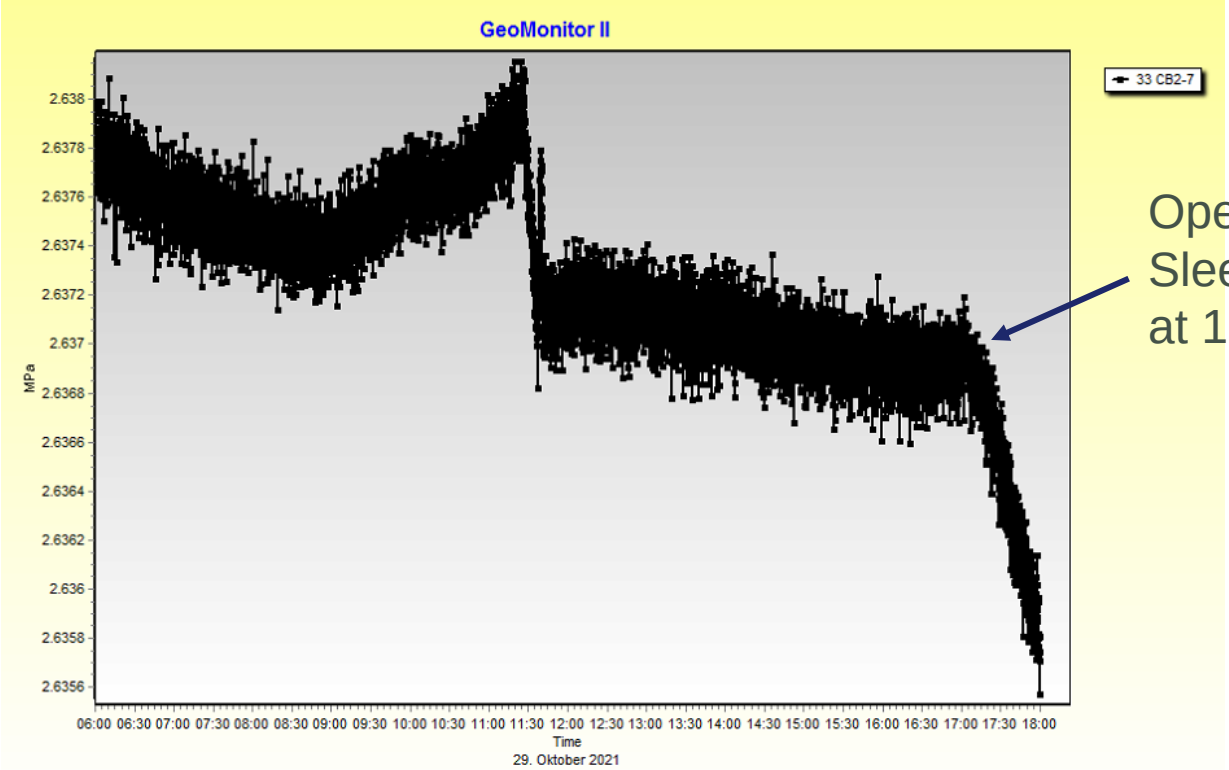
Opening Sliding Sleeve interval 2 at 16:50

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

Injection: 08:21 – 08:45 Shut-in: 08:45 – 09:32

Injection: 10:05 – 10:11 Shut-in: 10:11 – 11:20

2.2 Interval 1 Reaction CB2 Interval 7



Opening Sliding Sleeve interval 2 at 16:50

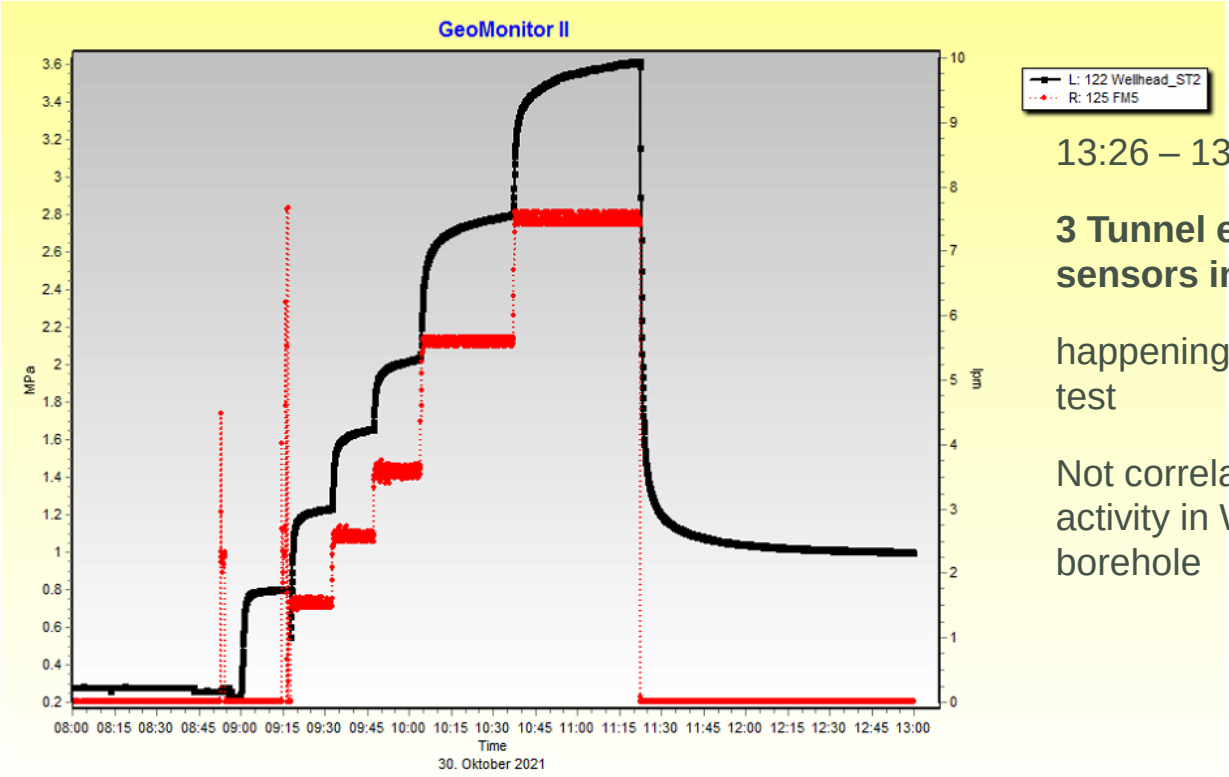
Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

