First Evaluation of stimulation tests in borehole ST2

Report Date: 31.10.2021

Authors: F. Christe, F. Serbeto and P. Meier

Table of Contents

1. INTRODUCTION

In the frame of ZoDrEx Work Packages 2 and 3, the Bedretto demonstration site in Switzerland aims to show that the zonal isolation of multi-stage stimulation concept is feasible in granitic rocks while ensuring connection to the reservoir.

From October 4th to 15th 2021 a series of stimulation tests were done by Geo-Energie Suisse AG (GES) in the ST2 borehole located in the Bedretto Underground Laboratory (BULG). The intervals were tested with a double packer system which was provided by Solexperts, a contractor of GES. The history of the stimulated intervals is different for each one of them (See the corresponding chapter of each interval). Some of the intervals were hydro-fracked and/or stimulated hydraulically before the whole borehole was cased with a 7'' liner. The connection through the casing to the reservoir was provided by notches drilled with a micro-turbine.

The goal of the stimulation tests was 1) to evaluate the connection to the reservoir and 2) to evaluate the connectivity of ST2 with the neighbouring ST1 borehole. The cementation of the casing may have indeed plugged partially or even totally some fractures of the reservoir.

2. SITE DESCRIPTION

2.1 Location and Geologic Overview

The Bedretto Underground Laboratory for Geoenergies (BULG) is located at 2km in the 5.2 km long tunnel connecting the Bedretto Valley of the Canton Tessin with the Furka tunnel. The lab sits within the Rotondo Granite Intrusion at an approximated depth of 1.1 km below the surface. Its location was chosen because enough crystalline rock volume can be accessed to create a reservoir of similar hydro-mechanical characteristics to a deep underground environment, except for the temperature that is between at 17°C and 22°C.

3. HYDRAULIC STIMULATION

3.1 Instrumentation

Uphole pressure measurements were continuously monitored in the ST2, MB1, MB3 and MB4 wellheads. ST1 and CB2 have multi-packer system installed where pressure is monitored for each of the respective intervals. For ST1 the interval pressures are monitored downhole while the interval pressures of CB2 are monitored uphole. Flow-rates of the Welltec borehole were measured frequently during the hydraulic stimulation activities.

The double packer system installed in ST2 for the hydrotests is equipped with two downhole pressure sensors located at 1) the interval and 2) bellow the lower packer. To isolate intervals, the packers were inflated together with water at pressures ranging between 50 and 210 bars. These packers are 1.2 m long each and are separated by a distance of 4.133 m.

A flowboard was used for inflating and deflating the packers as well as the injection into and the extraction out of the interval between the packers (See Attachment 5).

3.2 Testing procedure

From October 4th to 15th 2021, hydraulic stimulation tests were performed by Geo-Energie Suisse AG (GES) in the ST2 borehole The goal of the testing procedure was to evaluate the connection to the rock reservoir and to evaluate the connectivity with borehole ST1. The hydraulic stimulation tests were realized with a double packer system, where both packers were inflated together.

The testing procedure of the borehole ST2 consisted in a hydraulic stimulation phase followed by a hydraulic testing phase.

The first phase consisted in the stimulation of interval 7 (273.2 m – 277.33 m), interval 8 (281.9 m – 286.03 m), interval 1 (305.16 m – 309.29 m) and interval 4 (322.15 m – 326.28 m) between October 4th and 13th. The stimulation of each of these intervals was preceded by a static pressure recovery phase with the shut-in valve of the interval closed. The interval was then stimulated by increasing gradually the injection flow-rates, followed by a pressure recovery phase. The stimulation phase continued eventually with a second or a third stimulation test and ended with a last pressure recovery phase.

The second phase consisted in the hydraulic testing of the interval 8, interval 1 and interval 4 to evaluate the bypass to the top or to the bottom of the borehole. This was executed on 14.10.2021

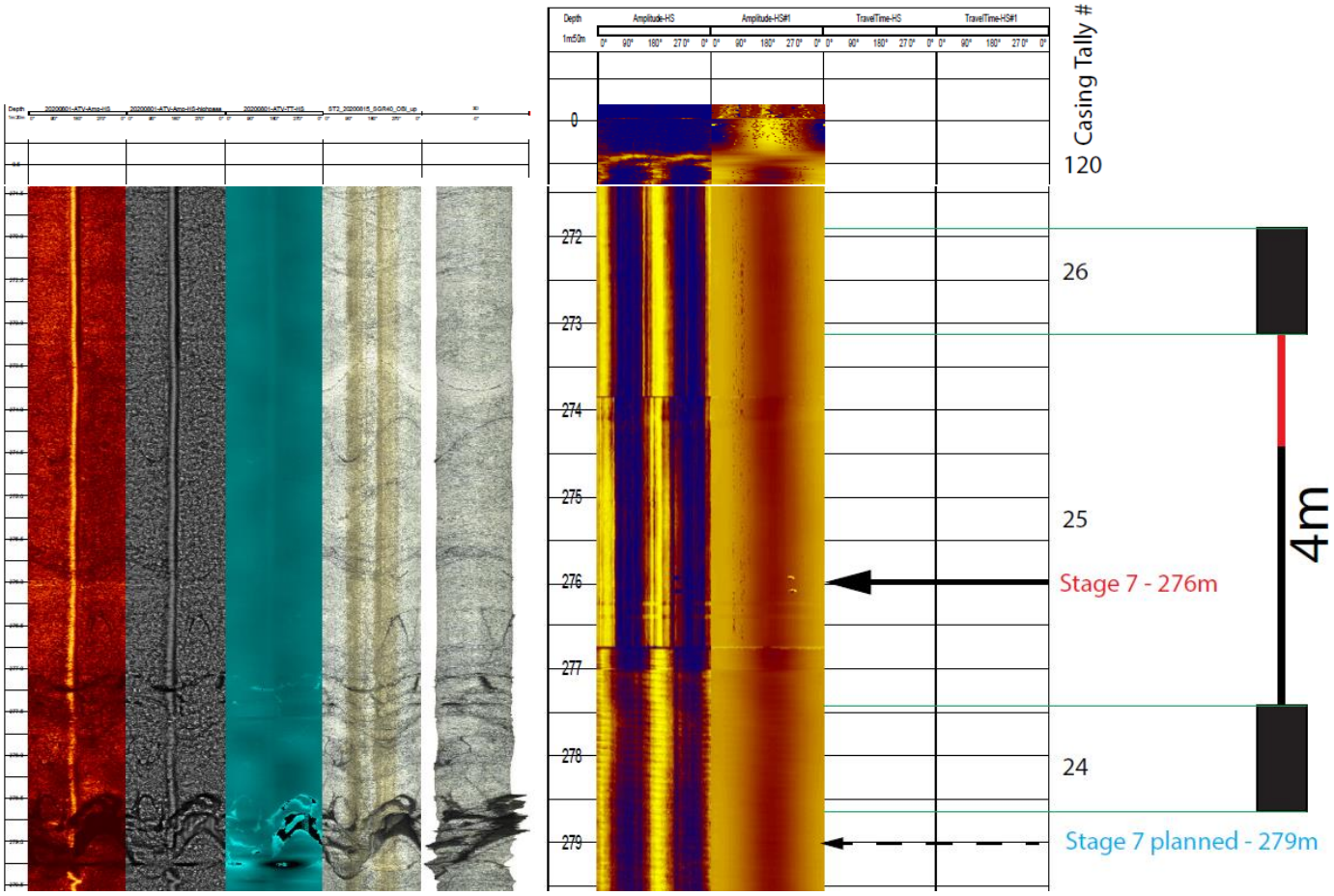
Interval 7
(273 m to 277 m)

Content:

1) ATV, OTV LOG
2) Result Table
3) Graphs

Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021

Interval 7 Depth: 273.2 m to 277.33 m. Target fracture: 279 m



Interval short history

Date	Action
July 2020	End drilling ST2
June 2021	Cemented Casing
September 2021	Notch at 276 m depth
October 2021	Hydraulic Stimulation

Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021

Borehole	ST2	**Interval Depth**	273.2 to 277.33 m
Test Interval	7	**Target Fracture**	279 m
Test Type	Double Packer	**Testing Date**	12.10.2021 - 14.10.2021
Authors	Fran, Fabien	**Report Date**	31.10.2021

Test Description: A double packer test system was installed at a depth of 273.2 m, which corresponds to the bottom of the top packer.
The following test sequences were conducted:

INF 12.10.2021 — Downhole pressures are hydrostatic at 1.82 MPa. The initial flow rate was 0.58 l/min.

BU-2 12.10 - 13.10 — The shut-in valve was closed to initiate a static pressure recovery period of 14.6 hours. The downhole pressure increased from 1.82 MPa to 4.83 MPa.

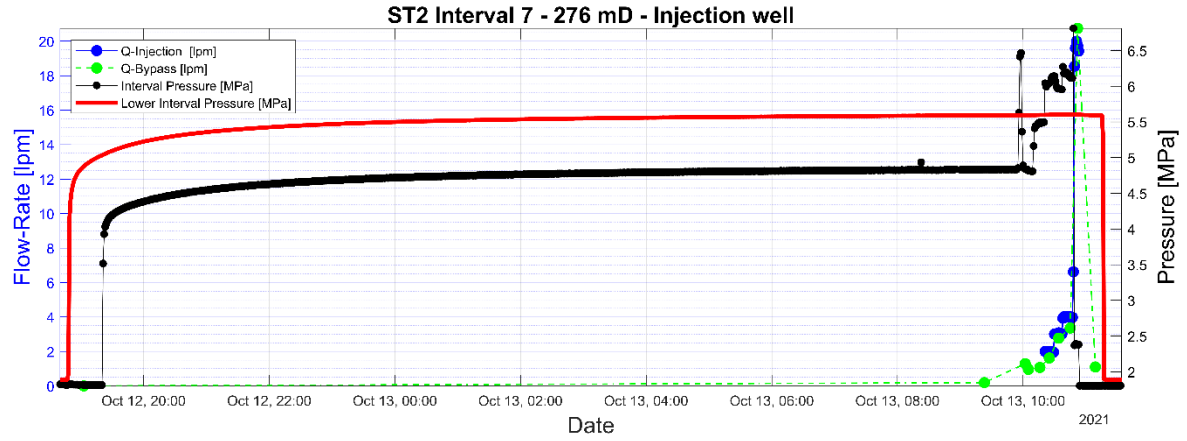
SR-1 13.10.2021 — A step-rate injection test was performed with increasing rates from 0.77 to 19.5 l/min during 57.6 min. The downhole pressure changed from 4.83 MPa to 2.38 Mpa.

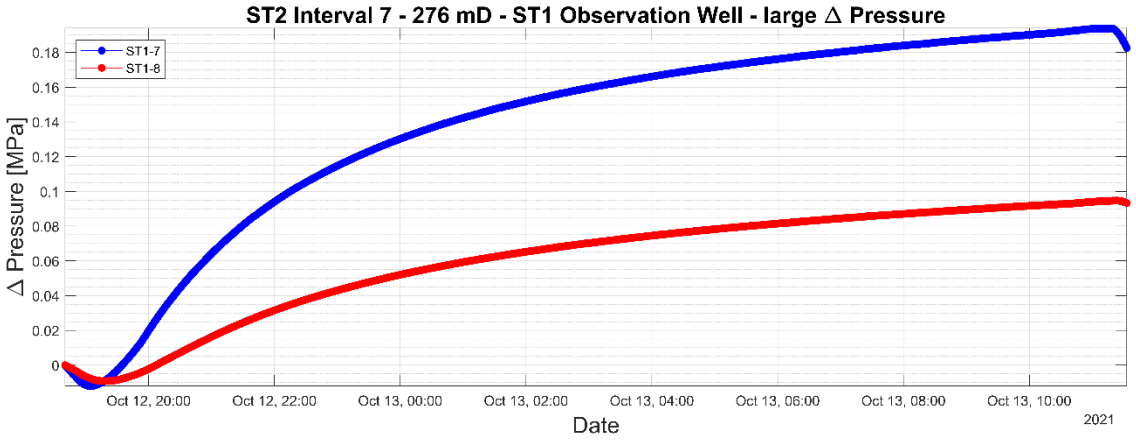
RE-1 13.10.2021 — The shut-in valve was closed to initiate a recovery period of 20.7 min. The pressure decreased from 2.38 Mpa to 1.8 MPa.

