P-04-311

Forsmark site investigation

Rock stress measurements with hydraulic fracturing and hydraulic testing of pre-existing fractures in borehole KFM01A, KFM01B, KFM02A and KFM04A

Results of in-situ tests

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MeSy GmbH

November 2004

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Keywords: Rock stress measurements, Hydraulic fracturing, Hydraulic testing of pre-existing fractures, State of stress, Hydraulic permeability, AP PF 400-04-023.

Abstract

During 27.04. to 21.05.2004, a total of 85 hydraulic fracturing (HF) and hydraulic injection tests on pre-existing fractures (HTPF) were conducted in borehole nos KFM01A, KFM01B, KFM02A, and KFM04A in order to determine the in-situ stress regime at the Forsmark candidate area. The in-situ tests in the NQ-size open-hole borehole sections were carried out using the MeSy wireline approach, where the hydrofrac- and impression packer units type Perfrac II were moved via a 7-conductor logging cable winch.

Since most of the pre-existing fractures acted like healed fractures, the majority of the initially planned 50 HTPF tests exhibited distinct breakdown events (an indication that new fractures may have been induced), and only in 25 HF or HTPF test sections the stimulation of existing fractures was observed. Nevertheless, the analysis of the characteristic hydrofrac pressure and fracture orientation data according to both the Hubbert and Willis approach and inversion calculations on the basis of the PSI method can be summarized as follows:

- For borehole nos KFM01A/B and KFM02A, the derived vertical stresses S_v are in close agreement with the vertical stress calculated for a mean rock mass density of 2.65 g/cm^3, while in borehole no KFM04A the derived vertical stress is about 20–25% larger than the overburden stress:

Borehole no	Depth range TVD [m]	S_v [MPa]
KFM01A/B	167–961	(4.6 ± 0.6) + (0.0275 ± 0.0025) · (TVD-167)
KFM02A	220–755	(5.2 ± 0.7) + (0.028 ± 0.002) · (TVD-220)
KFM04A	171–503	(5.4 ± 0.3) + (0.033 ± 0.002) · (TVD-171)

- Both analysis methods yield a consistent estimation of the minimum horizontal stress S_h:

Borehole no	Depth range TVD [m]	Hubbert and Willis approach S_h [MPa]	Inversion calculations S_h [MPa]
KFM01A/B	183–961	(6.0±1.7)+(0.025±0.004)·(TVD-183)	
	167–961		(6.7±0.6)+(0.021±0.001)·(TVD-167)
KFM02A	220–755	(6.8±0.4)+(0.031±0.001)·(TVD-220)	(5.8±0.7)+(0.032±0.002)·(TVD-220)
KFM04A	171–503		(5.1±0.7)+(0.026±0.004)·(TVD-171)

Down to approximately 500 m depth, the minimum horizontal stress is in all boreholes slightly larger than the vertical stress calculated for a mean rock mass density of 2.65 g/cm^3. Below 500 m, the results suggest that the minimum horizontal stress is the least principal stress in borehole no KFM01A/B, while in borehole no KFM02A the vertical stress is the minor principal stress.

- In contrary, the stress-profiles for the maximum horizontal stress S_H differs significantly and may be considered as an upper and lower bound estimation:

Borehole no	Depth range TVD [m]	Hubbert and Willis approach S_H [MPa]	Inversion calculations S_H [MPa]
KFM01A/B	183–961	(10.1±3.5)+(0.055±0.008)·(TVD-183)	
	167–961		(11.4±2.1)+(0.032±0.005)·(TVD-167)
KFM02A	220–755	(10.8±1.0)+(0.072±0.003)·(TVD-220)	(12.1±1.7)+(0.032±0.007)·(TVD-220)
KFM04A	171–503		(13.6±0.8)+(0.012±0.002)·(TVD-171)

- The direction of the maximum horizontal stress S_H in relation to magnetic North was consistently determined as N 125° ± 5° in borehole no KFM01A/B, N 137° ± 8° in borehole no KFM02A, and N 143° ± 5° in borehole no KFM04A. The NW-SE orientation is in agreement with existing stress data for the Forsmark area.

Due to the a-priori assumption of a linear stress-depth dependence, the results characterize the general trend of the stress-field at Forsmark. The existence of zones of e.g. higher stresses as indicated by the overcoring stress measurements, locally observed high shut-in pressures during the hydraulic injection tests, and the core disking can not be refuted.

The analysis of the pressure pulse tests conducted prior to the hydraulic injection tests yields an average permeability of 25 ± 40 µDarcy (10^{-18} m^2) for the granitic rock mass with only minor differences between intact and pre-fractured test-sections. The permeability after hydrofracturing/hydraulic stimulation increased by a factor of 1 to 40. Only at two test sections in borehole no KFM01B a significant increase of the permeability was observed. Both results indicate that pre-existing fractures are hydraulically sealed and almost completely closed after testing.

Sammanfattning

Under våren 2004 utfördes totalt 85 hydrauliska tester, dels hydraulisk spräckning (HF) och dels hydrauliska tester av befintliga sprickor (HTPF), i borrhålen KFM01A, KFM01B, KFM02A och KFM04A, för att bestämma in-situ spänningarna i Forsmark. Vid undersökningarna användes MeSys wirelinesystem, där dubbelmanschetter och avtrycksmanschetter flyttas i borrhålen med en vinsch och en loggningskabel med sju ledare.

Från början planerades att 50 stycken HTPF tester skulle utföras. Utav dessa resulterade endast 25 stycken i att en befintlig spricka öppnades. I de övriga testerna initierades troligtvis nya sprickor. Att så få av de befintliga sprickorna kunde öppnas beror sannolikt på att många av dessa är läkta med mineral med hög hållfasthet.

Analysen av karakteristiska tryck och uppmätta sprickorienteringar resulterade i nedanstående spänningsresultat, baserat på klassisk analys enligt Hubbert & Willis och inversberäkningar enligt PSI metoden:

- För borrhål KFM01A/B och KFM02A visar resultatet från mätningarna en vertikalspänning, S_v, som är i god överensstämmelse med en vertikalspänning beräknad för en densitet på 2,65 g/cm^3. Den beräknade vertikalspänningen i borrhål KFM04A är däremot 20–25 % högre än vad som svarar mot den överliggande bergmassan.

Borrhåls id	Djupintervall TVD [m]	S_v [MPa]
KFM01A/B	167–961	(4.6 ± 0.6) + (0.0275 ± 0.0025) · (TVD-167)
KFM02A	220–755	(5.2 ± 0.7) + (0.028 ± 0.002) · (TVD-220)
KFM04A	171–503	(5.4 ± 0.3) + (0.033 ± 0.002) · (TVD-171)

- De båda analysmetoderna ger överensstämmande resultat avseende minsta horisontella spänningen S_h:

Borrhåls id	Djupintervall TVD [m]	Hubbert & Willis-metoden S_h [MPa]	Inversberäkningar S_h [MPa]
KFM01A/B	183–961	(6.0±1.7)+(0.025±0.004)·(TVD-183)	
	167–961		(6.7±0.6)+(0.021±0.001)·(TVD-167)
KFM02A	220–755	(6.8±0.4)+(0.031±0.001)·(TVD-220)	(5.8±0.7)+(0.032±0.002)·(TVD-220)
KFM04A	171–503		(5.1±0.7)+(0.026±0.004)·(TVD-171)

Ner till ett djup av ca 500 meter är den minsta horisontella spänningen något större än den vertikala spänningen. Under 500 meters djup indikerar beräkningarna för borrhål KFM01A och KFM01B att den minsta horisontella spänningen är den minsta huvudspänningen, medan istället den vertikala spänningen är den minsta huvudspänningen i KFM02A.

- Resultaten av spänningsprofilerna för den största horisontella spänningen, S_H, skiljer sig signifikant mellan Hubbert & Willis-metoden och inversberäkningarna. Resultaten från de två metoderna kan tolkas som en övre och nedre gräns för den största horisontella spänningen.

Borrhåls id	Djupintervall TVD [m]	Hubbert & Willis-metoden S_H [MPa]	Inversberäkningar S_H [MPa]
KFM01A/B	183–961	(10.1±3.5)+(0.055±0.008)·(TVD-183)	
	167–961		(11.4±2.1)+(0.032±0.005)·(TVD-167)
KFM02A	220–755	(10.8±1.0)+(0.072±0.003)·(TVD-220)	(12.1±1.7)+(0.032±0.007)·(TVD-220)
KFM04A	171–503		(13.6±0.8)+(0.012±0.002)·(TVD-171)

- I borrhål KFM01A och KFM01B visade resultaten av beräkningarna att riktningen för den maximala horisontella spänningen, S_H, är N125° ± 5°. För borrhål KFM02A är motsvarande riktning N137° ± 8° och i borrhål KFM04A N143° ± 5°. Resultaten skiljer sig inte i jämförelse med tidigare spänningsmätningar i området.

Vid analysen antas à-priori att det föreligger ett linjärt djupberoende för spänningsmagnituderna, vilket innebär att resultaten kan ses som en generell bild av spänningsfältet vid Forsmark.

De indikationer om höga spänningar inom vissa djupintervall som man erhållit dels från tidigare överborrningsmätningar, dels från höga shut-in tryck vid några av de hydrauliska testerna samt från observationer av core disking, kan inte verifieras med de beräkningar som utförts inom ramen för denna utredning.

Resultaten av pulstesterna, som utfördes före HF och HTPF testerna, visar att bergmassan har en medelpermeabilitet på 25 ± 40 μDarcy (10^{-18} m^2). Det var endast små skillnader i permeabilitet mellan testsektioner i det intakta berget (HF) och testsektioner med en befintlig spricka (HTPF). Permeabiliteten ökade i allmänhet med en faktor 1–40 efter utförda HF och HTPF tester. Endast i två testsektioner i borrhål KFM01B kunde en signifikant ökning av permeabiliteten observeras. Sammanfattningsvis indikerar resultaten att de befintliga sprickorna inte är vattenförande och att sprickorna stängs nästan helt efter utförda tester.

Contents

1 Introduction

This document reports the results gained by rock stress measurements with hydraulic fracturing (HF) and hydraulic testing of pre-existing fractures (HTPF) in boreholes nos KFM01A, KFM01B, KFM02A and KFM04A, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-04-023. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

The location of the test boreholes within the Forsmark candidate area is shown in Figure 1-1. Borehole nos KFM01A, KFM02A and KFM04A are percussion drilled in the interval c 0–100 m and core-drilled from c 100 m to about 1,000 m borehole length, while borehole no KFM01B has a length of approximately 500 m. The boreholes are inclined between 5 and 40 degrees from the vertical plane and have a diameter of 76 to 77 mm. Only the upper 100 m (15.5 m in borehole no KFM01B) are protected with a casing. Each borehole penetrates an essentially homogenous granitic rock.

During 27.04. to 21.05.2004, a total of 85 hydraulic fracturing or hydraulic injection tests on pre-existing fractures as well as 49 impression packer tests for fracture orientation determination were carried out in the four boreholes. Objective of the tests was to determine the magnitude and the orientation of the in-situ stress regime in order to compare the results with earlier performed stress measurements and contribute to the site descriptive model. The results of the investigation are stored in the SKB database SICADA, field note no 202.

Table 1-1. Controlling documents for performance of the activity.

Activity plan	Number	Version
Rock stress measurements with HF and HTPF in boreholes KFM01A, 1B, 2A and 4A	AP PF 400-04-023	1.0
Method descriptions	**Number**	**Version**
Rock stress measurement with hydraulic methods	SKB MD 182.003e	1.1
Instruction for length calibration in investigation of core boreholes	SKB MD 620.010e*	1.0
Instructions for cleaning borehole equipment and certain surface equipment	SKB MD 600.004e	1.0

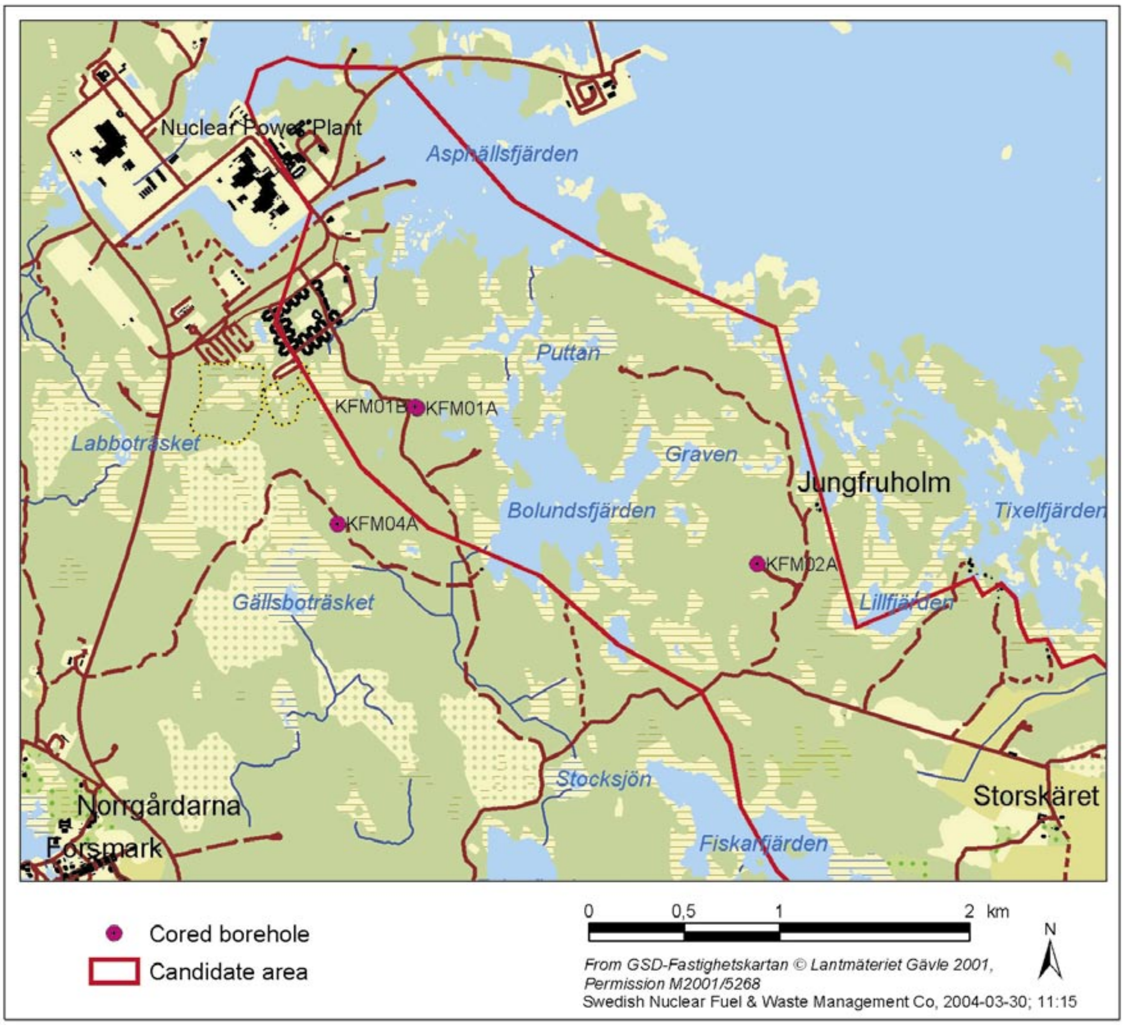


***Figure 1-1.** General overview over Forsmark site investigation area and location of borehole nos KFM01A, KFM01B, KFM02A, and KFM04A.*

2 Objective and scope

Existing stress data in the vicinity of the candidate area, recent overcoring stress measurements in borehole no KFM01B /Sjöberg, 2004/, as well as the partly observed core disking suggest the existence of anomalous high horizontal stresses in the Forsmark area. Although the data include considerable uncertainties, they are summarized in the present site descriptive model (version 1.1, cited in the Activity Plan) by:

S_h [MPa] $= 1.4 + 0.028 \cdot z$ [m]

S_H [MPa] $= 4.0 + 0.09 \cdot z$ [m]

S_v [MPa] $= 0.027 \cdot z$ [m]

where S_h and S_H denote the minimum and maximum horizontal principal stresses, S_v the vertical principal stress and z the depth.

In order to determine the constraints of the in-situ stress regime, to compare the results with existing stress data and thus to contribute to a more site specific version of the site descriptive model, a rather comprehensive program of in-situ hydraulic fracturing tests (HF) and hydraulic tests on pre-existing fractures (HTPF) was planned in four deep boreholes at the Forsmark candidate area. The in-situ tests are accompanied by a series of laboratory tests relevant to hydraulic fracturing on the core material of the test boreholes. The results of the laboratory investigations are presented in a separate volume of the present report (MeSy Report No 28.04B). Since each HF and HTPF test is preceded by a short pressure pulse test, the tests also yield an estimation of the hydraulic permeability of the borehole wall rock.

Detailed information on the in-situ stress testing methods are given in /Amadei and Stephansson, 1997/ or in the ISRM Suggested Method /Haimson and Cornet, 2003/. In both, the HF and HTPF methods, a sealed off borehole section is pressurized by fluid injection until either a tensile fracture is initiated (HF) or a pre-existing fracture is hydraulically opened (HTPF). The characteristic pressure values necessary to create, re-open and extend the fractures together with the spatial orientation of the fractures allow deriving the in-situ stresses.

A summary of the test program in boreholes nos KFM01A, KFM01B, KFM02A, and KFM04A is presented in Table 2-1. In total, 35 hydraulic fracturing tests (HF) in borehole sections without visible fractures and 50 hydraulic tests on pre-determined existing fractures (HTPF) were planned. Together with the planned impression packer tests on each hydrofrac test section for fracture orientation determination, the database was considered to be sufficient for a reliable derivation of the stress regime for the area. However, it has to be stated already here, that the majority of the HTPF tests exhibits distinct breakdown events. This observation indicates that new fractures may have been initiated although the test sections contained pre-existing fractures. Only in borehole no KFM04A, a relatively large number of existing fractures were stimulated since more pronounced fractures in the core material were selected for the HTPF tests. As a consequence, several HTPF test results could not be considered for the stress analysis due to the lack of reliable fracture orientation data.

Table 2-1. Summary of the hydraulic fracturing (HF) and hydraulic tests on pre-existing fractures (HTPF) program (IMP: impression packer tests).

Borehole no	Measured depth MD [m]	True vertical depth TVD * [m]	Number of tests Planned HF (incl IMP)	HTPF	Conducted HF	HTPF	IMP
KFM01A	249.43–975.00	247.99–960.32	12	13	21	4	13
KFM01B	171.00–476.10	167.07–459.32	9	3	7	5	12
KFM02A	149.58–757.43	147.10–753.75	12	25	29	8	13
KFM04A	194.58–593.93	171.43–502.91	2	9	3	8	11
Total			35	50	60	25	49

* the true vertical depth was calculated on the basis of the borehole trajectory data.

3 Test equipment and calibration

3.1 In-situ test equipment

The hydraulic fracturing/hydraulic injection stress measurements at Forsmark were carried out using the MeSy wireline technique, where the straddle packer tool is moved within the borehole on a seven conductor borehole logging cable and a winch system (MKW-1500). This technique allows fast "stress-logging" similar to conventional geophysical borehole logging in the absence of an on-site drill rig. Compared to conventional systems with drill rods, the wireline testing approach enables detailed pressure and fracture growth control due to its high system stiffness of about 10^{-11} m^3/Pa and the possibility of on-line downhole pressure recording. A schematic view of the system is given in Figure 3-1, a photo of the system set-up at borehole no KFM02A is presented in Figure 3-2.

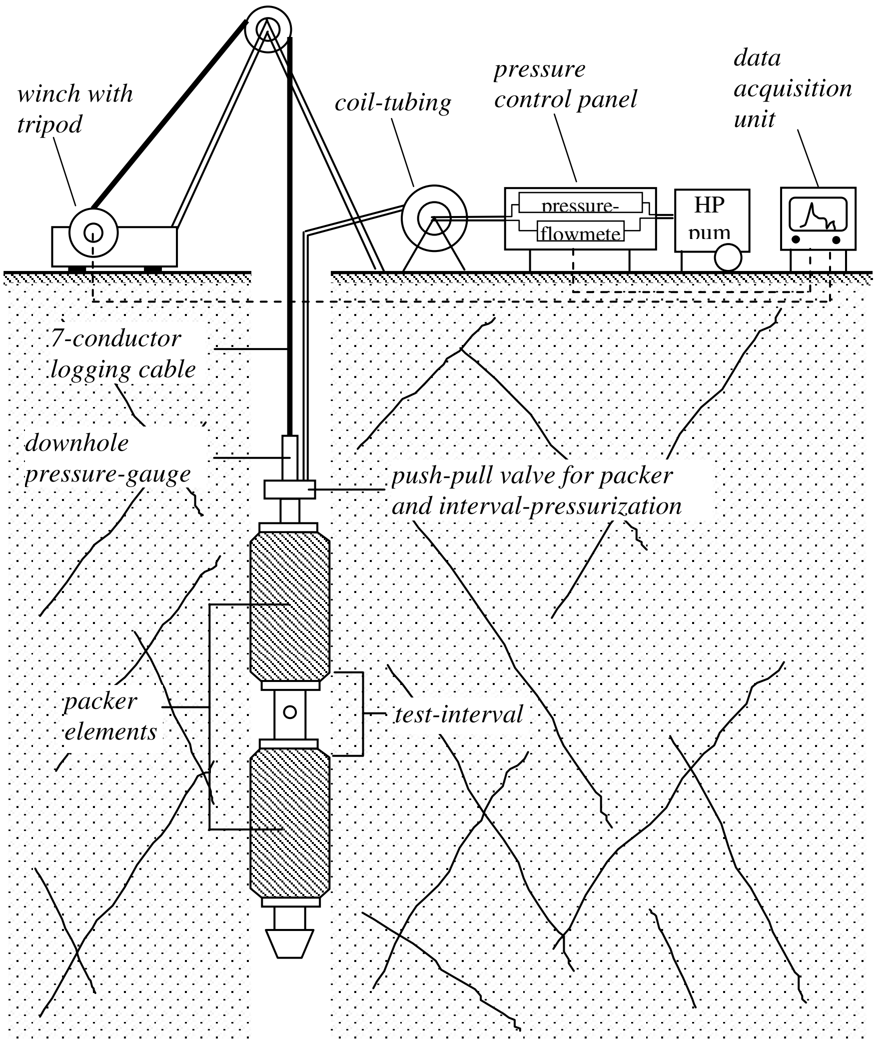


Figure 3-1. Schematic view of the wireline hydrofrac system.

Figure 3-2. *Photo showing the wireline hydrofrac system at the location of borehole no KFM02A.*

For the case of the hydraulic injection/hydrofrac experiments in the 76 to 77 mm diameter borehole sections, the MeSy straddle packer assembly PERFRAC II equipped with nylon-reinforced packer elements (S & K, type TK 48-V-1300, OD: 71 mm) was used. The sealing length of each packer element was about 1.0 m; the length of the test interval between the two packers was about 0.6 m.

The packer elements were pressurized via a high pressure stainless steel coil tubing (OD: 10 mm, ID: 8 mm, maximum operating pressure 60 MPa) which was clamped to the logging cable at 30 m intervals. A push-pull valve mounted on top of the packer assembly allows to switch from packer pressurization to injection into the test interval, and the reverse, simply by controlling the tension of the logging cable. For pressurization of both packer elements and the test interval, an electric driven three-plunger pump (SPECK, type HP 400/2-12) with a maximum working pressure of 40 MPa and a maximum injection rate of 12 l/min was used. The injection fluid was water (mixed with Uranin as tracer).

Packer- and interval pressure were measured uphole and downhole with high precision electric pressure transducers (KELLER, type PA-23, 0–60 MPa and PA-23, 0–40 MPa). Pressure values and the injection flow rate (UNIMESS turbine type flow-meter, QPT 04, 1.2–10 l/min) were recorded by a digital data acquisition system (SILVI, 8 channels, 16 bit resolution, sampling rate: 5 Hz).

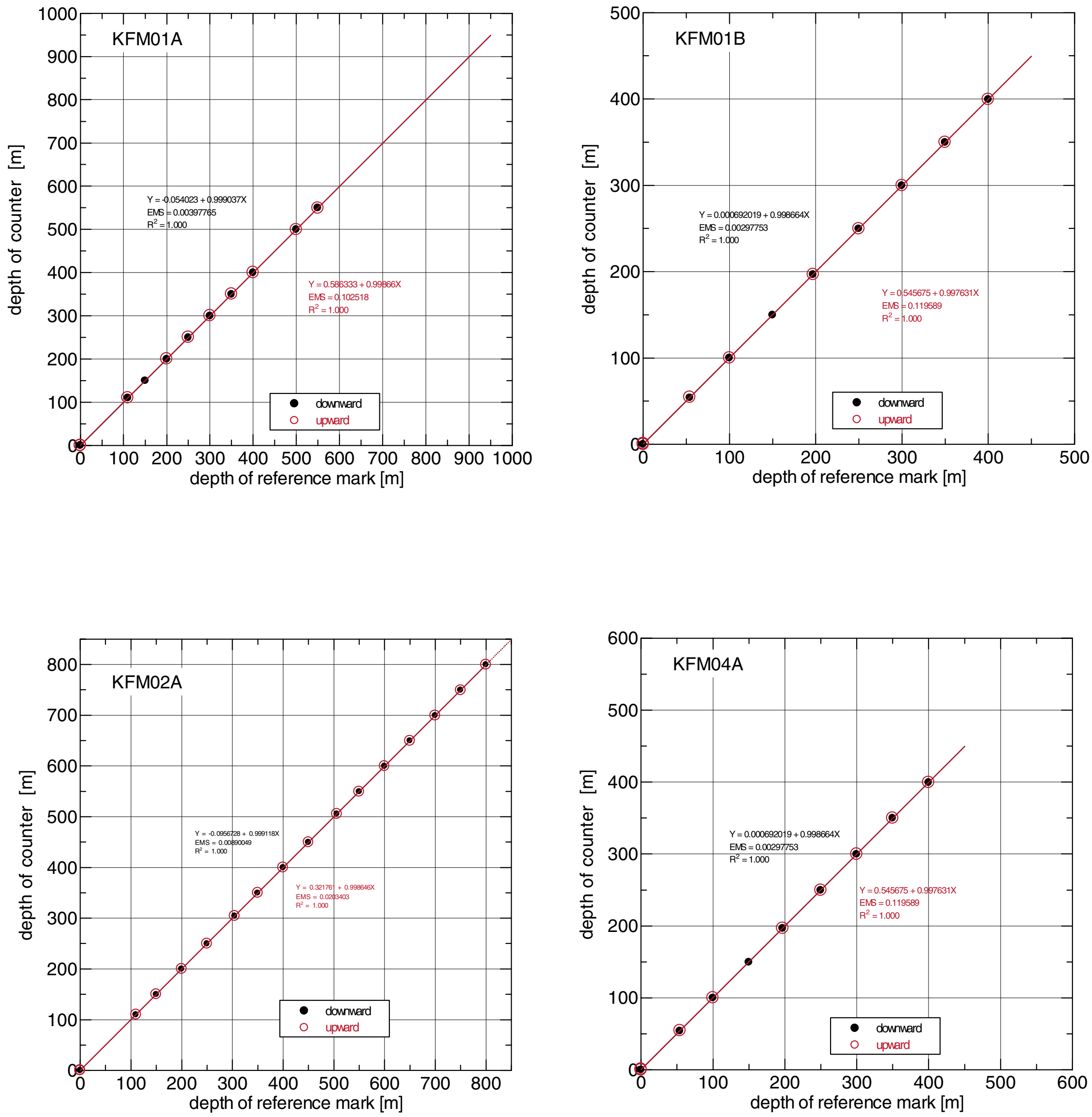
The impression packer tool to measure the orientation of induced or stimulated fractures consisted of a single packer (S & K, type TK 48-V-1300, OD: 71 mm) with a soft rubber sleeve, in conjunction with a magnetic single shot device (EW, type RW). The packer preserves the imprint of the borehole wall and of the fracture traces when it is pressurized to a pressure level higher than the fracture re-opening pressure for a time of approximately 10 minutes.

3.2 Equipment calibration

As part of the MeSy quality assurance, the pressure transducers and the flow-meters were calibrated prior to in-situ testing. The calibrations are documented in the MeSy quality plan prepared for SKB. In general, the pressure transducers were tested against a reference load cell, the flow-meter was examined by mass determination per unit of time with a precise balance. The calibrations were continuously checked during the execution of the field tests.

The depth counting systems on the MKW-1500 winch were calibrated against the reference tracks in each of the boreholes using the SKB depth detector in conjunction with an adaptor to the winch cable head and a sub-weight to simulate the straddle packer tool. The procedure is described in detail in SKB MD 620.010e (SKB internal document). In addition, depth reference marks were fixed on the cable every approximately 100 m enabling depth corrections during each trip into the boreholes.

The results of the depth calibrations in each borehole are summarized in Figure 3-3. Since it is only necessary to consider the slopes of the regression lines between the depth reference marks fixed on the cable, the error of the depth measuring system during upward movement is 13 to 24 cm within a 100 m interval.



Borehole no	Downward	Upward
KFM01A	counter = –0.05 + 0.9990·z	counter = 0.59 + 0.9987·z
KFM01B	counter = 0.00 + 0.9987·z	counter = 0.55 + 0.9976·z
KFM02A	counter = –0.10 + 0.9991·z	counter = 0.32 + 0.9986·z
KFM04A	counter = 0.03 + 0.9986·z	counter = 0.74 + 0.9976·z

Figure 3-3. *Results of depth calibrations in boreholes no KFM01A, KFM01B, KFM02A, and KFM04A.*

4 Execution

4.1 Selection of test sections

Suitable test sections in each borehole were selected by SKB on the basis of the analysis of the rock core material and borehole logs. For HF tests, homogenous borehole sections without visible fractures were selected, for HTPF tests, solitary fractures with different spatial orientation (dip and strike) were selected in order to allow an inversion type stress analysis. As it turned out during testing that the majority of the HTPF tests exhibited typical breakdown events (an indication that new fractures may have been initiated), it was decided to select more pronounced fractures in the core material for testing in borehole no KFM04A.

4.2 Preparations

After installation of electric power and water supply on site, the field preparations included:

- Cleaning of the downhole equipment (packer tools, logging cable, cable clamps, coil tubing) with the MeSy cable cleaner and hot steam according to level 1 of SKB MD 620.004e (SKB internal document) to prevent a contamination of the borehole or the borehole fluid.
- Calibration of depth counting system of the winch unit according to SKB MD 620.010e (SKB internal document, see Section 3.2). These runs were also used to check whether the borehole is free of obstacles.
- Venting of the hydraulic system.
- Test of system function and tightness in a test pipe of 76 mm ID at surface; the test also yields the system stiffness dP/dV in the order of 25–45 MPa/l equivalent to 2–4 $\cdot 10^{-11}$ m^3/Pa, depending on the volume of the hydraulic system. The stiffness is compared with the stiffness determined from the refract pressure test (see Section 4.5.2).

4.3 Execution of field work

Two typical test records illustrating the test procedure are shown in Figures 4-1 and 4-2. The two examples from borehole no KFM02A were chosen to illustrate a hydrofrac test with a typical breakdown (fracture initiation) event (test no 2 at 707.0 m MD/703.75 m TVD) and a test where obviously a pre-existing fracture was stimulated (test no 5 at 655.99 m MD/653.16 m TVD). The test conduction followed closely the recommendations of the ISRM-standard /Haimson and Cornet, 2003/ and the SKB document MD 182.003e (SKB internal document). It consisted of the following injection cycles after packer inflation to a differential pressure of 10–15 MPa:

- Rapid pressurization of the test interval to a differential pressure of about 2 MPa and subsequent monitoring the pressure decay for about 5 minutes in case of test sections without visible fractures (HF tests) and 15 minutes in case of test sections containing a pre-existing fracture (HTPF tests). The test is marked with P-test (or first P-Test) in Figures 4-1 and 4-2.

- Release of the interval pressure.
- Pressurization of the test interval with an injection rate of 1 to 2 l/min until a drop of interval pressure associated with the initiation of a fracture occurs (Frac test in Figure 4-1) or a constant injection pressure level for the case of the presence of a pre-existing fracture is reached (first Refrac test in Figure 4-2); termination of injection and system shut-in for about 3 minutes.
- Release of the interval pressure and monitoring the recovered fluid volume.
- Re-pressurization of the test interval until constant injection pressure is observed (first Refrac test in Figure 4-1); termination of injection and system shut-in for about 3 minutes.
- Release of the interval pressure and monitoring the recovered fluid volume.
- Several repetitions of the refrac test with injection rates of 2 to 5 l/min (increasing order) until reproducible shut-in pressure values are observed.
- Conduction of a Slow-Pump/Step-Rate injection test with stepwise increase of the injection flow-rate and observation of the corresponding injection pressure; termination of injection and system shut-in for about 3 minutes.
- Release of the interval pressure and monitoring the recovered fluid volume.
- In case of HTPF testing, repetition of the pressure pulse test (second P-test in Figure 4-2)
- Finally packer deflation and movement of the packer tool to the next test section.

After completion of all HF and HTPF tests, the straddle packer tool was replaced by the impression packer unit:

- The impression packer tests consisted of an inflation of the impression packer element to a pressure approximately 20% above the fracture re-opening pressure for a period of about 15 minutes. After recovery of the packer tool to the surface, the fracture trace is marked on the packer sleeve and transferred to a transparent plastic cover sheet wrapped around the packer. The film disc of the single-shot unit was developed documenting the orientation of the reference mark with respect to magnetic North. A typical example of fracture traces marked on the plastic cover sheets is shown in Figure 4-3 for the test section at 603.0 m MD/600.58 m TVD in borehole no KFM02A.