Injection: 08:21 – 08:45 Shut-in: 08:45 – 09:32

Injection: 10:05 – 10:11 Shut-in: 10:11 – 11:20

* No particular reaction at the other intervals of CB2

2.1 Interval 2 Hydrotest 30.10.2021



13:26 – 13:33

3 Tunnel events on sensors in MB7

happening after the test

Not correlated with activity in Welltec borehole

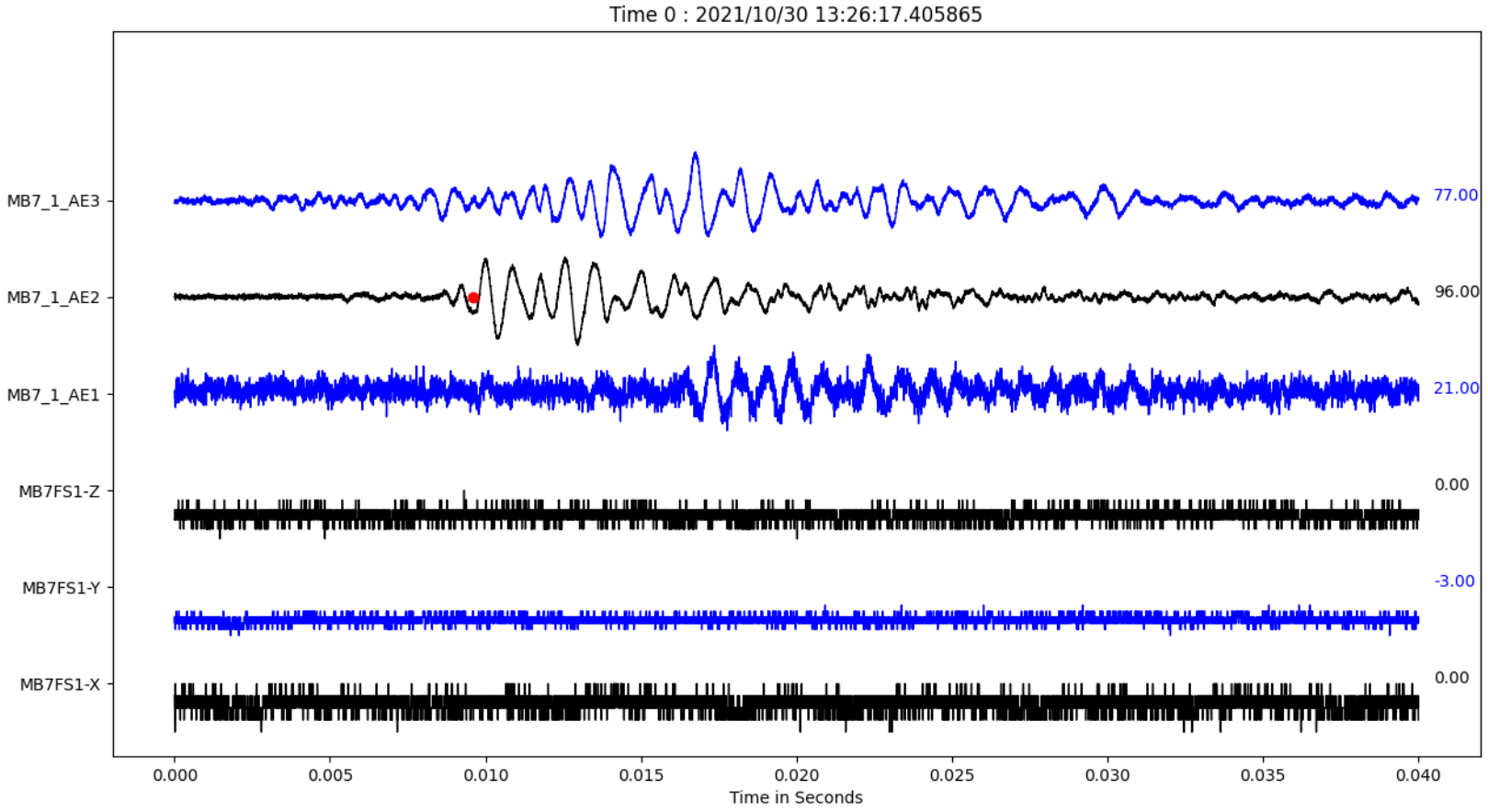
Opening of Sliding Sleeve of Interval 2 succeeded
-> injection into the reservoir/an open system

Injection: 09:17 – 11:21 Shut-in: 11:21 – 13:16

Bypass: 50% of injected flowrate into the interval comes out of annulus between casing and borehole

2.1 Interval 2 Hydrotest 30.10.2021

- 3 events detected detected on sensors in MB7, also detected in MB3, MB5, MB8
- First arrival at AE3, Second arrival at AE2. Thus probably coming from another place than injection point in Welltec borehole (from tunnel?)



2.2 Interval 2 Hydrotest 30.10.2021

Welltec interval	Activity	Date Time	Duration (min)	Number of "Frac-events"	"Frac-events" rate per min	Seismic Events at single sensor	"Single Sensor Seismic-events" rate per min	Inflow Interval (Injection) (l/min)	Interval uphole pressure (Mpa)	Welltec annulus outflow (l/min)
2	Shut-in	30.10.2021 09:10	7.88	1	0.13	0	0.00		0.8	2.39
2	Step-Rate-test Step 1	30.10.2021 09:17	14.63	3	0.21	0	0.00	1.5	1.23	3.18
2	Step-Rate-test Step 2	30.10.2021 09:32	14.92	1	0.07	0	0.00	2.6	1.65	3.75
2	Step-Rate-test Step 3	30.10.2021 09:47	16.52	2	0.12	0	0.00	3.5	2.02	4
2	Step-Rate-test Step 4	30.10.2021 10:03	33.07	3	0.09	0	0.00	5.5	2.79	5.07
2	Step-Rate-test Step 5	30.10.2021 10:37	44.82	12	0.27	1	0.02	7.5	3.61	5.8
2	Shut-in	30.10.2021 11:21	114.27	51	0.45	3	0.03		0.99	No meas.
2	Opening Shut-in valve	30.10.2021 13:16	42.90	5	0.12	5	0.12		0.29	0
	End events observation	30.10.2021 13:59								

- Red = higher than Standard-deviation, Blue = lower than Standard-dev.
- “Frac-events”: no visible correlation
- “Single Sensor Seismic-events”: no visible correlation
- 50% bypass when injecting into the interval, coming out of annulus

Opening of Sliding Sleeve of Interval 2 succeeded
-> injection into the reservoir/an open system

Statistics "Frac-events"	Statistics "Single Sensor Seismic-events"
Mean	Mean
0.18	0.02
Standard-dev	Standard-dev
0.12	0.04

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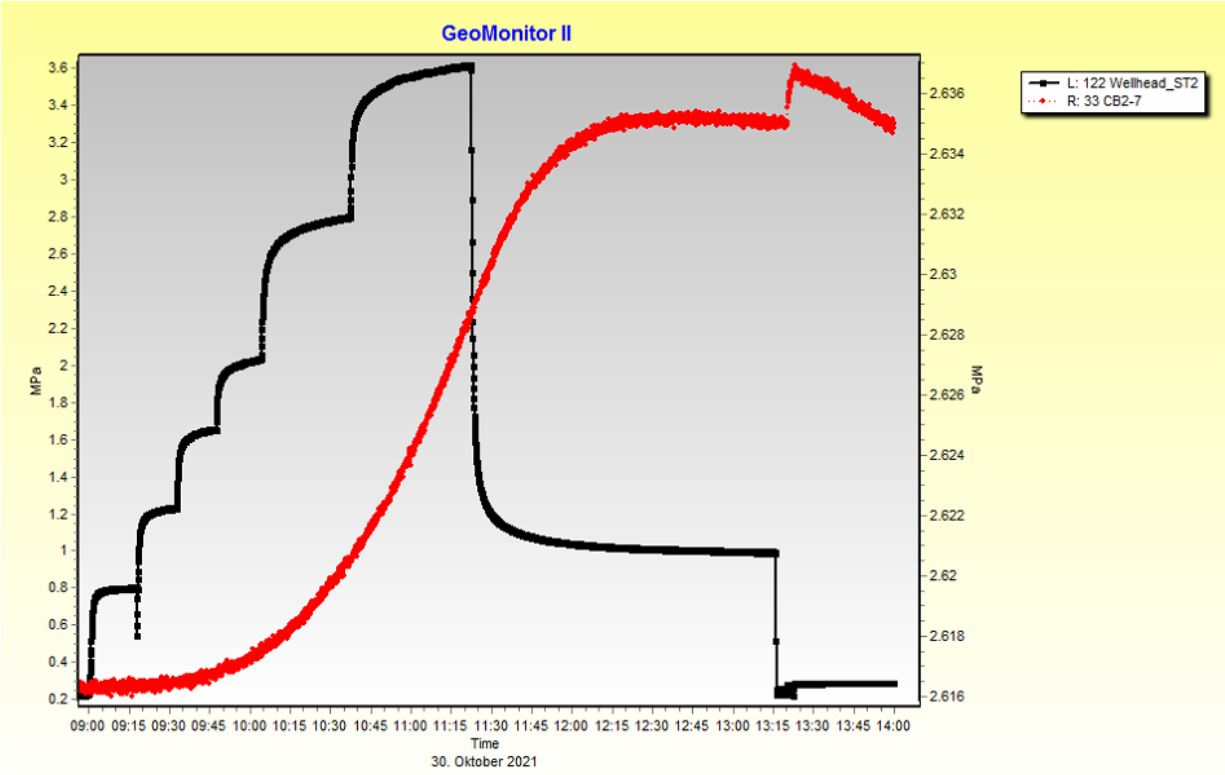
2.2 Interval 2 Reaction CB2 Interval 7