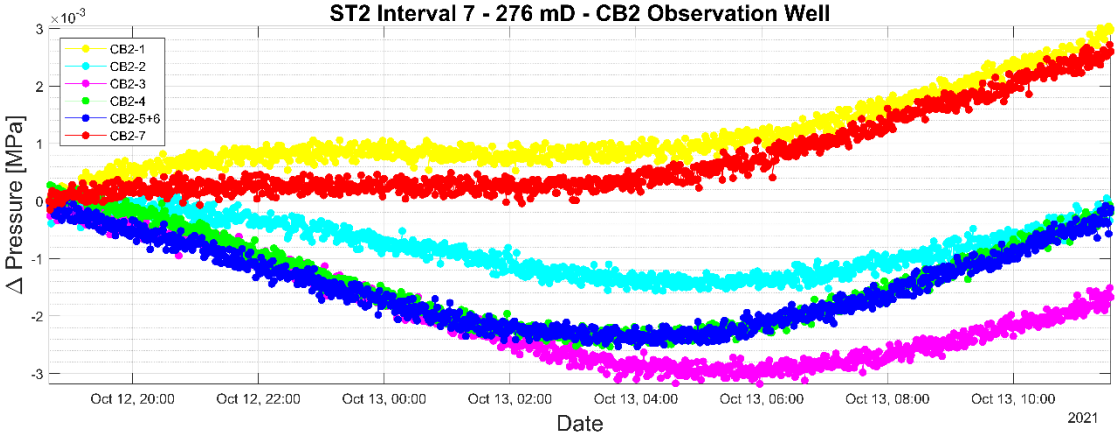
Test Interval Specifications:

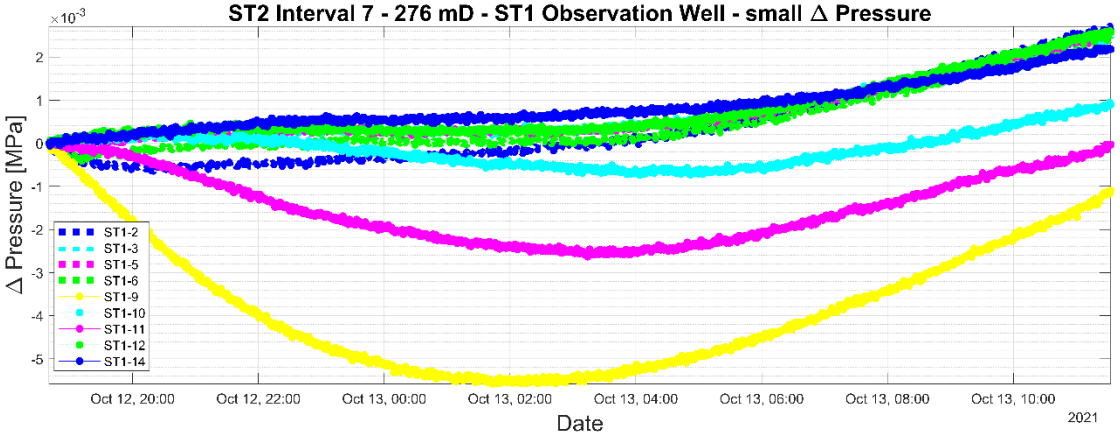
Interval Length	4.133 [m]	Wellbore Radius	0.08 [m]

* Abreviations. INF: Initial conditions before Inflating Packers. BU: Static Pressure Recovery. SR: Step-Rate Injection Test. CR: Constant-Rate Injection Test. RE: Pressure recovery Test. CH: Constant Head Withdrawal Test.

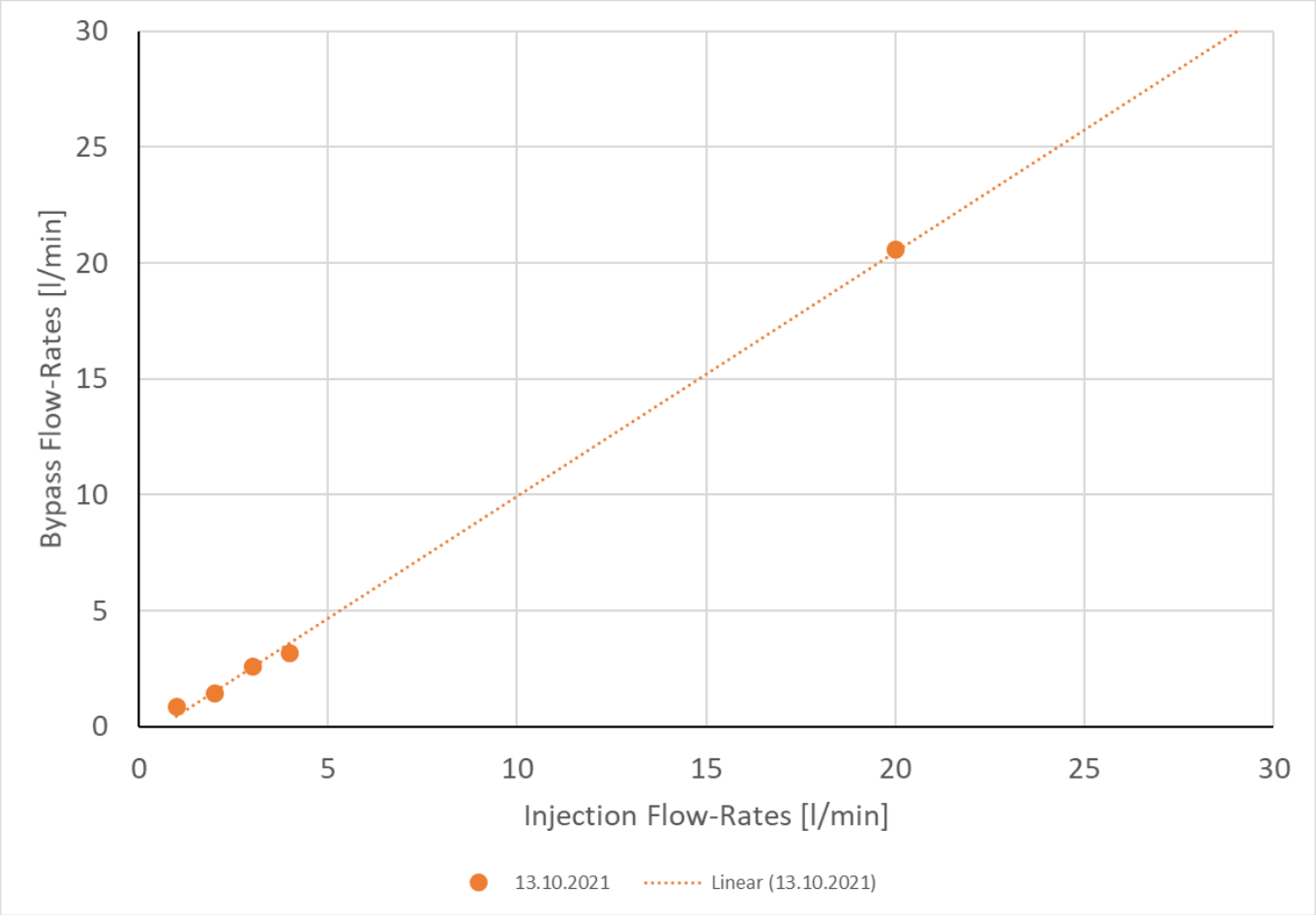








Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021



Bypass flowrates measured at the top of the wellhead (inside of the casing) compared to the injected flow-rates. Each set of points corresponds to a day when a test was performed with a corresponding linear trendline.

Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021

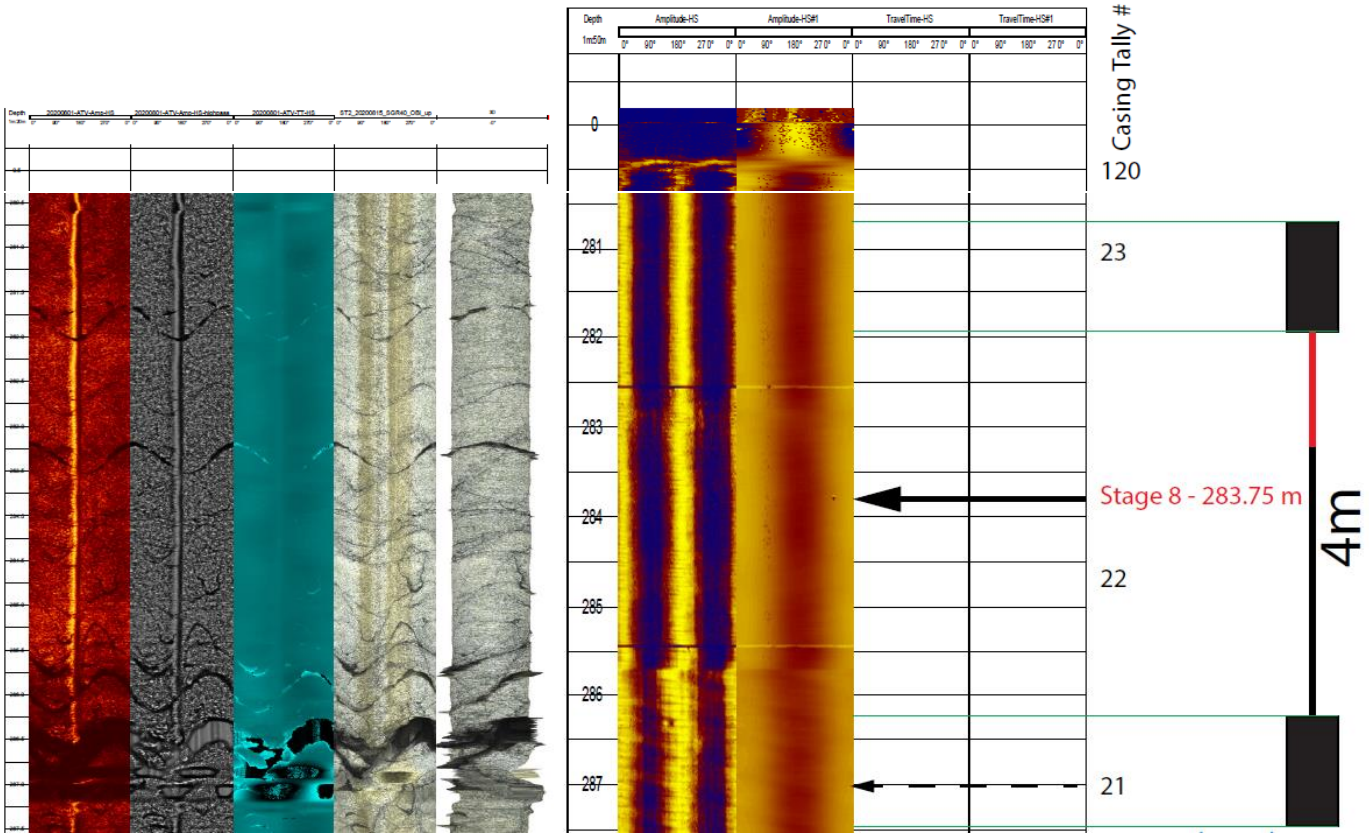
Interval 8
(282 m to 291 m)