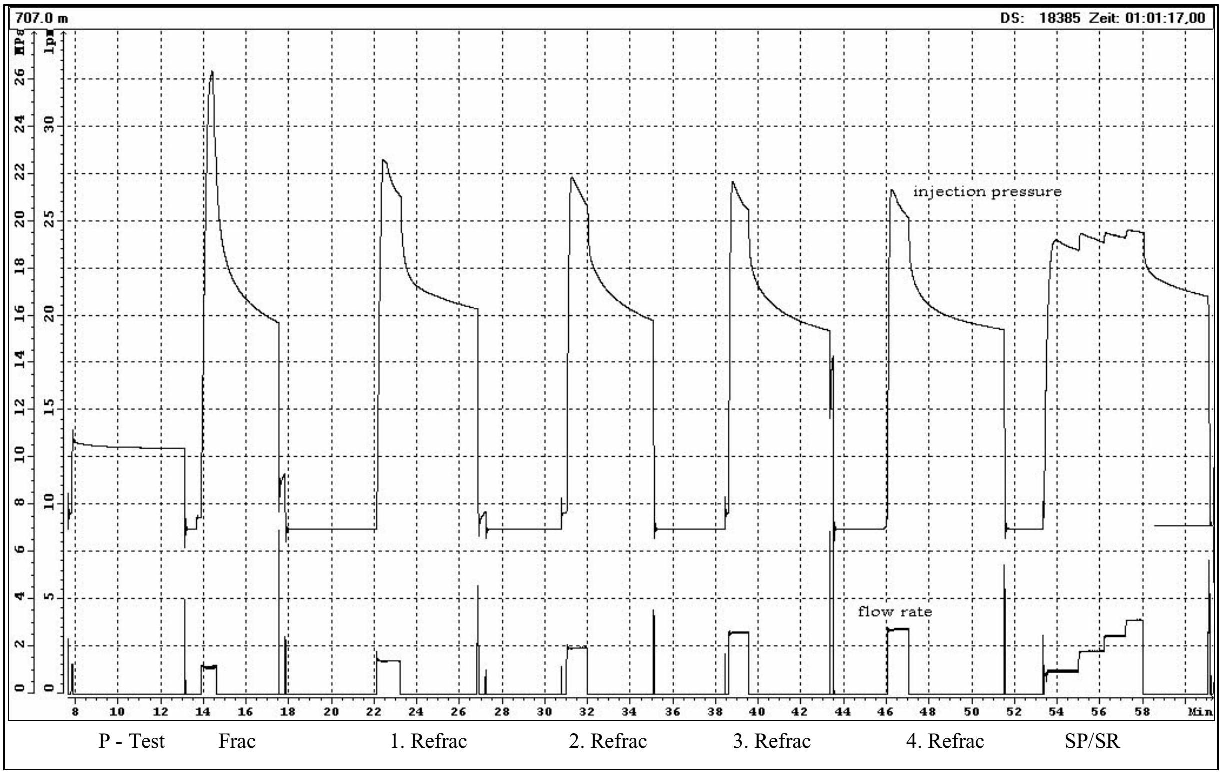


Figure 4-1. *Downhole pressure and surface flow-rate record of the HF test at 707.0 m measured depth (MD)/703.75 m true vertical depth (TVD) in borehole no KFM02A.*

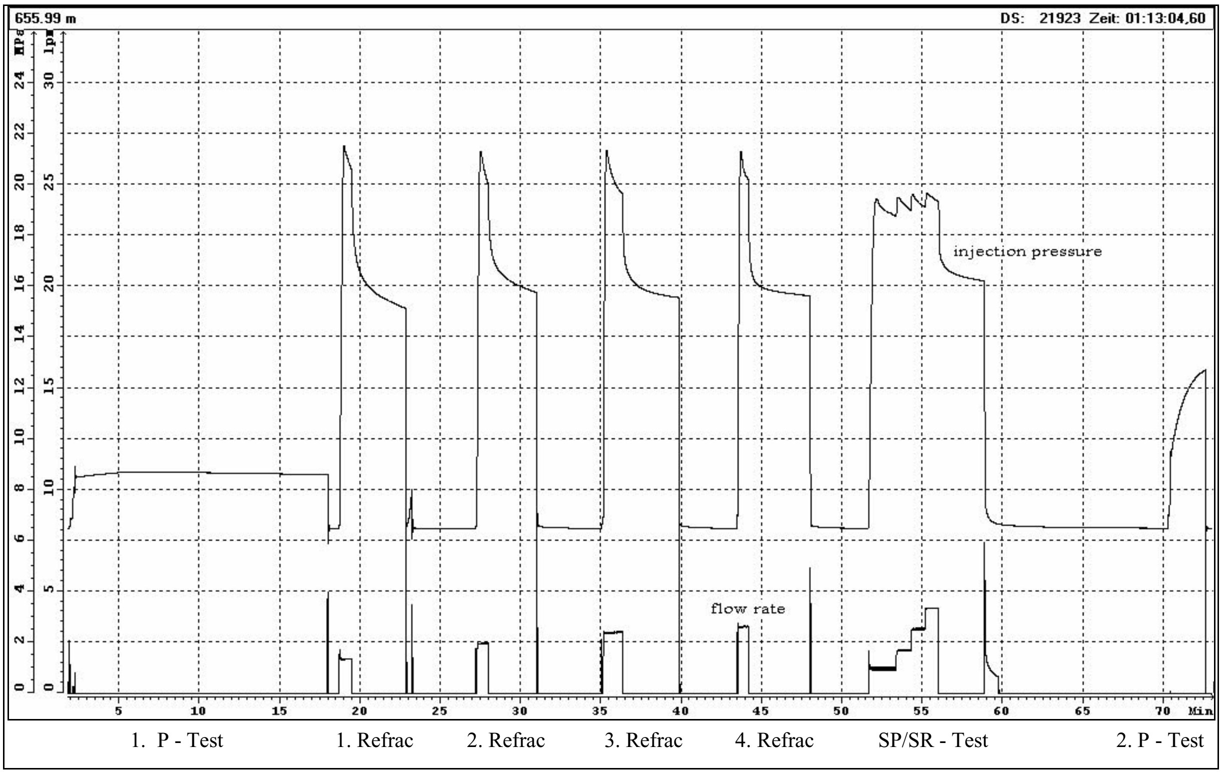


Figure 4-2. *Downhole pressure and surface flow-rate record of the HTPF test at 655.99 m measured depth (MD)/653.16 m true vertical depth (TVD) in borehole no KFM02A.*

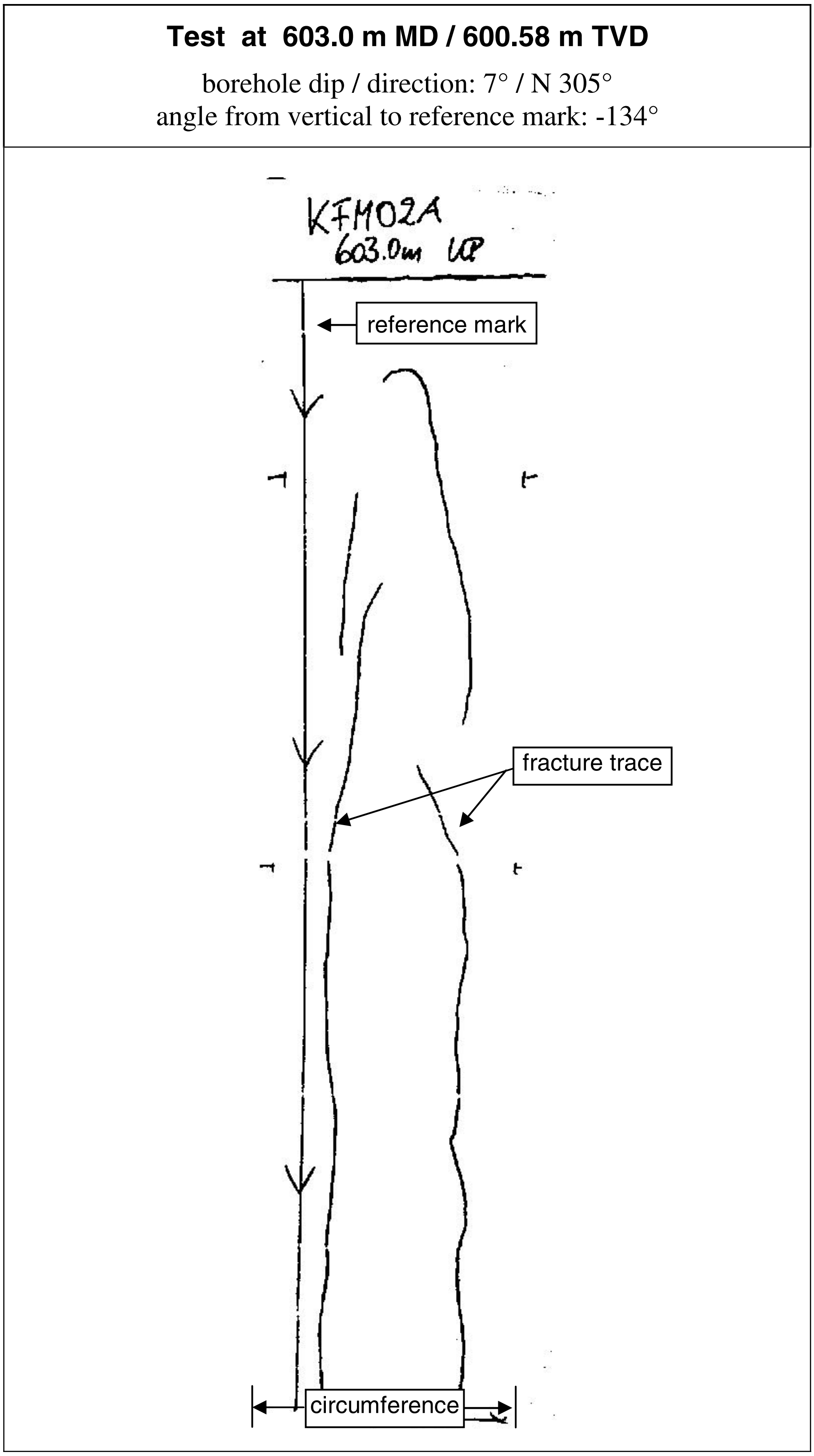


Figure 4-3. *Fracture traces of the impression packer test at 603.0 m measured depth (MD)/ 600.58 m true vertical depth (TVD) in borehole no KFM02A. The circumference of the packer is approximately 225 mm, the length is approximately 1,000 mm.*

4.4 Data handling/post processing

During each test, the injection pressure (downhole and uphole), and the injection flow rate were recorded by the MeSy digital data acquisition system SILVI. Due to the lower resolution limit of the flow-meter (flow-rate less than about 1 l/min is not recorded), the recovered fluid volume was measured manually with a measuring cup. The digital data were stored on the hard disc of the recording computer in a binary code; safety copies were produced immediately after each test and were stored on a back-up computer. The flow-rate records were integrated to determine the injected fluid volume by using the MeSy routine analysis software package GEOCALC. No further data processing (filtering, spike removal, drift correction) was applied. Copies of the data files in ASCII-format were produced and delivered to SKB. The data are stored in the SKB database SICADA, field note no 202.

4.5 Analyses and interpretations

4.5.1 Pressure pulse tests

The process of fluid transport through permeable rock is mathematically described by the diffusion equation. For the case of a pressurized borehole of radius R, and radial flow into homogenous rock, the diffusion equation can be written in the form:

$$\frac{\partial^2 p}{dr^2} + \frac{1}{r}\frac{\partial r}{\partial r} - \frac{1}{\chi}\frac{\partial p}{\partial t} = 0 \qquad (1)$$

where p is the fluid pressure within the pore volume (function of distance r and time t) and χ is the diffusivity (related to the permeability K of the rock, the viscosity η of the fluid and the storage capacity c of the rock).

A solution of the problem is presented in the classical method suggested by /Cooper et al. 1967/ for the analysis of conventional slug tests. For the analysis of pulse tests with the wireline hydraulic system of high system stiffness, MeSy has developed the software code PERM which allows matching numerical calculated pressure decline curves with the observed pressure decline. The matching is carried out by using an inversion technique (master curve method) for model calculations with a variety of input values for transmissivity and the storage coefficient. The results are given as the average of all models which satisfy the linear error regression analysis standard. The results are presented as permeability K or as hydraulic conductivity k:

$$k = K \cdot \frac{\rho_{water} \cdot g}{\eta} \qquad (2)$$

where ρ_{water} is the density of water and g the gravitational acceleration.

It should be noted here, that for the analysis the rock is simplified as a uniformly permeable rock mass, although in reality the fluid leak-off in crystalline rocks occurs along distinct fractures in the rock mass.

4.5.2 Stress evaluation from hydraulic injection tests

To derive stresses from measurements in boreholes, it is necessary to consider the stress distribution around a circular hole subjected to far-field compressive stresses. This stress concentration was first derived by /Kirsch, 1898/. In the case where the borehole axis is parallel to the intermediate principal stress, it is used in the /Hubbert and Willis formula, 1957/ for the critical pressure P_c at the moment of fracture initiation:

$$P_c = 3 \cdot S_h - S_H + P_{co} - P_p \tag{3}$$

where S_h and S_H are the horizontal far-field principal stresses, P_{co} is the in-situ hydraulic tensile strength of the rock, and P_p is the pore pressure in the rock mass. P_c is often called the breakdown pressure during the hydraulic fracturing process. It is assumed that the vertical stress is a principal stress and equal to the overburden stress, the rock is homogeneous, isotropic and initially impermeable, and that the induced fracture is oriented perpendicular to the minimum horizontal principal stress S_h. The last assumption yields:

$$P_{si} = S_h \tag{4}$$

where P_{si} is the shut-in pressure to merely keep the fracture open after the pressurizing system is shut-in. After pressure release, the fracture may close. It can be re-opened during subsequent pressure cycles at a pressure of

$$P_r = 3 \cdot S_h - S_H - P_p \tag{5}$$

Using this linear elastic approach and neglecting the pore pressure in crystalline rocks, the principal stresses can be expressed by the relations:

$$\begin{aligned} S_h &= P_{si} \\ S_H &= 3 \cdot P_{si} - P_r \\ S_v &= \rho \cdot g \cdot z \\ P_{co} &= P_c - P_r \end{aligned} \tag{6}$$

Thus, the stress analysis only requires knowledge on the rock mass density ρ, the determination of characteristic pressure values (in particular the shut-in pressure P_{si} and fracture re-opening pressure P_r) at depth z where the fracture is induced. The azimuth of the induced vertical fracture corresponds to the orientation of the maximum horizontal principal stress S_H.

Considering the simple and idealistic assumptions used in the /Hubbert and Willis, 1957/ approach, the determination of stresses by these equations may sometimes be questioned. This, in particular, applies to the assumptions on rock mass isotropy.

In addition, the rock at depth is always characterized by the presence of pre-existing (micro-) fractures or weakness planes with different orientations with respect to the orientation of the principal stresses. By fluid injection into a sealed-off borehole interval containing such a fracture, it will open as soon as the fluid pressure exceeds the normal stress S_n acting across the (arbitrarily oriented) fracture plane. In this case the shut-in pressure P_{si} to keep the fracture open after the pressurizing system is shut-in is equal to the normal stress S_n. However, due to rock mass inhomogeneties, dip and strike directions may scatter considerably. Assuming that the horizontal stress components linearly vary with depth z and the vertical stress S_v is a principal stress, the normal stress S_n acting across the fracture plane of given orientation then is related to the far-field stresses by (e.g. Baumgärtner and Rummel, 1989/:

$$
\begin{aligned}
S_n(z_i) = & \left(S_{v_o} + \delta_v \cdot z_i\right)\cdot \cos^2\alpha_i + \frac{1}{2}\sin^2\alpha_i \Big\{ S_{H_o} + S_{h_o} + \\
& (\delta_H + \delta_h)\cdot z_i - \left(S_{H_o} - S_{h_o}\right)\cos 2\left(\Theta_i' - \Theta''\right) - \\
& (\delta_H - \delta_h)\cdot z_i \cos 2\left[\Theta_i' - \left(\Theta'' + \eta\right)\right] \Big\} \\
& = P_{si}
\end{aligned}
\qquad (7)
$$

where θ_i' and α_i are the strike and dip angle of the fracture plane, S_{vo}, S_{Ho} and S_{ho} are the principal horizontal stresses at the upper limit of the investigated borehole section, δ_v, δ_H, and δ_h are the vertical and horizontal stress gradients, and θ'' is the orientation of S_{Ho} with respect to North. The angle η is introduced to take into account a possible stress field rotation with depth if long depth profiles are considered. For $\eta = 0°$ the equation still includes 6 unknowns and the solution therefore requires at least 6 measurements of S_n at various depths on fractures with different orientations. Then, the stresses can be estimated by an inversion technique. In principle this procedure minimizes the difference between theoretically calculated P_{si}-values and the in-situ measured P_{si}-values. The computations are accompanied by a plot of the average deviation (AVE) between theoretical and measured stress values as a function of the orientation of S_H computed for the respective stress field model:

$$
AVE = \sqrt{\frac{\sum_{1}^{n}\left(P_{si,theor.} - P_{si,measured}\right)^2}{n-1}} \qquad (8)
$$

where n is the number of measurements. The result is presented as the average stress-depth profile of the 10 best models.

This technique is known as HTPF /Cornet, 1986/ or PSI /e.g. Baumgärtner and Rummel, 1989/ method and requires no assumptions on the pore pressure. The numerical computation is conducted by the MeSy code SESAM.

Since the accuracy of hydrofrac stress measurements essentially depends on the identification of the characteristic pressure values, an extensive analysis with the MeSy interactive graphical program package GEOCALC is conducted to derive the breakdown pressure P_c, the re-opening pressure P_r, and the shut-in pressure P_{si}:

- The breakdown pressure P_c is defined as the maximum pressure observed during the frac-cycle (first pressurization). P_c is determined from a detailed pressure P vs time t plot.
- The determination of the refrac pressure P_r is based on the analysis of the stiffness (dP/dV) during the pressurization of the test interval. Fracture opening is correlated with a significant deviation of the stiffness from linearity.
- The shut-in pressure P_{si} is determined by the following three step procedure:
  - A plot of pressure P vs injection flow-rate Q allows to determine the exact pressure value at which the hydraulic flow terminates (Q = 0). Therefore, the P vs Q plot yields an upper-limit estimate of the shut-in pressure.
  - A Muskat-type plot of the logarithm of the difference between the pressure P and an asymptotic pressure level P_a vs time t yields the lower-limit of the shut-in pressure, assuming that the linear part of the plot characterizes radial flow, i.e. the stimulated fracture is nearly closed.

- Within these two limits the shut-in pressure, which corresponds to the acting stress across the fracture plane, marks the transition from a rapid linear pressure drop (observed immediately after shut-in) to the beginning of a diffusion-dominated slow pressure decrease. The transition can be determined by the tangent to the linear pressure decrease in a detailed P vs time t plot.

- The final slow pump/step rate tests were analyzed similar to classical Lugeon tests using the steady-state P-Q data pairs determined from a detailed pressure P and flow-rate Q vs time t plot.

4.6 Nonconformities

As shown in the data record of the test at 655.99 m MD/653.16 m TVD in borehole no KFM02A (Figure 4-2), the second pulse test at the end of the HTPF test is characterized by a significant pressure increase. The pressure increase is due to the back-flow of the previously injected fluid volume from the rock mass/fracture system with low permeability into the borehole. Deviating from the planned test program, therefore, it was decided after 3 initial tests in borehole no KFM02A to conduct the second pressure pulse test about six hours after the termination of the HTPF test and to limit this test to 4 test sections per borehole.

In order to compare the results of the impression packer tests with the orientation of pre-existing fractures visible in the core material, some impression packer tests were also conducted in test sections selected for HTPF tests. In particular for borehole no KFM04A, it was decided to carry out an impression packer test on each test section due to the limited number of only 11 tests.

As it turned out during the data analysis that only a limited number of fractures with different spatial orientation were initiated or stimulated in borehole no KFM01B, the proposed separate inversion type stress computations for boreholes nos KFM01A and KFM01B according to the Activity Plan were dropped. Instead, a combined analysis for both boreholes was conducted (see Section 5.2.1)

5 Results of in-situ tests

5.1 Pressure pulse tests

The analysis of the pressure pulse tests is given in Appendix A1 to A4, and the results are summarized in Table 5-1 as permeability data K (in µDarcy = 10^{-18} m²) and as hydraulic conductivity k. The data are shown in Figures 5-1 to 5-4 as a function of depth. It has to be noted that the pulse-tests carried out on 12.05.2004 in borehole no KFM01A are doubtful due to a small leakage in the coil tubing which was difficult to detect since the tubing was tight when spooled on the drum (see Daily Log 13.05.2004). Furthermore, the low permeabilities of less than 1 µDarcy determined for some of the test sections are close to the resolution limit of the hydraulic system.

Table 5-1. Results of pressure pulse tests (K: permeability, k: conductivity).

Borehole no	Measured depth	True vertical depth	Initial test type	Before stimulation		After stimulation		Comment
	MD [m]	TVD [m]		K [µDarcy]	k [m/s]	K [µDarcy]	k [m/s]	
KFM01A	249.43	247.99	HTPF	(2,446.1)	($2.4·10^{-8}$)			coil tubing damaged
	422.0	419.00	HF	(2,090.4)	($2.1·10^{-8}$)			coil tubing damaged
	426.5	423.45	HF	(1,237.7)	($1.2·10^{-8}$)			coil tubing damaged
	430.5	427.40	HF	(341.9)	($3.4·10^{-9}$)			coil tubing damaged
	433.41	430.28	HTPF	(202.5)	($2.0·10^{-9}$)	(2,434.3)	($2.4·10^{-8}$)	coil tubing damaged
	437.96	434.78	HTPF	1.1	$1.1·10^{-11}$	1.5	$1.5·10^{-11}$	
	452.16	448.81	HTPF	1.1	$1.1·10^{-11}$			
	456.26	452.87	HTPF	0.2	$1.8·10^{-12}$			
	457.57	454.16	HTPF	9.1	$9.1·10^{-11}$			
	475.90	472.27	HTPF	(2,191.2)	($2.2·10^{-8}$)			coil tubing damaged
	478.96	475.29	HTPF	0.7	$6.8·10^{-12}$	0.7	$7.5·10^{-12}$	
	488.63	484.84	HTPF	0.9	$9.0·10^{-12}$	31.1	$3.1·10^{-10}$	
	491.0	487.17	HF	5.3	$5.3·10^{-11}$			
	496.0	492.11	HF	0.9	$9.3·10^{-12}$			
	502.0	498.03	HF	0.6	$6.3·10^{-12}$			
	503.45	499.46	HTPF	4.3	$4.3·10^{-11}$			
	571.80	566.74	HTPF	(4,765.8)	($4.8·10^{-8}$)			coil tubing damaged
	628.00	621.90	HTPF	(1,911.6)	($1.9·10^{-8}$)			coil tubing damaged
	685.31	678.02	HTPF	(469.3)	($4.7·10^{-9}$)			coil tubing damaged
	689.5	682.13	HF	11.2	$1.1·10^{-10}$			
	692.0	684.58	HF					no pressure decrease
	695.0	687.51	HF	10.3	$1.0·10^{-10}$			
	952.0	938.55	HF					no pressure decrease

Borehole no	Measured depth MD [m]	True vertical depth TVD [m]	Initial test type	Before stimulation K [μDarcy]	k [m/s]	After stimulation K [μDarcy]	k [m/s]	Comment
KFM01A	954.0	939.52	HF					pressure increase
	975.5	960.32	HF	11.7	$1.2 \cdot 10^{-10}$			
KFM01B	171.00	167.07	HTPF	16.0	$1.6 \cdot 10^{-10}$	8,943.5	$8.9 \cdot 10^{-8}$	
	187.90	183.46	HTPF	7.5	$7.5 \cdot 10^{-11}$	1,570.3	$1.6 \cdot 10^{-8}$	
	216.50	211.13	HTPF	3,313.7	$3.3 \cdot 10^{-8}$			
	235.0	228.97	HF	2.0	$2.0 \cdot 10^{-11}$			
	236.0	229.94	HF	2.6	$2.6 \cdot 10^{-11}$			
	237.0	230.90	HF	12.7	$1.3 \cdot 10^{-10}$			
	407.1	393.77	HF	3.7	$3.7 \cdot 10^{-11}$			
	410.5	397.00	HF	3.9	$3.9 \cdot 10^{-11}$			
	412.8	399.18	HF	7.9	$7.9 \cdot 10^{-11}$			
	471.2	454.68	HF	1.4	$1.4 \cdot 10^{-11}$			
	474.0	457.33	HF	1.3	$1.3 \cdot 10^{-11}$			
	476.1	459.32	HF	35.1	$3.5 \cdot 10^{-10}$			
KFM02A	149.58	149.20	HTPF	229.5	$2.3 \cdot 10^{-9}$			
	214.30	213.71	HTPF	44.0	$4.4 \cdot 10^{-10}$			
	220.7	220.09	HF	42.9	$4.3 \cdot 10^{-10}$			
	223.5	222.88	HF	16.3	$1.6 \cdot 10^{-10}$			
	226.5	225.87	HF	80.2	$8.0 \cdot 10^{-10}$			
	376.0	374.78	HF	22.5	$2.2 \cdot 10^{-10}$			
	413.5	412.12	HF	17.8	$1.8 \cdot 10^{-10}$			
	414.96	413.57	HTPF	59.7	$6.0 \cdot 10^{-10}$	299.1	$3.0 \cdot 10^{-9}$	
	428.52	427.07	HTPF	99.5	$1.0 \cdot 10^{-9}$			
	430.56	428.66	HTPF	13.0	$1.3 \cdot 10^{-10}$			
	442.34	440.83	HTPF	30.5	$3.1 \cdot 10^{-10}$			
	445.96	444.44	HTPF	37.4	$3.7 \cdot 10^{-10}$			
	449.90	448.36	HTPF	42.9	$4.3 \cdot 10^{-10}$			
	451.5	449.15	HF	12.2	$1.2 \cdot 10^{-10}$			
	457.34	455.77	HTPF	38.0	$3.8 \cdot 10^{-10}$	95.9	$9.6 \cdot 10^{-10}$	
	473.03	471.39	HTPF	58.7	$5.9 \cdot 10^{-10}$	48.2	$4.8 \cdot 10^{-10}$	
	520.22	518.34	HTPF	3.7	$3.7 \cdot 10^{-11}$			
	551.6	549.53	HF	0.6	$6.2 \cdot 10^{-12}$			
	553.2	551.12	HF					pressure increase
	564.00	561.86	HTPF	1.1	$1.1 \cdot 10^{-11}$			

Borehole no	Measured depth MD [m]	True vertical depth TVD [m]	Initial test type	Before stimulation K [µDarcy]	k [m/s]	After stimulation K [µDarcy]	k [m/s]	Comment
KFM02A	568.43	566.26	HTPF			7.7	$7.7 \cdot 10^{-11}$	1. pulse test: pressure increase
	573.27	571.07	HTPF					pressure increase
	577.38	575.15	HTPF	0.7	$6.6 \cdot 10^{-12}$			
	589.11	586.80	HTPF	22.0	$2.2 \cdot 10^{-10}$	6.6	$6.6 \cdot 10^{-11}$	
	594.62	592.27	HTPF	18.3	$1.8 \cdot 10^{-10}$			
	603.0	600.58	HF	20.4	$2.0 \cdot 10^{-10}$			
	608.47	606.01	HTPF	32.6	$3.3 \cdot 10^{-10}$			
	611.47	608.98	HTPF	63.3	$6.3 \cdot 10^{-10}$			
	626.19	623.59	HTPF	20.1	$2.0 \cdot 10^{-10}$			
	637.16	634.48	HTPF	7.2	$7.2 \cdot 10^{-11}$	32.3	$3.2 \cdot 10^{-10}$	
	645.21	642.47	HTPF	143.7	$1.4 \cdot 10^{-9}$			2. pulse test: pressure increase
	646.76	644.00	HTPF	138.6	$1.4 \cdot 10^{-9}$			
	655.99	653.16	HTPF					1. and 2. pulse test: pressure increase
	701.5	698.30	HF	0.6	$5.7 \cdot 10^{-12}$			
	704.3	701.08	HF	2.2	$2.2 \cdot 10^{-11}$			
	707.0	703.75	HF	2.2	$2.2 \cdot 10^{-11}$			
	757.43	753.75	HTPF	13.5	$1.4 \cdot 10^{-10}$			2. pulse test: pressure increase
KFM04A	194.58	171.43	HTPF	64.0	$6.4 \cdot 10^{-10}$			
	196.91	173.47	HTPF	4.9	$4.9 \cdot 10^{-11}$			
	266.33	233.61	HTPF	88.3	$8.8 \cdot 10^{-10}$			
	277.99	243.63	HTPF	4.0	$4.0 \cdot 10^{-11}$			
	371.2	322.95	HF	4.6	$4.6 \cdot 10^{-11}$			
	398.0	345.30	HF	6.7	$6.7 \cdot 10^{-11}$			
	535.88	457.03	HTPF	1.8	$1.8 \cdot 10^{-11}$			
	553.90	471.33	HTPF	2.5	$2.5 \cdot 10^{-11}$	91.0	$9.1 \cdot 10^{-10}$	
	558.33	474.84	HTPF	9.9	$9.9 \cdot 10^{-11}$	17.8	$1.8 \cdot 10^{-10}$	
	564.02	479.34	HTPF	8.3	$8.3 \cdot 10^{-11}$	28.6	$2.9 \cdot 10^{-10}$	
	593.63	502.91	HTPF	12.0	$1.2 \cdot 10^{-10}$	14.3	$1.4 \cdot 10^{-10}$	

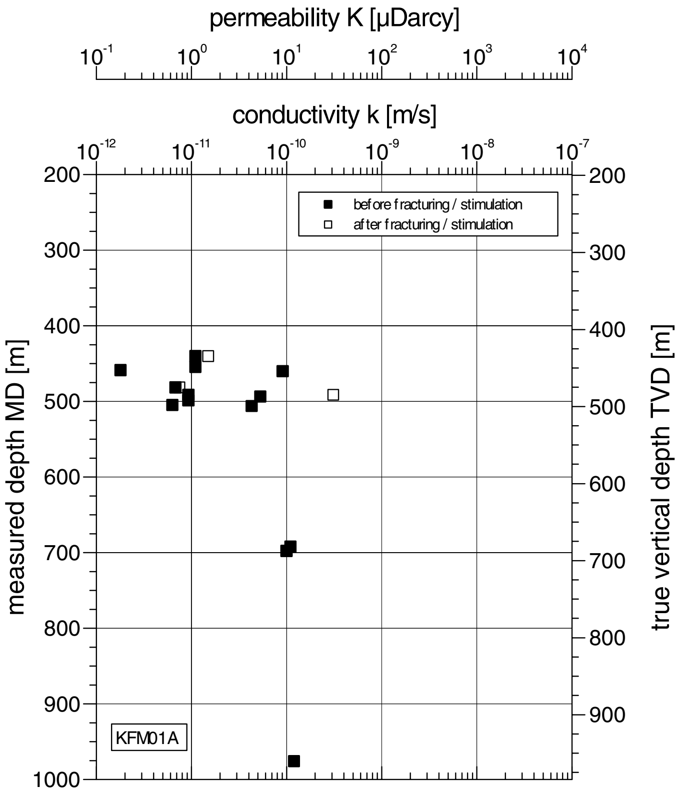


Figure 5-1. *Permeability and hydraulic conductivity derived from pressure pulse tests in borehole no KFM01A (doubtful data in parenthesis of Table 5-1 are neglected).*

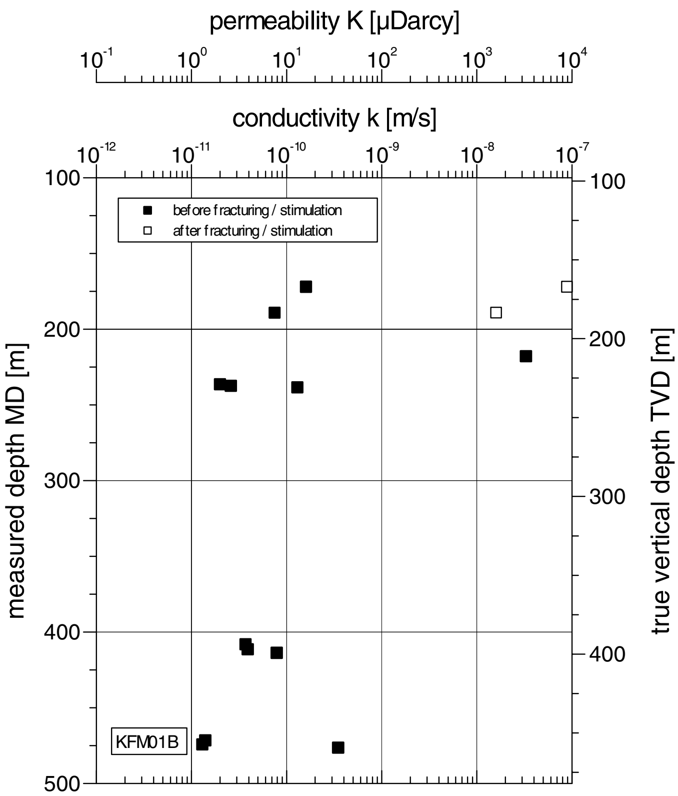


Figure 5-2. *Permeability and hydraulic conductivity derived from pressure pulse tests in borehole no KFM01B.*

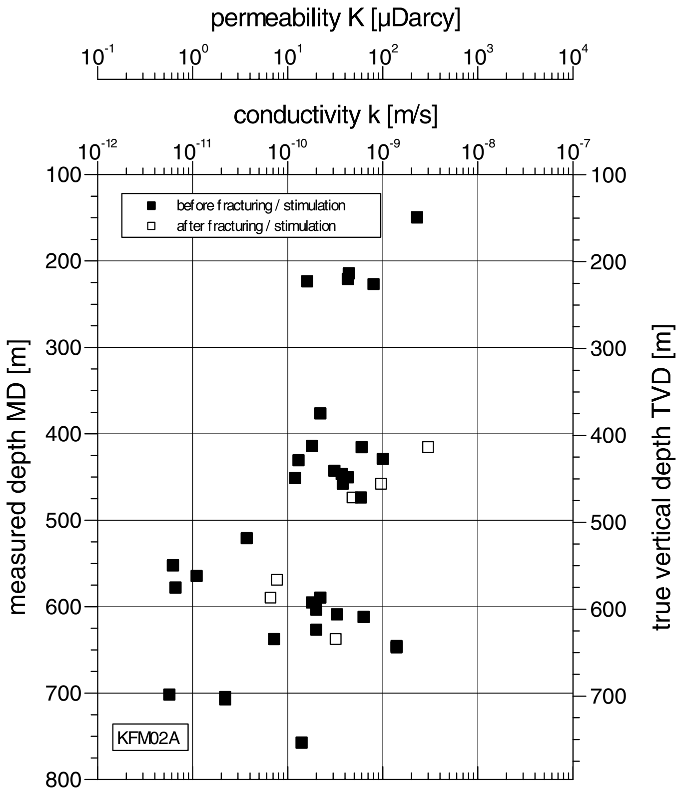


Figure 5-3. *Permeability and hydraulic conductivity derived from pressure pulse tests in borehole no KFM02A.*

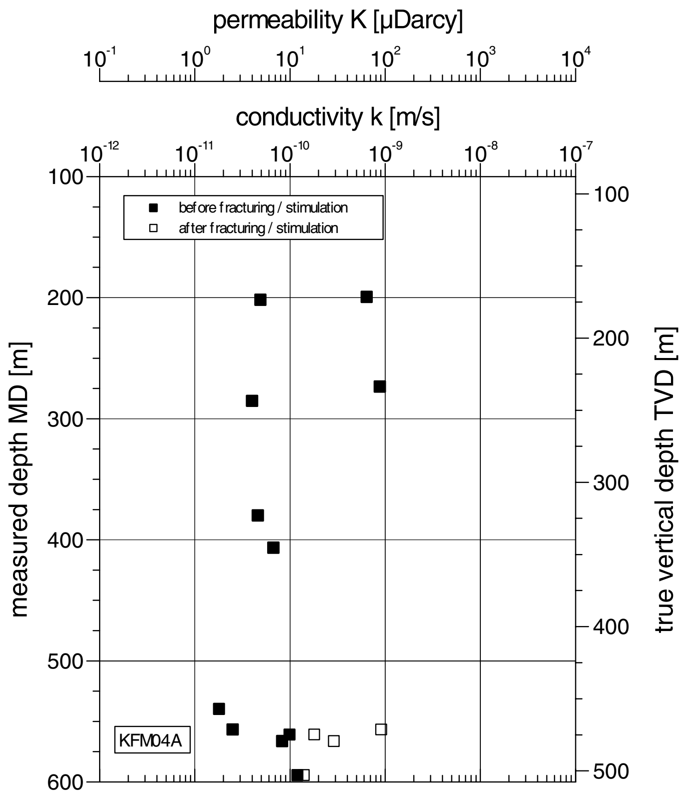


Figure 5-4. *Permeability and hydraulic conductivity derived from pressure pulse tests in borehole no KFM04A.*

5.2 Hydraulic injection tests

5.2.1 Borehole nos KFM01A and KFM01B

A total of 25 hydrofrac/hydraulic injection and 13 impression packer tests were carried out in borehole no KFM01A between 249.43 m and 975.0 m measured depth MD (corresponding true vertical depth TVD: 247.99–960.32 m). The initial test program consisted of 12 hydraulic fracturing (HF) tests and 13 hydraulic tests of pre-existing fractures (HTPF). Further 9 HF, 3 HTPF and 12 impression packer tests were conducted in borehole no KFM01B between 171.0 m and 476.1 m MD (TVD: 167.07–459.32 m). The graphical test record analysis is given in Appendix B1 for borehole no KFM01A and in Appendix B2 for borehole no KFM01B, and copies of the fracture traces observed during impression packer testing are given in Appendix C1 and C2. All data are stored in the SKB database SICADA, field note no 202.