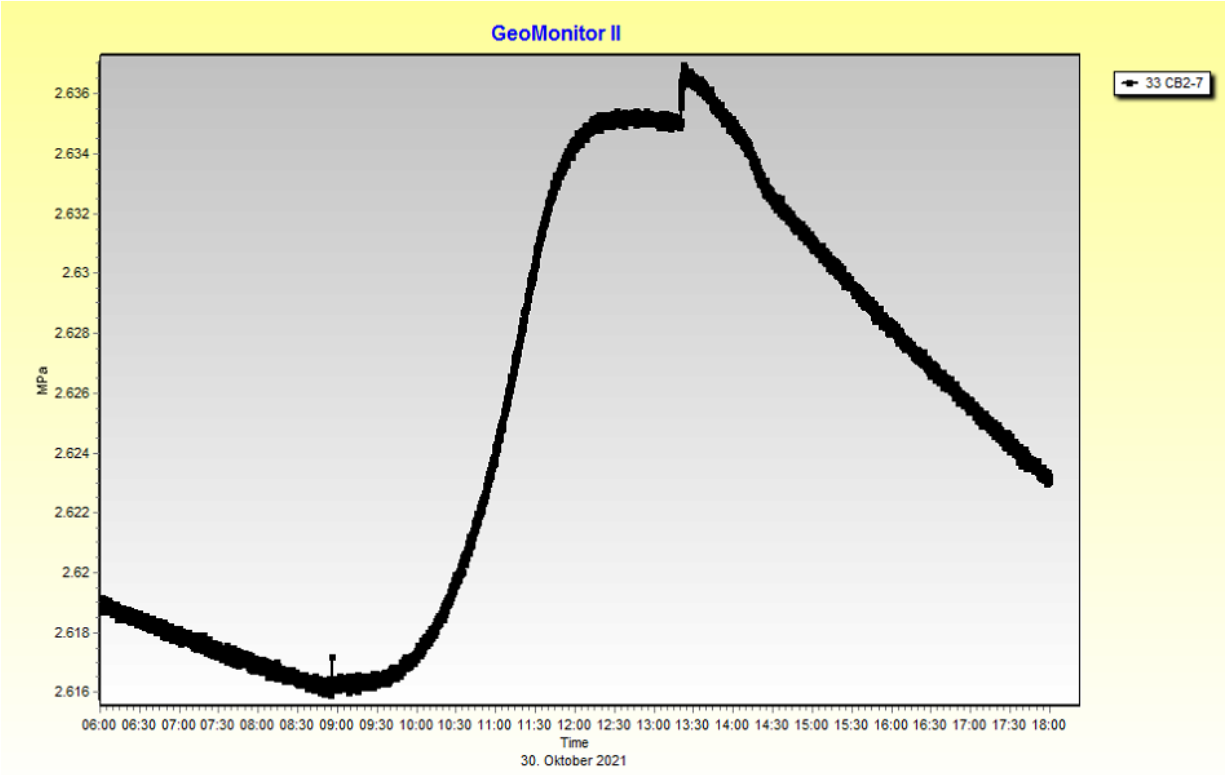


Opening of Sliding Sleeve of Interval 2 succeeded
-> injection into the reservoir/an open system

Injection: 09:17 – 11:21 Shut-in: 11:21 – 13:16

Bypass: 50% of injected flowrate comes out of annulus between casing and borehole

2.2 Interval 2 Reaction CB2 Interval 7

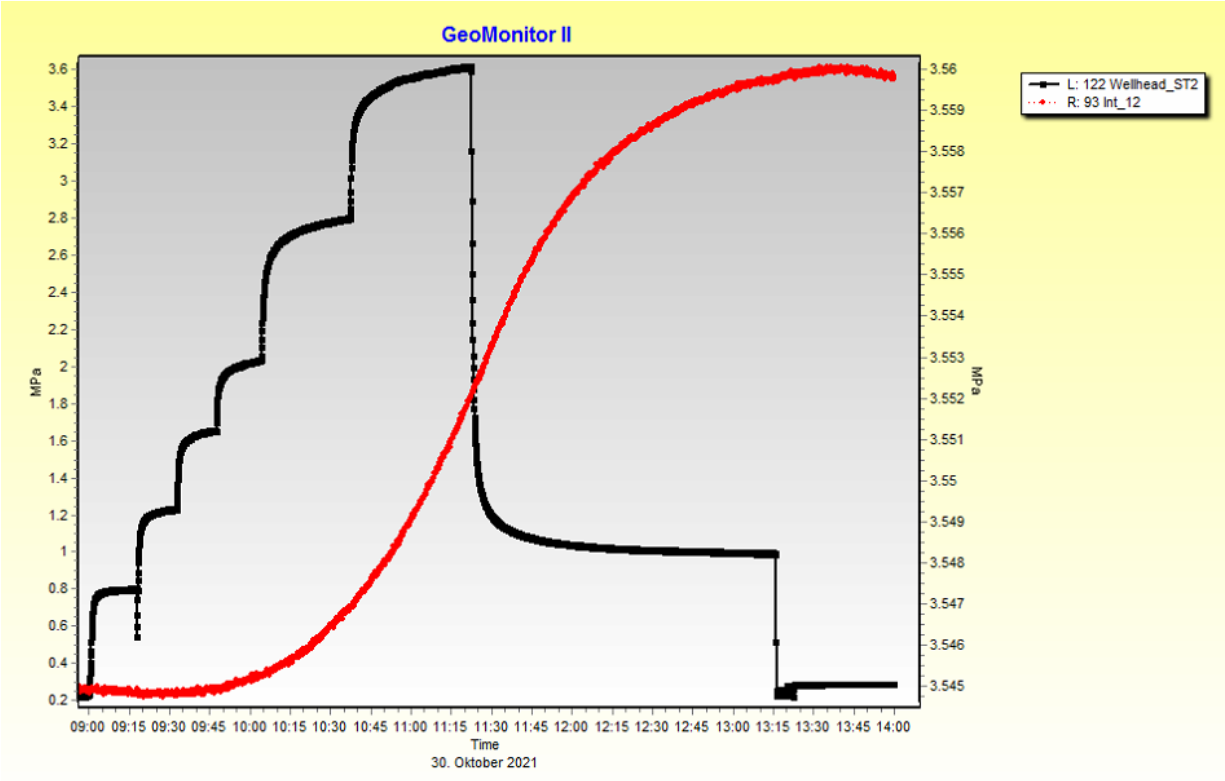


Opening of Sliding Sleeve of Interval 2 succeeded
-> injection into the reservoir/an open system

Injection: 09:17 – 11:21 Shut-in: 11:21 – 13:16

Bypass: 50% of injected flowrate comes out of annulus between casing and borehole

2.2 Interval 2 Reaction ST1 Interval 12

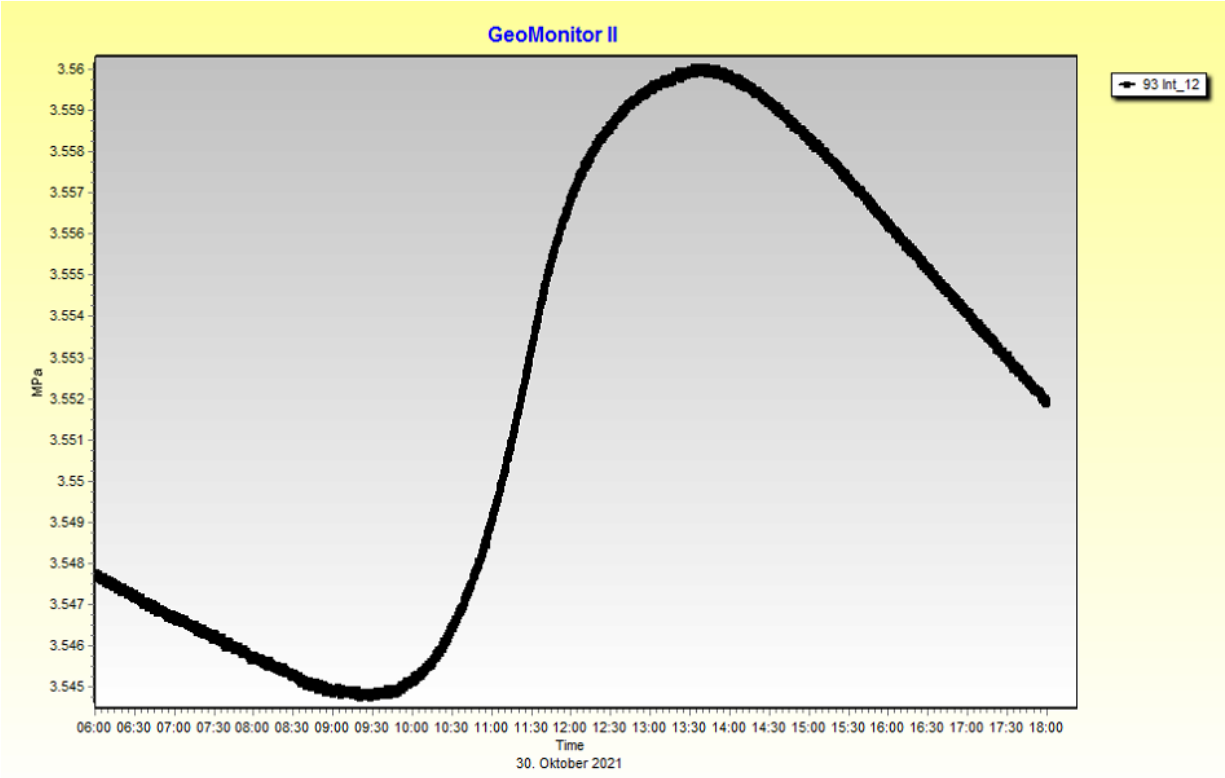


Opening of Sliding Sleeve of Interval 2 succeeded
-> injection into the reservoir/an open system