Content:

1) ATV, OTV LOG
2) Result Table
3) Graphs

Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021

Interval 8 Depth: 281.9 m to 286.03 m. Target fracture: 287 m



Interval short history

Date	Action
July 2020	End drilling ST2
June 2021	Cemented Casing
September 2021	Notch at 283.75 m depth
October 2021	Hydraulic Stimulation

Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021

Borehole	ST2	**Interval Depth**	281.9 to 286.03 m
Test Interval	8	**Target Fracture**	287 m
Test Type	Double Packer	**Testing Date**	08.10.2021 - 14.10.2021
Authors	Fran, Fabien	**Report Date**	31.10.2021

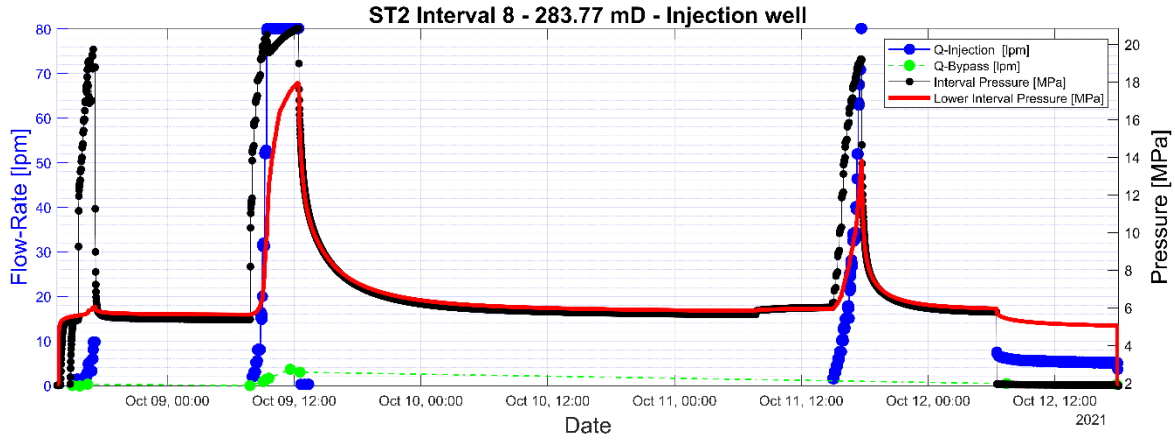
Test Description: A double packer test system was installed at a depth of 281.9 m, which corresponds to the bottom of the top packer.
The following test sequences were conducted:

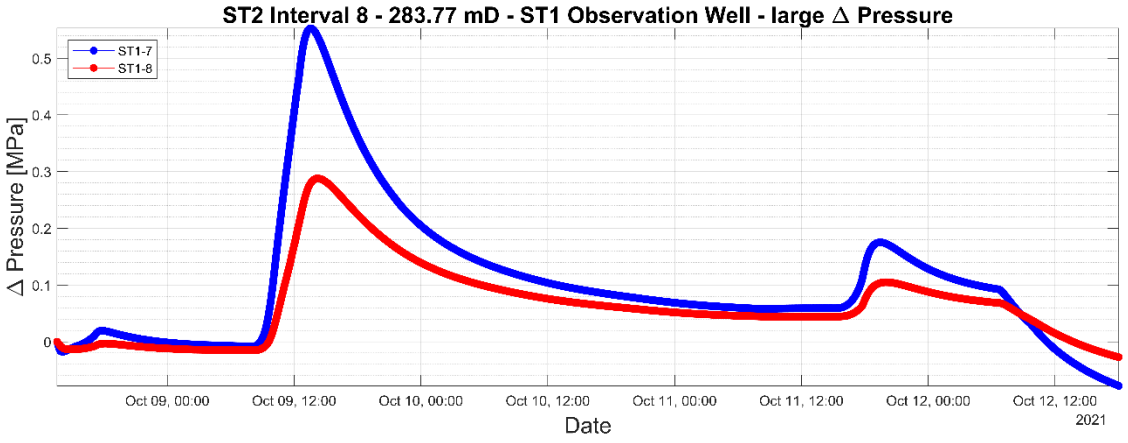
INF 08.10.2021	Downhole pressures are hydrostatic at 1.88 MPa. The initial flow rate was 0.079 l/min.
BU-1 08.10.2021	The shut-in valve was closed to initiate a static pressure recovery period of 54 min. The downhole pressure increased from 1.88 MPa to 5.3 MPa.
CH-1 08.10.2021	A constant head withdrawl test was conducted by opening the shut-in valve for 2 seconds (Pulse-test). The downhole pressure decreased from 5.3 MPa to 1.46 MPa. A volume of 0.42 L was measured.
BU-2 08.10.2021	The shut-in valve was closed to initiate a static pressure recovery period of 46 min. The downhole pressure increased from 1.46 MPa to 5.36 MPa.
SR-1 08.10.2021	A step-rate injection test was performed with increasing rates from 0.2 to 9.6 l/min during 96 min. The downhole pressure changed from 5.36 MPa to 18.79 Mpa.
RE-1 08.10 - 09.10	The shut-in valve was closed to initiate a recovery period of 14.7 hours. The pressure decreased from 18.79 Mpa to 5.38 MPa.
SR-2 09.10.2021	A step-rate injection test was performed with increasing rates from 1.1 to 80 l/min during 4.6 hours. The downhole pressure changed from 5.38 MPa to 20.71 Mpa.
RE-2 09.10 - 11.10	The shut-in valve was closed to initiate a recovery period of 43.2 hours. The pressure decreased from 20.71 Mpa to 5.64 MPa.
SR-3 11.10.2021	A step-rate injection test was performed with increasing rates from 0.66 to 80 l/min during 10 hours. The downhole pressure changed from 5.64 MPa to 19.21 Mpa.
RE-3 11.10 - 12.10	The shut-in valve was closed to initiate a recovery period of 12.8 hours. The pressure decreased from 19.21 Mpa to 5.78 MPa.
CH-2 12.10.2021	A constant head withdrawl test was conducted for 11.4 hours. The pressure decreased from 5.78 Mpa to 1.91 MPa.
INF-2 14.10.2021	Downhole pressures are hydrostatic at 1.86 MPa. The initial flow rate was 10.57 l/min.
BU-3 14.10.2021	The shut-in valve was closed to initiate a static pressure recovery period of 34 min. The downhole pressure changed from 1.86 MPa to 4.27 MPa.
SR-4 14.10.2021	A step-rate injection test was performed with increasing rates from 1.7 to 24 l/min during 85 min. The downhole pressure changed from 4.27 MPa to 10.35 MPa.
RE-4 14.10.2021	The shut-in valve was closed to initiate a recovery period of 12.8 hours. The pressure decreased from 10.35 Mpa to 5.29 MPa.

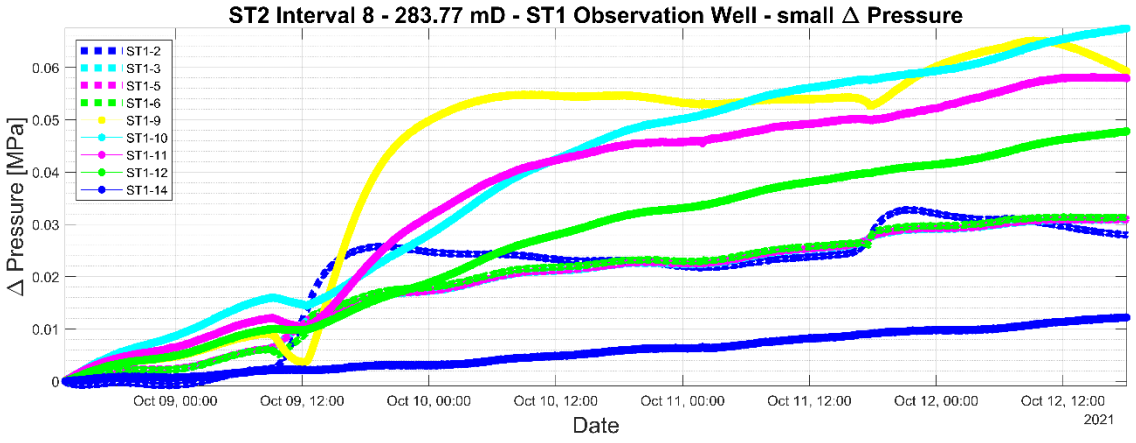
Test Interval Specifications:

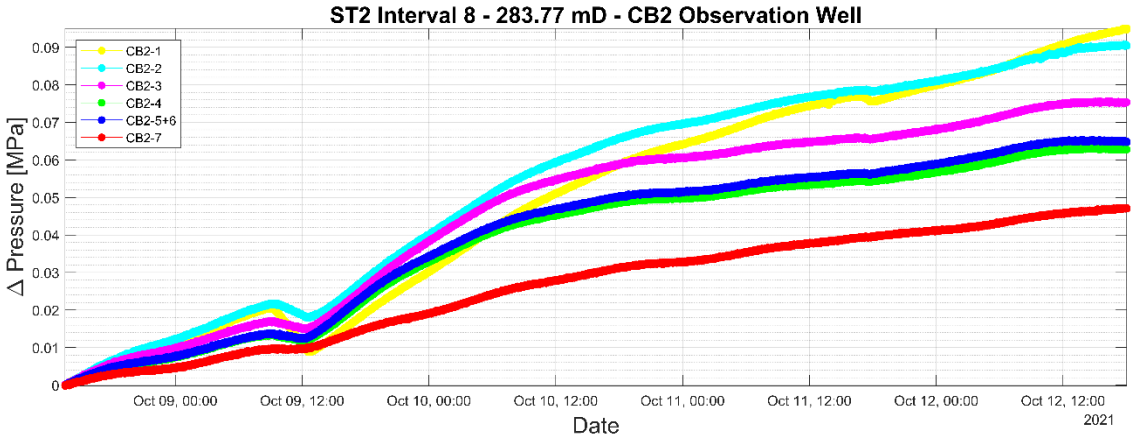
Interval Length	4.133 [m]	Wellbore Radius	0.08 [m]

* Abreviations. INF: Initial conditions before Inflating Packers. BU: Static Pressure Recovery. SR: Step-Rate Injection Test. CR: Constant-Rate Injection Test. RE: Pressure recovery Test. CH: Constant Head Withdrawal Test.