The derived characteristic pressure data of the tests in borehole no KFM01A (breakdown pressure P_c at fracture initiation, fracture re-opening pressure P_r, shut-in pressure P_{si}, and the resulting in-situ tensile strength $P_{co} = P_c – P_r$) as well as the results of the impression packer tests (fracture strike direction θ, dip direction β, dip α) are summarized in Table 5-2. The pressure data are listed as downhole pressure values, and fracture orientation data are given with respect to geographic North. Table 5-2 also contains information on the orientation of pre-existing fractures visible in the rock cores, the observed system stiffness during pressurization, and the injected and recovered fluid volume.

The corresponding test results in borehole no KFM01B are given in Table 5-3. Combined pressure data are shown graphically in Figures 5-5 to 5-7, pole-plots of the fracture orientation data are presented in Figure 5-8.

As stated before, 9 out of 13 HTPF tests in borehole no KFM01A and 2 out of 3 HTPF tests in borehole no KFM01B showed breakdown (fracture initiation) events. Only 4 HTPF tests in borehole no KFM01A and 1 HTPF test in borehole no KFM01B are characterized by the stimulation of existing fractures. A detailed consideration shows that the stimulated pre-existing fractures are mainly oriented sub-horizontally (tests nos 9, 6, 18 in borehole no KFM01A, test no 3 in borehole no KFM01B), while fracturing occurred in all types of test sections, independent of the orientation of pre-existing fractures (horizontal, vertical-parallel and vertical-perpendicular to the assumed direction of the maximum horizontal stress). The 12 HF tests in borehole no KFM01A resulted in 11 breakdown events, while the test at 952.0 m MD was abandoned at an injection pressure of 39.9 MPa to prevent a damage of the packer elements. Five out of 9 HF tests in borehole no KFM01B yield breakdown events, while 4 HF tests (tests nos 12, 7, 6, 4) resulted in the stimulation of existing fractures (mainly low-dipping fractures).

The test record analysis yields unambiguous characteristic pressure data. In both boreholes, the characteristic pressure data do not differ; in particular the refrac and shut-in pressure values are in the same order and are close to the vertical stress calculated for an average rock mass density of 2.65 g/cm^3. Remarkably higher shut-in pressures were observed at 422.0, 426.5, 478.96, 502.0, and 692.0 m MD in borehole no KFM01A and at 235.0, 236.0, 237.0, and 471.2 m MD in borehole no KFM01B.

Table 5-2. Results of hydraulic injection tests in borehole no KFM01A (V_i: injected fluid volume, V_r: recovered fluid-volume, P_c: breakdown pressure, P_r: refrac pressure, P_{co}: in-situ hydraulic tensile strength, P_{si}: shut-in pressure, θ: strike direction (North over East), β: dip direction (North over East), α: dip (with respect to horizontal).

Test no	Measured depth MD [m]	True vertical depth TVD [m]	Initial test type	V_i [l]	V_r [l]	P_c [MPa]	P_r [MPa]	P_{co} [MPa]	P_{si} [MPa]	Orientation of pre-existing fracture (core analysis) strike/dip [deg]	Frac-ture trace	θ [deg]	β [deg]	α [deg]	Remark
25	249.43	247.99	HTPF	17.4	7.05	13.7 (21)	7.55 (20)	6.15	6.3	35/ 7	no impression test conducted				
24	422.0	419.00	HF	27.0	10.9	25.5 (20)	15.4 (20)	10.1	15.1		A	180	270	10	
											B	105	15	87	axial single trace
											C	24	294	70	
23	426.5	423.45	HF	19.1	1.05	25.2 (21)	15.7 (21)	9.5	16.0		no fracture detected				
22	430.5	427.40	HF	17.65	9.5	30.3 (22)	14.0 (21)–14.6 (22)	15.7–16.3	12.3		A	136	226	35	
17	433.41	430.28	HTPF	31.25	12.15	–	17.7 (23)	–	11.95	138/69	A	71	341	82	axial single trace
16	437.96	434.78	HTPF	16.6	14.5	26.3 (23)	10.9 (20)	15.4	10.1	36/ 9	no impression test conducted				
9	452.16	448.81	HTPF	16.5	4.55	–	16.2 (24)	–	11.8	92/11	no impression test conducted				
8	456.26	452.87	HTPF	15.45	9.9	26.7 (23)	10.8 (21)–12.0 (21)	14.7–15.9	11.0	60/81	A	9	279	18	
											B	121	31	87	axial single trace
7	457.57	454.16	HTPF	16.8	6.0	22.9 (24)	14.0 (21)	8.9	10.0	54/86	no impression test conducted				
21	475.90	472.27	HTPF	18.55	13.45	19.75 (21)	13.1 (20)	6.65	10.8	58/46	A	147	237	18	
6	478.96	475.29	HTPF	17.7	2.1	–	23.25 (24)	–	19.1	99/ 7	A	164	74	7	
											B	0	270	82	axial single trace
											C	82	172	72	
5	488.63	484.84	HTPF	20.75	5.55	24.0 (25)	18.0 (23)	6.0	12.8	343/86	no impression test conducted				
4	491.0	487.17	HF	18.65	6.35	27.9 (24)	12.1 (22)–12.5 (22)	15.4–15.8	12.6		no impression test conducted				

Test no	Measured depth MD [m]	True vertical depth TVD [m]	Initial test type	V_i [l]	V_r [l]	P_c [MPa]	P_r [MPa]	P_{co} [MPa]	P_{si} [MPa]	Orientation of pre-existing fracture (core analysis) strike/dip [deg]	Frac-ture trace	θ [deg]	β [deg]	α [deg]	Remark
3	496.0	492.11	HF	13.55	9.8	25.6 (26)	13.15 (23)	12.45	12.4		A	46	136	21	
											B	159	249	14	
											C	140	230	88	axial single trace
2	502.0	498.03	HF	19.35	2.75	26.4 (25)	17.8 (25)–17.9 (25)	8.5–8.6	17.2		A	160	250	85	two axial single traces, not diametral
											B	86	356	83	to each other
1	503.45	499.46	HTPF	25.8	19.2	24.4 (24)	12.0 (20)–12.5 (21)	11.9–12.4	10.5	110/ 5	no impression test conducted				
20	571.80	566.74	HTPF	19.2	8.65	21.0 (20)	12.6 (19)	8.4	12.6	114/67	no impression test conducted				
19	628.00	621.90	HTPF	22.4	7.35	20.8 (21)	14.3 (20)	6.5	15.5	34/ 9	no impression test conducted				
18	685.31	678.02	HTPF	18.8	7.7	–	15.1 (21)	–	15.9	99/ 3	no impression test conducted				
15	689.5	682.13	HF	18.1	8.6	36.3 (27)	17.3 (25)	19.0	16.2		no impression test conducted				P_c: max. pressure during frac attempt
14	692.0	684.58	HF	19.0	4.65	30.2 (27)	20.6 (24)	9.6	24.0		A	64	334	79	axial double trace
13	695.0	687.51	HF	14.65	11.7	23.6 (24)	16.3 (22)	7.3	15.6		A	108	18	86	axial single trace
12	952.0	938.55	HF			> 39.9 (29)									no fracture initiation
11	954.0	939.52	HF	19.3	11.75	38.1 (25)	25.8 (25)	12.3	26.9		A	87	357	80	axial single trace
10	975.5	960.32	HF	19.7	6.25	33.4 (24)	22.1 (25)–24.9 (22)	8.5–11.3	25.1		A	102	12	83	axial double trace

Table 5-3. Results of hydraulic injection tests in borehole no KFM01B (V_i: injected fluid volume, V_r: recovered fluid-volume, P_c: breakdown pressure, P_r: refrac pressure, P_{co}: in-situ hydraulic tensile strength, P_{si}: shut-in pressure, θ: strike direction (North over East), β: dip direction (North over East), α: dip (with respect to horizontal).

Test no	Measured depth MD [m]	True vertical depth TVD [m]	Initial test type	V_i [l]	V_r [l]	P_c [MPa]	P_r [MPa]	P_{co} [MPa]	P_{si} [MPa]	Orientation of pre-existing fracture (core analysis) strike/dip [deg]	Frac-ture trace	θ [deg]	β [deg]	α [deg]	Remark
1	171.00	167.07	HTPF	17.4	8.2	20.5 (50/33)	5.6 (26)–6.1 (30)	14.4–14.9	3.0	213/89	A	18	288	19	
2	187.90	183.46	HTPF	18.0	4.05	16.0 (47)/ 17.8 (52)	6.9 (37)	10.9	5.0	137/76	A	85	175	3	P_c: 2. breakdown during 3. refrac cycle
											B	77	347	87	axial single trace
3	216.50	211.13	HTPF	41.5	10.0	–	7.3 (35)	–	4.1	68/10	A	118	28	7	P_{si}: derived from slow -pump/step-rate test
12	235.0	228.97	HF	18.0	1.75	–	16.4 (52)–21.6 (50)	–	16.0		A	141	231	39	
											B	152	242	35	
11	236.0	229.94	HF	20.7	3.7	29.7 (52/37)	20.1 (38)	9.6	16.1		A	161	251	23	P_c: observed
											B	174	264	37	during 2. frac-cycle
10	237.0	230.90	HF	20.0	1.35	26.5 (51/41)	17.7 (44)–18.5 (45)	8.0–8.8	13.5		A	128	218	24	
9	407.1	393.77	HF	14.8	9.9	17.6 (52)	14.0 (45)	3.6	12.7		A	136	226	35	
											B	40	130	84	
8	410.5	397.00	HF	14.7	0.75	22.2 (55)	13.8 (51)–14.3 (51)	7.9–8.4	15.3		A	5	95	13	
											B	3	273	72	axial single trace
7	412.8	399.18	HF	20.5	6.15	–	19.2 (56)–21.1 (57)	–	13.2		A	137	227	26	
6	471.2	454.68	HF	20.1	2.4	–	20.3 (56)	–	24.2		A	144	234	76	axial double trace
5	474.0	457.33	HF	17.3	7.0	24.9 (56)	19.0 (52)	5.9	16.9		A	101	191	38	
4	476.1	459.32	HF	16.3	3.0	–	17.0 (55)	–	17.2		A	124	214	41	

In parenthesis: system stiffness dP/dV during pressurization (in MPa/l).

A, B etc mark different fracture traces.

Underlined orientation data were used for the stress analysis.

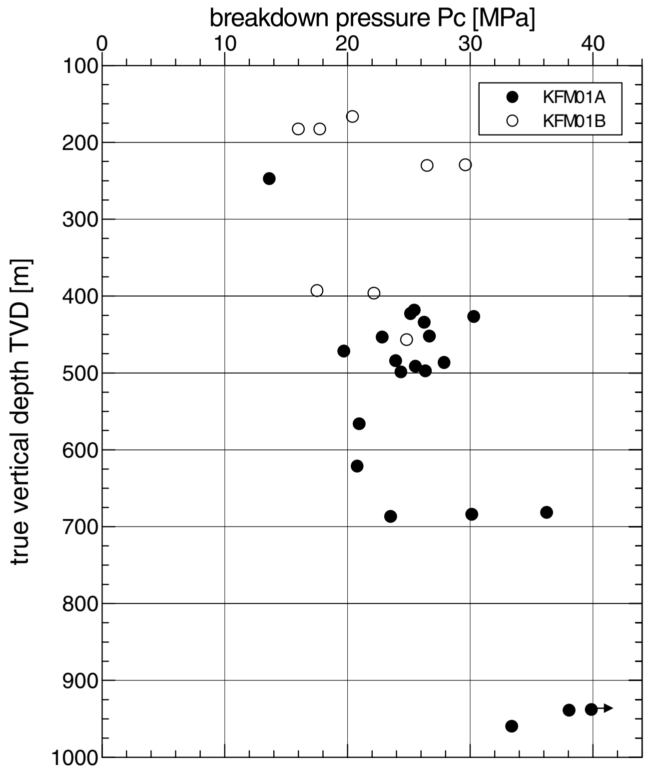


Figure 5-5. *Breakdown (fracture initiation) pressure P_c in boreholes nos KFM01A and KFM1B.*

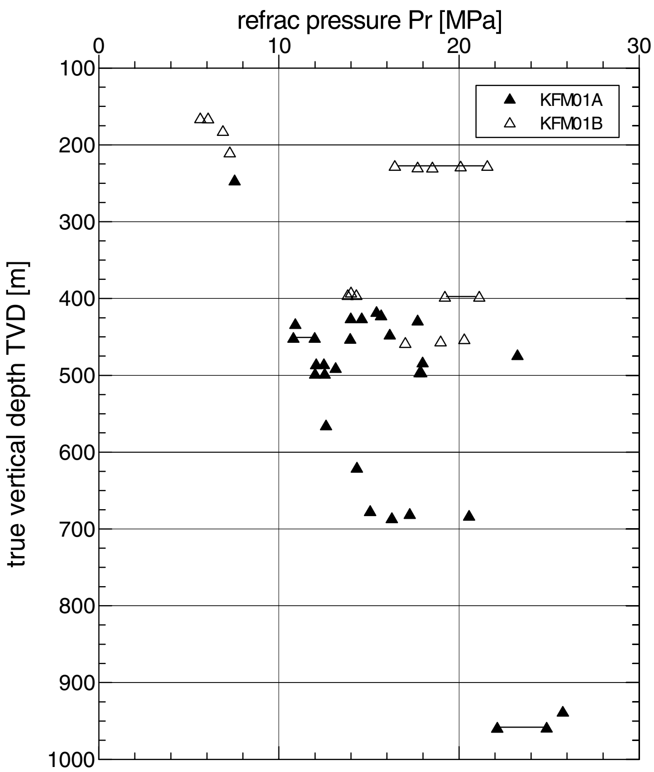


Figure 5-6. *Refrac (fracture re-opening) pressure P_r in boreholes nos KFM01A and KFM1B.*

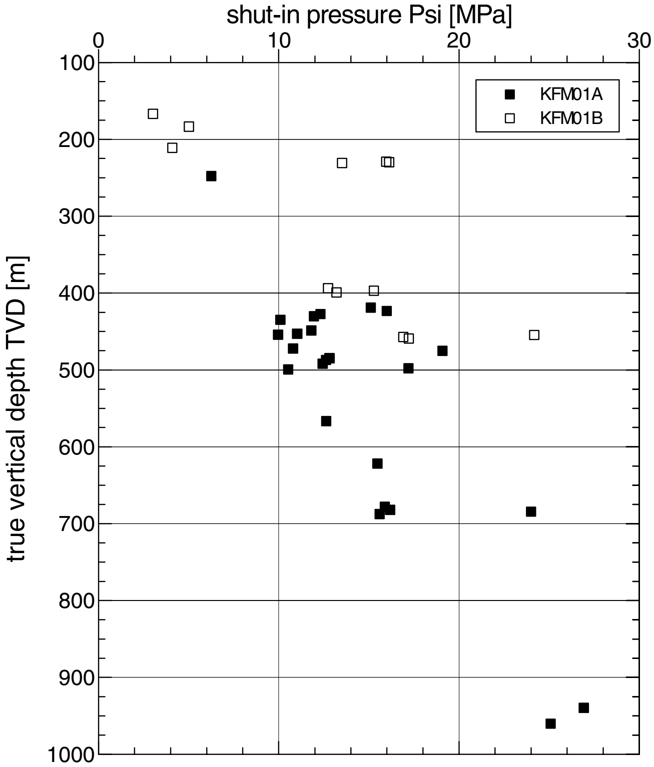
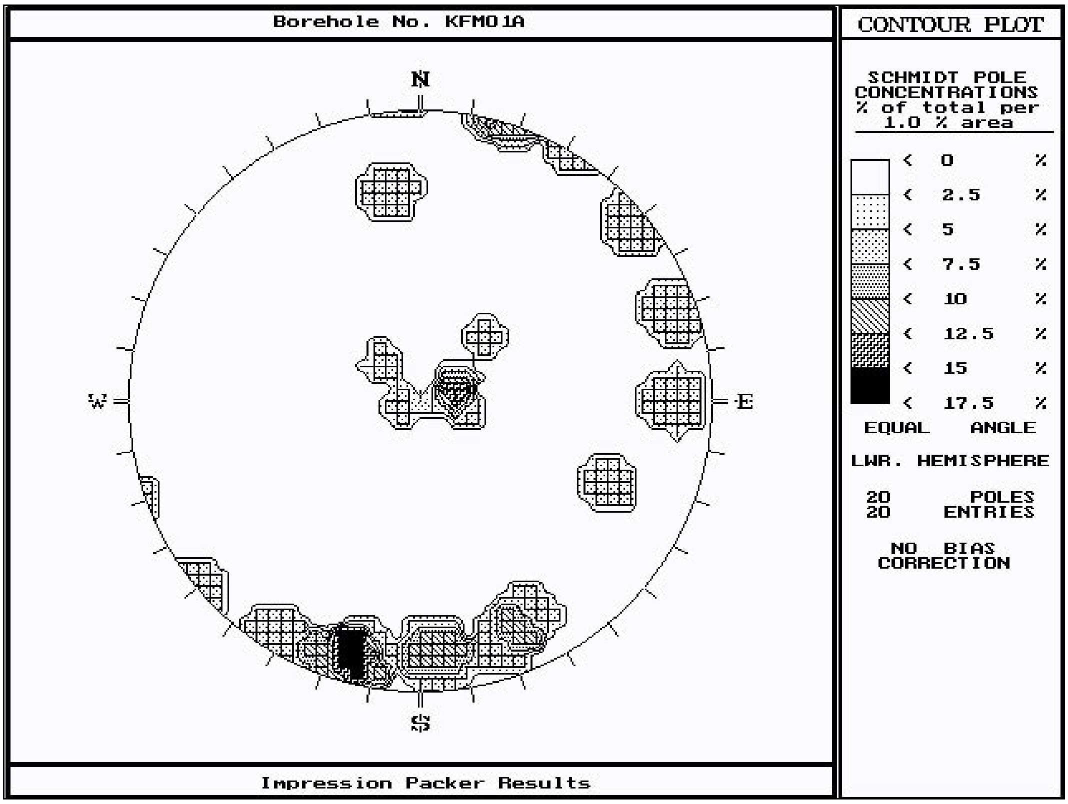


Figure 5-7. *Shut-in pressure P_{si} in boreholes nos KFM01A and KFM1B.*

Although some of the fracture traces in borehole no KFM01A were rather difficult to identify on the impression packer elements, the tests yield mainly steeply inclined fractures with a strike direction of E-W to NW-SE, while the more distinct impression packer tests in borehole no KFM01B showed mainly sub-horizontal fractures. However, it has to be noted, that the comparison between impression packer test results and the orientation of pre-existing fractures derived from the analysis of the core material for the tests at 433.41 m, 456.26 m, 475.90 m, and 478.96 m MD in borehole no KFM01A and 171.00 m, 187.90 m, and 216.50 m MD in borehole KFM01B shows no agreement. The discrepancy seems to be due to the initiation of fractures and the fact that the pre-existing fractures acted like closed fractures during the tests.



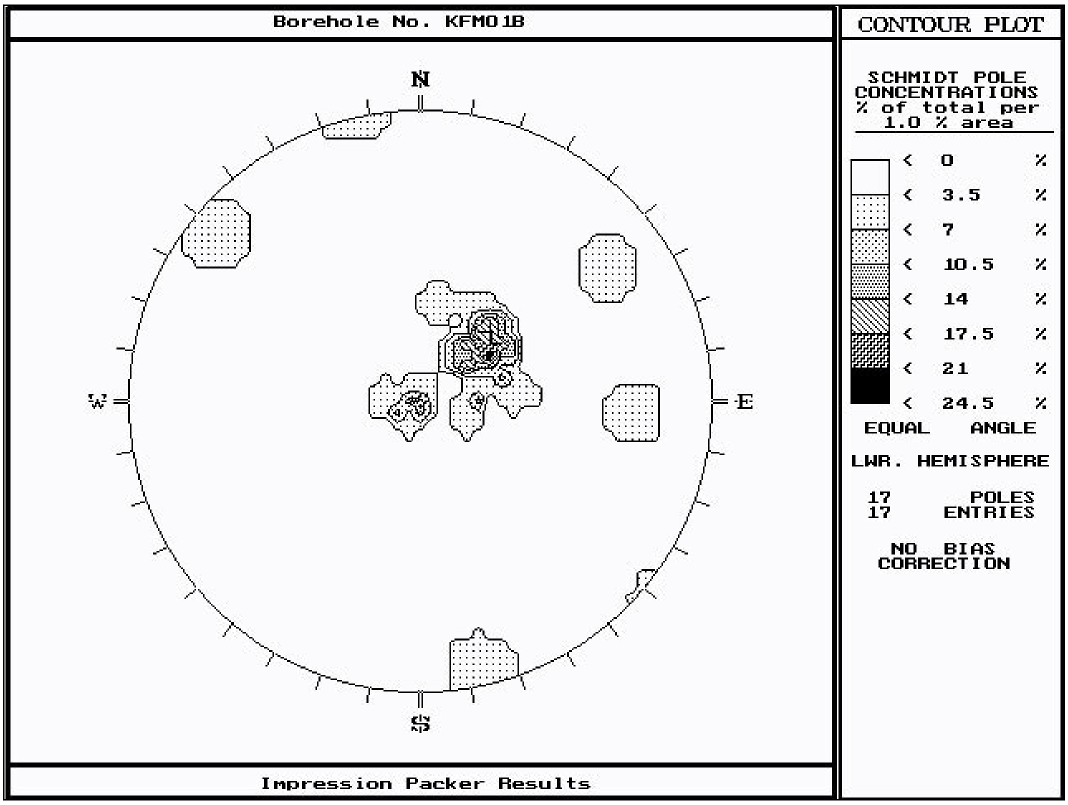


Figure 5-8. *Orientation of induced or stimulated fractures derived from impression packer testing in boreholes nos KFM01A (top) and KFM1B (bottom). Shown is the pole concentration in the lower hemisphere projection of all fractures detected on the impression packer.*

Due to the limited number of fractures with different spatial orientation in borehole no KFM01B, a combined stress evaluation for borehole nos KFM01A and KFM01B was carried out using the following procedure:

- First, the "classical" Hubbert and Willis approach (equation 6) was applied to those test data, where the impression packer tests showed that axial fractures were initiated or stimulated. The resulting minimum and maximum principal stresses S_h and S_H are listed in Table 5-3 and are shown graphically in Figure 5-9. For the calculation of the maximum horizontal stress S_H, the ambient pore-pressure in crystalline rocks with low permeability was neglected. Although the data base is limited, the results can be summarized by the following stress-depth profiles between 183 m and 961 m TVD:

  S_h [MPa] $= (6.0 \pm 1.7) + (0.025 \pm 0.004) \cdot$ (TVD [m]-183)

  S_H [MPa] $= (10.1 \pm 3.5) + (0.055 \pm 0.008) \cdot$ (TVD [m]-183)

  The tests yield a direction of the maximum horizontal stress of N 103° ± 21°.

- In the second step, inversion calculations on the basis of the PSI method (equation 7) were conducted by including the test results with fracture orientation data only derived from impression packer testing. The calculations started by considering the test results with unambiguous fracture orientation data, followed by stepwise including the data sets where more than one fracture was observed within the test section. In this case, alternative calculations were conducted while the difference between measured and calculated normal stresses was observed. Finally, "real" HTPF tests without breakdown (fracture initiation) events were included in the inversion calculations by assuming the stimulation of the pre-existing fracture visible in the rock core. The input data and the result of the calculation are presented in Figure 5-10. However, several test data were neglected:
  - HF tests without fracture orientation data (tests at 426.5 m, 491.0 m, 689.5 m MD in borehole no KFM01A).
  - HTPF tests which showed the initiation of a fracture and without fracture orientation data derived from impression packer testing (tests at 249.43 m, 437.96 m, 457.57 m, 488.63 m, 503.45 m, 571.80 m, 628.00 m MD in borehole no KFM01A).
  - Tests with inconsistent pressure and fracture orientation data (235.0 m, 236.0 m, 237.0 m, 471.2 m MD in borehole KFM01B).

  Nevertheless, the calculations with 22 data sets yield the following stress-depth relations between 167 m and 961 m TVD:

  S_h [MPa] $= (6.7 \pm 0.6) + (0.021 \pm 0.001) \cdot$ (TVD [m]-167)

  S_H [MPa] $= (11.4 \pm 2.1) + (0.032 \pm 0.005) \cdot$ (TVD [m]-167)

  S_v [MPa] $= (4.6 \pm 0.6) + (0.0275 \pm 0.0025) \cdot$ (TVD [m]-167)

  The inversion calculations yield a direction of the acting maximum horizontal principal stress S_H of N 125° ± 5° (WNW-ESE).

  The stress-depth profiles together with the scatter of the 10 best models are displayed in Figure 5-11, a comparison between the stress-profiles derived from the /Hubbert and Willis, 1957/ approach and the inversion result is given in Figure 5-12. The comparison shows a close agreement between the minimum horizontal stresses derived from both methods as well as for the derived vertical stress and the calculated vertical stress for a mean rock mass density of 2.65 g/cm^3. In contrary, the inversion calculations yield a considerable lower estimation of the maximum horizontal stress below about 300 m TVD, mainly controlled by the test results with N-S and NE-SW striking sub-vertical fractures at 475.29 m and 684.58 m TVD in borehole no KFM01A and 397.00 m TVD in borehole no KFM01B.

Table 5-4. Results of the stress evaluation using the /Hubbert and Willis, 1957/ approach for boreholes nos KFM01A and KFM01B (S_h: minimum horizontal stress, S_H: maximum horizontal stress, θ_{SH}: strike direction of S_H).

Borehole no	Test no	Measured depth MD [m]	True vertical depth TVD [m]	S_h [MPa]	S_H [MPa]	θ_{SH} N over E [deg]
KFM01A	24	422.0	419.00	15.1	29.9	105
	17	433.41	430.28	(11.95)	(18.15)	(71)
	8	456.26	452.87	11.0	21.0–22.2 <21.6>	121
	6	478.96	475.29		(19.1)	(0)
	3	496.0	492.11	12.4	24.05	140
	2	502.0	498.03	17.2	33.7–33.8 <33.75>	86
	14	692.0	684.58	(24.0)	(51.4)	(64)
	13	695.0	687.51	15.6	30.5	108
	11	954.0	939.52	26.9	54.9	87
	10	975.5	960.32	25.1	50.4–53.2 <51.8>	102
KFM01B	2	187.90	183.46	5.0	8.1	77
	8	410.5	397.00	(15.3)	(31.6–33.0)	(3)
	6	471.2	454.68	(24.2)	(52.3)	(144)

< > mean value.
( ) not used for the analysis.

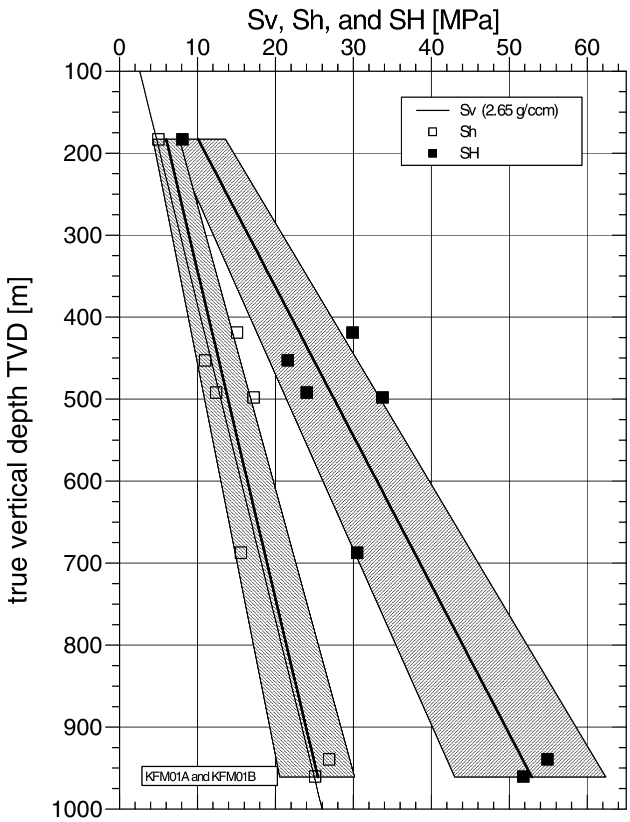
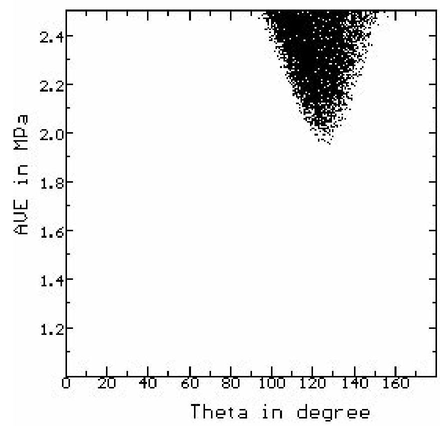


__Figure 5-9.__ Principal stresses on the basis of the /Hubbert and Willis, 1957/ concept in boreholes nos KFM01A and KFM01B. The dashed area represents the standard deviation of the stress-depth profiles.