Injection: 09:17 – 11:21 Shut-in: 11:21 – 13:16

Bypass: 50% of injected flowrate comes out of annulus between casing and borehole

2.2 Interval 2 Reaction ST1 Interval 12

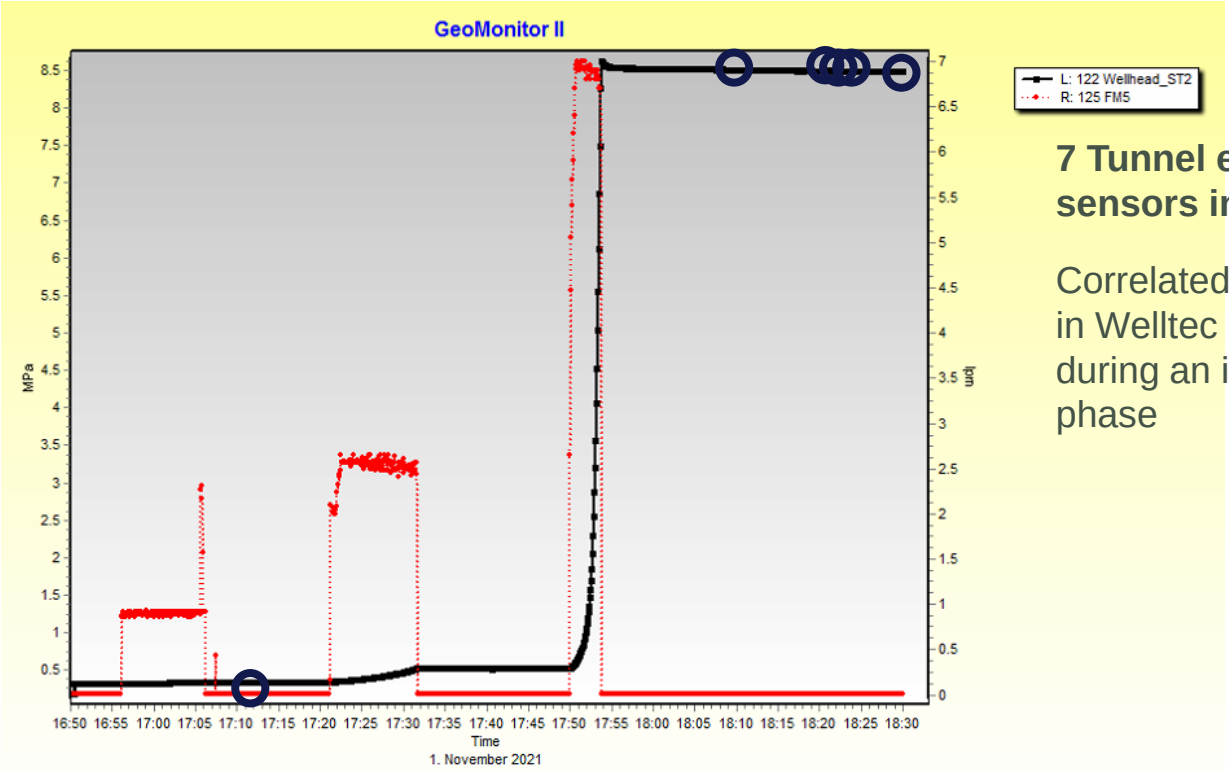


Opening of Sliding Sleeve of Interval 2 succeeded
-> injection into the reservoir/an open system

Injection: 09:17 – 11:21 Shut-in: 11:21 – 13:16

Bypass: 50% of injected flowrate comes out of annulus between casing and borehole

2.1 Interval 1 Hydrotest 01.11.2021



7 Tunnel events on sensors in MB7

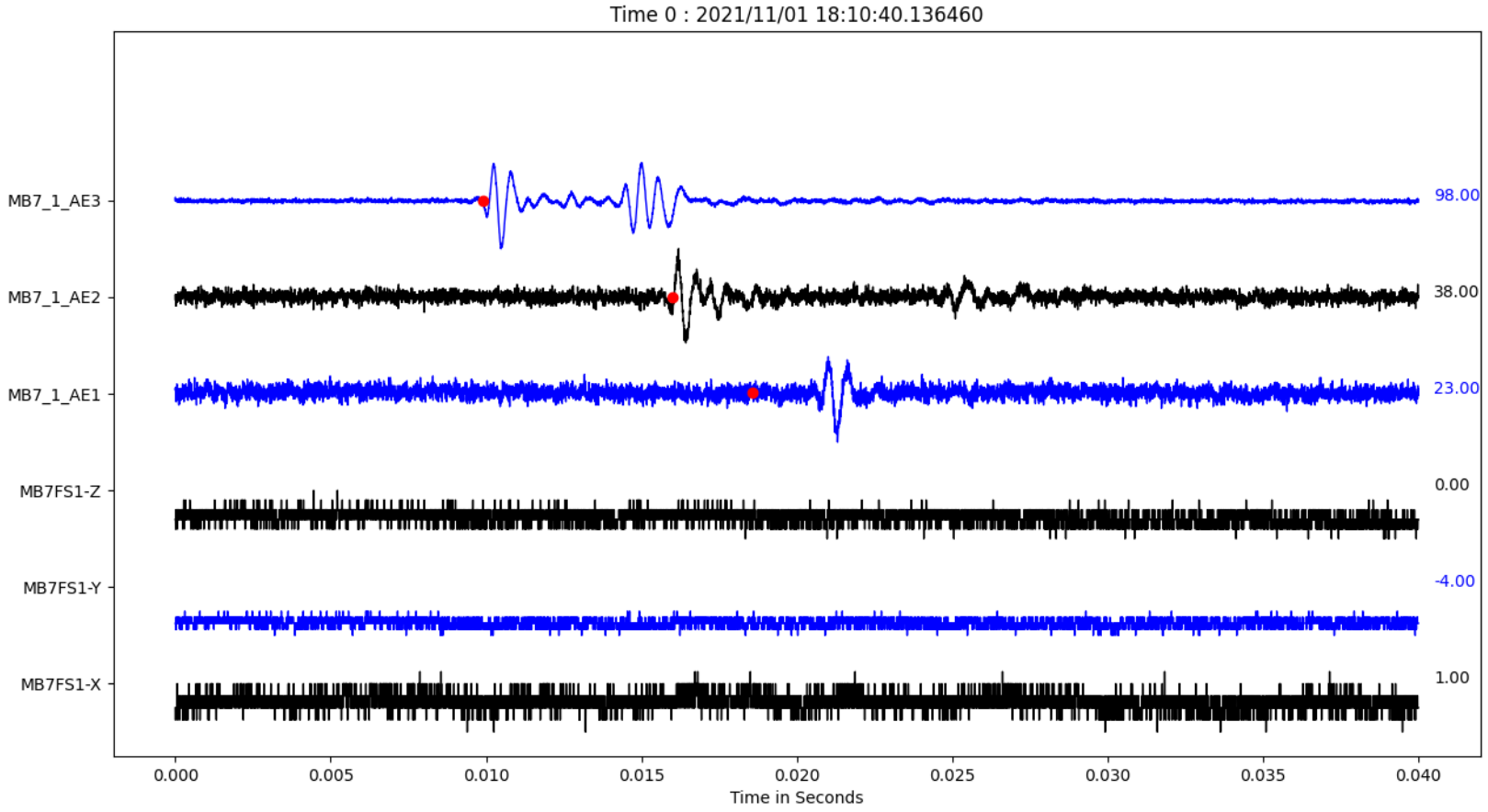
Correlated with activity in Welltec borehole, during an injection phase

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

Injection: 16:56 – 17:06	Shut-in: 17:06 – 17:21
Injection: 17:21 – 17:31	Shut-in: 17:31– 17:49
Injection: 17:49 – 17:53	Shut-in: 17:53 – 09:10

2.1 Interval 1 Hydrotest 01.11.2021

- 7 events detected detected on sensors in MB7, also detected in MB3, MB5, MB7, MB8
- First arrival at AE3, Second arrival at AE2. Thus probably coming from another place than injection point in Welltec borehole (from tunnel?)