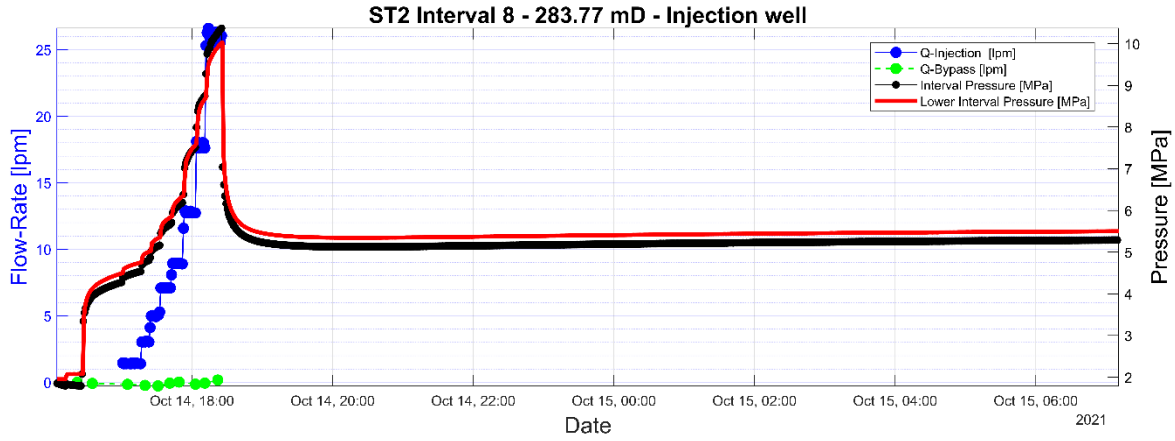


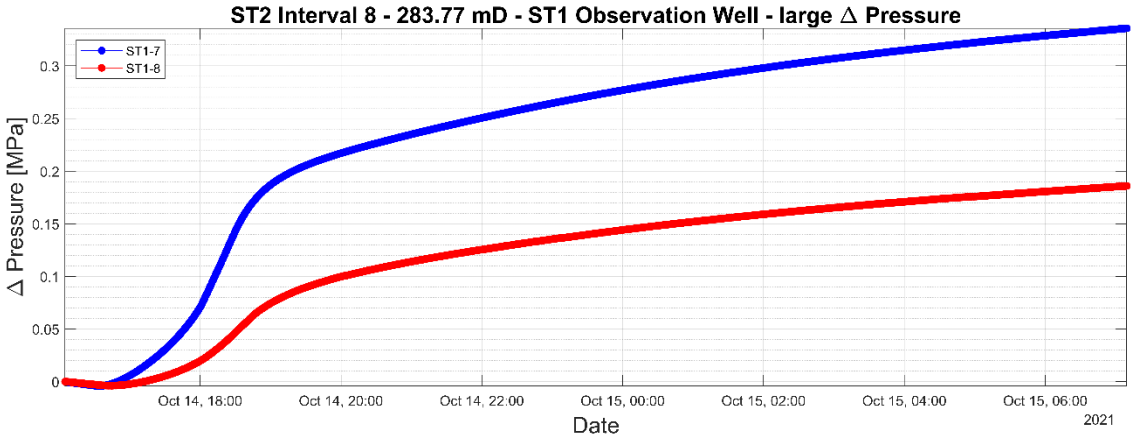


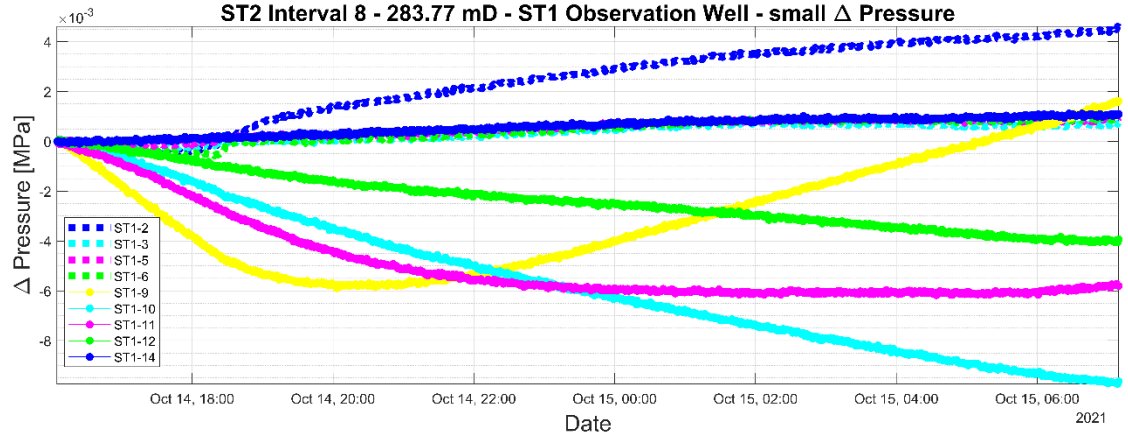


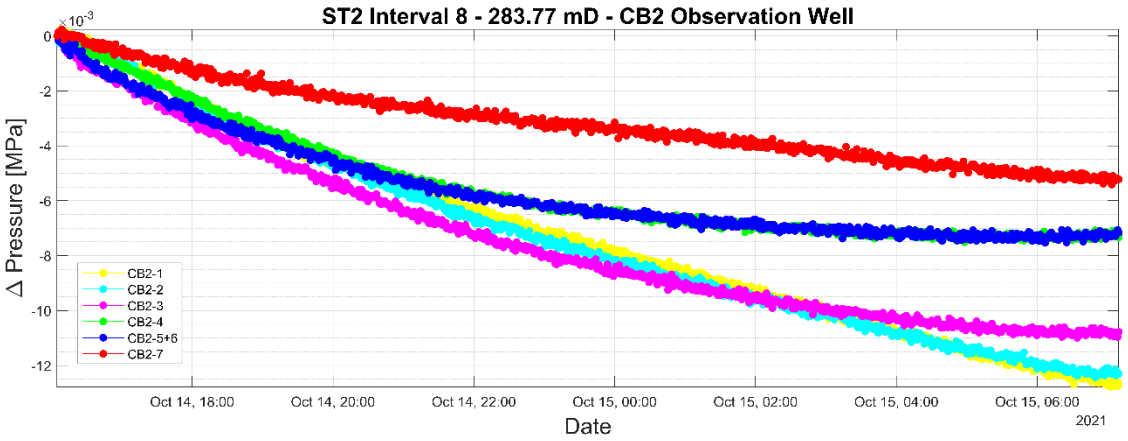
Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021

14.10.2021 - Bypass Assessment Hydrotest

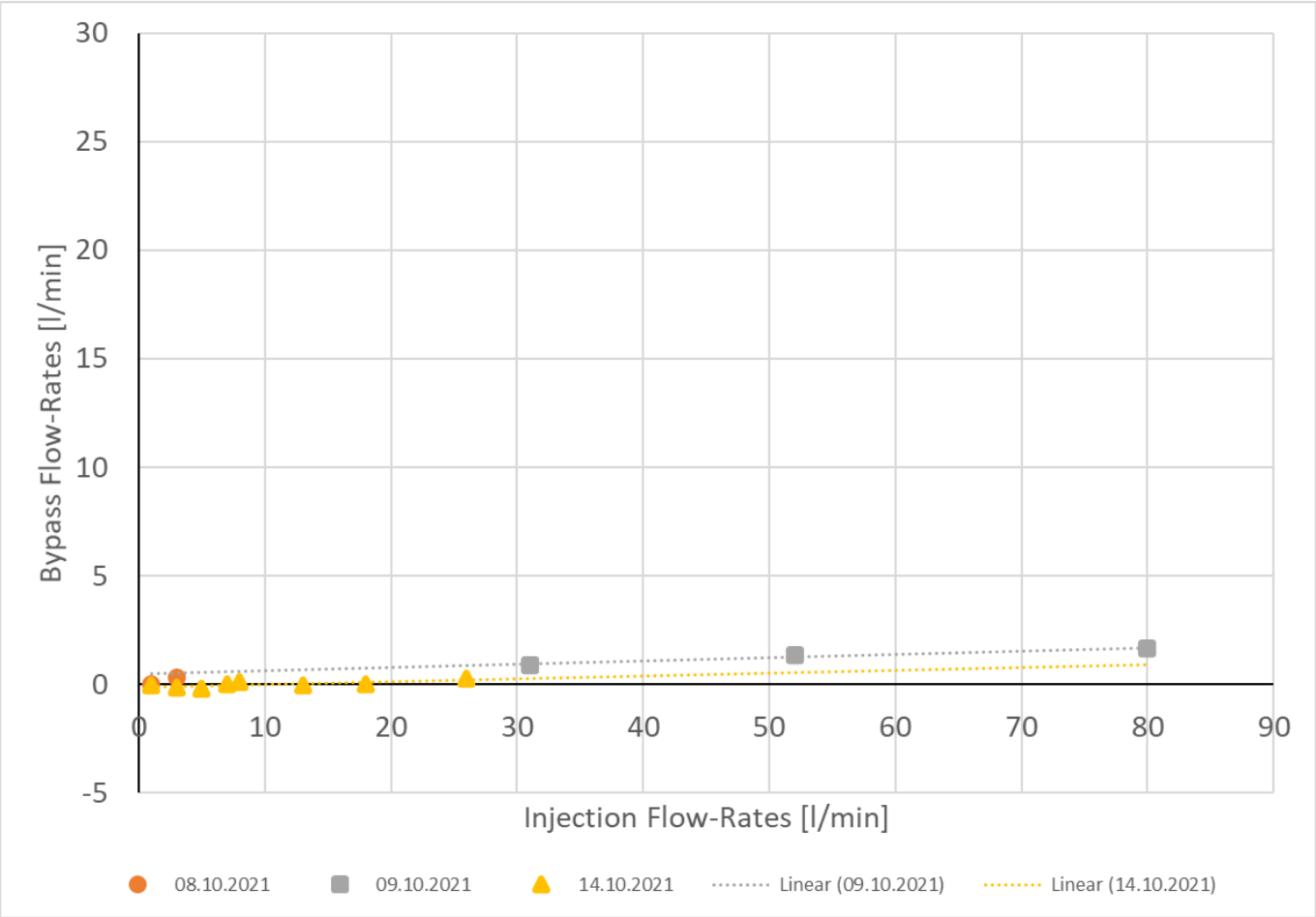








Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021



Bypass flowrates measured at the top of the wellhead (inside of the casing) compared to the injected flow-rates. Each set of points corresponds to a day when a test was performed with a corresponding linear trendline.

Authors: F. Christe, F. Serbeto and P. Meier

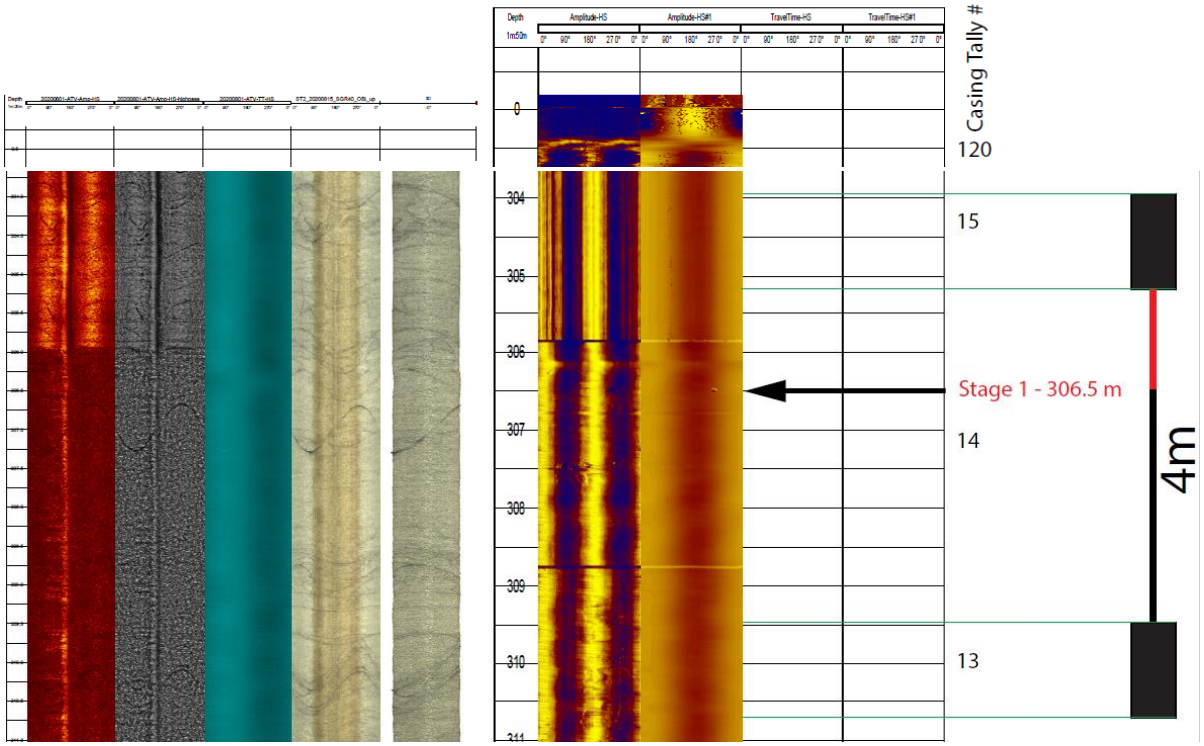
Interval 1
(305 m to 309 m)