Input data

Borehole no	TVD [m]	P_{si} [MPa]	Fracture strike θ N over E [deg]	Fracture dip α [deg]
KFM01A	419.00	15.1	105	87
	427.40	12.3	136	35
	430.28	11.95	138	69
	448.81	11.8	92	11
	452.87	11.0	121	87
	472.27	10.8	147	18
	475.29	19.1	0	82
	492.11	12.4	140	88
	498.03	17.2	86	83
	678.02	15.9	99	3
	684.58	24.0	64	79
	687.51	15.6	108	86
	939.52	26.9	87	80
	960.32	25.1	102	83
KFM01B	167.07	3.0	18	19
	183.46	5.0	85	3
	211.13	4.1	118	7
	393.77	12.7	136	35
	397.00	15.3	3	72
	399.18	13.2	137	26
	457.33	16.9	101	38
	459.32	17.2	124	41

Result



Result.....: 167.00 m

SH, MPa = 11.36 + 0.0320 * (z,m - 167.00)

Sh, MPa = 6.72 + 0.0207 * (z,m - 167.00)

Sv, MPa = 4.63 + 0.0275 * (z,m - 167.00)

Theta,° = 121 - 130

Number of tested models........:200000

Number of fitting models.......:7853

Sv MPa	dSv/dz MPa/m	SH MPa	dSH/dz MPa/m	Sh MPa	dSh/dz MPa/m	Theta degree	AVE MPa
4.09	0.0299	12.56	0.0287	6.71	0.0201	128	1.95
4.43	0.0279	10.82	0.0307	6.44	0.0209	127	1.96
4.13	0.0283	11.07	0.0282	7.00	0.0212	126	1.97
4.35	0.0269	12.56	0.0292	7.11	0.0203	123	1.97
4.53	0.0267	11.21	0.0305	6.90	0.0213	122	1.97
4.11	0.0287	10.79	0.0315	6.24	0.0208	125	1.97
4.10	0.0288	12.59	0.0285	6.13	0.0209	129	1.97
4.20	0.0279	11.35	0.0309	6.22	0.0205	125	1.97
5.15	0.0269	13.41	0.0269	6.22	0.0200	130	1.99
5.18	0.0251	9.32	0.0372	7.31	0.0201	121	1.99

Figure 5-10. *Input data and result of the stress field inversion calculations for boreholes nos KFM01A and KFM1B.*

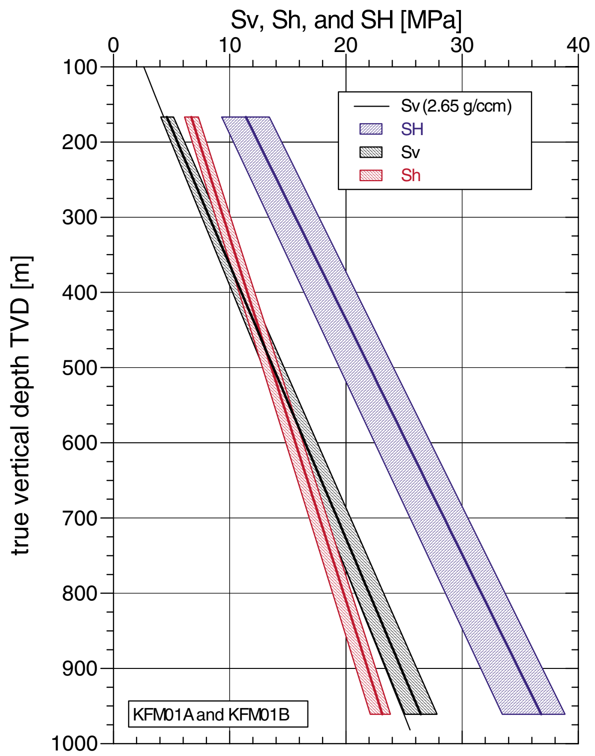


Figure 5-11. *Principal stresses derived from inversion calculations according to the PSI method in boreholes nos KFM01A and KFM01B. The dashed area represents the scatter of the 10 best models, S_v (2.65 g/cm^3) marks the vertical stress calculated for an average rock mass density of 2.65 g/cm^3.*

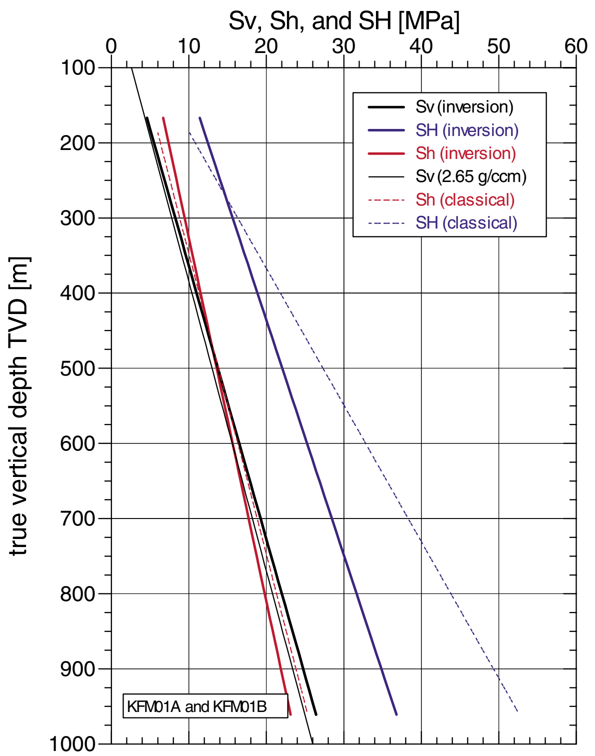


Figure 5-12. *Comparison between principal stress profiles derived from the classical /Hubbert and Willis, 1957/ approach and inversion calculations according to the PSI method in boreholes nos KFM01A and KFM01B. S_v (2.65 g/cm^3) represents the vertical stress calculated for an average rock mass density of 2.65 g/cm^3.*

5.2.2 Borehole no KFM02A

A total of 37 hydrofrac/hydraulic injection and 13 impression packer tests were carried out in borehole no KFM02A between 149.58 m and 757.43 m measured depth MD (corresponding true vertical depth TVD: 149.20–753.75 m). The initial test program consisted of 12 hydraulic fracturing (HF) tests and 25 hydraulic tests of pre-existing fractures (HTPF). The graphical test record analysis is given in Appendix B3, whereas copies of the fracture traces observed during impression packer testing are given in Appendix C3. All data are stored in the SKB database SICADA, field note no 202.

The derived characteristic pressure data (breakdown pressure P_c at fracture initiation, fracture re-opening pressure P_r, shut-in pressure P_{si}, and the resulting in-situ tensile strength $P_{co} = P_c – P_r$) as well as the results of the impression packer tests (fracture strike direction θ, dip direction β, dip α) are summarized in Table 5-5 and are shown graphically in Figures 5-13 to 5-16. The pressure data are listed as downhole pressure values, and fracture orientation data are given with respect to geographic north. Table 5-5 also contains information on the orientation of pre-existing fractures visible in the rock cores, the observed system stiffness during pressurization, and the injected and recovered fluid volume.

Like for boreholes nos KFM01A and KFM01B, 14 out of 25 HTPF tests in borehole no KFM02A showed breakdown (fracture initiation) events. Furthermore, the 3 tests at 594.62 m, 608.47 m, and 646.76 m MD were abandoned at an injection pressure of about 36 MPa to prevent a damage of the packer elements. Only 8 HTPF tests are characterized by the stimulation of existing fractures. A detailed consideration shows that the stimulated pre-existing fractures are orientated mainly sub-vertically with a strike direction approximately parallel to the direction of the maximum horizontal stress or sub-horizontal. Only at 457.34 m MD, a sub-vertical fracture with a strike direction perpendicular to the direction of the maximum horizontal stress was stimulated. The 14 breakdown events during HTPF testing were observed in all types of test sections, independent of the orientation of pre-existing fractures (horizontal, vertical-parallel and vertical-perpendicular to the assumed direction of the maximum horizontal stress).

The 12 HF tests in borehole no KFM02A resulted in 12 breakdown events. The majority of the distinct impression packer tests showed that axial or steeply inclined fractures with a strike direction of NW-SE were initiated. The comparison between impression packer test results and the orientation of pre-existing fractures derived from the analysis of the core material for the tests at 457.34 m and 473.03 m MD shows reasonably good agreement within the uncertainties of the methods (Table 5-5).

The test record analysis yields distinct refrac and shut-in pressure values which are in the same order and are close or slightly higher than the vertical stress calculated for an average rock mass density of 2.65 g/cm^3. A remarkably higher shut-in pressure was observed at 457.34 m MD, where a sub-vertical NNE-SSW striking fracture was stimulated. On the other hand, lower shut-in pressure values were observed at 413.5 m MD, and during the 4 tests between 442.34 m to 451.5 m MD.

Table 5-5. Results of hydraulic injection tests in borehole no KFM02A (V_i: injected fluid volume, V_r: recovered fluid-volume, P_c: breakdown pressure, P_r: refrac pressure, P_{co}: in-situ hydraulic tensile strength, P_{si}: shut-in pressure, θ: strike direction (North over East), β: dip direction (North over East), α: dip (with respect to horizontal).

Test no	Measured depth MD [m]	True vertical depth TVD [m]	Initial test type	V_i [l]	V_r [l]	P_c [MPa]	P_r [MPa]	P_{co} [MPa]	P_{si} [MPa]	Orientation of pre-existing fracture (core analysis) strike/dip [deg]	Frac-ture trace	θ [deg]	β [deg]	α [deg]	Remark
37	149.58	149.20	HTPF	21.25	3.7	17.5 (38/25)	11.6 (35)–12.0 (36)	5.5–5.9	8.2	12/ 4	no impression test conducted				
36	214.30	213.71	HTPF	21.8	2.8	21.3 (39/33)	8.4 (35)–11.35 (34)	9.95–12.9	8.2	19/ 5	no impression test conducted				
35	220.7	220.09	HF	18.35	2.1	19.2 (37)	9.5 (32)	9.7	7.1		A	110	20/200	90	axial double trace
											B	131	221	40	
34	223.5	222.88	HF	16.5	1.85	19.6 (39/33)	9.7 (33)	9.9	6.8		A	125	215	89	axial single trace
											B	150	60	9	
33	226.5	225.87	HF	18.6	0.5	16.95 (36)	11.0 (36)	5.95	6.7		A	147	57	29	
											B	113	203	73	
32	376.0	374.78	HF	14.35	7.4	22.15 (39/29)	10.2 (31)	11.95	8.7		A	24	294	85	axial single trace
31	413.5	412.12	HF	18.6	12.9	15.8 (39)	8.2 (22)	7.6	7.2		A	169	79	40	
											B	31	301	68	
30	414.96	413.57	HTPF	18.35	7.1	20.1 (34/20)	12.5 (29)–13.5 (32)	6.6–7.6	12.0	25/ 5	no impression test conducted				
29	428.52	427.07	HTPF	14.3	0.1	–	12.2 (38)	–	11.4	110/25	no impression test conducted				
28	430.56	428.66	HTPF	16.8	0.55	16.45 (38)	12.25 (33)–12.5 (34)	3.95–4.2	10.8	25/ 5	no impression test conducted				
27	442.34	440.83	HTPF	17.55	0.85	18.7 (39)	10.6 (33)	8.1	8.1	292/77	no impression test conducted				
26	445.96	444.44	HTPF	18.0	4.8	20.5 (41)	13.6 (38)	6.9	8.8	107/50	no impression test conducted				
25	449.90	448.36	HTPF	15.45	5.25	18.4 (43)	10.5 (34)	7.9	7.5	26/ 5	no impression test conducted				
24	451.5	449.15	HF	17.55	3.25	19.7 (40)	12.45 (36)	7.25	8.2		no impression test conducted				
23	457.34	455.77	HTPF	17.0	0.95	–	17.9 (39)–18.4 (38)	–	18.8	56/80	A B	28 21	118 111	81 88	
22	473.03	471.39	HTPF	22.25	1.8	–	17.5 (32)	–	13.9	103/63	A	121	31	59	

Test no	Measured depth MD [m]	True vertical depth TVD [m]	Initial test type	V_i [l]	V_r [l]	P_c [MPa]	P_r [MPa]	P_{co} [MPa]	P_{si} [MPa]	Orientation of pre-existing fracture (core analysis) strike/dip [deg]	Frac-ture trace	θ [deg]	β [deg]	α [deg]	Remark
321	520.22	518.34	HTPF	17.45	7.35	22.4 (40)	16.5 (38)	5.9	13.1	31/ 6	no impression test conducted				
20	551.6	549.53	HF	17.65	8.9	21.6 (39)	16.3 (40)	5.3	16.4		A	128	218	89	axial double trace
19	553.2	551.12	HF	15.1	4.15	19.65 (41)	15.65 (38)	4.0	15.9		A	131	221	58	2 times observed
											B	151	241	58	
18	564.00	561.86	HTPF	14.7	1.45	–	18.0 (40)	–	17.7	135/67	no impression test conducted				
17	568.43	566.26	HTPF	18.0	7.35	35.5 (>40)	17.5 (40)–18.1 (39)	17.4–18.0	18.15	26/ 6	no impression test conducted				P_c: max. pressure during frac attempt
16	573.27	571.07	HTPF	11.3	3.1	35.5 (–)	18.2 (>40)	17.3	18.3	23/81	no impression test conducted				P_c: max. pressure during frac attempt
15	577.38	575.15	HTPF	16.3	4.1	35.6 (–)	16.9 (>40)	18.7	16.6	152/80	no impression test conducted				
14	589.11	586.80	HTPF	20.4	6.65	24.5 (32)	16.2 (31)	8.3	16.3	70/56	no impression test conducted				
13	594.62	592.27	HTPF			>35.4 (–)				211/53					no fracture initiation
12	603.0	600.58	HF	16.65	11.8	22.2 (36)	17.4 (35)	4.8	18.3		A	137	227	88	axial double trace
11	608.47	606.01	HTPF			>35.6 (50)				34/ 7					no fracture initiation
10	611.47	608.98	HTPF	13.65	10.05	–	19.5 (37)	–	18.6	157/69	no impression test conducted				
9	626.19	623.59	HTPF	18.8	12.2	28.0 (35)	19.3 (37)	8.7	19.1	178/77	no impression test conducted				P_c: observed during 3. frac cycle
8	637.19	634.48	HTPF	12.3	3.55	–	19.2 (40)	–	19.2	164/88	no impression test conducted				
7	645.21	642.47	HTPF	10.6	5.4	23.4 (38)	18.0 (35)	5.4	20.2	33/ 7	no impression test conducted				
6	646.76	644.00	HTPF			>35.8 (–)				51/58					no fracture initiation
5	655.99	653.16	HTPF	19.9	9.75	–	19.2 (40)	–	17.8	133/77	no impression test conducted				
4	701.5	698.30	HF	18.1	3.3	24.75 (39)	20.3 (36)	4.45	21.6		A	142	232	88	axial double trace
3	704.3	701.08	HF	20.05	5.35	26.6 (41/35)	20.3 (36)	6.3	22.6		A	136	226	89	axial double trace
2	707.0	703.75	HF	22.9	2.45	26.3 (41/29)	17.7 (38)	8.6	18.8		A	153	63	12	
1	757.43	753.75	HTPF	24.5	0.7	–	20.05 (32)	–	20.5	35/ 8	no impression test conducted				

In parenthesis: system stiffness dP/dV during pressurization (in MPa/l).

A, B etc mark different fracture traces.

Underlined orientation data were used for the stress analysis.

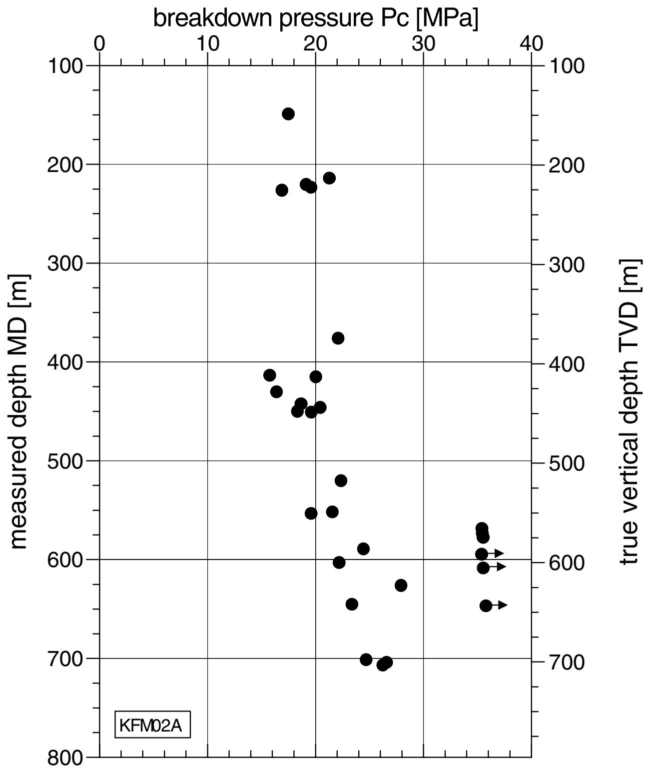


Figure 5-13. *Breakdown (fracture initiation) pressure P_c in borehole no KFM02A.*

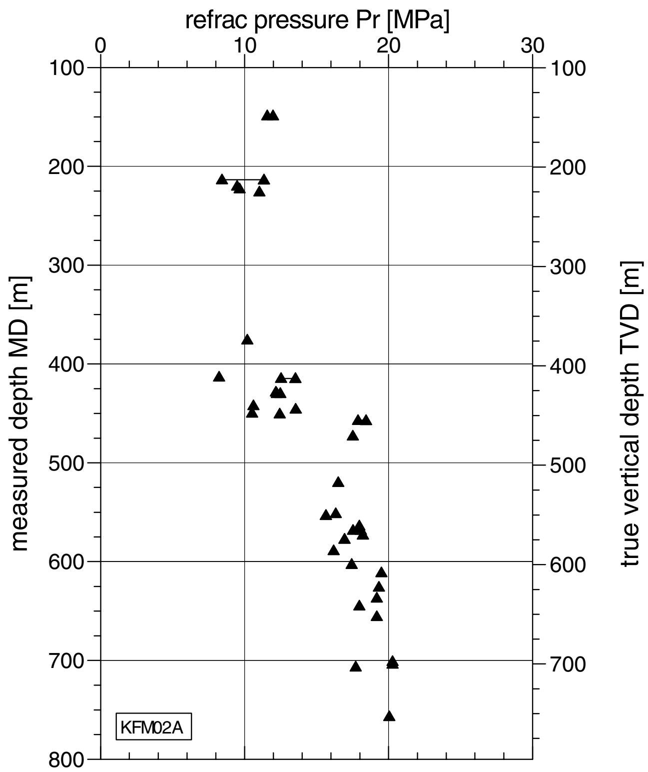


Figure 5-14. *Refrac (fracture re-opening) pressure P_r in borehole no KFM02A.*

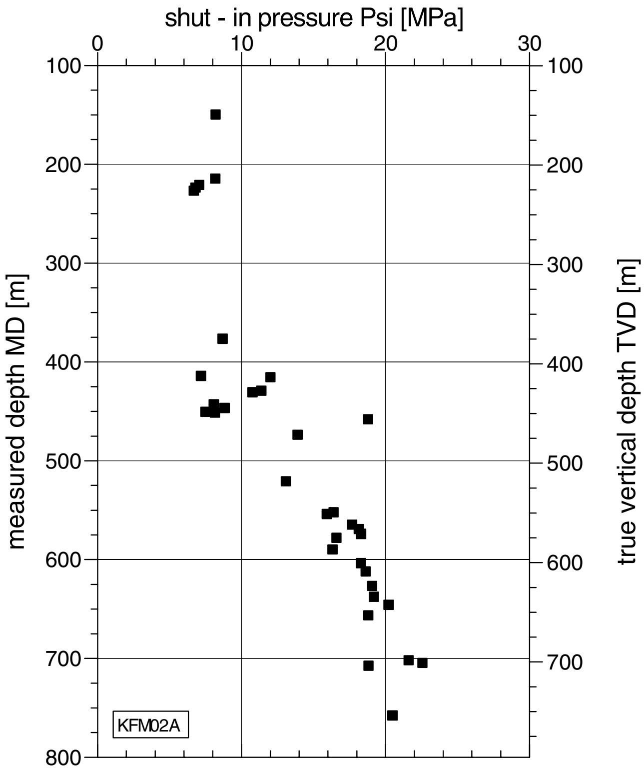


Figure 5-15. Shut-in pressure P_{si} in borehole no KFM02A.

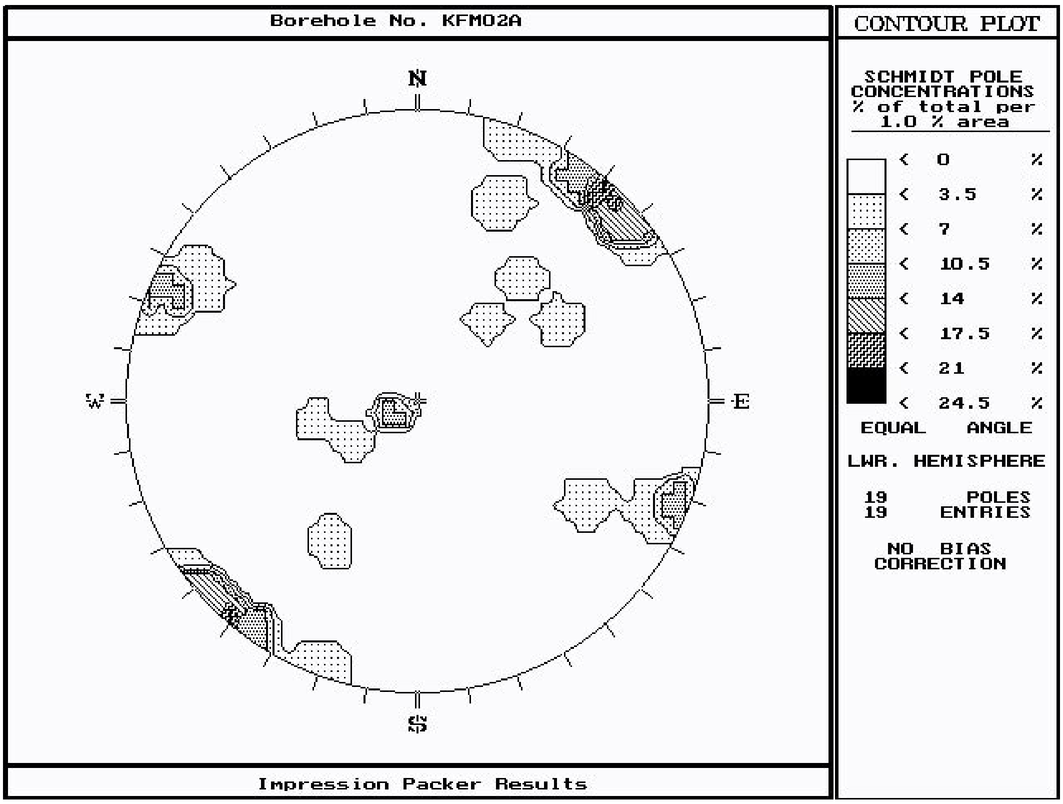


Figure 5-16. Orientation of induced or stimulated fractures derived from impression packer testing in borehole no KFM02A. Shown is the pole concentration in the lower hemisphere projection of all fractures detected on the impression packer.

The stress evaluation for borehole no KFM02A was carried out using the following procedure:

- First, the "classical" Hubbert and Willis approach (equation 6) was applied to those test data, where the impression packer tests showed that axial fractures were initiated or stimulated. The resulting minimum and maximum principal stresses S_h and S_H are listed in Table 5-6 and are shown graphically in Figure 5-17. For the calculation of the maximum horizontal stress S_H, the ambient pore-pressure in crystalline rocks with low permeability was neglected. Although the data base is limited, the results can be summarized by the following stress-depth profiles between 220 m and 702 m TVD:

  S_h [MPa] = (6.8 ± 0.4) + (0.031 ± 0.001) · (TVD [m]-220)

  S_H [MPa] = (10.8 ± 1.0) + (0.072 ± 0.003) · (TVD [m]-220)

  The tests yield a direction of the maximum horizontal stress of N 130° ± 11°.

- In the second step, inversion calculations on the basis of the PSI method (equation 7) were conducted by including the test results with fracture orientation data only derived from impression packer testing. The calculations started by considering the test results with unambiguous fracture orientation data, followed by stepwise including the data sets where more than one fracture was observed within the test section. In this case, alternative calculations were conducted while the difference between measured and calculated normal stresses was observed. Finally, "real" HTPF tests without breakdown (fracture initiation) events were included in the inversion calculations by assuming the stimulation of the pre-existing fracture visible in the rock core. The input data and the result of the calculation are presented in Figure 5-18. However, several test data were neglected:
  - HF test without fracture orientation data (test at 451.5 m MD).
  - HTPF tests which showed the initiation of a fracture and without fracture orientation data derived from impression packer testing (tests at 149.58 m, 214.30 m, 414.96 m, 430.56 m, 442.34 m, 445.96 m, 449.90 m, 520.22 m, 568.43m, 573.27 m, 577.38 m, 589.11 m, 626.19 m, 645.21 m MD).
  - Tests with inconsistent pressure and fracture orientation data (376.0 m MD) or with a low shut-in pressure value (413.5 m MD).

  Nevertheless, the calculations with 17 data sets yield the following stress-depth relations between 220 m and 755 m TVD:

  S_h [MPa] = (5.8 ± 0.7) + (0.032 ± 0.002) · (TVD [m]-220)

  S_H [MPa] = (12.1 ± 1.7) + (0.032 ± 0.007) · (TVD [m]-220)

  S_v [MPa] = (5.2 ± 0.7) + (0.028 ± 0.002) · (TVD [m]-220)

  The inversion calculations yield a direction of the acting maximum horizontal principal stress S_H of N 137° ± 8° (NW-SE).

  The stress-depth profiles together with the scatter of the 10 best models are presented in Figure 5-19, a comparison between the stress-profiles derived from the /Hubbert and Willis, 1957/ approach and the inversion result is given in Figure 5-20. Again, the comparison shows a close agreement between the minimum horizontal stresses derived from both methods as well as for the derived vertical stress and the calculated vertical stress for a mean rock mass density of 2.65 g/cm^3. In contrary, the inversion calculations yield a considerable lower estimation of the maximum horizontal stress below about 250 m TVD, mainly controlled by the test result with a NE-SW striking sub-vertical fractures at 457.34 m MD.

Table 5-6. Results of the stress evaluation using the /Hubbert and Willis, 1957/ approach for borehole nos KFM02A (S_h: minimum horizontal stress, S_H: maximum horizontal stress, θ_{SH}: strike direction of S_H).

Test no	Measured depth MD [m]	True vertical depth TVD [m]	S_h [MPa]	S_H [MPa]	θ_{SH} N over E [deg]
35	220.7	220.09	7.1	11.8	110
34	223.5	222.88	6.8	10.7	125
32	376.0	374.78	(8.7)	(15.9)	(24)
20	551.6	549.53	16.4	32.9	128
12	603.0	600.58	18.3	37.5	137
4	701.5	698.30	21.6	44.5	142
3	704.3	701.08	22.6	47.5	136

( ) not used for the analysis.

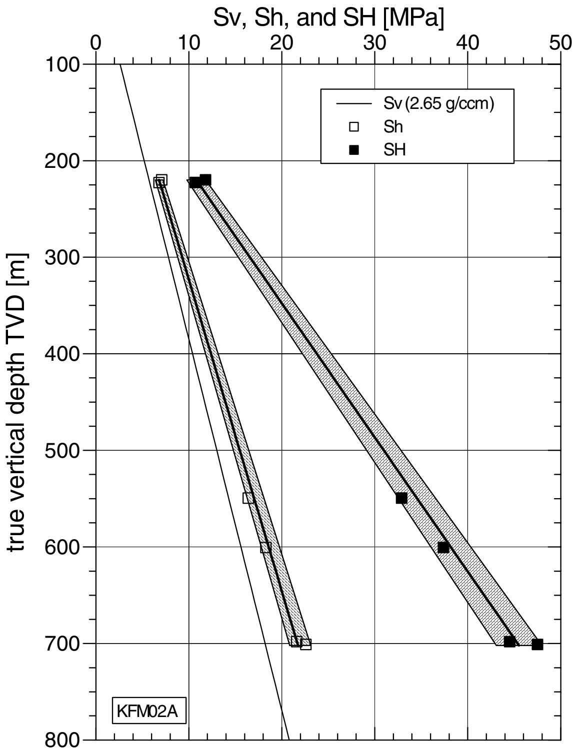
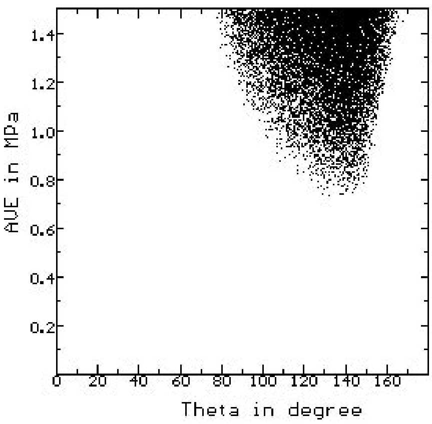


Figure 5-17. Principal stresses on the basis of the /Hubbert and Willis, 1957/ concept in borehole no KFM02A. The dashed area represents the standard deviation of the stress-depth profiles.

Input data

Borehole no	TVD [m]	P_{si} [MPa]	Fracture strike θ N over E [deg]	Fracture dip α [deg]
KFM02A	220.09	7.1	110	90
	222.88	6.8	125	89
	225.87	6.7	113	73
	427.07	11.4	110	25
	455.77	18.8	28	81
	471.39	13.9	121	59
	549.53	16.4	128	89
	551.12	15.9	131	58
	561.86	17.7	135	67
	600.58	18.3	137	88
	608.98	18.6	157	69
	634.48	19.2	164	88
	653.16	17.8	133	77
	698.30	21.6	142	88
	701.08	22.6	136	89
	703.75	18.8	153	12
	753.75	20.5	35	8

Result



Result.....: 220.00 m
SH, MPa = 12.08 + 0.0317 * (z,m - 220.00)
Sh, MPa = 5.82 + 0.0318 * (z,m - 220.00)
Sv, MPa = 5.21 + 0.0283 * (z,m - 220.00)
Theta,° = 129 - 144

Number of tested models........:750000
Number of fitting models.......:13761

Sv MPa	dSv/dz MPa/m	SH MPa	dSH/dz MPa/m	Sh MPa	dSh/dz MPa/m	Theta degree	AVE MPa
4.97	0.0281	12.19	0.0269	6.08	0.0320	132	0.73
5.03	0.0286	10.41	0.0377	6.44	0.0301	139	0.74
5.82	0.0264	12.52	0.0272	5.82	0.0316	138	0.74
4.53	0.0301	12.45	0.0306	5.91	0.0326	137	0.74
4.65	0.0299	11.96	0.0267	6.54	0.0308	129	0.74
4.53	0.0294	13.74	0.0252	5.11	0.0334	144	0.75
5.19	0.0279	11.02	0.0338	6.08	0.0308	140	0.75
5.13	0.0272	11.34	0.0382	6.08	0.0316	141	0.76
4.82	0.0297	11.61	0.0316	5.89	0.0328	140	0.76
5.90	0.0264	10.90	0.0379	6.03	0.0318	144	0.76

Figure 5-18. *Input data and result of the stress field inversion calculations for borehole no KFM02A.*

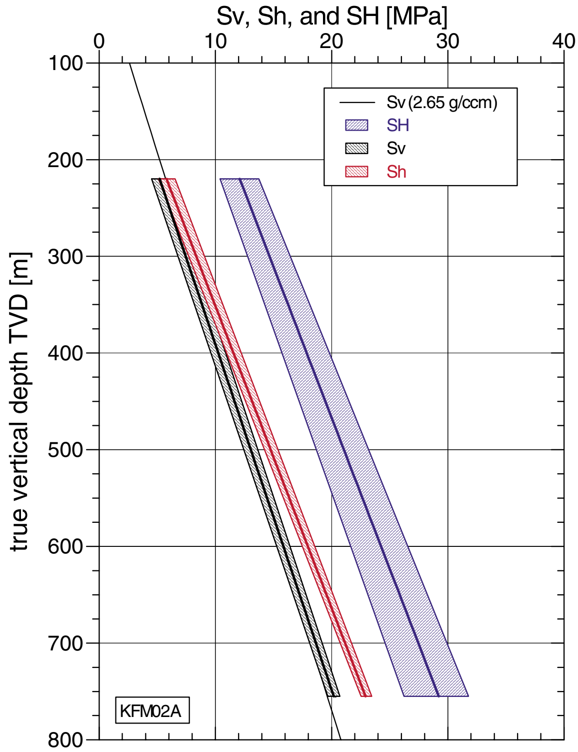


***Figure 5-19.** Principal stresses derived from inversion calculations according to the PSI method in borehole no KFM02A. The dashed area represents the scatter of the 10 best models, S_v (2.65 g/cm^3) marks the vertical stress calculated for an average rock mass density of 2.65 g/cm^3.*

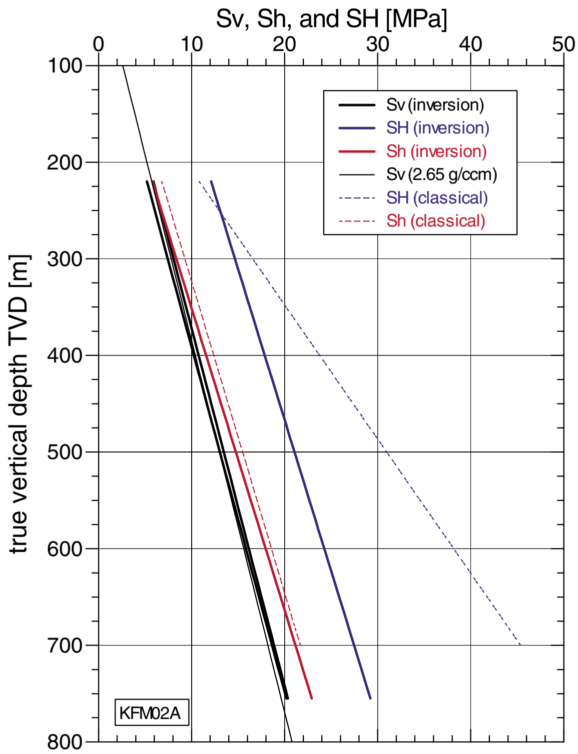


***Figure 5-20.** Comparison between principal stress profiles derived from the classical /Hubbert and Willis, 1957/ approach and inversion calculations according to the PSI method in borehole no KFM02A. S_v (2.65 g/cm^3) represents the vertical stress calculated for an average rock mass density of 2.65 g/cm^3.*

5.2.3 Borehole no KFM04A

Eleven hydrofrac/hydraulic injection and 11 impression packer tests were carried out in borehole no KFM04A between 194.58 m and 593.93 m measured depth MD (corresponding true vertical depth TVD: 171.43–502.91 m). The initial test program consisted of 2 hydraulic fracturing (HF) tests and 9 hydraulic tests of pre-existing fractures (HTPF). The graphical test record analysis is given in Appendix B4, whereas copies of the fracture traces observed during impression packer testing are given in Appendix C4. All data are stored in the SKB database SICADA, field note no 202.

The derived characteristic pressure data (breakdown pressure P_c at fracture initiation, fracture re-opening pressure P_r, shut-in pressure P_{si}, and the resulting in-situ tensile strength $P_{co} = P_c – P_r$) as well as the results of the impression packer tests (fracture strike direction θ, dip direction β, dip α) are summarized in Table 5-7 and are shown graphically in Figures 5-21 to 5-24. The pressure data are listed as downhole pressure values, and fracture orientation data are given with respect to geographic north. Table 5-7 also contains information on the orientation of pre-existing fractures visible in the rock cores, the observed system stiffness during pressurization, and the injected and recovered fluid volume.

Since more pronounced pre-existing fractures in the core material were selected, only 3 HTPF tests in borehole no KFM04A exhibited breakdown (fracture initiation) events, while 6 HTPF tests are characterized by the stimulation of existing fractures. A detailed consideration shows that the stimulated pre-existing fractures are orientated sub-vertically with a strike direction approximately parallel and perpendicular to the direction of the maximum horizontal stress as well as sub-horizontal. The 3 breakdown events during HTPF testing were observed in test sections containing both pre-existing fractures oriented parallel and perpendicular to the direction of the maximum horizontal stress.

The 2 HF tests in borehole no KFM04A resulted in the stimulation of an inclined existing fracture at 371.2 m MD and a NW-SE striking axial fracture at 398.0 m MD.