2.2 Interval 1 Hydrotest 01.11.2021

Welltec interval	Activity	Date Time	Duration (min)	Number of "Frac-events"	"Frac-events" rate per min	Seismic Events at single sensor	"Single Sensor Seismic-events" rate per min	Inflow Interval (Injection) (l/min)	Interval uphole pressure (Mpa)	Welltec annulus outflow (l/min)
1	Shut-in	01.11.2021 16:51	5.07	10	1.97	0	0.00		0.31	2.49
1	Injection-test	01.11.2021 16:56	10.12	6	0.59	0	0.00	0.9	0.3355	2.54
1	Shut-in	01.11.2021 17:06	14.95	3	0.20	1	0.07		0.3362	2.5
1	Injection-test	01.11.2021 17:21	10.52	3	0.29	0	0.00	2.56	0.516	2.53
1	Shut-in	01.11.2021 17:31	18.30	1	0.05	3	0.16		0.515	2.51
1	Injection-test	01.11.2021 17:49	3.80	1	0.26	0	0.00	6.9	8.622	2.79
1	Shut-in	01.11.2021 17:53	65.25	11	0.17	2	0.03		7.45	2.51
	End events observation	01.11.2021 18:59								

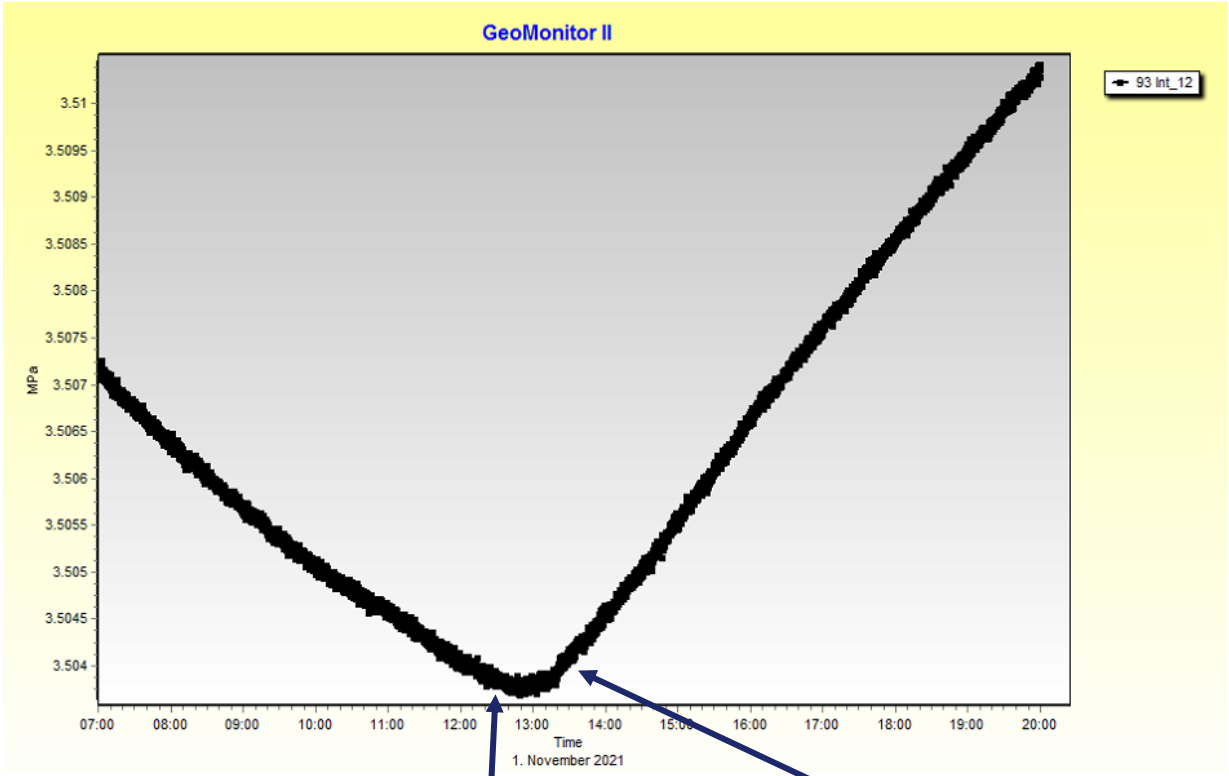
- Red = higher than Standard-deviation, Blue = lower than Standard-dev.
- “Frac-events”: no visible correlation
- “Single Sensor Seismic-events”: no visible correlation

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

- Less outflow through annulus when shut-in, more outflow when injecting
  - Pressure increase inside casing causes a ballooning of the casing, pushing against borehole wall/fractures

Statistics "Frac-events"	Statistics "Single Sensor Seismic-events"
Mean	Mean
0.51	0.04
Standard-dev	Standard-dev
0.62	0.06

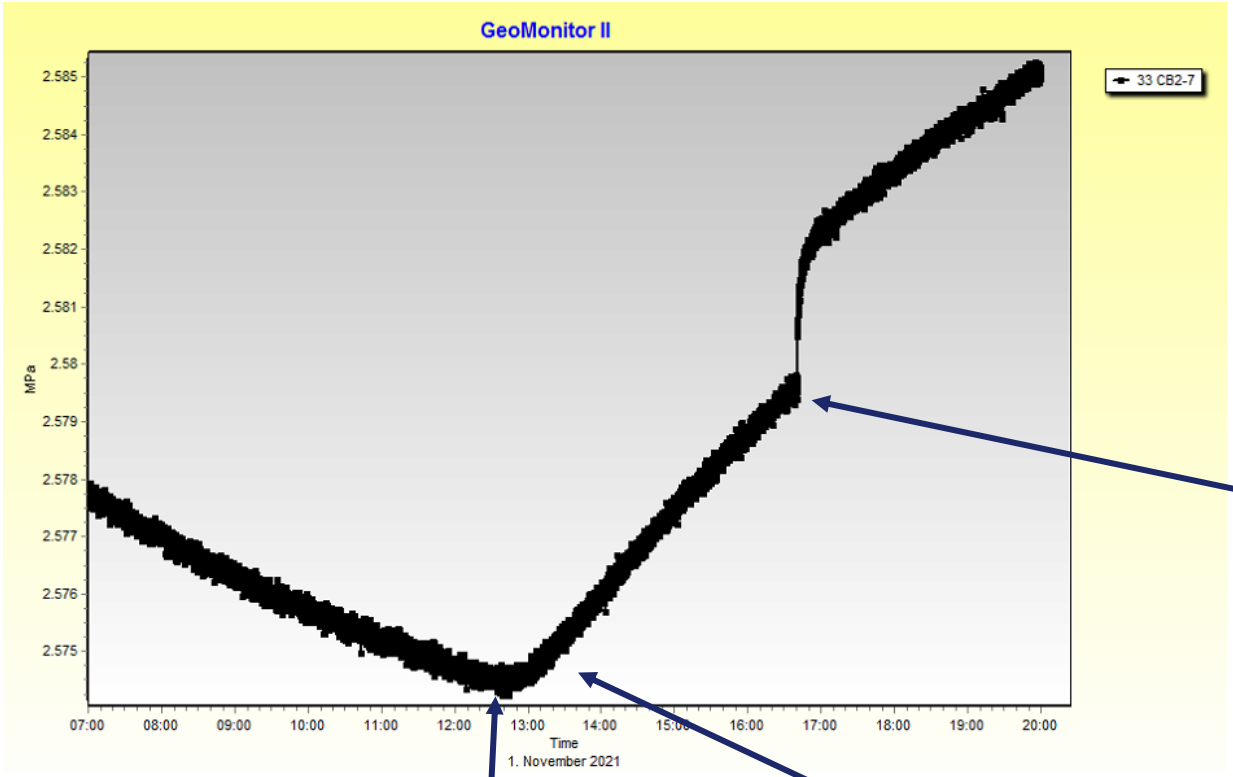
2.2 Interval 1 Reaction ST1 Interval 12



Closing of interval 2 at 12:28

Opening of interval 1 not visible at 13:40

2.2 Interval 1 Reaction CB2 Interval 7



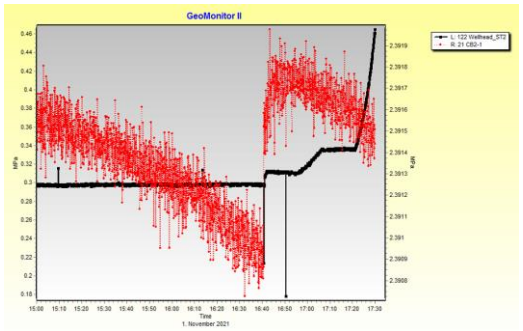
??