Content:

1) ATV, OTV LOG
2) Result Table
3) Graphs

Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021

Interval 1 Depth: 305.16 m to 309.29 m. Target fracture: 307 m



Interval short history

Date	Action
July 2020	End drilling ST2
October 2020	Hydrofracturing
November 2020	Hydraulic Stimulation
June 2021	Cemented Casing
September 2021	Notch at 306.5 m depth
October 2021	Hydraulic Stimulation

Borehole	ST2	**Interval Depth**	305.16 to 309.29 m
Test Interval	1	**Target Fracture**	307 m
Test Type	Double Packer	**Testing Date**	06.10.2021 - 14.10.2021
Authors	Fran, Fabien	**Report Date**	31.10.2021

GEO ENERGIE SUISSE

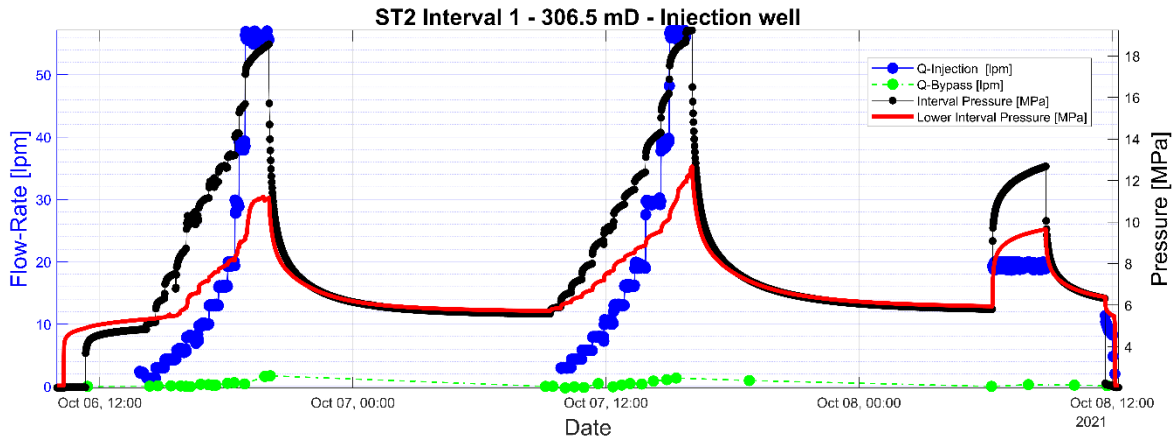
Test Description: A double packer test system was installed at a depth of 305.16 m, which corresponds to the bottom of the top packer.
The following test sequences were conducted:

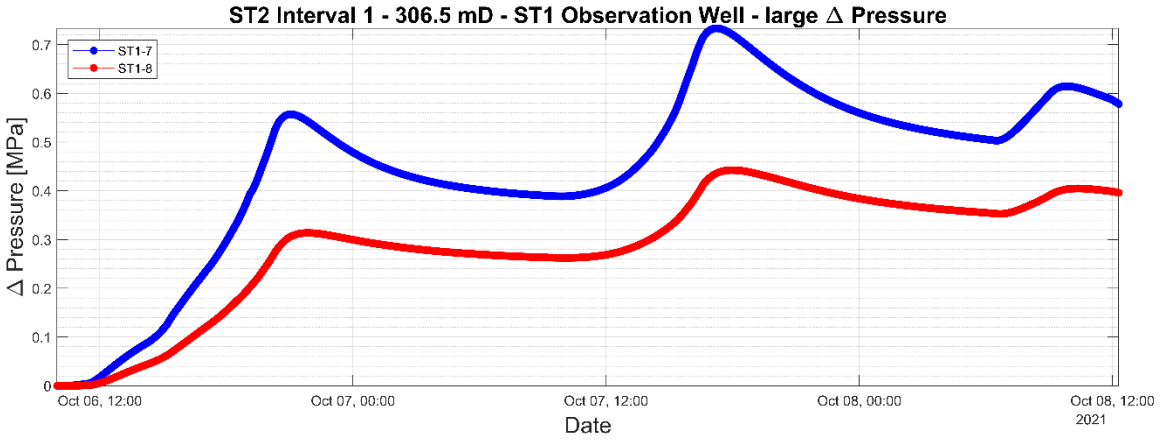
INF-1 06.10.2021	Downhole pressures are hydrostatic at 2.05 MPa. The initial flow rate was 3.48 l/min.
BU-1 06.10.2021	The shut-in valve was closed to initiate a static pressure recovery period of 173 min. The downhole pressure increased from 2.04 MPa to 3.83 MPa.
SR-1 06.10.2021	A step-rate injection test was performed with increasing rates from 1 to 56 l/min during 5.8 hours. The downhole pressure changed from 3.83 MPa to 18.57 Mpa.
RE-1 06.10 - 07.10	The shut-in valve was closed to initiate a recovery period of 13.3 hours. The pressure decreased from 18.57 Mpa to 5.58 MPa.
SR-2 07.10.2021	A step-rate injection test was performed with increasing rates from 1 to 69 l/min during 6.7 hours. The downhole pressure changed from 5.58 MPa to 19.23 Mpa.
RE-2 07.10 - 08.10	The shut-in valve was closed to initiate a recovery period of 14.25 hours. The pressure decreased from 19.23 Mpa to 5.8 MPa.
CR-1 08.10.2021	A constant-rate injection test was performed with rates of 20 l/min during 152 min. The downhole pressure changed from 5.8 MPa to 12.68 MPa
RE-3 08.10.2021	The shut-in valve was closed to initiate a recovery period of 169 min. The pressure decreased from 12.68 Mpa to 6.32 MPa.
CH-1 08.10.2021	A constant head withdrawl test was conducted for 25 minutes. The pressure decreased from 6.32 Mpa to 2.07 MPa.
INF-2 14.10.2021	Downhole pressures are hydrostatic at 2.05 MPa. The initial flow rate was 2.72 l/min.
BU-2 14.10.2021	The shut-in valve was closed to initiate a static pressure recovery period of 76 min. The downhole pressure increased from 2.05 MPa to 3.49 MPa.
SR-3 14.10.2021	A step-rate injection test was performed with increasing rates from 1 to 27 l/min during 8.8 min. The downhole pressure changed from 3.83 MPa to 5.95 Mpa.
RE-4 14.10.2021	The shut-in valve was closed to initiate a recovery period of 9 min. The pressure decreased from 5.95 Mpa to 2.98 MPa.

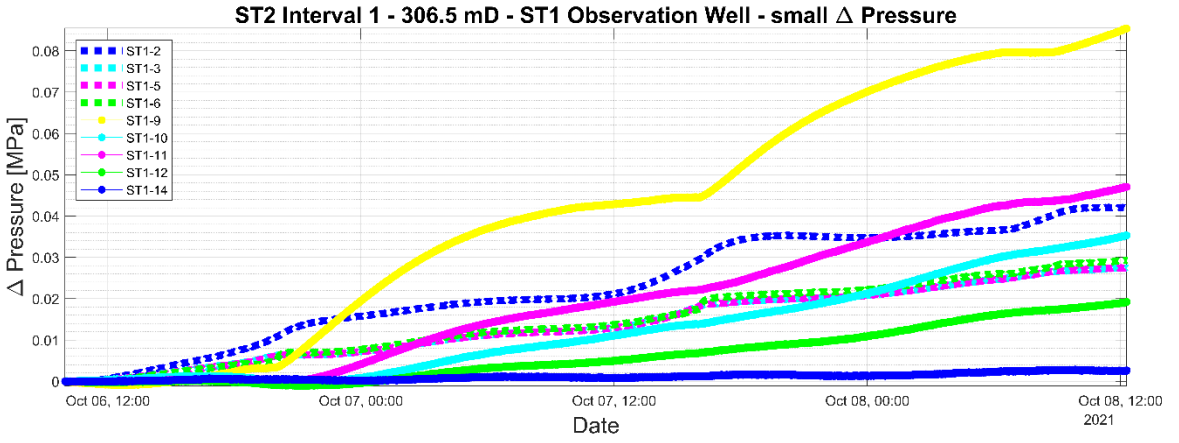
Test Interval Specifications:

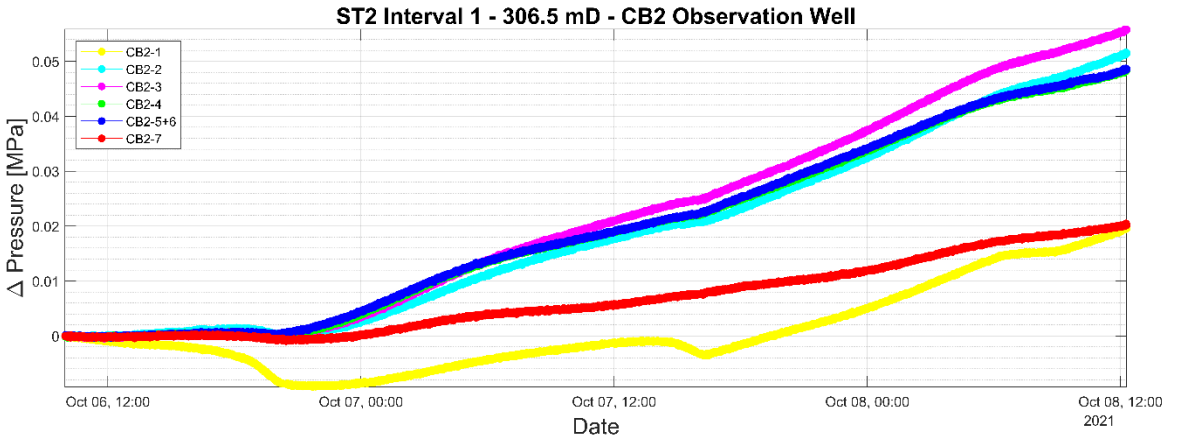
Interval Length	4.133 [m]	Wellbore Radius	0.08 [m]

* Abreviations. INF: Initial conditions before Inflating Packers. BU: Static Pressure Recovery. SR: Step-Rate Injection Test. CR: Constant-Rate Injection Test. RE: Pressure recovery Test. CH: Constant Head Withdrawal Test.