The distinct impression packer tests showed that steeply inclined fractures with a strike direction of NW-SE and NE-SW as well as sub-horizontal fractures were initiated or stimulated. The comparison between impression packer test results and the orientation of pre-existing fractures derived from the analysis of the core material shows close agreement for the tests at 194.58 m, 196.91 m, 277.99 m, 535.88 m, 558.33 m, and 564.02 m MD. Contrary results were observed at 266.33 m, 553.90 m, and 593.93 m MD.

The test record analysis yields unambiguous characteristic pressure data. Deviating from the tests in the other boreholes, shut-in pressure values in the order of the vertical stress calculated for an average rock mass density of 2.65 g/cm^3 were observed only for the test sections at 194.58 m, 196.91 m, 553.90 m, and 558.33 m MD; the other tests yield higher shut-in pressure values, in particular at 266.33 m, 277.91 m, 371.2 m, and 398.0 m MD. However, only at 266.33 m MD a fracture approximately perpendicular to the direction of the maximum horizontal stress was stimulated, while the other tests showed the stimulation of fractures perpendicular to the minimum horizontal stress or the vertical stress.

Table 5-7. Results of hydraulic injection tests in borehole no KFM04A (V_i: injected fluid volume, V_r: recovered fluid-volume, P_c: breakdown pressure, P_r: refrac pressure, P_{co}: in-situ hydraulic tensile strength, P_{si}: shut-in pressure, θ: strike direction (North over East), β: dip direction (North over East), α: dip (with respect to horizontal).

Test no	Measured depth MD [m]	True vertical depth TVD [m]	Initial test type	V_i [l]	V_r [l]	P_c [MPa]	P_r [MPa]	P_{co} [MPa]	P_{si} [MPa]	Orientation of pre-existing fracture (core analysis) strike/dip [deg]	Frac-ture trace	θ [deg]	β [deg]	α [deg]	Remark
11	194.58	171.43	HTPF	18.4	4.8	–	4.5 (11)	–	4.9	316/11	A	<u>172</u>	<u>82</u>	<u>15</u>	distinct joint
10	196.91	173.47	HTPF	14.7	7.0	10.5 (32)	6.4 (23)	4.1	5.2	133/71	A	<u>125</u>	<u>35</u>	<u>61</u>	axial double trace
											B	104	14	36	
9	266.33	233.61	HTPF	17.5	1.0	–	13.9 (34)	–	14.3	18/86	A	113	23	22	
											B	57	327	48	
											C	<u>59</u>	<u>329</u>	<u>63</u>	
8	277.99	243.63	HTPF	17.7	1.0	–	15.6 (36)	–	17.6	133/81	A	131	221	81	
											B	142	232	80	
											C	94	4	66	axial double trace
7	371.2	322.95	HF	21.6	10.4	–	17.3 (34)	–	18.2		A	140	50	17	
											B	13	103	32	
											C	145	55	41	
6	398.0	345.30	HF	16.3	4.9	–	18.6 (34)	–	22.15		A	120	30	58	axial double trace
											B	121	31	31	
5	535.88	457.03	HTPF	20.6	8.5	–	19.2 (34)	–	16.2	4/79	A	<u>21</u>	<u>111</u>	<u>86</u>	
											B	59	149	13	
4	553.90	471.33	HTPF	17.9	10.5	21.1 (34)	13.55 (32)	7.55	14.0	74/57	A	<u>99</u>	<u>189</u>	<u>9</u>	
3	558.33	474.84	HTPF	13.0	10.0	22.4 (35)	15.0 (34)–15.8 (34)	6.6–7.4	15.0	232/70	A	<u>46</u>	<u>316</u>	<u>78</u>	
2	564.02	479.34	HTPF	16.6	10.2	–	18.9 (33)	–	17.0	139/12	A	<u>114</u>	<u>204</u>	<u>12</u>	
1	593.93	502.91	HTPF	18.3	16.0	–	19.9 (30)	–	17.0	120/76	A	175	85	7	
											B	138	48	52	
											C	<u>77</u>	<u>347</u>	<u>52</u>	

In parenthesis: system stiffness dP/dV during pressurization (in MPa/l).

A, B etc mark different fracture traces.

Underlined orientation data were used for the stress analysis.

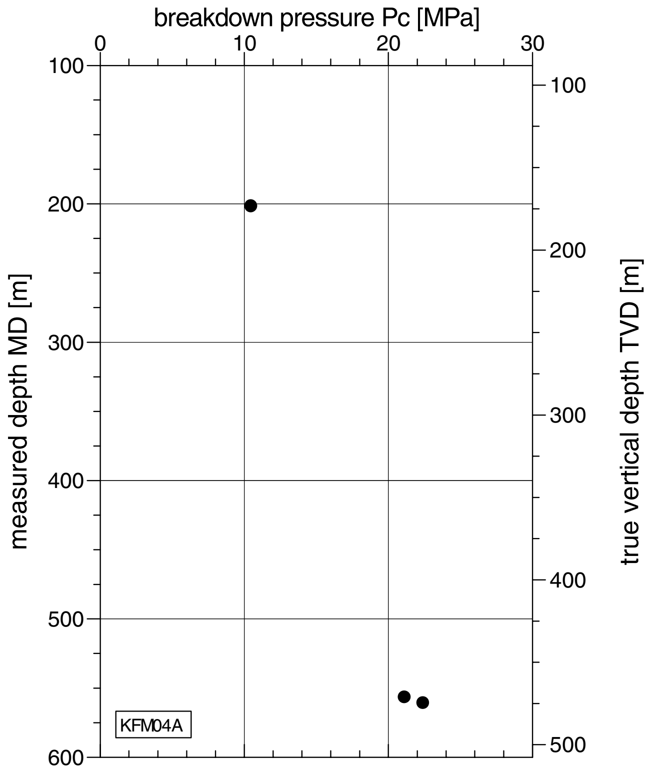


Figure 5-21. *Breakdown (fracture initiation) pressure P_c in borehole no KFM04A.*

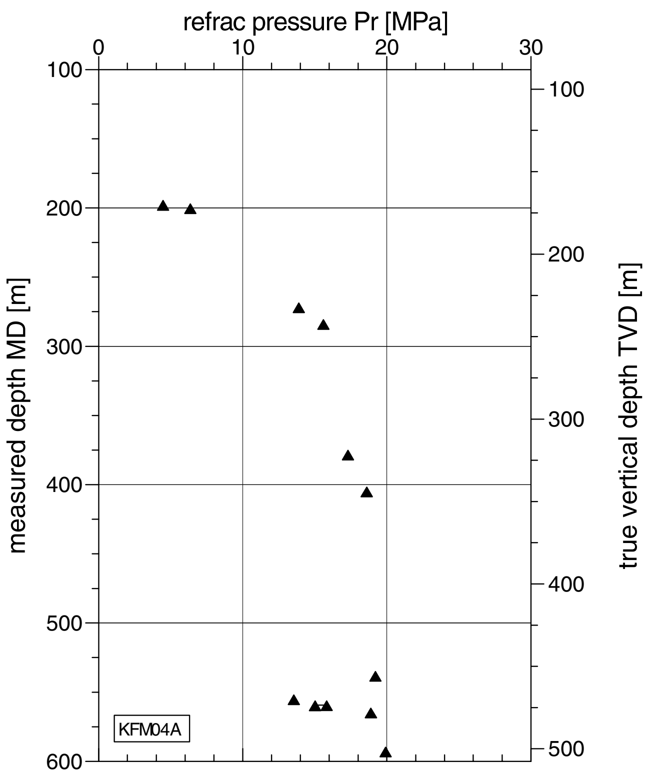


Figure 5-22. *Refrac (fracture re-opening) pressure P_r in borehole no KFM04A.*

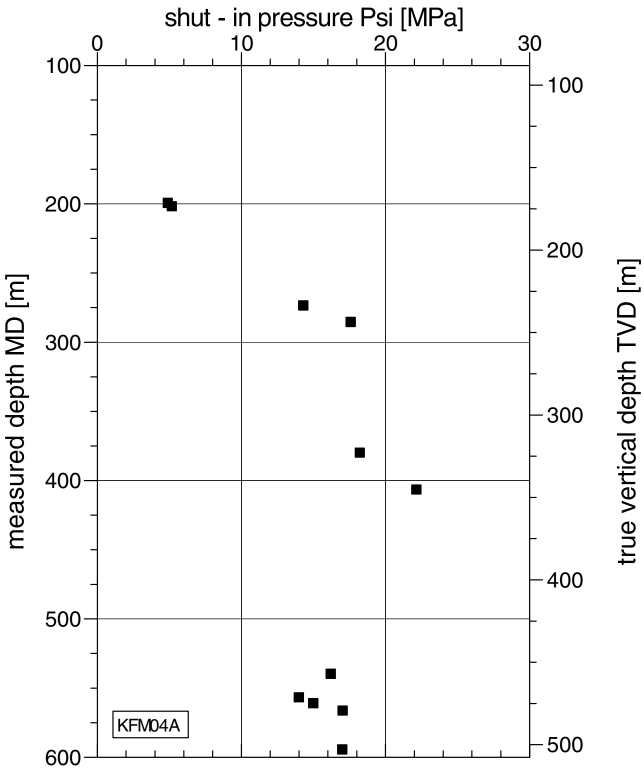


***Figure 5-23.** Shut-in pressure P_{si} in borehole no KFM04A.*

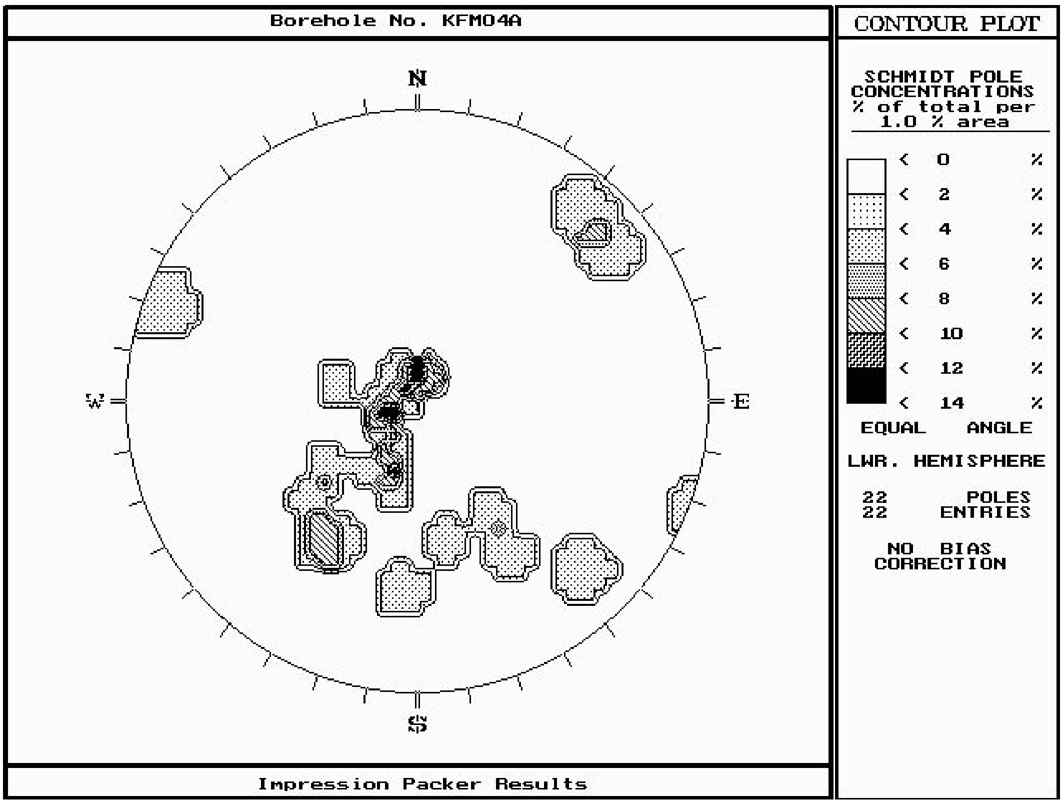


***Figure 5-24.** Orientation of induced or stimulated fractures derived from impression packer testing in borehole no KFM04A. Shown is the pole concentration in the lower hemisphere projection of all fractures detected on the impression packer.*

Due to the strong inclination of borehole no KFM04A (30–38 degrees from the vertical plane within the test interval), the /Hubbert and Willis, 1957/ approach cannot be applied for test sections with axial fracture initiation or stimulation. Nevertheless, it should be noted that the axial fractures observed at 196.91 m, 277.99 m, 398.0 m, and 593.93 m MD show an average strike direction of N 119° ± 18°. Hence, the stress evaluation was carried out on the basis of the PSI inversion method. The calculations started by considering the test results with unambiguous fracture orientation data, followed by stepwise including the data sets where more than one fracture was observed within the test section. In this case, alternative calculations were conducted while the difference between measured and calculated normal stresses was observed. However, the tests at 277.99 m, 371.2 m, and 398.0 m MD with considerable high shut-in pressure values and inconsistent fracture orientations were excluded from the calculations. The input data and the final result of the calculation are presented in Figure 5-25. Although the data base with the remaining 8 data sets is limited, the calculations yield the following stress-depth relations between 171 m and 503 m TVD:

S_h [MPa] = (5.1 ± 0.7) + (0.026 ± 0.004) · (TVD [m]-171)

S_H [MPa] = (13.6 ± 0.8) + (0.012 ± 0.002) · (TVD [m]-171)

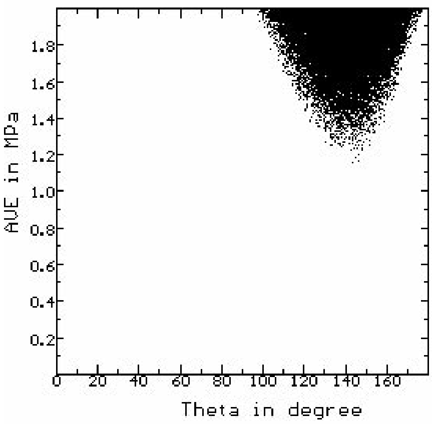
S_v [MPa] = (5.4 ± 0.3) + (0.033 ± 0.002) · (TVD [m]-171)

The inversion calculations yield a direction of the acting maximum horizontal principal stress S_H of N 143° ± 5° (NW-SE).

The stress-depth profiles together with the scatter of the 10 best models are shown in Figure 5-26. While the derived minimum and maximum horizontal stresses are comparable with the results in the neighbored boreholes, the derived vertical stress is larger than the calculated vertical stress for a mean rock mass density of 2.65 g/cm^3.

Input data				
Borehole no	**TVD [m]**	**P_{si} [MPa]**	**Fracture strike θ N over E [deg]**	**Fracture dip α [deg]**
KFM04A	171.43	4.9	172	15
	173.47	5.2	125	61
	233.61	14.3	59	63
	457.03	16.2	21	86
	471.33	14.0	99	9
	474.84	15.0	46	78
	479.34	17.0	114	12
	502.91	17.0	77	52

Result



Result.....: 171.00 m
SH, MPa = 13.63 + 0.0116 * (z,m - 171.00)
Sh, MPa = 5.10 + 0.0264 * (z,m - 171.00)
Sv, MPa = 5.41 + 0.0330 * (z,m - 171.00)
Theta,° = 138 - 148
Number of tested models........:750000
Number of fitting models.......:31082

Sv MPa	dSv/dz MPa/m	SH MPa	dSH/dz MPa/m	Sh MPa	dSh/dz MPa/m	Theta degree	AVE MPa
5.20	0.0343	14.29	0.0103	4.58	0.0265	144	1.16
5.59	0.0342	13.31	0.0101	4.38	0.0298	146	1.17
5.35	0.0346	14.16	0.0102	5.34	0.0266	145	1.19
5.42	0.0314	13.84	0.0104	4.43	0.0260	147	1.20
5.36	0.0321	14.30	0.0111	4.76	0.0282	148	1.23
5.53	0.0343	13.18	0.0100	5.02	0.0241	143	1.23
5.14	0.0337	13.64	0.0131	4.59	0.0274	144	1.24
5.12	0.0326	14.42	0.0107	4.73	0.0230	146	1.24
5.44	0.0347	13.50	0.0104	5.82	0.0271	148	1.24
5.71	0.0330	12.84	0.0112	5.00	0.0282	138	1.24

Figure 5-25. *Input data and result of the stress field inversion calculations for borehole no KFM04A.*

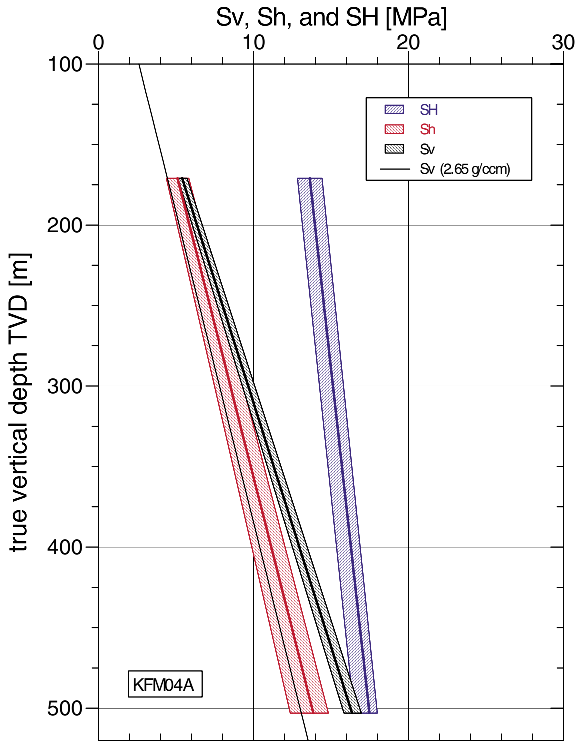


Figure 5-26. *Principal stresses derived from inversion calculations according to the PSI method in borehole no KFM04A. The dashed area represents the scatter of the 10 best models, S_v (2.65 g/cm³) marks the vertical stress calculated for an average rock mass density of 2.65 g/cm³.*

6 Summary and discussions

6.1 Rock mass hydraulics

Despite some doubtful test results in borehole no KFM01A and the high permeability observed at 216.50 m MD in borehole no KFM01B, the short pressure pulse tests yield an average permeability of 25 ± 40 µDarcy (10^{-18} m^2) for the granitic rock mass around the boreholes. Intact test sections without visible fractures yield an average permeability of 12 ± 17 µDarcy, while test sections with pre-existing fractures are characterized by an average permeability of 34 ± 48 µDarcy. It is interesting to note that during 6 tests no pressure decline or even a pressure increase was observed. In addition, no significant higher permeability was observed in borehole no KFM04A, where more pronounced fractures in the core material were tested.

In most cases, the permeability after the stimulation test is increased by a factor of about 1 to 40. Higher ratios were observed only at 171.00 m and 187.90 m MD in borehole no KFM01B.

Both the minor difference between the permeability of intact and fractured test sections and the minor increase of the permeability after stimulation indicate that pre-existing fractures are hydraulically sealed and almost completely closed after testing.

6.2 Stress data

It has to be expressively mentioned that the results of the present stress measurements at Forsmark were derived by linear regression in case of the Hubbert and Willis approach or by the à-priori assumption of a linear stress-depth dependence in case of inversion calculations. This assumption is based on the result of stress measurements all over the world, which demonstrate a linear increase of the in-situ stresses with depth. The remarkably higher shut-in pressures (e.g. at 230 m TVD in borehole no KFM01B, at 244 m, 323 m, and 345 m TVD in borehole no KFM04A) as well as lower values (e.g. 440–450 m TVD in borehole no KFM02A) deviating from the linear trend had to be neglected for the analysis. Thus, the results characterize the general stress-field for the Forsmark area. The existence of zones with e.g. higher stresses as indicated by the overcoring stress measurements in borehole no KFM01B /Sjöberg, 2004/ and the locally observed core disking can not be refuted. However, using the stress magnitudes derived from the overcoring tests in borehole no KFM01B (S_h = 23 MPa, S_H = 40 MPa at 240 m depth) and the stress directions of θ_{SH} = 90° (overcoring-tests) or θ_{SH} = 125° (HF/HTPF tests), the theoretical normal stress S_n can be calculated for the different fractures observed at 230 m TVD and compared with the measured shut-in pressure P_{si}:

Measured depth MD m	Fracture strike/dip deg	θ_{SH} = 90° S_n MPa	θ_{SH} = 125° S_n MPa	P_{si} MPa
235.0	141/39	16.8	13.2	16.0
	152/35	15.9	12.7	
236.0	161/23	10.9	9.5	16.1
	174/37	18.2	15.7	
237.0	128/24	9.9	8.8	13.5

The partial agreement between S_n and P_{si} (for the different stress directions) may be considered as an indication of locally high stresses in the order of the magnitude of the overcoring tests. Besides, the following conclusions can be derived for the stress situation at Forsmark:

Vertical stress S_v

The inversion calculations yield the following stress-depth profiles:

Borehole no	Depth range TVD [m]	S_v [MPa]
KFM01A/B	167–961	(4.6 ± 0.6) + (0.0275 ± 0.0025) · (TVD-167)
KFM02A	220–755	(5.2 ± 0.7) + (0.028 ± 0.002) · (TVD-220)
KFM04A	171–503	(5.4 ± 0.3) + (0.033 ± 0.002) · (TVD-171)

As shown in Figure 6-1, the derived vertical stresses for boreholes nos KFM01A/B and KFM02A are in close agreement with both the present site descriptive model (SDF) and the vertical stress estimated for a mean rock mass density of 2.65 g/cm³. In contrary, the tests in borehole no KFM04A yield a vertical stress about 20–25% larger than the calculated vertical stress for a mean density of 2.65 g/cm³. The discrepancy is mainly caused by the test result at 564.02 m MD/479.34 m TVD in borehole no KFM04A, where a sub-horizontal fracture was stimulated with a corresponding shut-in pressure gradient P_{si}/TVD of 0.0355 MPa/m. Therefore, for further considerations, a reliable estimation of the vertical stress S_v can be achieved simply by using stress gradients of 0.026 to 0.027 MPa/m.

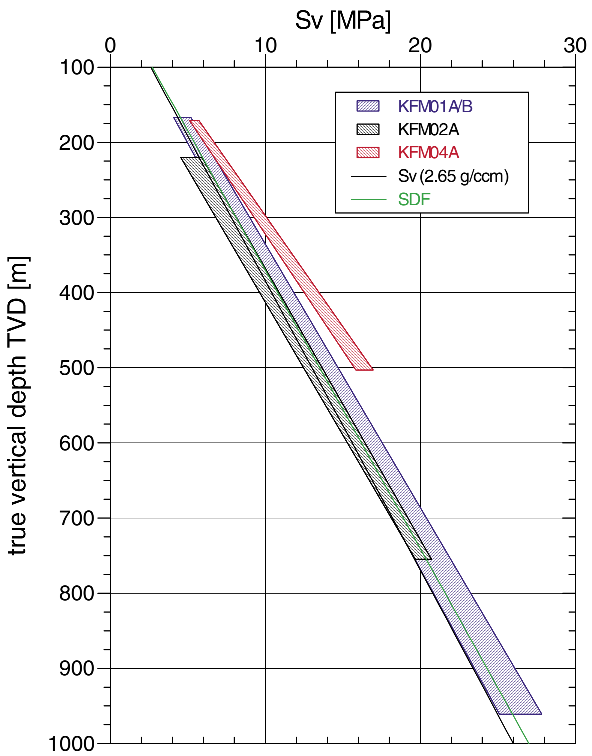


__Figure 6-1.__ Comparison of vertical principal stresses derived in boreholes nos KFM01A/B, KFM02A, and KFM04A. Shown is the scatter of the 10 best models according to inversion calculations. S_v (2.65 g/cm³) marks the vertical stress calculated for an average rock mass density of 2.65 g/cm³, SDF represents the site descriptive model.

Minimum horizontal stress S_h

The estimation of the minimum horizontal stress for the different boreholes can be summarized as follows:

Borehole no	Depth range TVD [m]	Hubbert and Willis approach S_h [MPa]	Inversion calculations S_h [MPa]
KFM01A/B	183–961	(6.0±1.7)+(0.025±0.004)·(TVD-183)	
	167–961		(6.7±0.6)+(0.021±0.001)·(TVD-167)
KFM02A	220–755	(6.8±0.4)+(0.031±0.001)·(TVD-220)	(5.8±0.7)+(0.032±0.002)·(TVD-220)
KFM04A	171–503		(5.1±0.7)+(0.026±0.004)·(TVD-171)

Despite the agreement between the results of the Hubbert and Willis approach and the inversion calculations, the comparison in Figure 6-2 shows that the derived stress profiles yield consistent results down to approximately 500 m depth, with a minimum horizontal stress slightly larger than the vertical stress calculated for a mean rock mass density of 2.65 g/cm^3. Below 500 m, the results indicate that the minimum horizontal stress is the least principal stress in boreholes no KFM01A/B, while in borehole no KFM02A the vertical stress is the least principal stress, in agreement with the site descriptive model (SDF).

Since the inversion result is well determined by the large number of shut-in pressures on fractures oriented parallel to the direction of the maximum horizontal stress (at least in boreholes nos KFM01A/B and KFM02A), it is suggested to use the inversion results for further considerations.

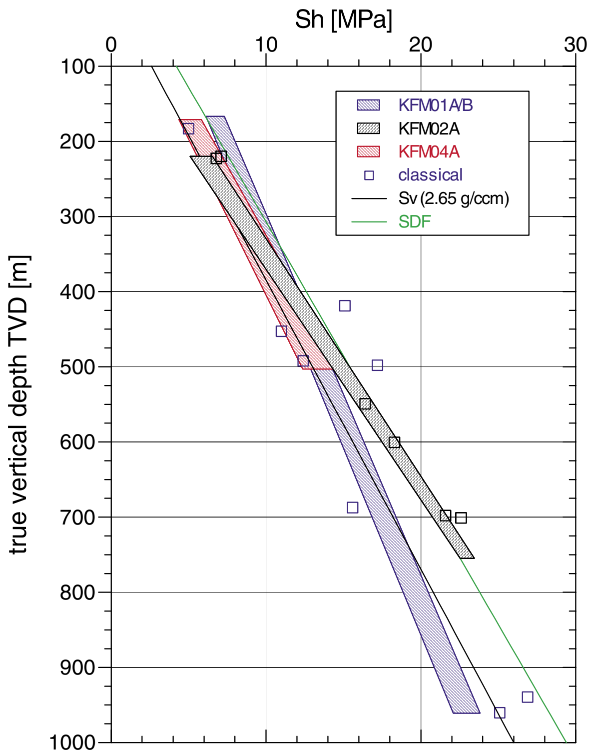


Figure 6-2. *Comparison of minimum horizontal principal stresses derived in boreholes nos KFM01A/B, KFM02A, and KFM04A. Shown is the scatter of the 10 best models according to inversion calculations. The open squares represent the result according to the "classical" /Hubbert and Willis, 1957/ approach, S_v (2.65 g/cm^3) marks the vertical stress calculated for an average rock mass density of 2.65 g/cm^3, SDF represents the site descriptive model.*

Maximum horizontal stress S_H

In contrary to the minimum horizontal stress S_h, the two analysis procedures yield stress-depth profiles for the maximum horizontal stress S_H which differ significantly and deviate from the site descriptive model (Figure 6-3):

Borehole no	Depth range TVD [m]	Hubbert and Willis approach S_H [MPa]	Inversion calculations S_H [MPa]
KFM01A/B	183–961	(10.1±3.5)+(0.055±0.008)·(TVD-183)	
	167–961		(11.4±2.1)+(0.032±0.005)·(TVD-167)
KFM02A	220–755	(10.8±1.0)+(0.072±0.003)·(TVD-220)	(12.1±1.7)+(0.032±0.007)·(TVD-220)
KFM04A	171–503		(13.6±0.8)+(0.012±0.002)·(TVD-171)

On the one side, the lower estimation of the maximum horizontal stress S_H by the inversion calculations in comparison to the Hubbert and Willis approach is based on shut-in pressures which are measured on some few fractures oriented perpendicular to the direction of S_H. Unfortunately, most of the proposed HTPF tests on fractures deviating from the direction of least resistance (parallel to S_H) resulted in the initiation of new fractures. On the other side, the discrepancy might be caused by an under-estimation of the true refrac pressure which results in too high S_H-magnitudes. Although the Hubbert and Willis approach is widely used, the reliability of the refrac pressure in case of fluid penetration into the fracture prior to the re-opening and the minimum system stiffness necessary for a correct identification of the refrac pressure is still controversially discussed /Ito et al. 1999; Rutquist et al. 2000/. Therefore, due to the uncertainties in the estimation of S_H, it is suggested to use the results of both methods as a lower and upper limit estimation of the maximum horizontal stress S_H.

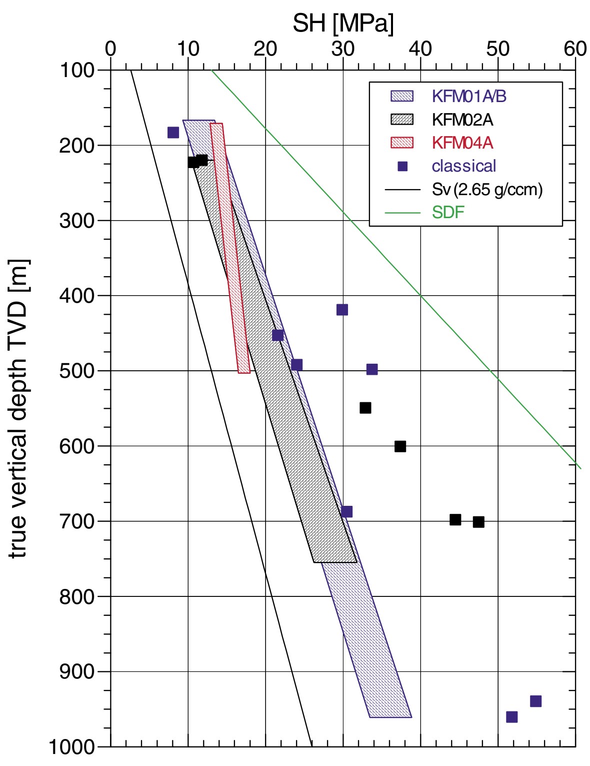


Figure 6-3. *Comparison of maximum horizontal principal stresses derived in boreholes nos KFM01A/B, KFM02A, and KFM04A. Shown is the scatter of the 10 best models according to inversion calculations. The closed squares represent the result according to the "classical" /Hubbert and Willis, 1957/ approach, S_v (2.65 g/cm^3) marks the vertical stress calculated for an average rock mass density of 2.65 g/cm^3, SDF represents the site descriptive model.*

Orientation of maximum horizontal stress θ_{SH}

The orientation of the maximum horizontal stress θ_{SH} was consistently determined as:

Borehole no	Hubbert and Willis approach θ_{SH} [deg]	Inversion calculations θ_{SH} [deg]
KFM01A/B	N 103° ± 21°	N 125° ± 5°
KFM02A	N 130° ± 11°	N 137° ± 8°
KFM04A		N 143° ± 5°

The NW-SE direction of the maximum horizontal stress S_H is in agreement with existing stress data for the Forsmark area, as shown in the stress-map in Figure 6-4.

In summary, the hydrofrac/hydraulic injection tests at the Forsmark area yield a stress field with thrust to strike-slip faulting stress conditions ($S_v \leq S_h < S_H$) and a NW-SE orientation of the maximum horizontal stress. The maximum horizontal stress appears to be much lower than expected from the present site descriptive model.

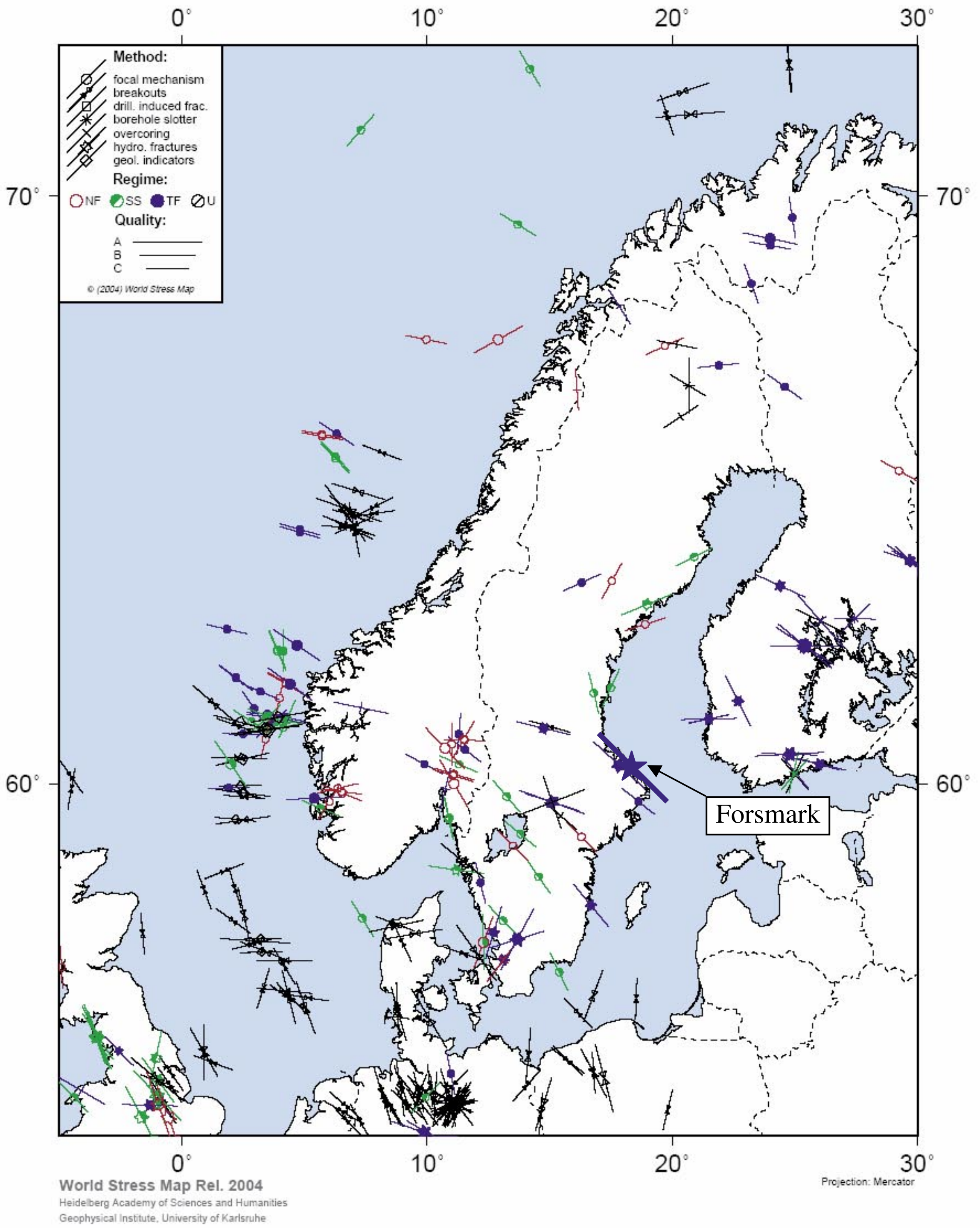


Figure 6-4. *Orientation of maximum horizontal stress in Scandinavia /Reinecker et al. 2004/ in comparison with the results of the in-situ tests at Forsmark.*

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Acknowledgement

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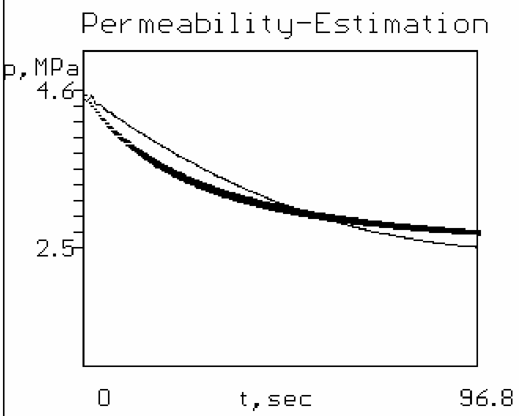
The in-situ measurements were conducted by the MeSy staff members Gerd Klee, Ludger Küperkoch, Hartmut Vogt and Ulrich Weber.