Closing of interval 2 at 12:28

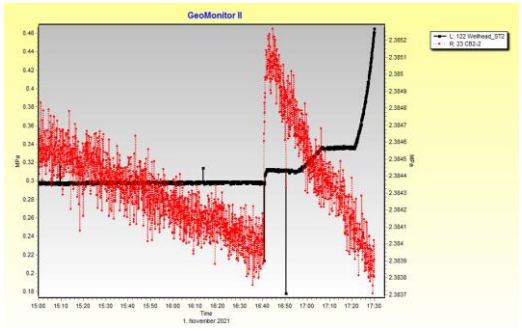
Opening of interval 1 not visible at 13:40

2.2 Interval 1 Reaction CB2 other Intervals

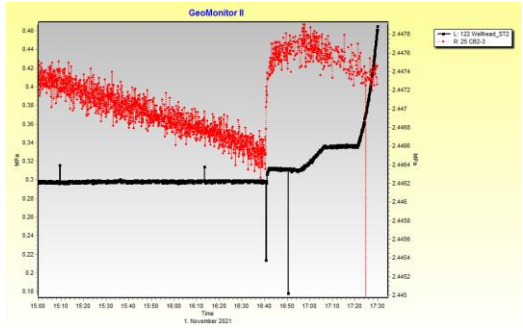
CB2-1



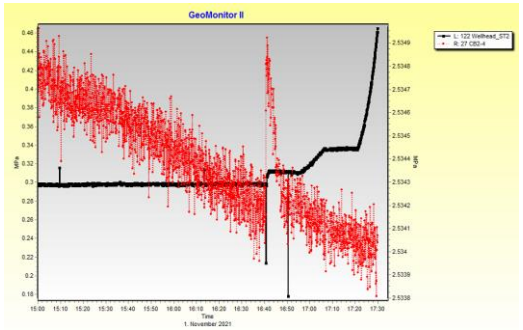
CB2-2



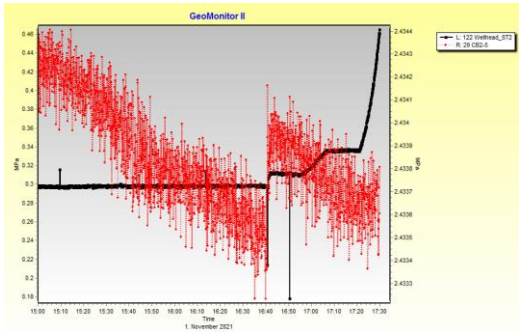
CB2-3



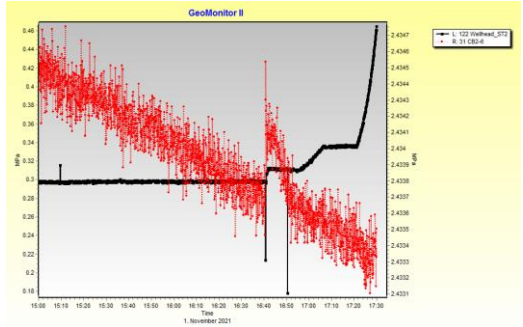
CB2-4



CB2-5

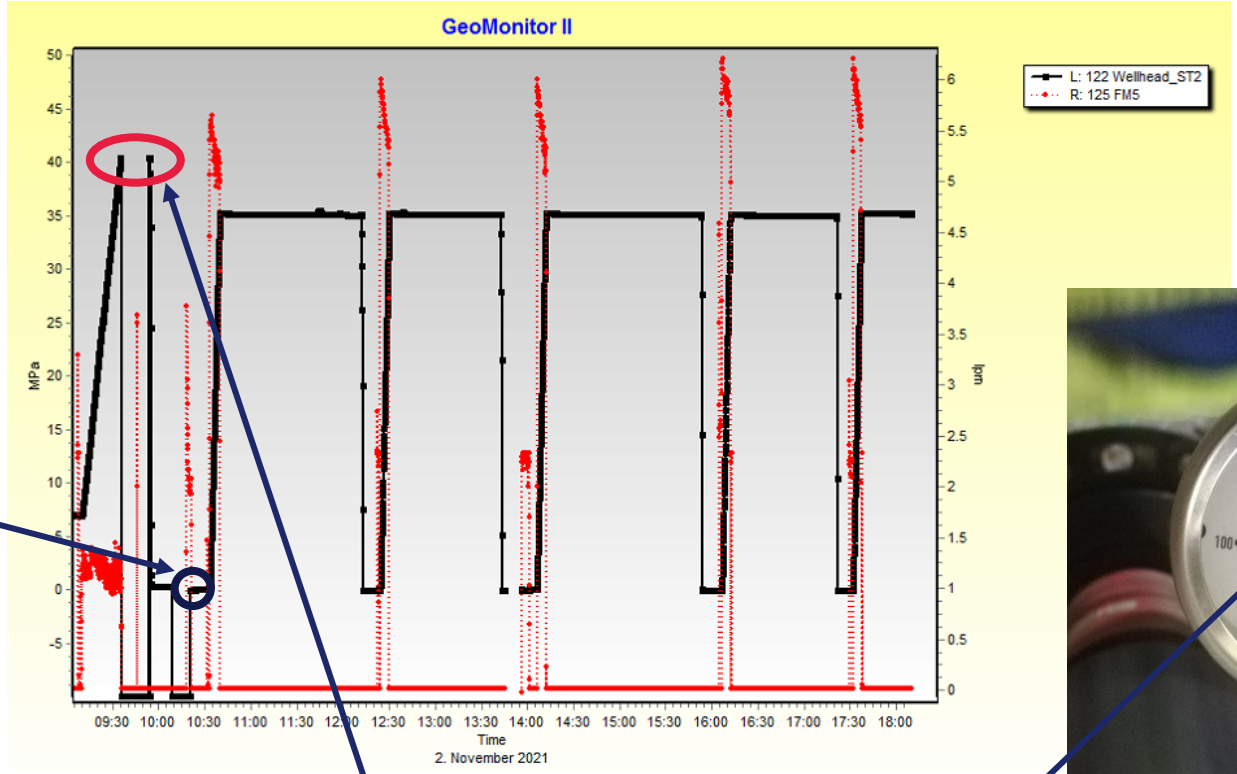


CB2-6



- What happened on 01.11.2021 around 16:40?
  - Installation of pressure sensor at wellhead Welltec borehole
  - Other possibilities??