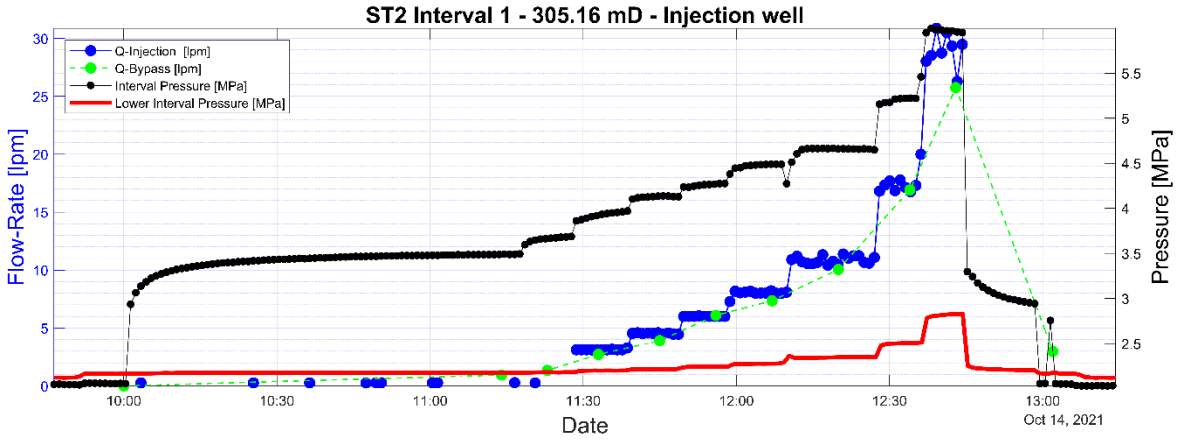


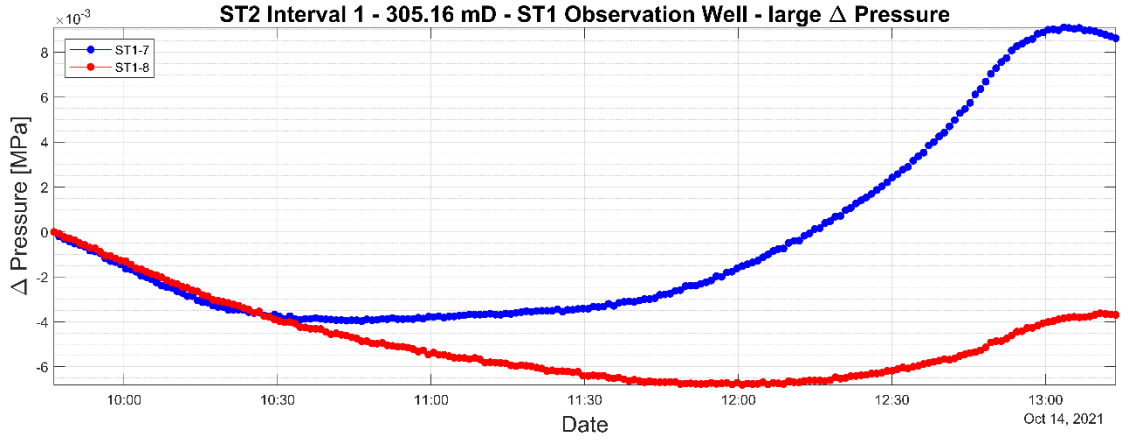


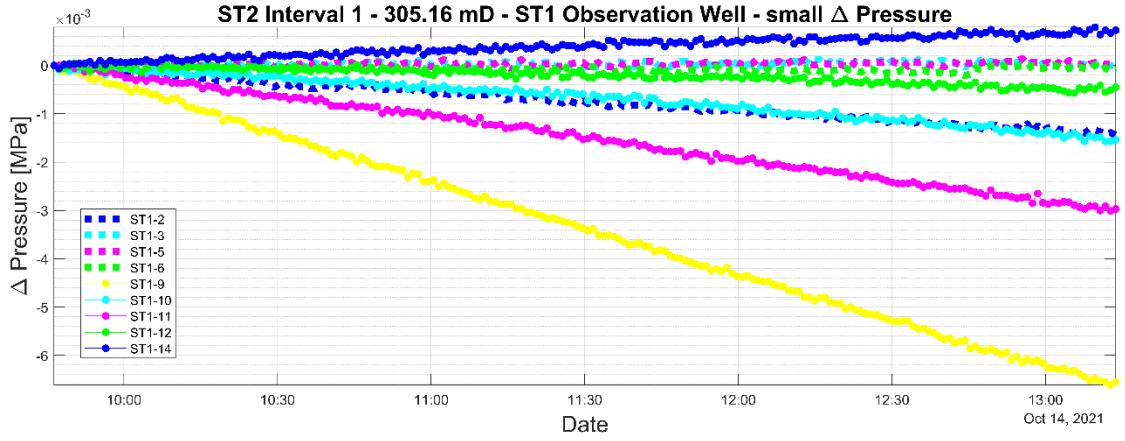


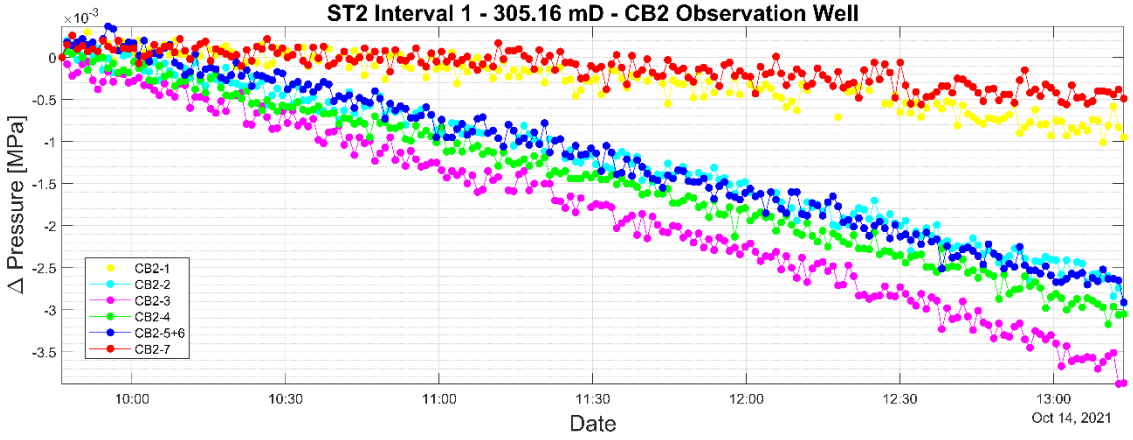
Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021

14.10.2021 - Bypass Assessment Hydrotest

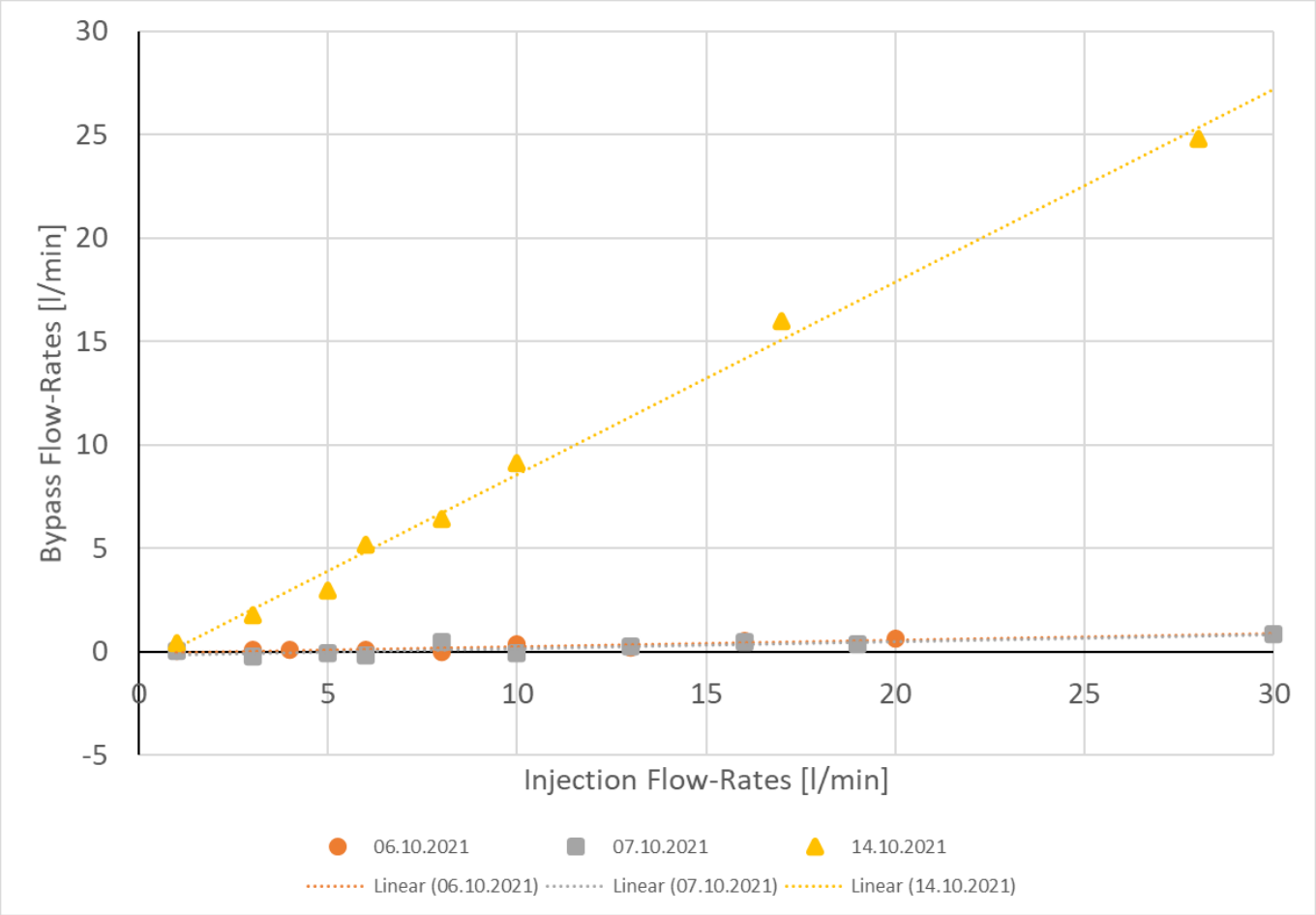








Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021



Bypass flowrates measured at the top of the wellhead (inside of the casing) compared to the injected flow-rates. Each set of points corresponds to a day when a test was performed with a corresponding linear trendline.