Appendix A1

Analysis of Pressure Pulse Tests, Borehole No. KFM01A

Test No. 25 at 249.43 m MD / 247.99 m TVD



INPUTPARAMETERS

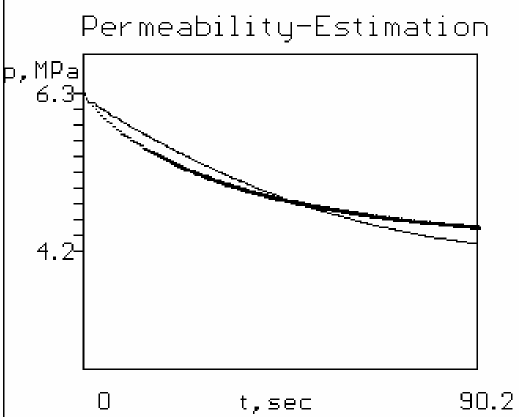
filename:	249.dat	
samplingrate, sec:	0.20	
inv. Stiffness m³.m/Pa:	5.3E-11	
interval length, m:	0.60	
hole diameter, mm:	76.30	
Phyd, MPa:	2.45	
Tm (min, max), sec:	6	17
number of models:	20000	
error:	5.0E-02	

result (mean value of all fitting models):

Permeability : (2446.1 ± 113.0) µdarcy
Kf : (2.4 ± 0.1) e -8 m/s
Alpha : (0.00010)

Number of fitting models: 640

Test No. 24 at 422.0 m MD / 419.00 m TVD



INPUTPARAMETERS

filename:	422.dat	
samplingrate, sec:	0.20	
inv. Stiffness m³.m/Pa:	5.5E-11	
interval length, m:	0.60	
hole diameter, mm:	76.30	
Phyd, MPa:	4.15	
Tm (min, max), sec:	7	21
number of models:	20000	
error:	2.5E-02	

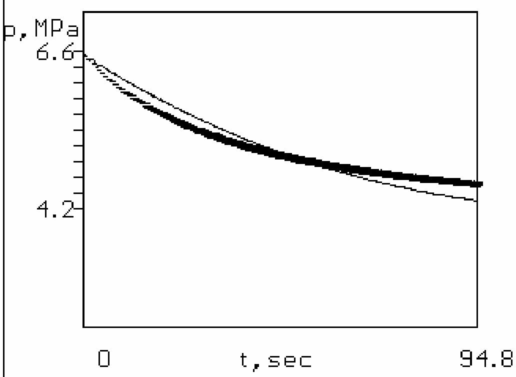
result (mean value of all fitting models):

Permeability : (2090.4 ± 38.6) µdarcy
Kf : (2.1 ± 0.0) e -8 m/s
Alpha : (0.00010)

Number of fitting models: 184

Test No. 23 at 426.5 m MD / 423.45 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	426.dat	
samplingrate, sec:	0.20	
inv. Stiffness m³.m/Pa:	3.6E-11	
interval length, m:	0.60	
hole diameter, mm:	76.30	
Phyd, MPa:	4.17	
Tm (min, max), sec:	8	24
number of models:	20000	
error:	2.8E-02	

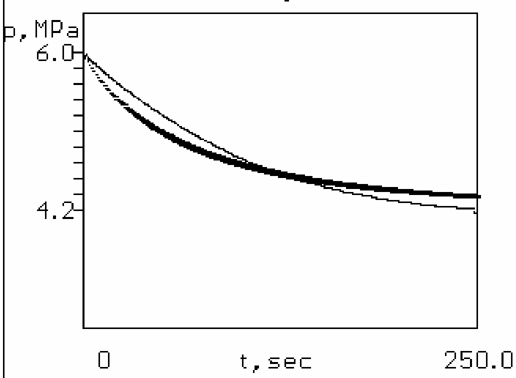
result (mean value of all fitting models):

Permeability	: (1237.7 ±	54.2)	µdarcy
Kf	: (1.2 ±	0.1)	e -8 m/s
Alpha	: (0.00010)		

Number of fitting models: 599

Test No. 22 at 430.5 m MD / 427.40 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	430.dat	
samplingrate, sec:	0.20	
inv. Stiffness m³.m/Pa:	1.8E-11	
interval length, m:	0.60	
hole diameter, mm:	76.30	
Phyd, MPa:	4.23	
Tm (min, max), sec:	13	39
number of models:	20000	
error:	2.3E-02	

result (mean value of all fitting models):

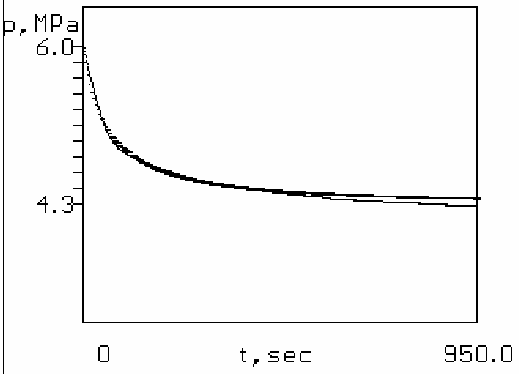
Permeability	: (341.9 ±	12.5)	µdarcy
Kf	: (3.4 ±	0.1)	e -9 m/s
Alpha	: (0.00010)		

Number of fitting models: 539

Test No. 17 at 433.41 m MD / 430.28 m TVD

prior to fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	433.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	3.8E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.25
Tm (min, max), sec:	48 143
number of models:	20000
error:	1.0E-02

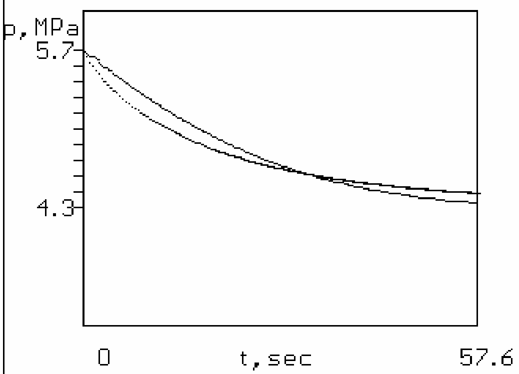
result (mean value of all fitting models):

Permeability : (202.5 ± 6.3) μdarcy
Kf : (2.0 ± 0.1) e -9 m/s
Alpha : (0.10000)

Number of fitting models: 440

after fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	433b.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	4.1E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.27
Tm (min, max), sec:	4 12
number of models:	20000
error:	1.8E-02

result (mean value of all fitting models):

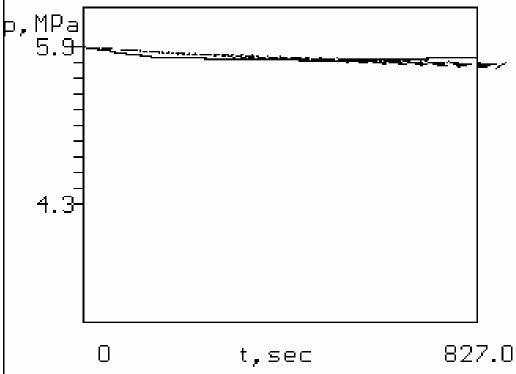
Permeability : (2434.3 ± 13.1) μdarcy
Kf : (2.4 ± 0.0) e -8 m/s
Alpha : (0.00100)

Number of fitting models: 71

Test No. 16 at 437.96 m MD / 434.78 m TVD

prior to fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	437.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.0E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.29
Tm (min, max), sec:	6776 20327
number of models:	20000
error:	6.0E-03

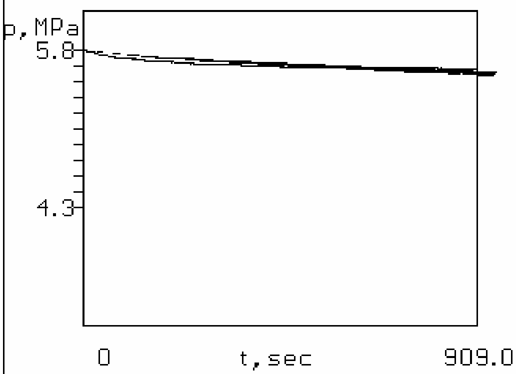
result (mean value of all fitting models):

Permeability	: (1.1 ± 0.1) µdarcy
Kf	: (1.1 ± 0.1) e-11 m/s
Alpha	: (0.01000)

Number of fitting models: 309

after fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	437b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.2E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.30
Tm (min, max), sec:	3951 11852
number of models:	20000
error:	4.5E-03

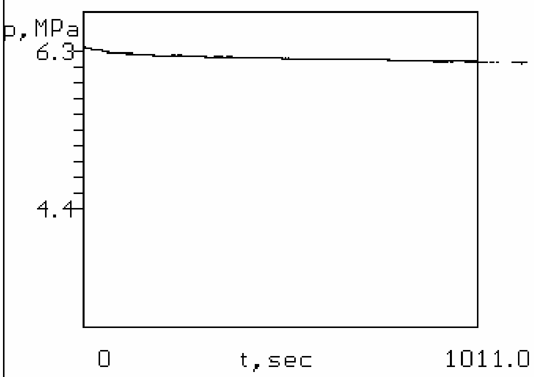
result (mean value of all fitting models):

Permeability	: (1.5 ± 0.1) µdarcy
Kf	: (1.5 ± 0.1) e-11 m/s
Alpha	: (0.01000)

Number of fitting models: 850

Test No. 9 at 452.16 m MD / 448.81 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	452.red
samplingrate, sec:	1.00
inv. Stiffness m².m/Pa:	5.0E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.44
Tm (min, max), sec:	9776 29327
number of models:	20000
error:	1.0E-03

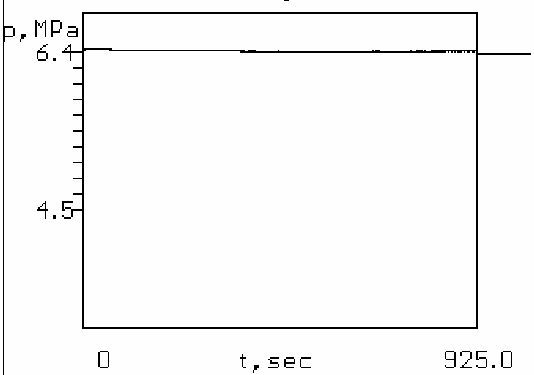
result (mean value of all fitting models):

Permeability	: (	1.1 ±	0.0) µdarcy
Kf	: (	1.1 ±	0.0) e-11 m/s
Alpha	: (	0.01000)	

Number of fitting models: 269

Test No. 8 at 456.26 m MD / 452.87 m TVD

Permeability-Estimation



INPUTPARAMETERS

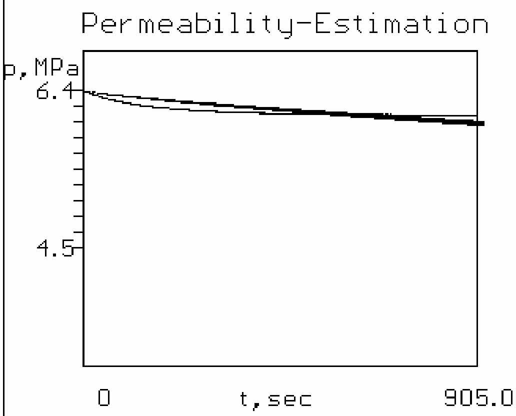
filename:	456.red
samplingrate, sec:	1.00
inv. Stiffness m².m/Pa:	3.4E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.46
Tm (min, max), sec:	35001105002
number of models:	20000
error:	1.0E-03

result (mean value of all fitting models):

Permeability	: (	0.2 ±	0.0) µdarcy
Kf	: (	1.8 ±	0.1) e-12 m/s
Alpha	: (	0.00010)	

Number of fitting models: 708

Test No. 7 at 457.57 m MD / 454.16 m TVD



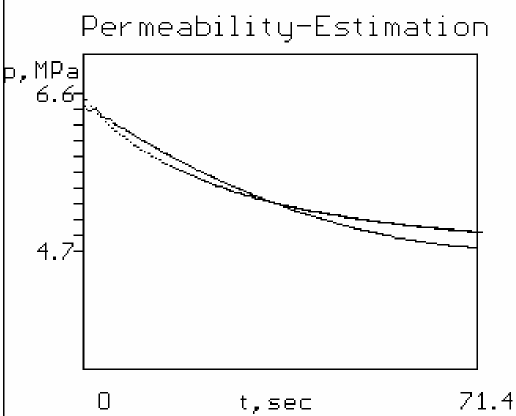
INPUTPARAMETERS
filename: 457.red
samplingrate, sec: 1.00
inv. Stiffness m³.m/Pa: 4.2E-11
interval length, m: 0.60
hole diameter, mm: 76.30
Phyd, MPa: 4.49
Tm (min, max), sec: 10 5000
number of models: 20000

error: 9.5E-03

result (mean value of all fitting models):
Permeability : (9.1 ± 0.4) µdarcy
Kf : (9.1 ± 0.4) e-11 m/s
Alpha : (0.00100)

Number of fitting models: 296

Test No. 21 at 475.9 m MD / 472.27 m TVD



INPUTPARAMETERS
filename: 475.dat
samplingrate, sec: 0.20
inv. Stiffness m³.m/Pa: 5.4E-11
interval length, m: 0.60
hole diameter, mm: 76.30
Phyd, MPa: 4.66
Tm (min, max), sec: 13 39
number of models: 20000

error: 2.0E-02

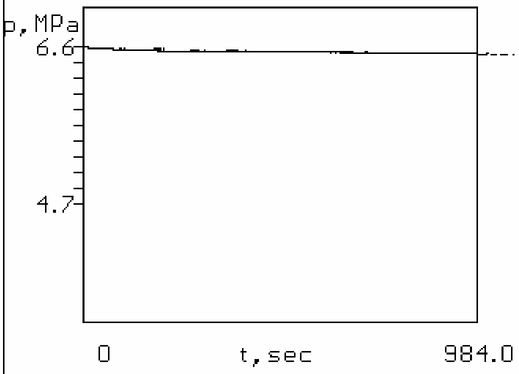
result (mean value of all fitting models):
Permeability : (2191.2 ± 13.0) µdarcy
Kf : (2.2 ± 0.0) e -8 m/s
Alpha : (0.00100)

Number of fitting models: 42

Test No. 6 at 478.96 m MD / 475.29 m TVD

prior to fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	478.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.4E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.68
Tm (min, max), sec:	12501 37502
number of models:	20000
error:	1.4E-03

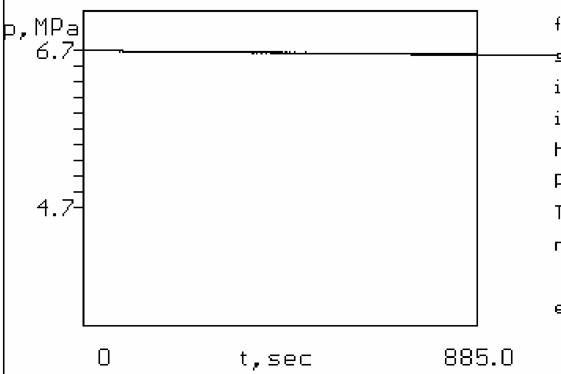
result (mean value of all fitting models):

Permeability	: (0.7 ±	0.0)	µdarcy
Kf	: (6.8 ±	0.2)	e-12 m/s
Alpha	: (0.00100)		

Number of fitting models: 119

after fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	478b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	4.8E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.71
Tm (min, max), sec:	17501 52502
number of models:	20000
error:	8.0E-04

result (mean value of all fitting models):

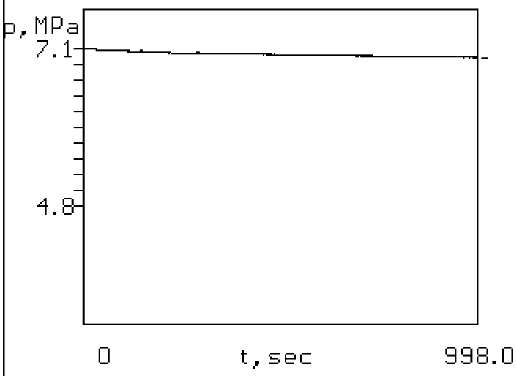
Permeability	: (0.7 ±	0.1)	µdarcy
Kf	: (7.5 ±	0.7)	e-12 m/s
Alpha	: (0.00100)		

Number of fitting models: 1082

Test No. 5 at 488.63 m MD / 484.84 m TVD

prior to fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	488.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	4.9E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.79
Tm (min, max), sec:	12501 37502
number of models:	20000
error:	1.0E-03

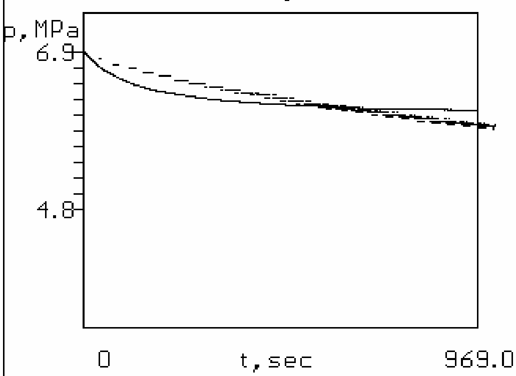
result (mean value of all fitting models):

Permeability	: (0.9 ± 0.0)	µdarcy
Kf	: (9.0 ± 0.0)	e-12 m/s
Alpha	: (0.01000)	

Number of fitting models: 42

after fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	488b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	4.7E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.80
Tm (min, max), sec:	100 4000
number of models:	20000
error:	1.9E-02

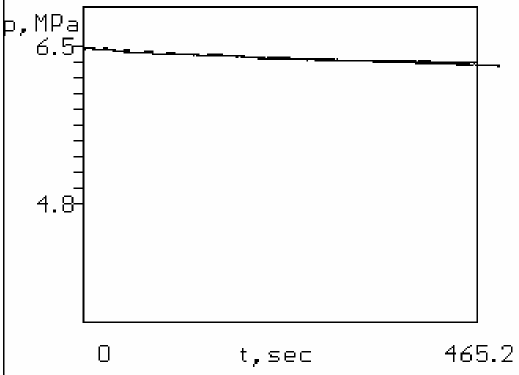
result (mean value of all fitting models):

Permeability	: (31.1 ± 1.2)	µdarcy
Kf	: (3.1 ± 0.1)	e-10 m/s
Alpha	: (0.00100)	

Number of fitting models: 90

Test No. 4 at 491.0 m MD / 487.17 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	491.red
samplingrate, sec:	0.40
inv. Stiffness m³.m/Pa:	5.1E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.81
Tm (min, max), sec:	2251 6752
number of models:	20000
error:	2.0E-03

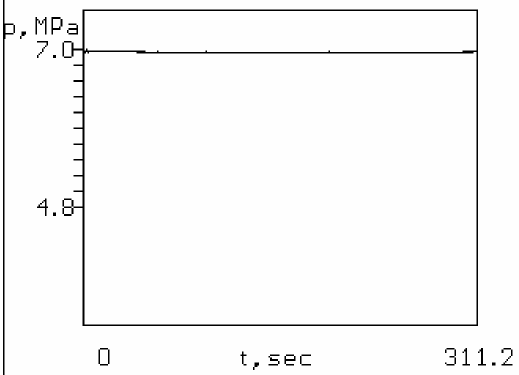
result (mean value of all fitting models):

Permeability : (5.3 ± 0.2) µdarcy
Kf : (5.3 ± 0.2) e-11 m/s
Alpha : (0.01000)

Number of fitting models: 361

Test No. 3 at 496.0 m MD / 492.11 m TVD

Permeability-Estimation



INPUTPARAMETERS

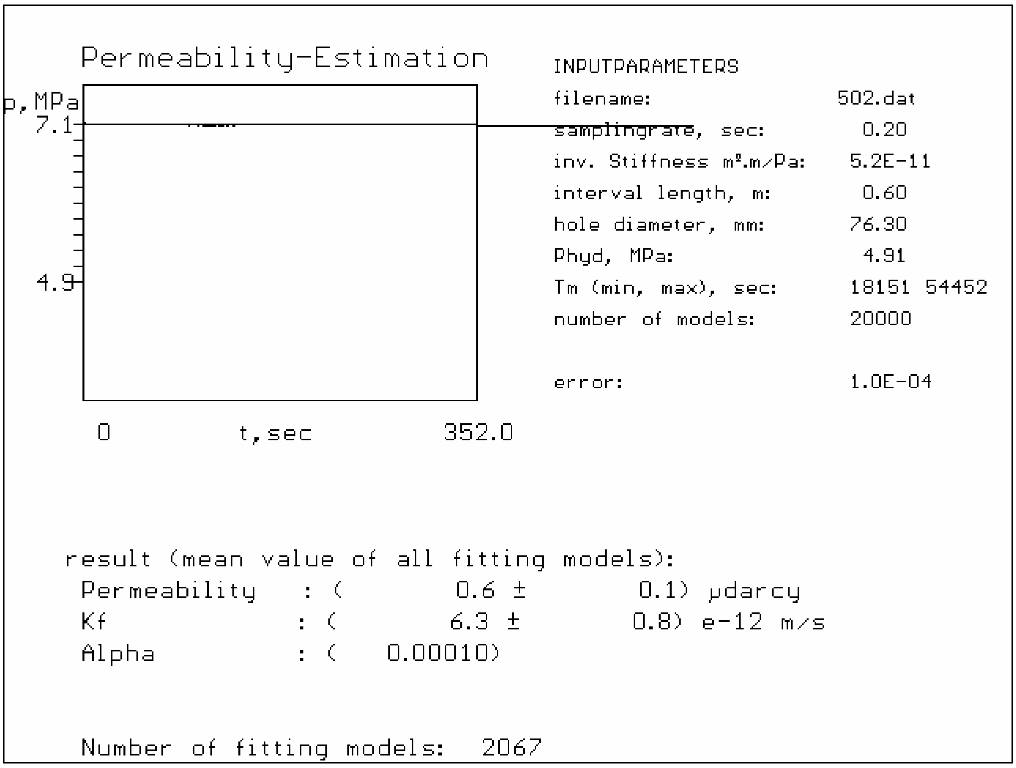
filename:	496.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	3.4E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.85
Tm (min, max), sec:	7001 21002
number of models:	20000
error:	1.1E-03

result (mean value of all fitting models):

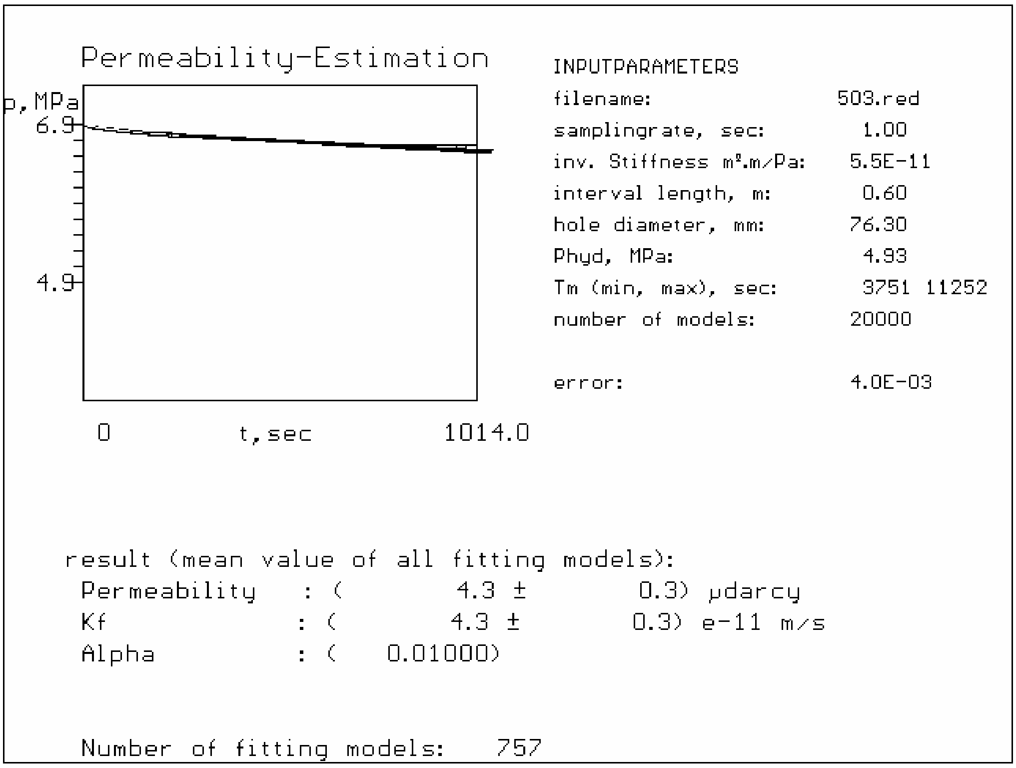
Permeability : (0.9 ± 0.0) µdarcy
Kf : (9.3 ± 0.0) e-12 m/s
Alpha : (0.00100)

Number of fitting models: 6

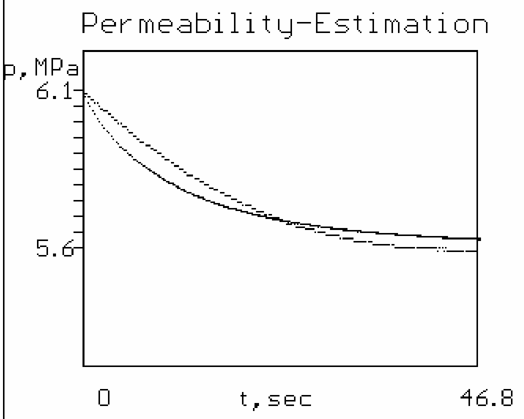
Test No. 2 at 502.0 m MD / 498.03 m TVD



Test No. 1 at 503.45 m MD / 499.46 m TVD



Test No. 20 at 571.8 m MD / 566.74 m TVD



INPUTPARAMETERS

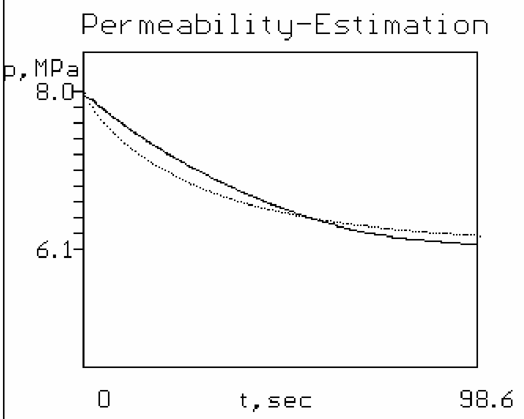
filename:	571.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	5.0E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	5.59
Tm (min, max), sec:	3 8
number of models:	20000
error:	6.9E-03

result (mean value of all fitting models):

Permeability	: (4765.8 ±	24.8) µdarcy
Kf	: (4.8 ±	0.0) e -8 m/s
Alpha	: (0.00100)	

Number of fitting models: 36

Test No. 19 at 628.00 m MD / 621.90 m TVD



INPUTPARAMETERS

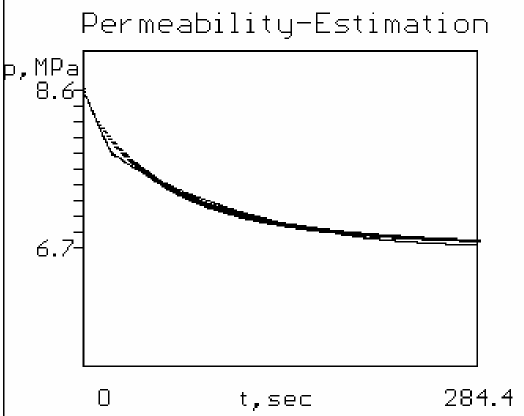
filename:	628.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	5.3E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	6.13
Tm (min, max), sec:	1 50
number of models:	20000
error:	1.7E-02

result (mean value of all fitting models):

Permeability	: (1911.6 ±	0.7) µdarcy
Kf	: (1.9 ±	0.0) e -8 m/s
Alpha	: (0.00100)	

Number of fitting models: 2

Test No. 18 at 685.31 m MD / 678.02 m TVD



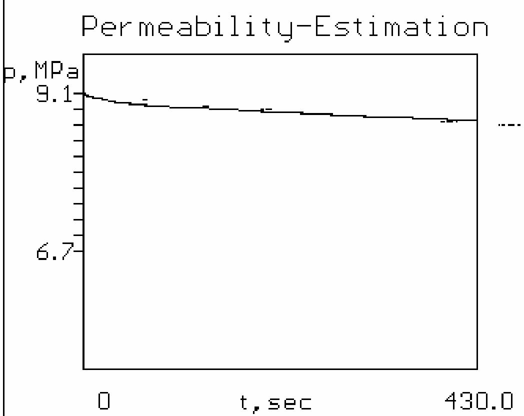
INPUTPARAMETERS
filename: 685.red
samplingrate, sec: 0.40
inv. Stiffness m³.m/Pa: 2.7E-11
interval length, m: 0.60
hole diameter, mm: 76.30
Phyd, MPa: 6.68
Tm (min, max), sec: 16 47
number of models: 20000

error: 6.0E-03

result (mean value of all fitting models):
Permeability : (469.3 ± 13.8) µdarcy
Kf : (4.7 ± 0.1) e -9 m/s
Alpha : (0.00100)

Number of fitting models: 390

Test No. 15 at 689.5 m MD / 682.13 m TVD



INPUTPARAMETERS
filename: 689.red
samplingrate, sec: 0.40
inv. Stiffness m³.m/Pa: 2.8E-11
interval length, m: 0.60
hole diameter, mm: 76.30
Phyd, MPa: 6.73
Tm (min, max), sec: 100 4000
number of models: 20000

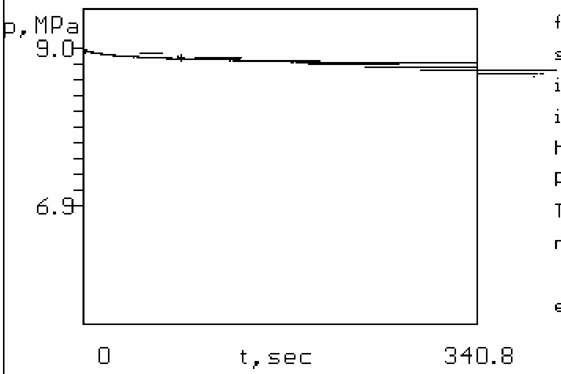
error: 3.0E-03

result (mean value of all fitting models):
Permeability : (11.2 ± 0.2) µdarcy
Kf : (1.1 ± 0.0) e-10 m/s
Alpha : (0.00100)

Number of fitting models: 34

Test No. 13 at 695.0 m MD / 687.51 m TVD

Permeability-Estimation



INPUTPARAMETERS		
filename:	695.dat	
samplingrate, sec:	0.20	
inv. Stiffness m³.m/Pa:	2.3E-11	
interval length, m:	0.60	
hole diameter, mm:	76.30	
Phyd, MPa:	6.87	
Tm (min, max), sec:	491	1472
number of models:	20000	
error:	4.5E-03	

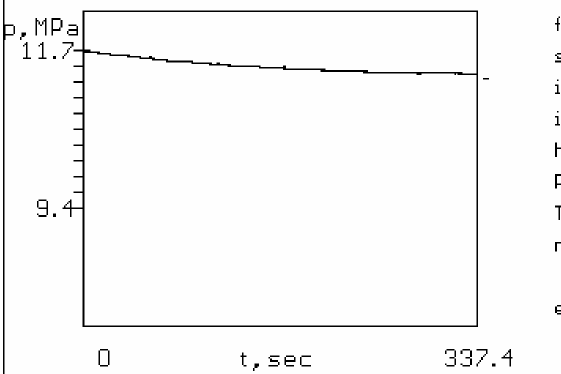
result (mean value of all fitting models):

Permeability : (10.3 ± 1.0) µdarcy
Kf : (1.0 ± 0.1) e-10 m/s
Alpha : (0.00010)

Number of fitting models: 1426

Test No. 10 at 975.5 m MD / 960.32 m TVD

Permeability-Estimation



INPUTPARAMETERS		
filename:	975.dat	
samplingrate, sec:	0.20	
inv. Stiffness m³.m/Pa:	2.5E-11	
interval length, m:	0.60	
hole diameter, mm:	76.30	
Phyd, MPa:	9.44	
Tm (min, max), sec:	566	1697
number of models:	20000	
error:	1.5E-03	

result (mean value of all fitting models):

Permeability : (11.7 ± 0.0) µdarcy
Kf : (1.2 ± 0.0) e-10 m/s
Alpha : (0.00100)