2.1 Interval 1 Frac cycles 02.11.2021



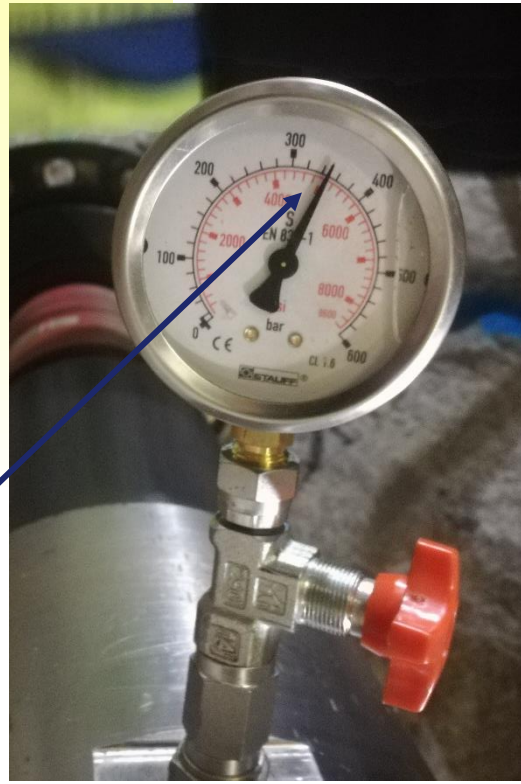
10:16 – 10:23

722 events on sensors in MB7

Not correlated with activity in Welltec borehole

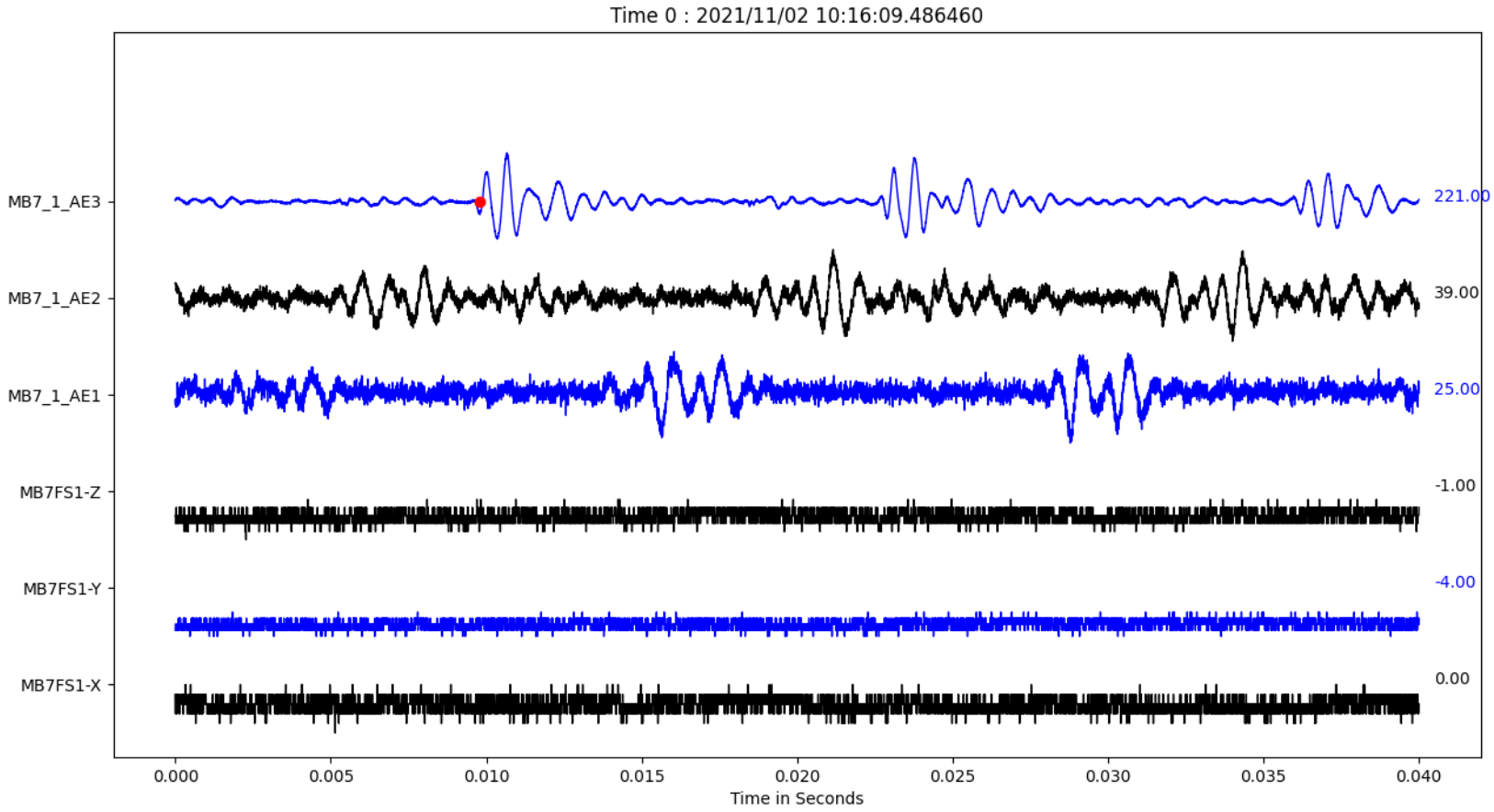
Calibration problem of pressure sensor

On the manometer = 35 MPa



2.1 Interval 1 Frac cycles 02.11.2021

- 722 events detected on sensors in MB7, also detected in MB1, MB3, MB4, MB5, MB8
- Not correlated with activity in Welltec borehole
- Most likely a piezo fireing because really regular and frequent



2.2 Interval 1 Frac cycles 02.11.2021

Welltec interval	Activity	Date Time	Duration (min)	Number of "Frac-events"	"Frac-events" rate per min	Seismic Events at single sensor	"Single Sensor Seismic-events" rate per min	Inflow Interval (Injection) (l/min)	Interval uphole pressure (Mpa)	Welltec annulus outflow (l/min)
1	Shut-in	02.11.2021 09:02	8.33	3	0.36	0	0.00		7.45	2.52
1	Frac-cycle 1	02.11.2021 09:10	25.45	9	0.35	2	0.08	1.25	35	3.04
1	Shut-in	02.11.2021 09:35	18.95	7	0.37	1	0.05		35	2.35
1	Opening Shut-in valve	02.11.2021 09:54	28.27	16	0.57	3	0.11		0.24	2.56
	End events observation	02.11.2021 10:23								

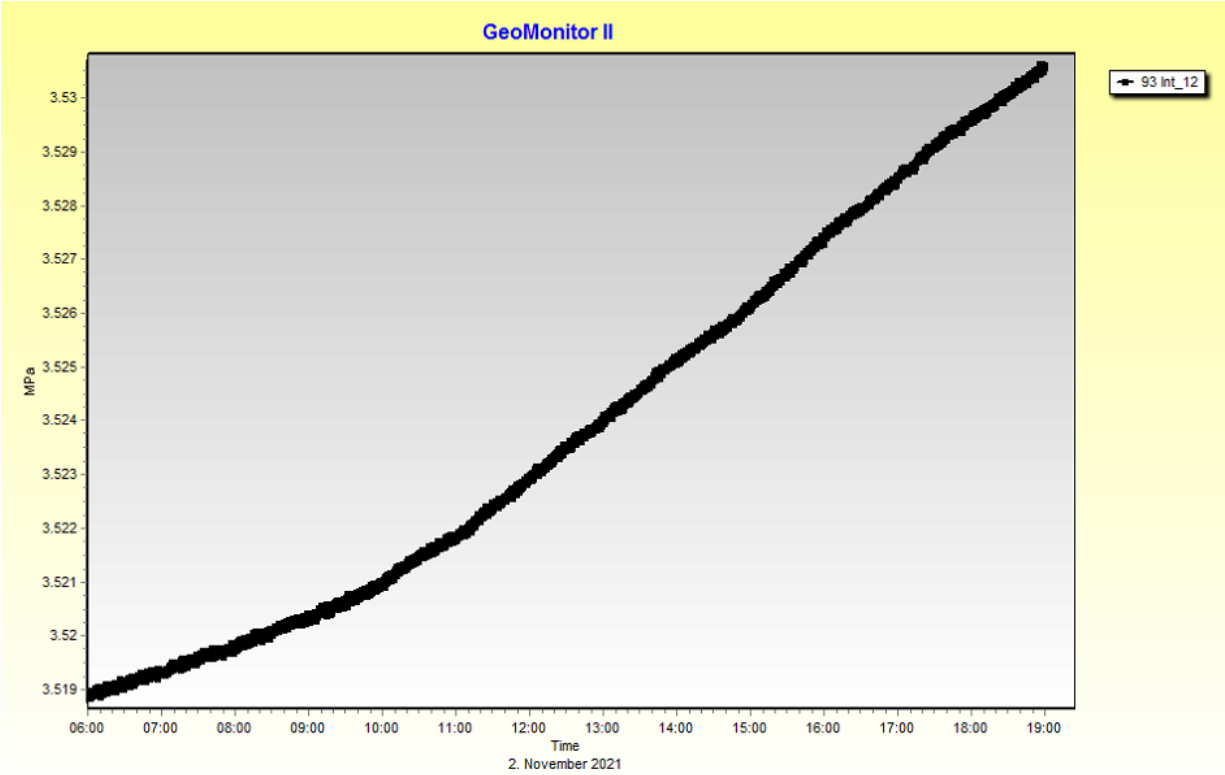
- Red = higher than Standard-deviation, Blue = lower than Standard-dev.
- “Frac-events”: Higher rates when open shut-in valve after post-injection shut-in
- “Single Sensor Seismic-events”: Higher rates when shut-in valve is open after post-injection shut-in
  - Need to control this by looking at the seismic events of the following frac cycles
  - However, the piezo fireing probably hides the signals.