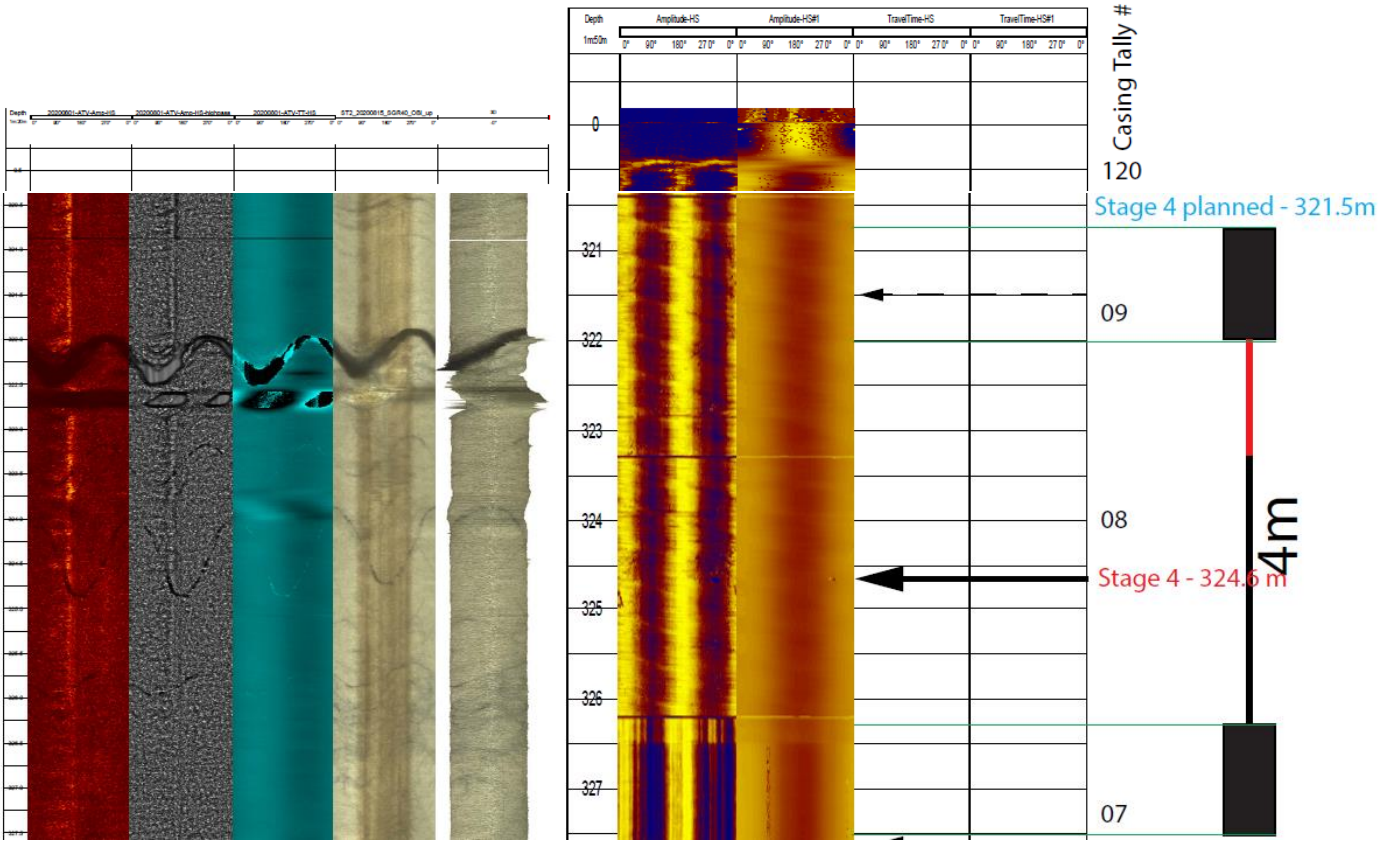
Interval 4
(322 m to 326 m)

Content:

1. ATV, OTV LOG
2. Result Table
3. Graphs

Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021

Interval 4 Depth: 322.15 m to 326.28 m. Target fracture: 322 m



Interval short history

Date	Action
July 2020	End drilling ST2
November 2020	Hydraulic Stimulation
June 2021	Cemented Casing
September 2021	Notch at 324.6m depth
October 2021	Hydraulic Stimulation

Borehole	ST2	**Interval Depth**	322.15 to 326.28 m
Test Interval	4	**Target Fracture**	322 m
Test Type	Double Packer	**Testing Date**	13.10.2021 - 14.10.2021
Authors	Fran, Fabien	**Report Date**	31.10.2021

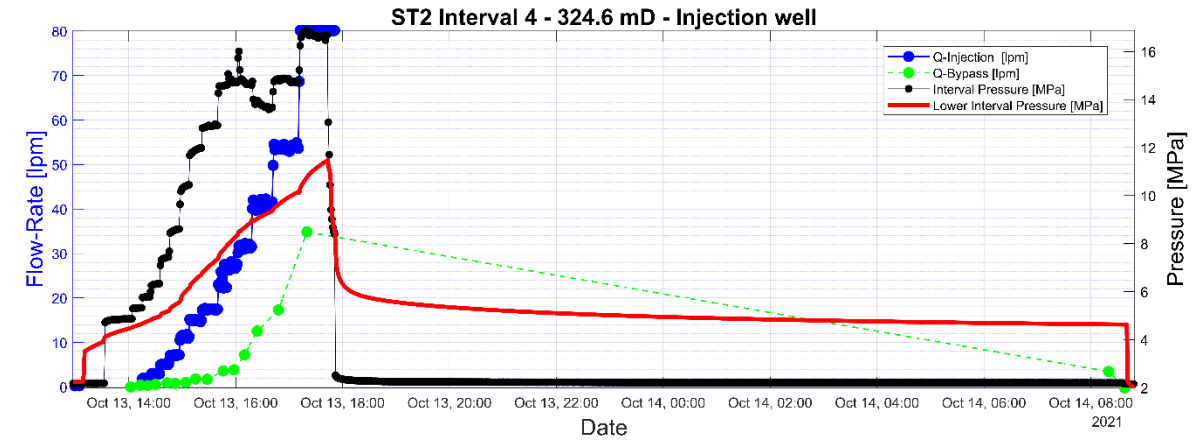
Test Description: A double packer test system was installed at a depth of 322.15 m, which corresponds to the bottom of the top packer.
The following test sequences were conducted:

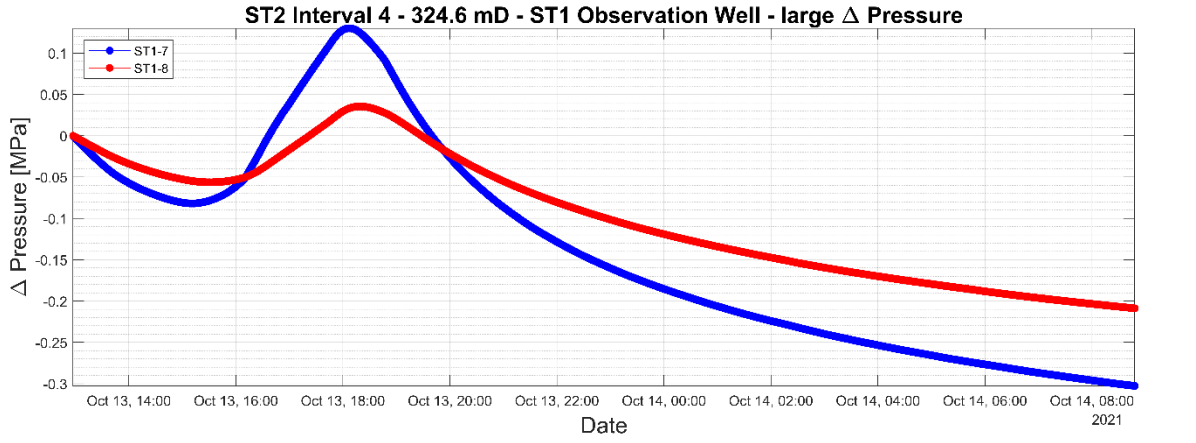
INF 13.10.2021	Downhole pressures are hydrostatic at 2.18 MPa. The initial flow rate was 5.53 l/min.
BU-1 13.10.2021	The shut-in valve was closed to initiate a static pressure recovery period of 32 min. The downhole pressure increased from 2.18 MPa to 4.87 MPa.
SR-1 13.10.2021	A step-rate injection test was performed with increasing rates from 0.9 to 80 l/min during 228 min. The downhole pressure changed from 4.87 MPa to 8.32 Mpa.
RE-1 13.10 - 14.10	The shut-in valve was closed to initiate a recovery period of 14.7 hours. The pressure decreased from 8.32 MPa to 2.2 MPa.
CH-1 14.10.2021	A constant head withdrawl test was conducted for 4 minutes. The pressure decreased from 2.2 MPa to 2.16 MPa.
INF-2 14.10.2021	Downhole pressures are hydrostatic at 2.17 MPa. The initial flow rate was 3.46 l/min.
BU-2 14.10.2021	The shut-in valve was closed to initiate a static pressure recovery period of 7 min. The downhole pressure changed from 2.17 MPa to 2.09 MPa.
SR-2 14.10.2021	A step-rate injection test was performed with increasing rates from 1.7 to 24 l/min during 46 min. The downhole pressure changed from 2.09 MPa to 2.73 MPa.
RE-2 14.10.2021	The shut-in valve was closed to initiate a recovery period of 6 min. The pressure decreased from 2.73 Mpa to 2.07 MPa.

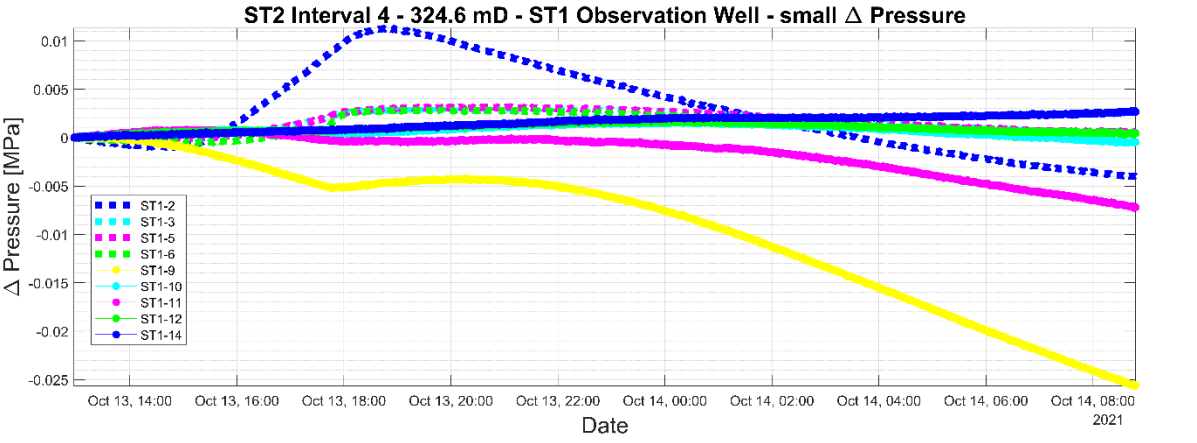
Test Interval Specifications:

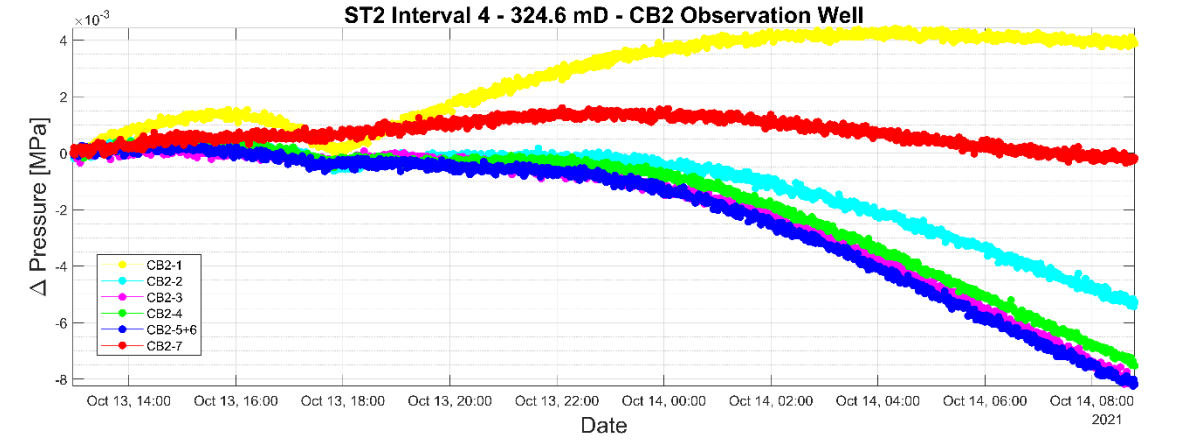
Interval Length	4.133 [m]	Wellbore Radius	0.08 [m]

* Abreviations. INF: Initial conditions before Inflating Packers. BU: Static Pressure Recovery. SR: Step-Rate Injection Test. CR: Constant-Rate Injection Test. RE: Pressure recovery Test. CH: Constant Head Withdrawal Test.