Number of fitting models: 9

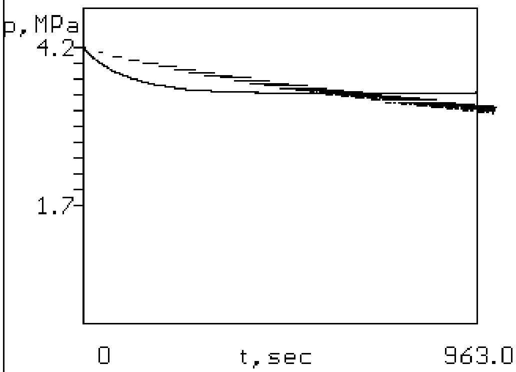
Appendix A2

Analysis of Pressure Pulse Tests, Borehole No. KFM01B

Test No. 1 at 171.00 m MD / 167.07 m TVD

prior to fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	171.red	
samplingrate, sec:	1.00	
inv. Stiffness m³.m/Pa:	2.5E-11	
interval length, m:	0.60	
hole diameter, mm:	76.30	
Phyd, MPa:	1.69	
Tm (min, max), sec:	396	1187
number of models:	20000	
error:	4.8E-02	

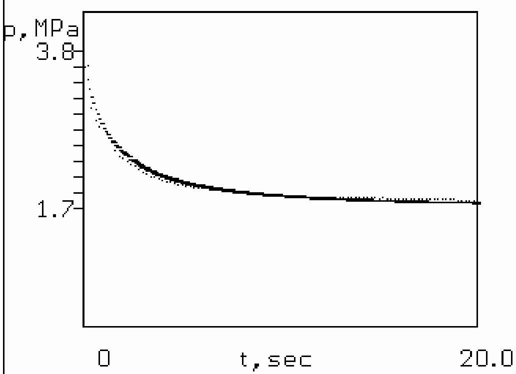
result (mean value of all fitting models):

Permeability : (16.0 ± 0.9) µdarcy
Kf : (1.6 ± 0.1) e-10 m/s
Alpha : (0.00010)

Number of fitting models: 741

after fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	171b.dat	
samplingrate, sec:	0.20	
inv. Stiffness m³.m/Pa:	3.6E-11	
interval length, m:	0.60	
hole diameter, mm:	76.30	
Phyd, MPa:	1.66	
Tm (min, max), sec:	1	3
number of models:	20000	
error:	2.0E-02	

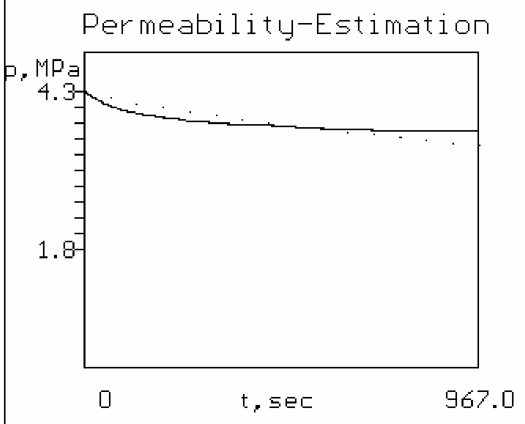
result (mean value of all fitting models):

Permeability : (8943.5 ± 275.6) µdarcy
Kf : (8.9 ± 0.3) e -8 m/s
Alpha : (0.10000)

Number of fitting models: 457

Test No. 2 at 187.90 m MD / 183.46 m TVD

prior to fracturing / stimulation



INPUTPARAMETERS

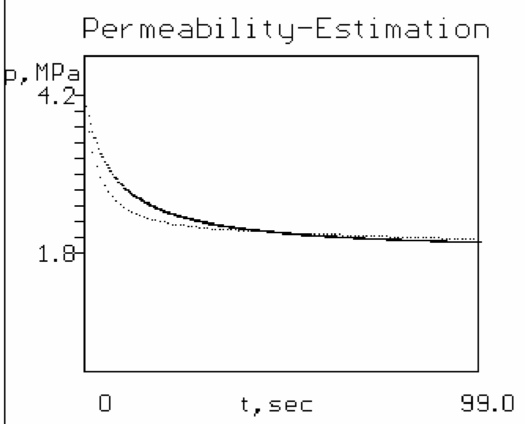
filename:	187.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	1.8E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	1.81
Tm (min, max), sec:	588 1764
number of models:	20000
error:	2.4E-02

result (mean value of all fitting models):

Permeability : (7.5 ± 0.0) µdarcy
Kf : (7.5 ± 0.0) e-11 m/s
Alpha : (0.00100)

Number of fitting models: 7

after fracturing / stimulation



INPUTPARAMETERS

filename:	187b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	3.0E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	1.82
Tm (min, max), sec:	6 17
number of models:	20000
error:	4.0E-02

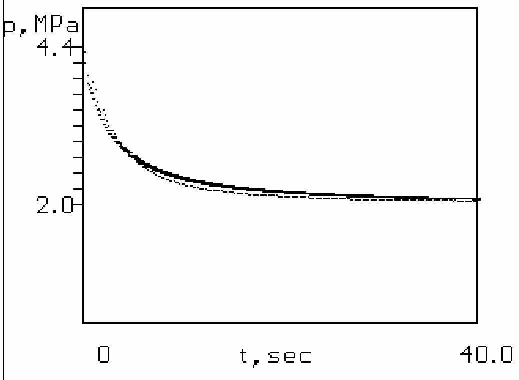
result (mean value of all fitting models):

Permeability : (1570.3 ± 22.5) µdarcy
Kf : (1.6 ± 0.0) e -8 m/s
Alpha : (1.00000)

Number of fitting models: 215

Test No. 3 at 216.5 m MD / 211.13 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	216.dat	
samplingrate, sec:	0.20	
inv. Stiffness m³.m/Pa:	2.6E-11	
interval length, m:	0.60	
hole diameter, mm:	76.30	
Phyd, MPa:	2.04	
Tm (min, max), sec:	2	6
number of models:	20000	
error:	5.0E-02	

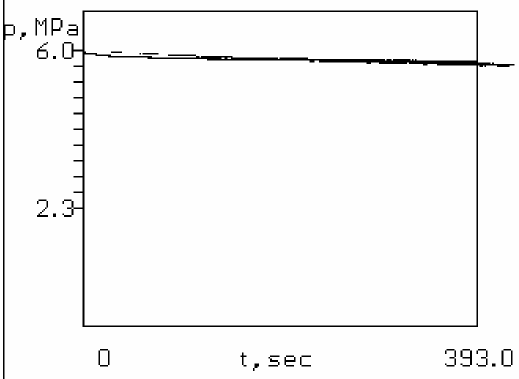
result (mean value of all fitting models):

Permeability : (3313.7 ± 102.7) µdarcy
Kf : (3.3 ± 0.1) e -8 m/s
Alpha : (0.10000)

Number of fitting models: 456

Test No. 12 at 235.0 m MD / 228.97 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	235.dat	
samplingrate, sec:	0.20	
inv. Stiffness m³.m/Pa:	2.5E-11	
interval length, m:	0.60	
hole diameter, mm:	76.30	
Phyd, MPa:	2.28	
Tm (min, max), sec:	3301	9902
number of models:	20000	
error:	8.0E-03	

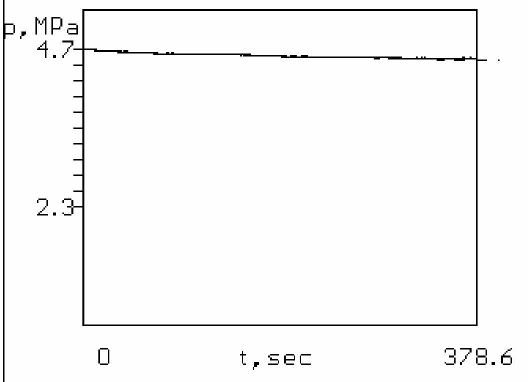
result (mean value of all fitting models):

Permeability : (2.0 ± 0.1) µdarcy
Kf : (2.0 ± 0.1) e-11 m/s
Alpha : (0.01000)

Number of fitting models: 508

Test No. 11 at 236.0 m MD / 229.94 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	236.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	2.1E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	2.29
Tm (min, max), sec:	2501 7502
number of models:	20000
error:	1.5E-03

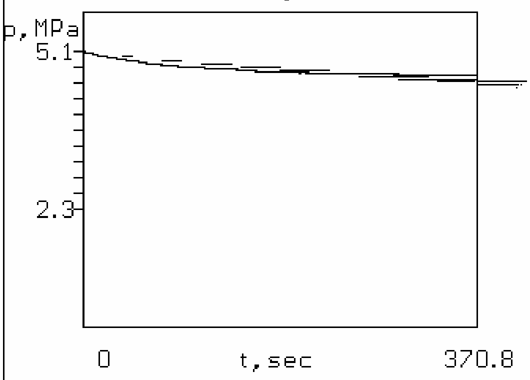
result (mean value of all fitting models):

Permeability	: (2.6 ± 0.1) µdarcy
Kf	: (2.6 ± 0.1) e-11 m/s
Alpha	: (0.00100)

Number of fitting models: 70

Test No. 10 at 237.0 m MD / 230.90 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	237.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	2.0E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	2.29
Tm (min, max), sec:	373 1119
number of models:	20000
error:	1.2E-02

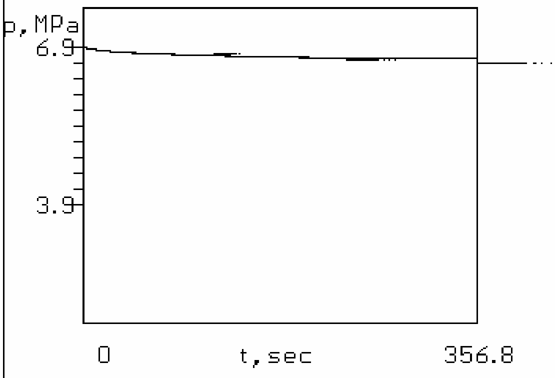
result (mean value of all fitting models):

Permeability	: (12.7 ± 0.8) µdarcy
Kf	: (1.3 ± 0.1) e-10 m/s
Alpha	: (0.00010)

Number of fitting models: 906

Test No. 9 at 407.1 m MD / 393.77 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	407.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	1.7E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	3.89
Tm (min, max), sec:	961 2882
number of models:	20000
error:	3.0E-03

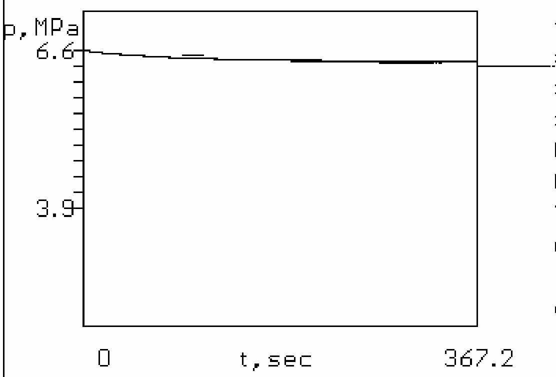
result (mean value of all fitting models):

Permeability	: (3.7 ± 0.1) µdarcy
Kf	: (3.7 ± 0.1) e-11 m/s
Alpha	: (0.00100)

Number of fitting models: 555

Test No. 8 at 410.5 m MD / 397.00 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	410.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	1.5E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	3.92
Tm (min, max), sec:	796 2387
number of models:	20000
error:	4.0E-03

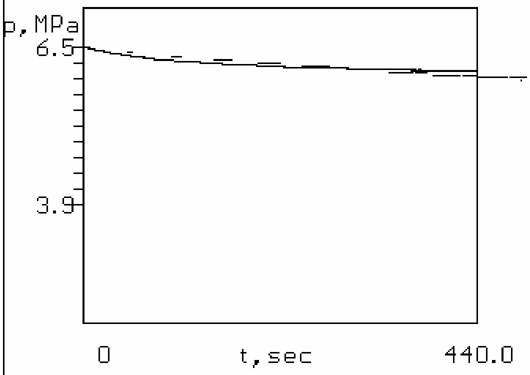
result (mean value of all fitting models):

Permeability	: (3.9 ± 0.2) µdarcy
Kf	: (3.9 ± 0.2) e-11 m/s
Alpha	: (0.00010)

Number of fitting models: 840

Test No. 7 at 412.8 m MD / 399.18 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	412.red
samplingrate, sec:	0.40
inv. Stiffness m³.m/Pa:	1.5E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	3.93
Tm (min, max), sec:	476 1427
number of models:	20000
error:	7.0E-03

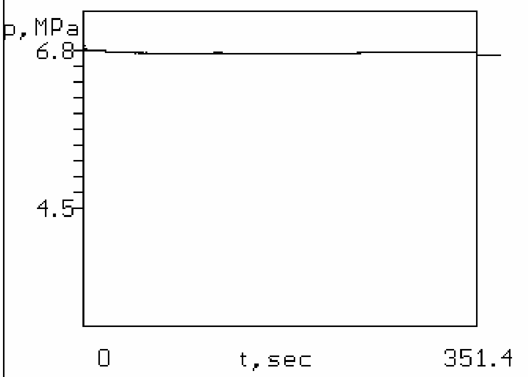
result (mean value of all fitting models):

Permeability	: (	7.9 ±	0.3) µdarcy
Kf	: (	7.9 ±	0.3) e-11 m/s
Alpha	: (	0.00010)	

Number of fitting models: 461

Test No. 6 at 471.2 m MD / 454.68 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	471.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	6.3E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.49
Tm (min, max), sec:	10018 30054
number of models:	20000
error:	1.6E-03

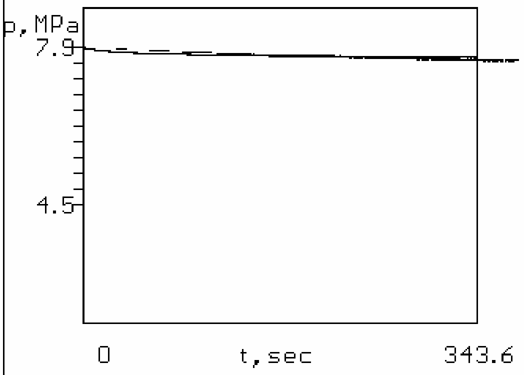
result (mean value of all fitting models):

Permeability	: (	1.4 ±	0.0) µdarcy
Kf	: (	1.4 ±	0.0) e-11 m/s
Alpha	: (	0.01000)	

Number of fitting models: 227

Test No. 5 at 474.0 m MD / 457.33 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	474.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	1.7E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.52
Tm (min, max), sec:	3501 10502
number of models:	20000
error:	4.5E-03

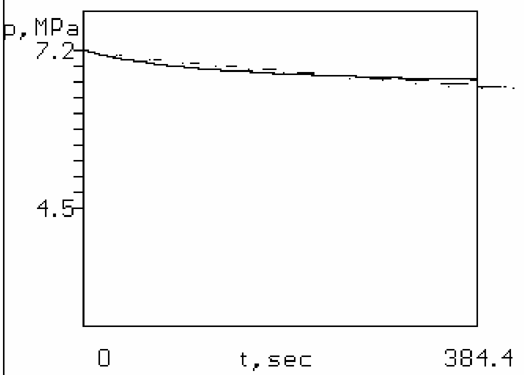
result (mean value of all fitting models):

Permeability : (1.3 ± 0.1) µdarcy
Kf : (1.3 ± 0.1) e-11 m/s
Alpha : (0.01000)

Number of fitting models: 570

Test No. 4 at 476.1 m MD / 459.32 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	476.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	4.8E-11
interval length, m:	0.60
hole diameter, mm:	76.30
Phyd, MPa:	4.54
Tm (min, max), sec:	301 902
number of models:	20000
error:	7.0E-03

result (mean value of all fitting models):

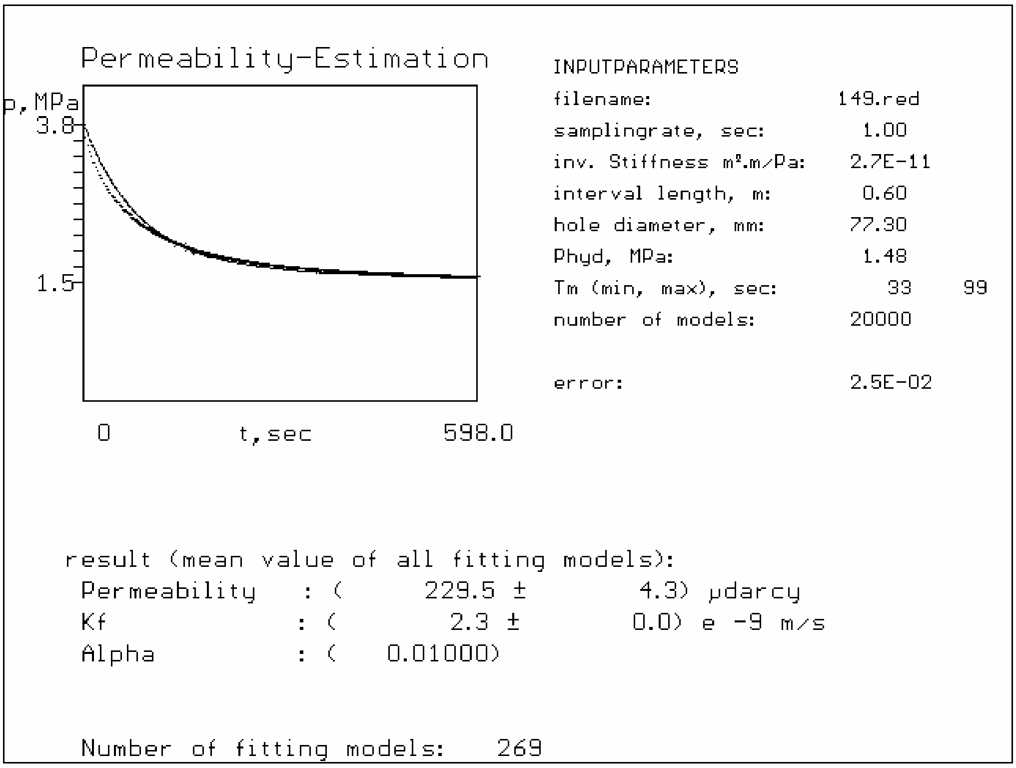
Permeability : (35.1 ± 0.8) µdarcy
Kf : (3.5 ± 0.1) e-10 m/s
Alpha : (0.00010)

Number of fitting models: 270

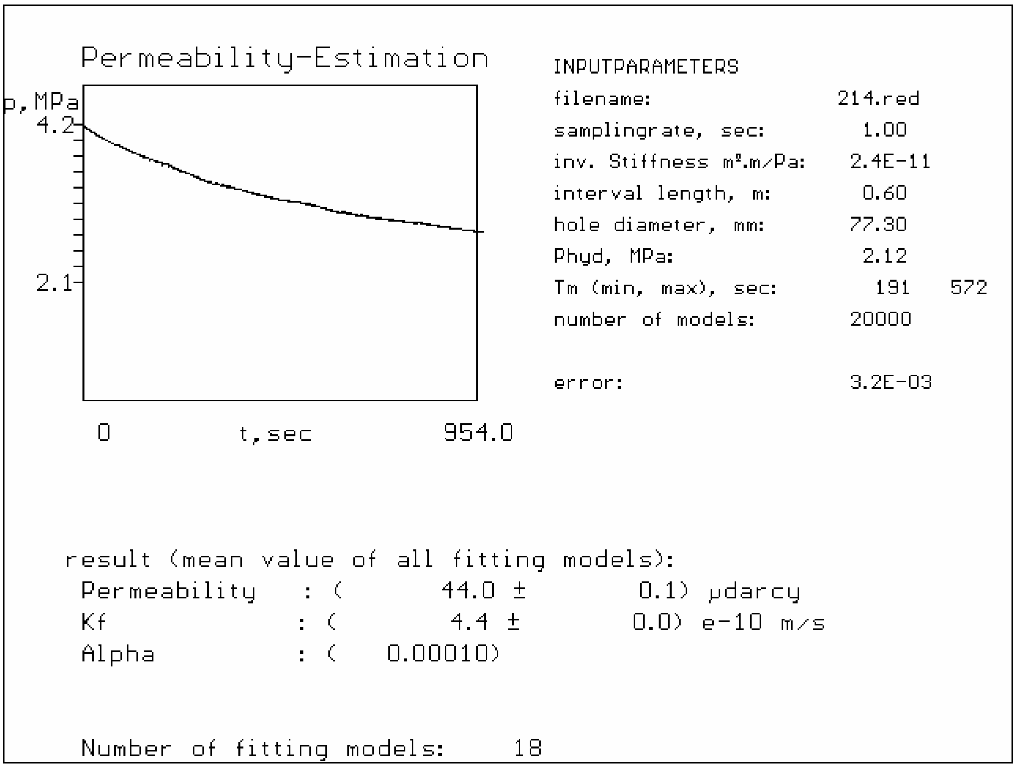
Appendix A3

Analysis of Pressure Pulse Tests, Borehole No. KFM02A

Test No. 37 at 149.58 m MD / 149.20 m TVD

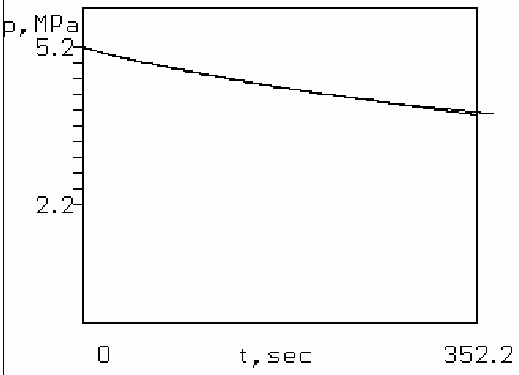


Test No. 36 at 214.30 m MD / 213.71 m TVD



Test No. 35 at 220.7 m MD / 220.09 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	220.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	2.2E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	2.17
Tm (min, max), sec:	176 527
number of models:	20000
error:	4.5E-03

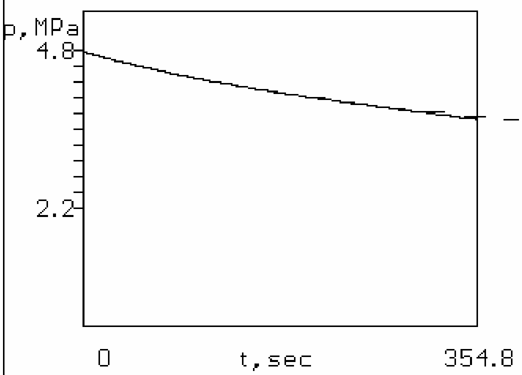
result (mean value of all fitting models):

Permeability : (42.9 ± 0.5) µdarcy
Kf : (4.3 ± 0.0) e-10 m/s
Alpha : (0.00010)

Number of fitting models: 92

Test No. 34 at 223.5 m MD / 222.88 m TVD

Permeability-Estimation



INPUTPARAMETERS

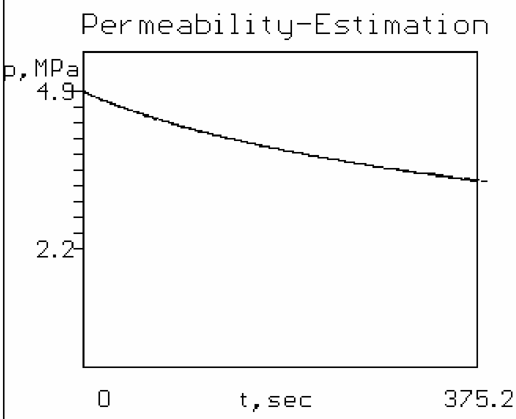
filename:	223.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	2.2E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	2.20
Tm (min, max), sec:	351 1052
number of models:	20000
error:	3.0E-03

result (mean value of all fitting models):

Permeability : (16.3 ± 0.2) µdarcy
Kf : (1.6 ± 0.0) e-10 m/s
Alpha : (1.00000)

Number of fitting models: 162

Test No. 33 at 226.5 m MD / 225.87 m TVD



INPUTPARAMETERS

filename:	226.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	2.6E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	2.22
Tm (min, max), sec:	111 332
number of models:	20000
error:	3.0E-03

result (mean value of all fitting models):

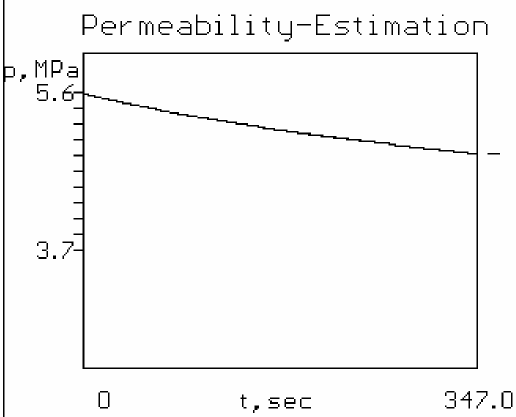
Permeability : (80.2 ± 0.3) µdarcy

Kf : (8.0 ± 0.0) e-10 m/s

Alpha : (0.00010)

Number of fitting models: 53

Test No. 32 at 376.0 m MD / 374.78 m TVD



INPUTPARAMETERS

filename:	376.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	3.4E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	3.69
Tm (min, max), sec:	401 1202
number of models:	20000
error:	1.0E-03

result (mean value of all fitting models):

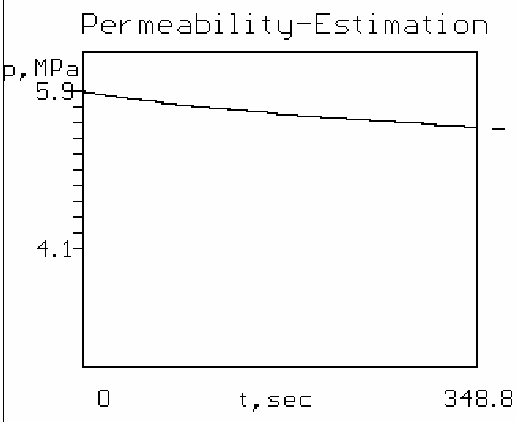
Permeability : (22.5 ± 0.2) µdarcy

Kf : (2.2 ± 0.0) e-10 m/s

Alpha : (1.00000)

Number of fitting models: 88

Test No. 31 at 413.5 m MD / 412.12 m TVD



INPUTPARAMETERS

filename:	413.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	4.9E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.08
Tm (min, max), sec:	751 2252
number of models:	20000
error:	4.0E-04

result (mean value of all fitting models):

Permeability : (17.8 ± 0.1) μdarcy

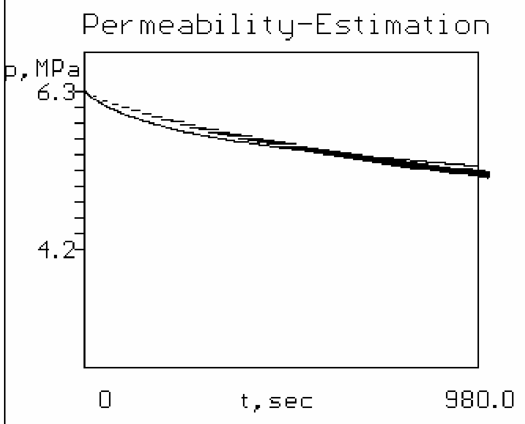
Kf : (1.8 ± 0.0) e-10 m/s

Alpha : (0.01000)

Number of fitting models: 74

Test No. 30 at 414.96 m MD

prior to fracturing / stimulation



INPUTPARAMETERS

filename:	414.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	5.8E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.16
Tm (min, max), sec:	251 752
number of models:	20000
error:	1.2E-02

result (mean value of all fitting models):

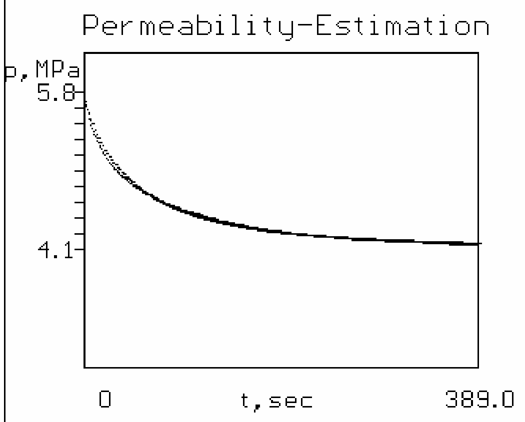
Permeability : (59.7 ± 2.5) μdarcy

Kf : (6.0 ± 0.3) e-10 m/s

Alpha : (0.00010)

Number of fitting models: 554

after fracturing / stimulation



INPUTPARAMETERS

filename:	414b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.4E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.09
Tm (min, max), sec:	21 62
number of models:	20000
error:	4.0E-03

result (mean value of all fitting models):

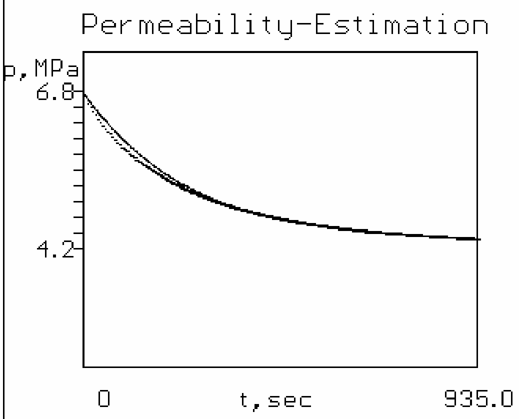
Permeability : (299.1 ± 4.9) μdarcy

Kf : (3.0 ± 0.0) e -9 m/s

Alpha : (0.01000)

Number of fitting models: 217

Test No. 29 at 428.52 m MD / 427.07 m TVD



INPUTPARAMETERS

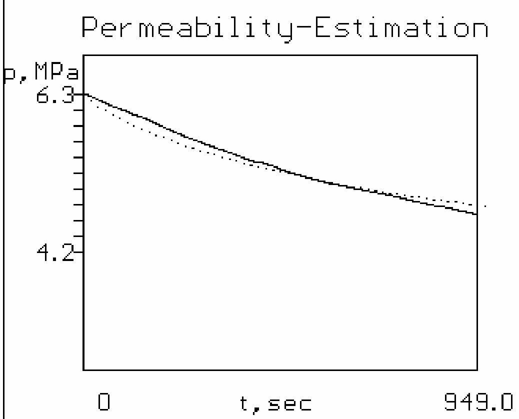
filename:	428.red	
samplingrate, sec:	1.00	
inv. Stiffness m³.m/Pa:	2.2E-11	
interval length, m:	0.60	
hole diameter, mm:	77.30	
Phyd, MPa:	4.22	
Tm (min, max), sec:	46	138
number of models:	20000	
error:	7.0E-03	

result (mean value of all fitting models):

Permeability : (99.5 ± 1.5) µdarcy
Kf : (10.0 ± 0.1) e-10 m/s
Alpha : (0.00100)

Number of fitting models: 264

Test No. 28 at 430.56 m MD / 428.66 m TVD



INPUTPARAMETERS

filename:	430.red	
samplingrate, sec:	1.00	
inv. Stiffness m³.m/Pa:	8.7E-12	
interval length, m:	0.60	
hole diameter, mm:	77.30	
Phyd, MPa:	4.24	
Tm (min, max), sec:	133	399
number of models:	20000	
error:	1.3E-02	

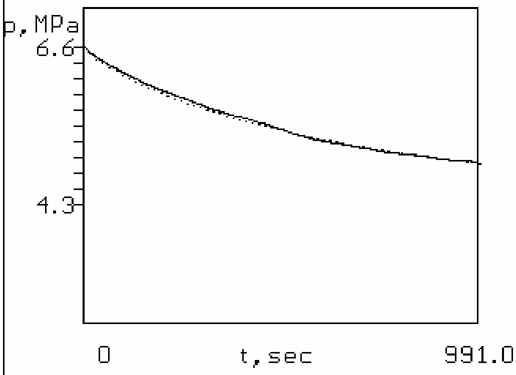
result (mean value of all fitting models):

Permeability : (13.0 ± 0.0) µdarcy
Kf : (1.3 ± 0.0) e-10 m/s
Alpha : (0.00100)

Number of fitting models: 12

Test No. 27 at 442.34 m MD / 440.83 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	442.red	
samplingrate, sec:	1.00	
inv. Stiffness m³.m/Pa:	1.9E-11	
interval length, m:	0.60	
hole diameter, mm:	77.30	
Phyd, MPa:	4.35	
Tm (min, max), sec:	131	392
number of models:	20000	
error:	4.4E-03	

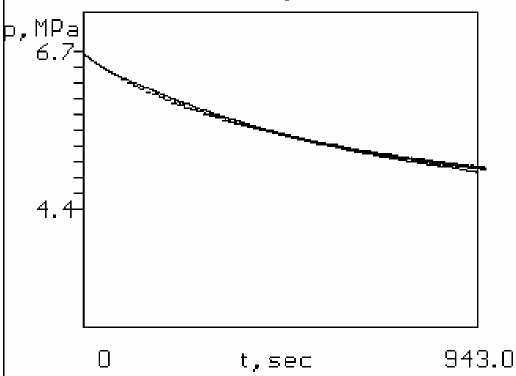
result (mean value of all fitting models):

Permeability : (30.5 ± 0.0) µdarcy
Kf : (3.1 ± 0.0) e-10 m/s
Alpha : (0.00100)

Number of fitting models: 17

Test No. 26 at 445.96 m MD / 444.44 m TVD

Permeability-Estimation



INPUTPARAMETERS

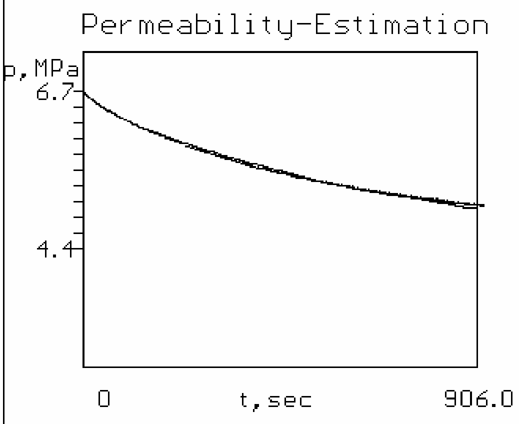
filename:	445.red	
samplingrate, sec:	1.00	
inv. Stiffness m³.m/Pa:	2.2E-11	
interval length, m:	0.60	
hole diameter, mm:	77.30	
Phyd, MPa:	4.38	
Tm (min, max), sec:	10	500
number of models:	20000	
error:	6.0E-03	

result (mean value of all fitting models):