Opening of Sliding Sleeve of Interval 1 failed
-> injection into the casing/a closed system

- Less outflow through annulus when shut-in, more outflow when injecting
  - Pressure increase inside casing causes a ballooning of the casing, pushing against borehole wall/fractures

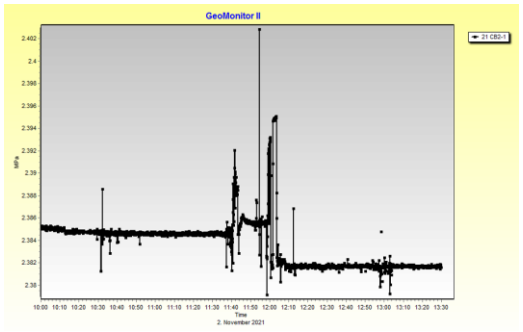
Statistics "Frac-events"	Statistics "Single Sensor Seismic-events"
Mean	Mean
0.41	0.06
Standard-dev	Standard-dev
0.09	0.04

2.2 Interval 1 Reaction ST1 Interval 12

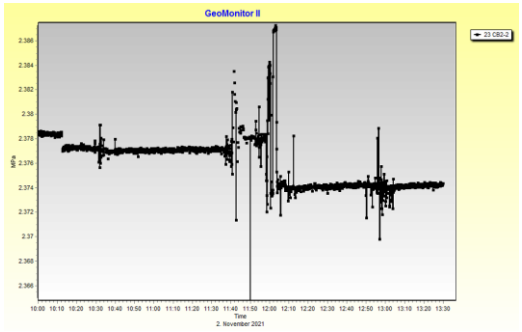


2.2 Interval 1 Reaction CB2 Intervals

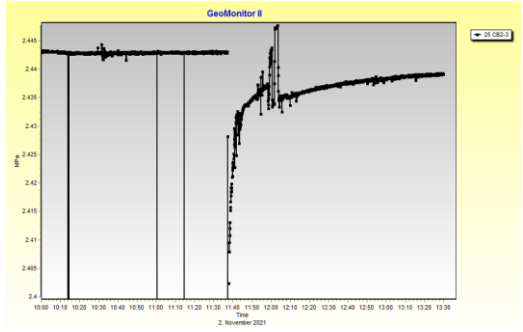
CB2-1



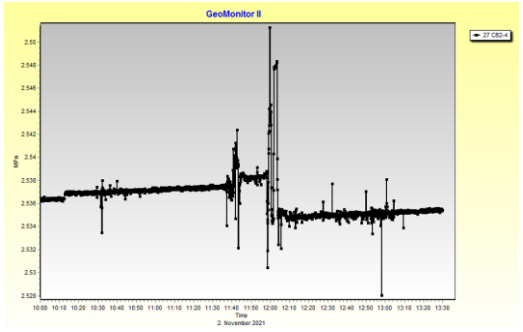
CB2-2



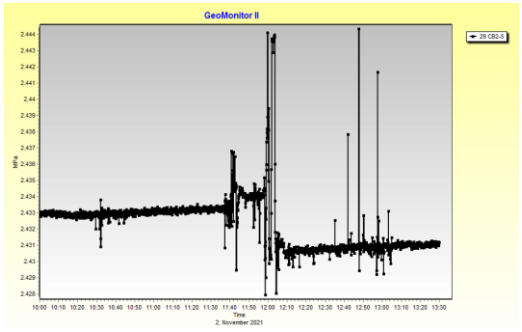
CB2-3



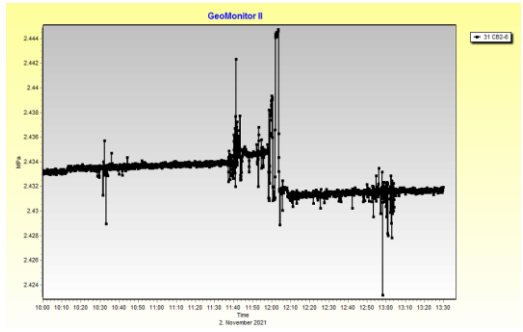
CB2-4



CB2-5



CB2-6



- What happened on 02.11.2021?
  - Solexperts working on reinstalling the CB2 flowboard and connecting/disconnecting the sensors
  - Other possibilities??

General Conclusions

- 1 “real” seismic event detected on several boreholes and several channels during injection into a closed casing at a pressure of 28MPa (not at the pressure maximum of the injection)
- AE sensors detect the removal of the hydrochain out of ST2
- AE sensors detect events coming most likely from the tunnel
- AE sensors detect piezo fireing signals, thus it is important to filter them out for the statistic analysis
- Statistic analysis of “Frac-events” and “Single Sensor Seismic-events”
  - A correlation with the injection- /shut-in-/ Open-valve activities or with the pressure / flow values is hard to find
  - It is noticeable that the rates that are out of standard deviation happen rather at the end of a succession of activities. This is true for closed and open sliding sleeves. What it means is unclear.

Conclusions

- Did the ETH monitoring system detect seismic events during the packer expansion?
  - *It was not running at that moment.*
- Did the ETH monitoring system detect seismic events during the injections tests?
  - *Yes, different types of events were detected.*
- Could the packer expansion cause axial fractures along the packers and thus, a flow bypass?
- Could the injection into the closed casing (ballooning effect) cause new fractures?
- Could the injection into the open interval stimulate fractures?
  - *It is a possibility. It is hard to answer to these questions because:*
  - *- the analyzed time frames are small and don't give a global overview during the injections tests.*
  - *- the injection into the closed system or into the reservoir has an effect on the flow-rates coming out of the annulus between the borehole and the casing…*
  - *-… but a correlation of the different types of detected seismic events with the injection- /shut-in-/ Open-valve activities or with the pressure / flow values is hard to find.*
  - *- 1 "real" seismic event was detected on several boreholes and several channels during injection into a closed casing at a pressure of 28MPa (not at the pressure maximum of the injection) but it was the first time the casing was re-pressurized since the packer expansion (also a pressure increase in a closed casing).*

Possible next steps

- Localize the 1 “real” seismic event detected on 22.10.2021

- Further Statistic analysis “Frac-events” or “Single Sensor Seismic-events”
  - Observe the time interval on 02.11.2021 during the Frac-cycles 2 – 5 with the hope that the piezo fireing stops after a while.

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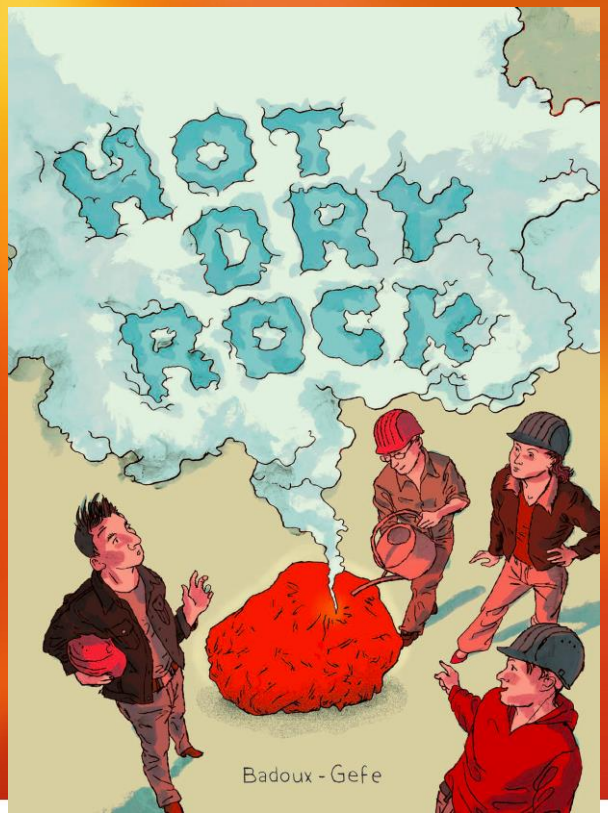

Thank you for your attention!