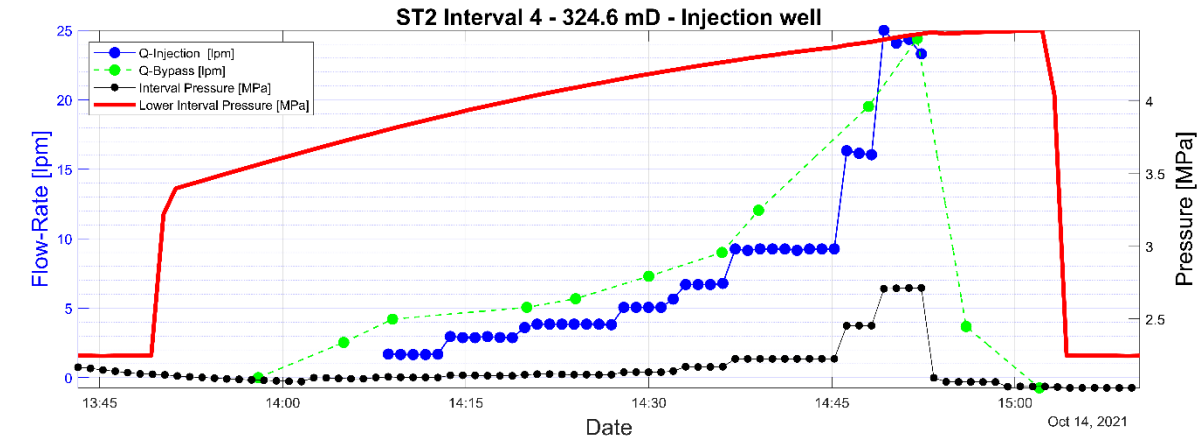


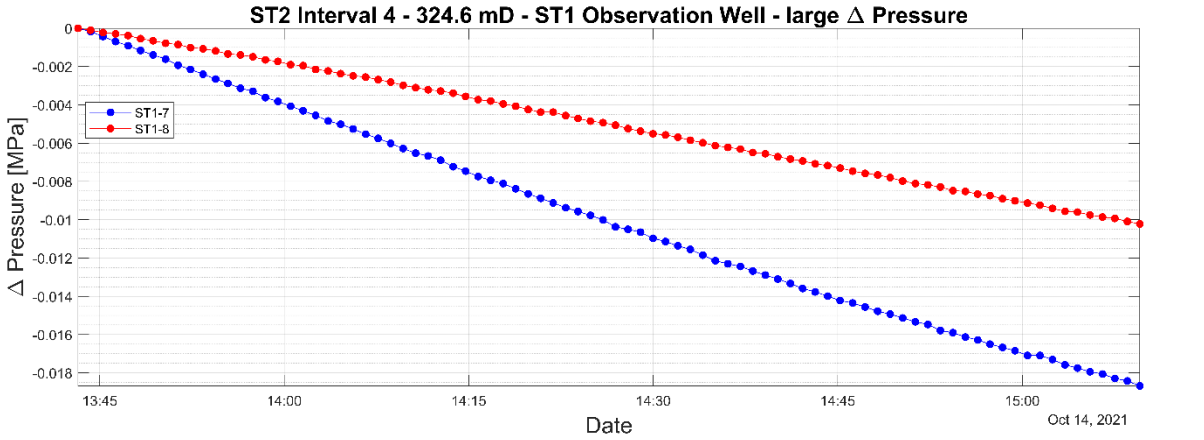


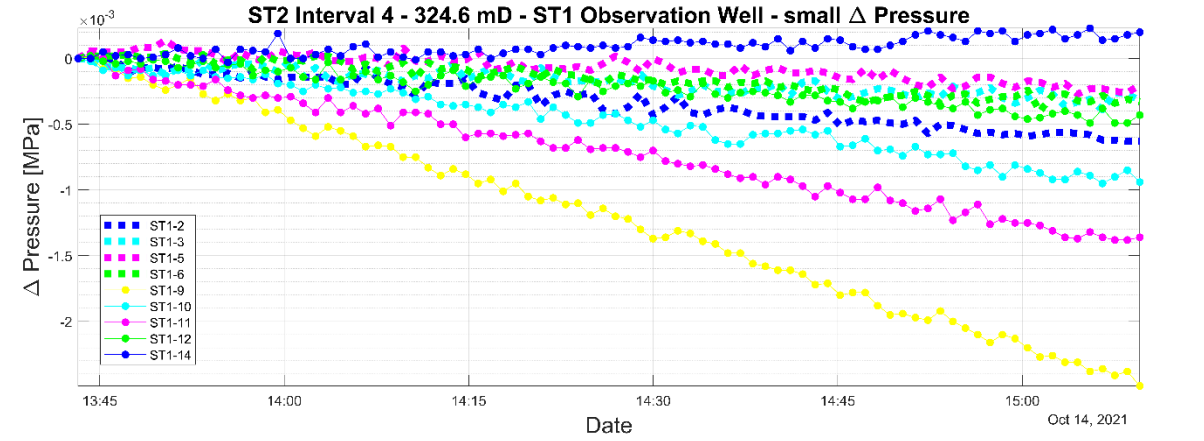


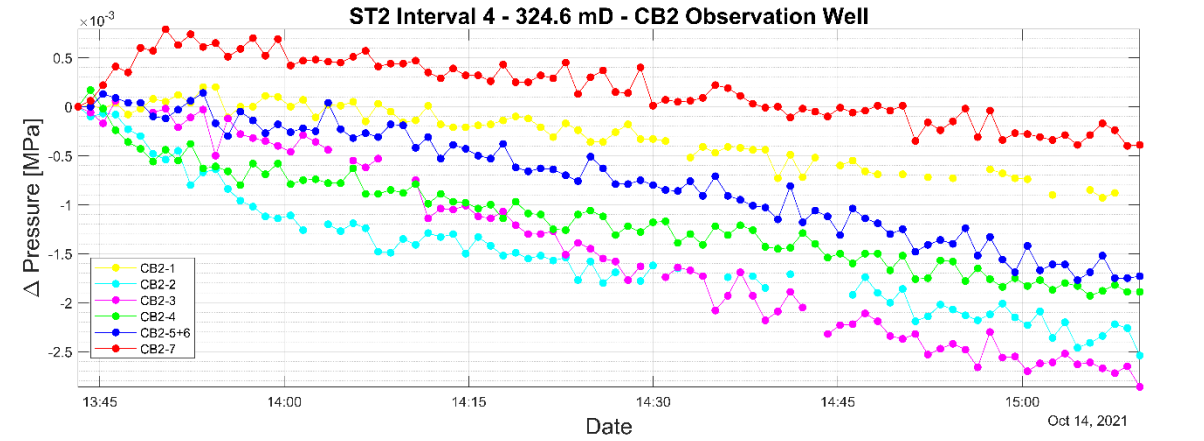
Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021

14.10.2021 - Bypass Assessment Hydrotest

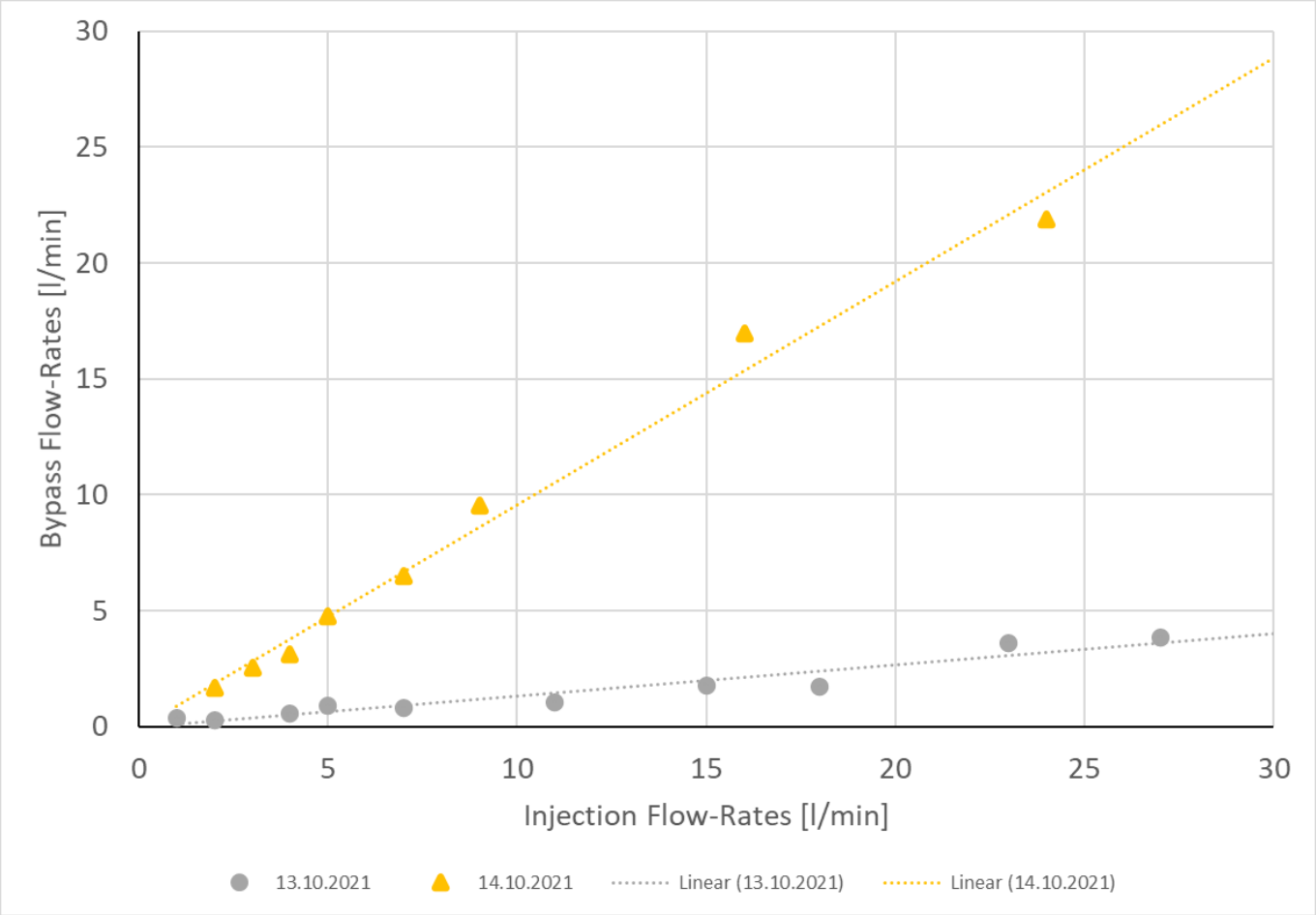








Authors: F. Christe, F. Serbeto and P. Meier
Date: 31.10.2021



Bypass flowrates measured at the top of the wellhead (inside of the casing) compared to the injected flow-rates. Each set of points corresponds to a day when a test was performed with a corresponding linear trendline.

Attachments

1. **ATV and OTV log with the interval packer seats**

Attached in document: ST2_log20092021_cased.pdf

2. **Tables with Results and Identity cards for each interval**

Attached in document: Stim-tests_tables_ST2_Oct2021.xslx

3. **Field measures taken during the hydraulic testing**

Attached in document: Field_measures_15.10.2021_Stim-ST2.xslx

4. **Field logbook of the hydraulic testing**

Attached in document: ActivityReport_LogBook_06.10.2021_STIMST2.xslx

5. **Diagram of the pump, the flowboards and the sensors used for the stimulation**

Attached in document: Lab Diagram V2 - ST2 Stim.pdf