Permeability : (37.4 ± 1.2) µdarcy
Kf : (3.7 ± 0.1) e-10 m/s
Alpha : (0.00010 - 0.00100)

Number of fitting models: 99

Test No. 25 at 449.90 m MD / 448.36 m TVD



INPUTPARAMETERS

filename:	449.red	
samplingrate, sec:	1.00	
inv. Stiffness m³.m/Pa:	1.9E-11	
interval length, m:	0.60	
hole diameter, mm:	77.30	
Phyd, MPa:	4.42	
Tm (min, max), sec:	120	360
number of models:	20000	
error:	4.0E-03	

result (mean value of all fitting models):

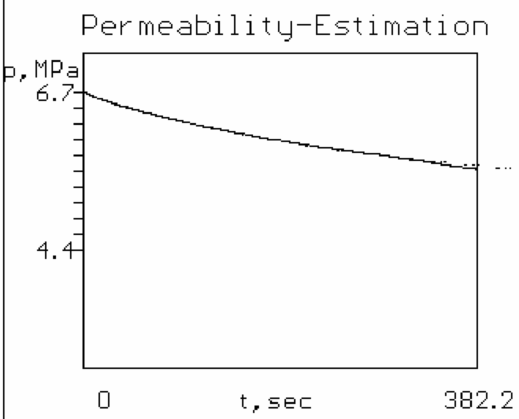
Permeability : (42.9 ± 0.3) µdarcy

Kf : (4.3 ± 0.0) e-10 m/s

Alpha : (0.00010)

Number of fitting models: 106

Test No. 24 at 451.5 m MD / 449.15 m TVD



INPUTPARAMETERS

filename:	451.dat	
samplingrate, sec:	0.20	
inv. Stiffness m³.m/Pa:	1.4E-11	
interval length, m:	0.60	
hole diameter, mm:	77.30	
Phyd, MPa:	4.44	
Tm (min, max), sec:	309	927
number of models:	20000	
error:	1.5E-03	

result (mean value of all fitting models):

Permeability : (12.2 ± 0.2) µdarcy

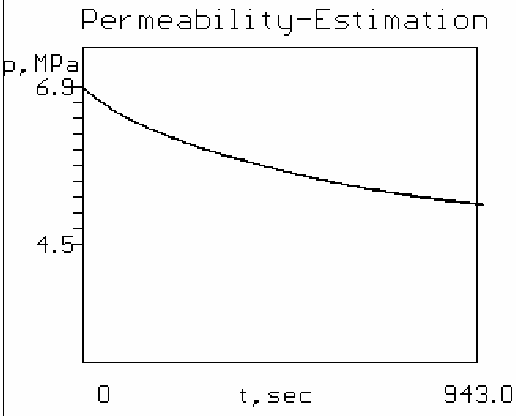
Kf : (1.2 ± 0.0) e-10 m/s

Alpha : (1.00000)

Number of fitting models: 52

Test No. 23 at 457.34 m MD / 455.77 m TVD

prior to fracturing / stimulation



INPUTPARAMETERS

filename:	457.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.2E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.49
Tm (min, max), sec:	153 459
number of models:	20000
error:	2.0E-03

result (mean value of all fitting models):

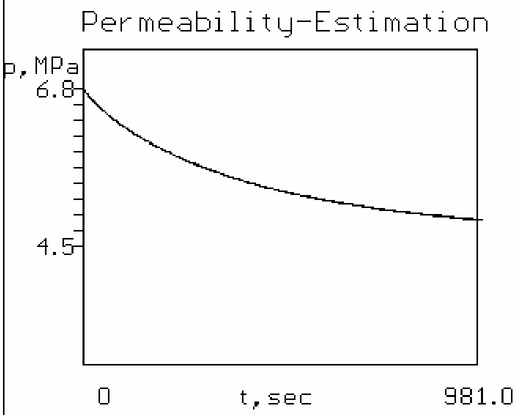
Permeability : (38.0 ± 0.2) μdarcy

Kf : (3.8 ± 0.0) e-10 m/s

Alpha : (0.00100)

Number of fitting models: 77

after fracturing / stimulation



INPUTPARAMETERS

filename:	457b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	3.0E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.50
Tm (min, max), sec:	111 332
number of models:	20000
error:	1.0E-03

result (mean value of all fitting models):

Permeability : (95.9 ± 0.3) μdarcy

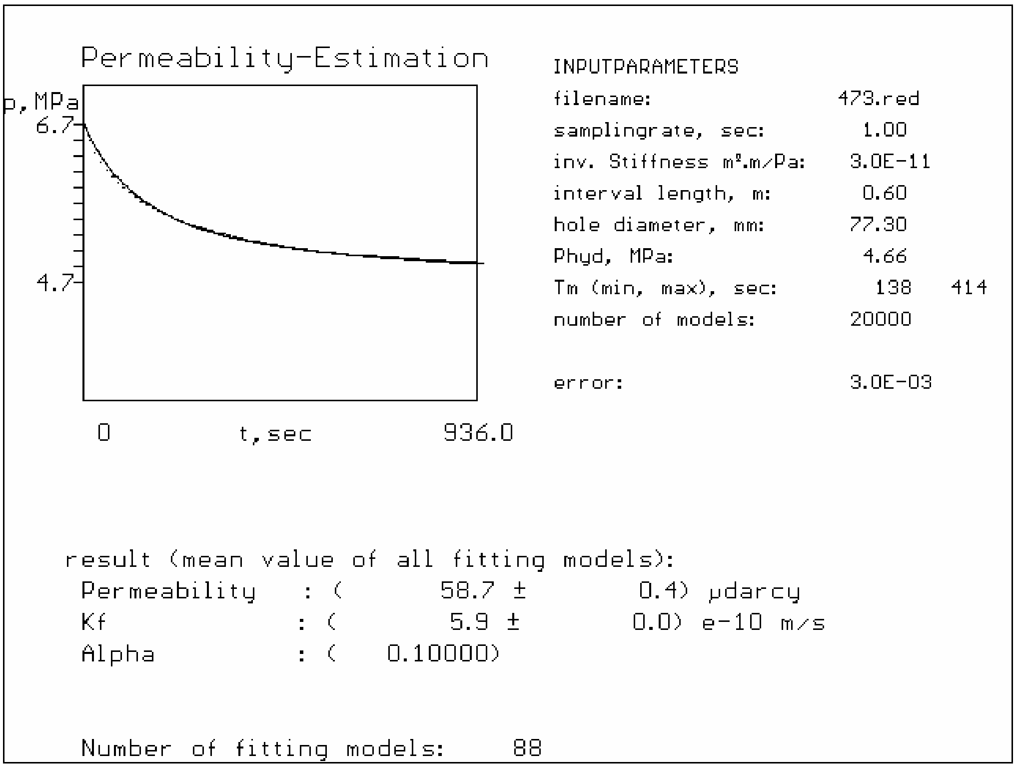
Kf : (9.6 ± 0.0) e-10 m/s

Alpha : (0.00010)

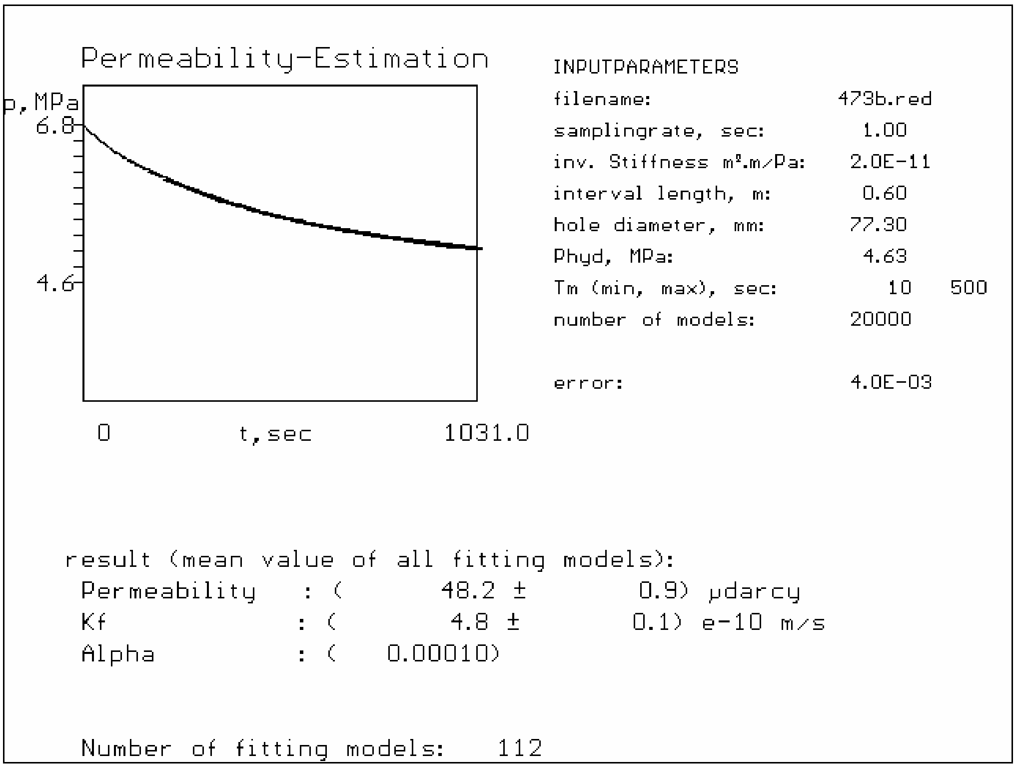
Number of fitting models: 47

Test No. 22 at 473.03 m MD / 471.39 m TVD

prior to fracturing / stimulation

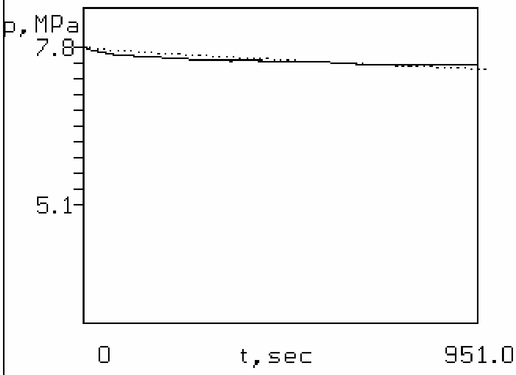


after fracturing / stimulation



Test No. 21 at 520.22 m MD / 518.34 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	520.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.3E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.13
Tm (min, max), sec:	100 5000
number of models:	20000
error:	5.0E-03

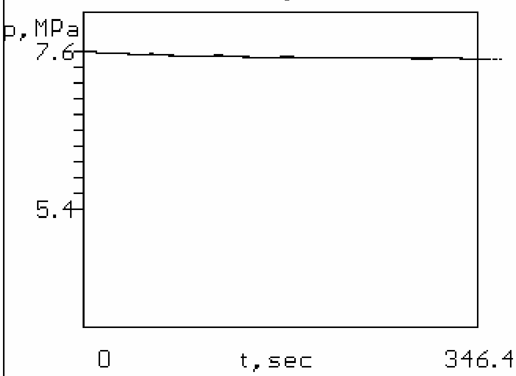
result (mean value of all fitting models):

Permeability	: (3.7 ± 0.0) µdarcy
Kf	: (3.7 ± 0.0) e-11 m/s
Alpha	: (0.00010)

Number of fitting models: 7

Test No. 20 at 551.6 m MD / 549.53 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	551.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	1.4E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.43
Tm (min, max), sec:	7351 22052
number of models:	20000
error:	1.5E-03

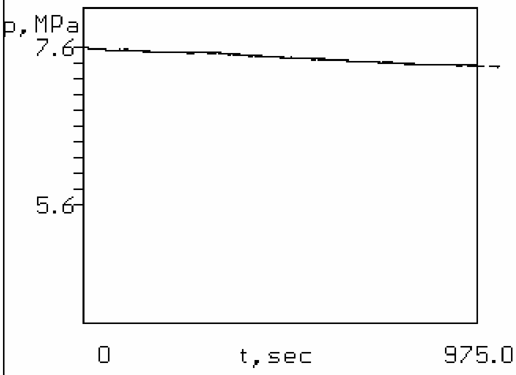
result (mean value of all fitting models):

Permeability	: (0.6 ± 0.0) µdarcy
Kf	: (6.2 ± 0.1) e-12 m/s
Alpha	: (0.01000)

Number of fitting models: 122

Test No. 18 at 564.00 m MD / 561.86 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	564.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.2E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.55
Tm (min, max), sec:	100 13000
number of models:	20000
error:	1.2E-03

result (mean value of all fitting models):

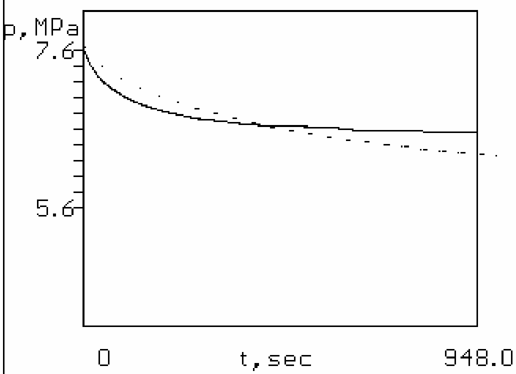
Permeability	: (1.1 ±	0.0)	µdarcy
Kf	: (1.1 ±	0.0)	e-11 m/s
Alpha	: (1.00000)		

Number of fitting models: 126

Test No. 17 at 568.43 m MD / 566.26 m TVD

after fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

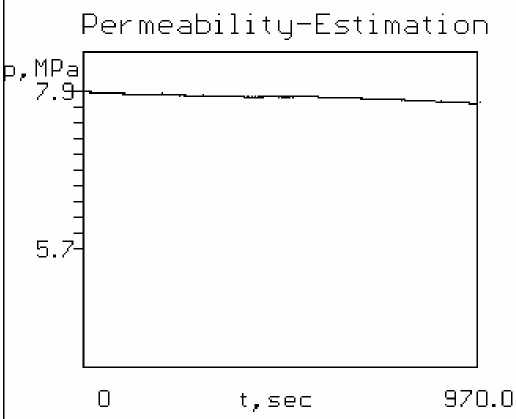
filename:	568b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	1.3E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.59
Tm (min, max), sec:	401 1202
number of models:	20000
error:	2.0E-02

result (mean value of all fitting models):

Permeability	: (7.7 ±	0.0)	µdarcy
Kf	: (7.7 ±	0.0)	e-11 m/s
Alpha	: (0.10000)		

Number of fitting models: 28

Test No. 15 at 577.38 m MD / 575.15 m TVD



INPUTPARAMETERS

filename:	577.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.4E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.67
Tm (min, max), sec:	10001 30002
number of models:	20000
error:	1.2E-03

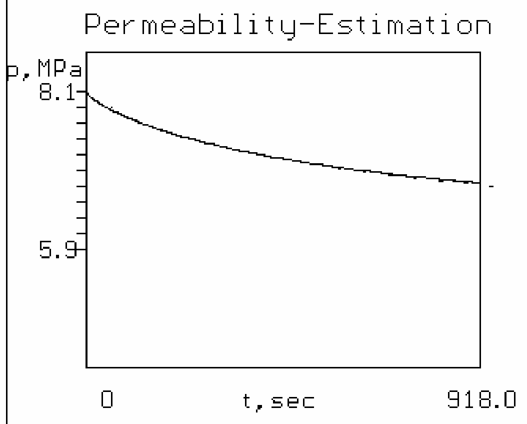
result (mean value of all fitting models):

Permeability	: (0.7 ± 0.0)	µdarcy
Kf	: (6.6 ± 0.0)	e-12 m/s
Alpha	: (1.00000)	

Number of fitting models: 8

Test No. 14 at 589.11 m MD / 586.80 m TVD

prior to fracturing / stimulation



INPUTPARAMETERS

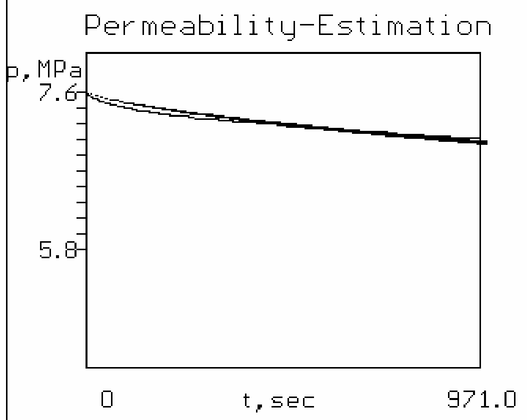
filename:	589.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	4.9E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.89
Tm (min, max), sec:	601 1802
number of models:	20000
error:	1.7E-03

result (mean value of all fitting models):

Permeability : (22.0 ± 0.0) µdarcy
Kf : (2.2 ± 0.0) e-10 m/s
Alpha : (0.10000)

Number of fitting models: 29

after fracturing / stimulation



INPUTPARAMETERS

filename:	589b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	3.1E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.83
Tm (min, max), sec:	2026 6077
number of models:	20000
error:	4.5E-03

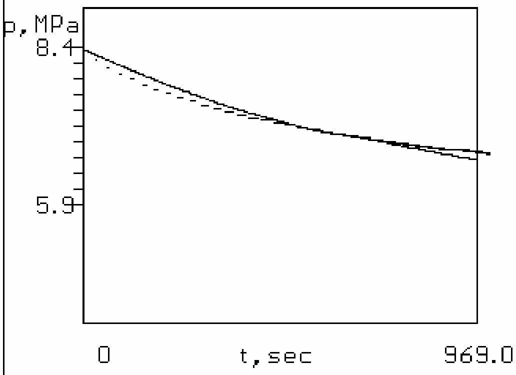
result (mean value of all fitting models):

Permeability : (6.6 ± 0.2) µdarcy
Kf : (6.6 ± 0.2) e-11 m/s
Alpha : (0.01000)

Number of fitting models: 243

Test No. 13 at 594.62 m MD / 592.27 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	594.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.1E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.86
Tm (min, max), sec:	476 1427
number of models:	20000
error:	9.5E-03

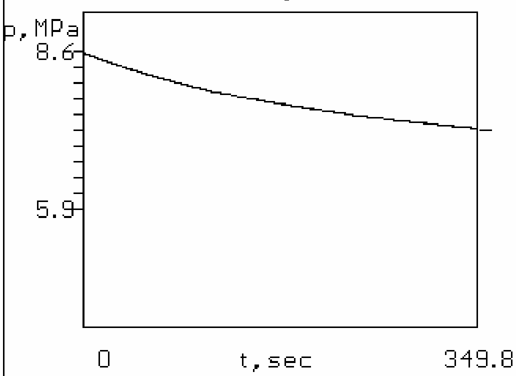
result (mean value of all fitting models):

Permeability : (18.3 ± 0.3) µdarcy
Kf : (1.8 ± 0.0) e-10 m/s
Alpha : (0.01000)

Number of fitting models: 106

Test No. 12 at 603.0 m MD / 600.58 m TVD

Permeability-Estimation



INPUTPARAMETERS

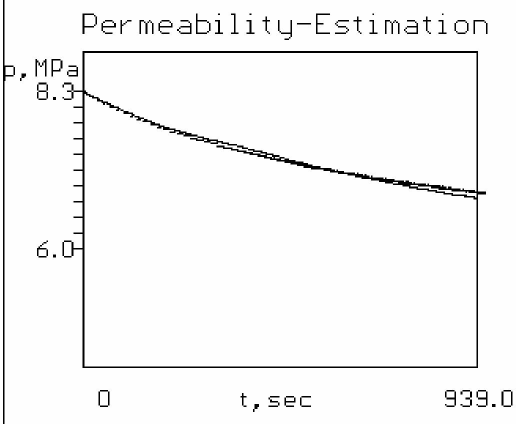
filename:	603.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	2.0E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.94
Tm (min, max), sec:	251 752
number of models:	20000
error:	1.1E-03

result (mean value of all fitting models):

Permeability : (20.4 ± 0.2) µdarcy
Kf : (2.0 ± 0.0) e-10 m/s
Alpha : (1.00000)

Number of fitting models: 105

Test No. 11 at 608.47 m MD / 606.01 m TVD



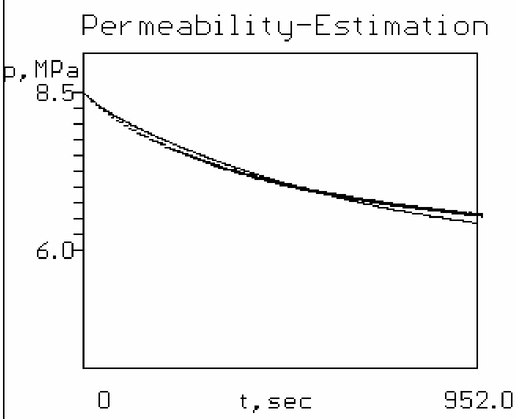
INPUTPARAMETERS
filename: 608.red
samplingrate, sec: 1.00
inv. Stiffness m³.m/Pa: 2.0E-11
interval length, m: 0.60
hole diameter, mm: 77.30
Phyd, MPa: 5.99
Tm (min, max), sec: 163 489
number of models: 20000

error: 5.5E-03

result (mean value of all fitting models):
Permeability : (32.6 ± 0.4) μdarcy
Kf : (3.3 ± 0.0) e-10 m/s
Alpha : (0.00010)

Number of fitting models: 131

Test No. 10 at 611.47 m MD / 608.98 m TVD



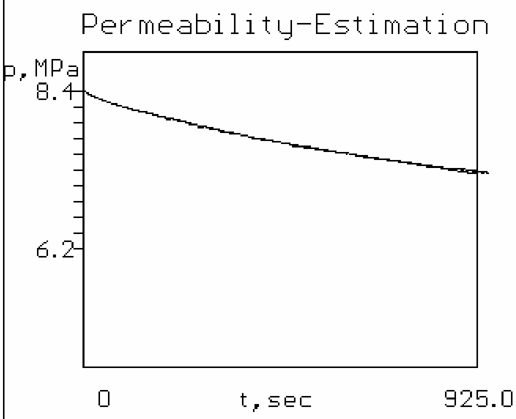
INPUTPARAMETERS
filename: 611.red
samplingrate, sec: 1.00
inv. Stiffness m³.m/Pa: 2.4E-11
interval length, m: 0.60
hole diameter, mm: 77.30
Phyd, MPa: 6.03
Tm (min, max), sec: 103 309
number of models: 20000

error: 9.0E-03

result (mean value of all fitting models):
Permeability : (63.3 ± 0.9) μdarcy
Kf : (6.3 ± 0.1) e-10 m/s
Alpha : (0.00010)

Number of fitting models: 181

Test No. 9 at 626.19 m MD / 623.59 m TVD



INPUTPARAMETERS		
filename:	626.red	
samplingrate, sec:	1.00	
inv. Stiffness m³.m/Pa:	1.9E-11	
interval length, m:	0.60	
hole diameter, mm:	77.30	
Phyd, MPa:	6.17	
Tm (min, max), sec:	251	752
number of models:	20000	
error:	1.5E-03	

result (mean value of all fitting models):

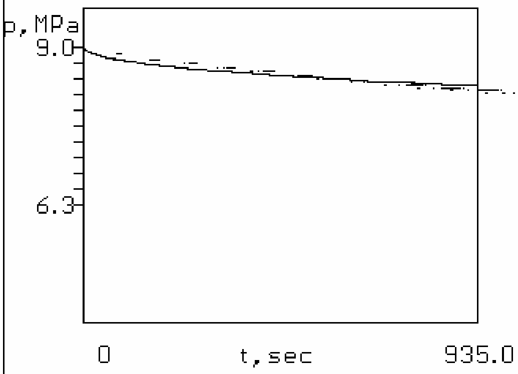
Permeability	: (	20.1 ±	0.2) µdarcy
Kf	: (	2.0 ±	0.0) e-10 m/s
Alpha	: (	0.00010)	

Number of fitting models: 139

Test No. 8 at 637.16 m MD / 634.48 m TVD

prior to fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	637.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.4E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	6.27
Tm (min, max), sec:	721 2162
number of models:	20000
error:	6.0E-03

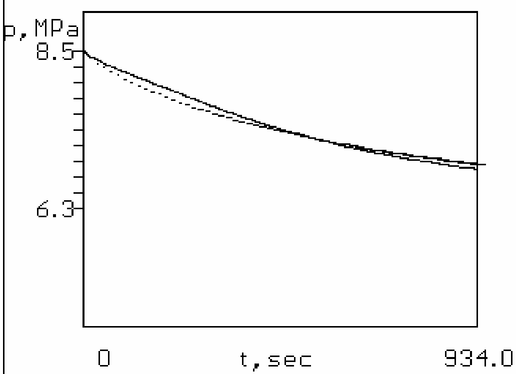
result (mean value of all fitting models):

Permeability	: (7.2 ± 0.2) µdarcy
Kf	: (7.2 ± 0.2) e-11 m/s
Alpha	: (0.00100)

Number of fitting models: 285

after fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

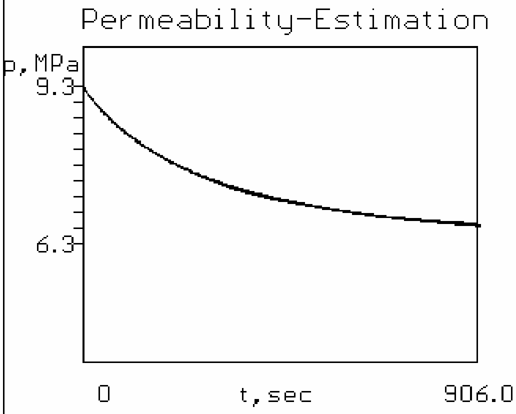
filename:	637b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.0E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	6.27
Tm (min, max), sec:	10 500
number of models:	20000
error:	8.2E-03

result (mean value of all fitting models):

Permeability	: (32.3 ± 0.3) µdarcy
Kf	: (3.2 ± 0.0) e-10 m/s
Alpha	: (0.00100)

Number of fitting models: 72

Test No. 7 at 645.21 m MD / 642.47 m TVD



INPUTPARAMETERS

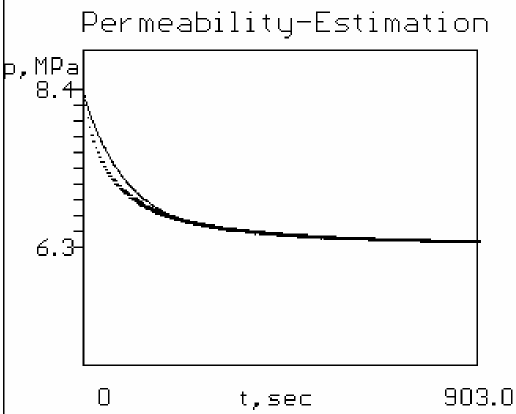
filename:	645.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	3.3E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	6.34
Tm (min, max), sec:	81 242
number of models:	20000
error:	3.0E-03

result (mean value of all fitting models):

Permeability : (143.7 ± 1.6) µdarcy
Kf : (1.4 ± 0.0) e -9 m/s
Alpha : (0.00010)

Number of fitting models: 109

Test No. 6 at 646.76 m / 644.00 m TVD



INPUTPARAMETERS

filename:	646.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.5E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	6.35
Tm (min, max), sec:	46 137
number of models:	20000
error:	7.0E-03

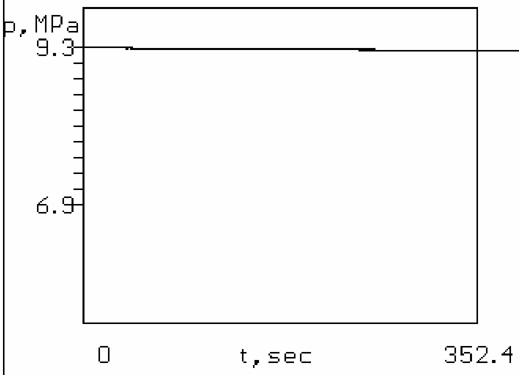
result (mean value of all fitting models):

Permeability : (138.6 ± 4.3) µdarcy
Kf : (1.4 ± 0.0) e -9 m/s
Alpha : (0.10000)

Number of fitting models: 446

Test No. 4 at 701.5 m MD / 698.30 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	701.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	2.3E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	6.89
Tm (min, max), sec:	10001 30002
number of models:	20000
error:	1.5E-04

result (mean value of all fitting models):

Permeability : (0.6 ± 0.1) µdarcy

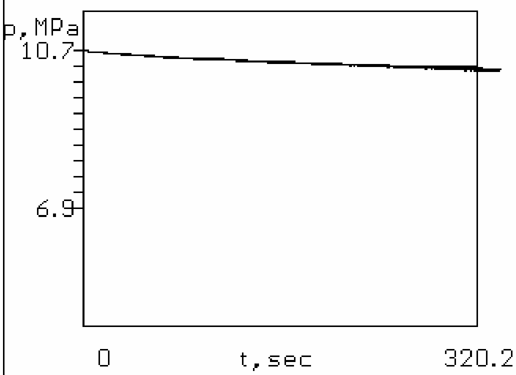
Kf : (5.7 ± 0.6) e-12 m/s

Alpha : (0.00100)

Number of fitting models: 1567

Test No. 3 at 704.3 m MD / 701.08 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	704.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	1.4E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	6.94
Tm (min, max), sec:	2506 7517
number of models:	20000
error:	2.5E-03

result (mean value of all fitting models):

Permeability : (2.2 ± 0.1) µdarcy

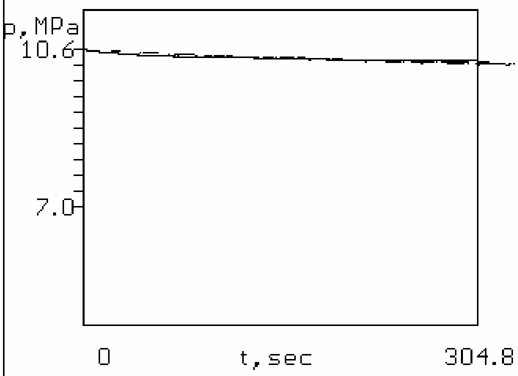
Kf : (2.2 ± 0.1) e-11 m/s

Alpha : (0.01000)

Number of fitting models: 533

Test No. 2 at 707. 0 m MD / 703.75 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	707b.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	2.1E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	6.96
Tm (min, max), sec:	3836 11507
number of models:	20000
error:	3.5E-03

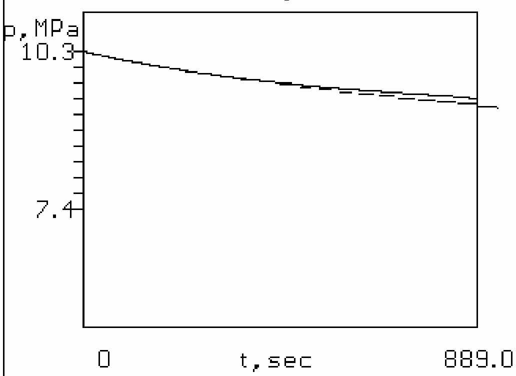
result (mean value of all fitting models):

Permeability : (2.2 ± 0.1) µdarcy
Kf : (2.2 ± 0.1) e-11 m/s
Alpha : (0.01000)

Number of fitting models: 352

Test No. 1 at 757.43 m MD / 753.75 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	757.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.3E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	7.43
Tm (min, max), sec:	100 4000
number of models:	20000
error:	5.0E-03

result (mean value of all fitting models):

Permeability : (13.5 ± 0.2) µdarcy
Kf : (1.4 ± 0.0) e-10 m/s
Alpha : (0.00010)

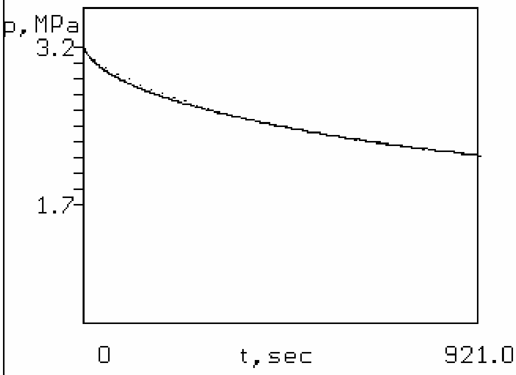
Number of fitting models: 47

Appendix A4

Analysis of Pressure Pulse Tests, Borehole No. KFM04A

Test No. 11 at 194.58 m MD / 171.43 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	194.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	6.4E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	1.70
Tm (min, max), sec:	328 984
number of models:	20000
error:	4.0E-03

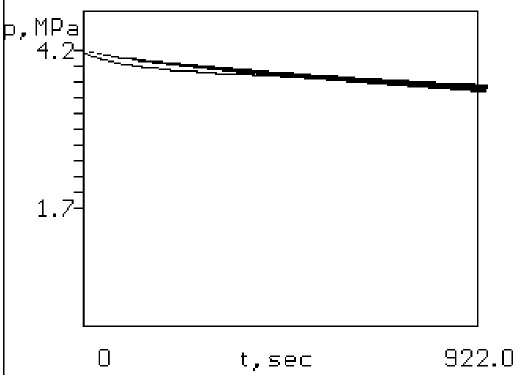
result (mean value of all fitting models):

Permeability	: (64.0 ± 0.1) µdarcy
Kf	: (6.4 ± 0.0) e-10 m/s
Alpha	: (0.01000)

Number of fitting models: 20

Test No. 10 at 196.91 m MD / 173.47 m TVD

Permeability-Estimation



INPUTPARAMETERS

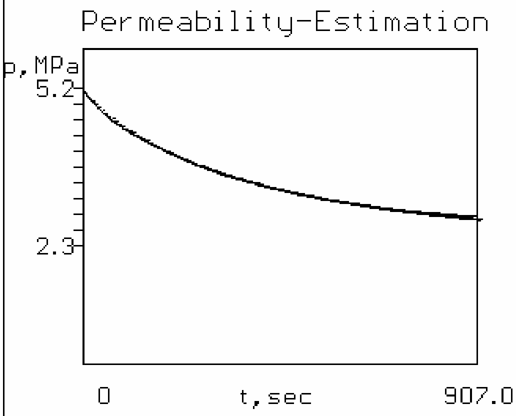
filename:	196.red#
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	3.4E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	1.73
Tm (min, max), sec:	100 6000
number of models:	20000
error:	1.5E-02

result (mean value of all fitting models):

Permeability	: (4.9 ± 0.3) µdarcy
Kf	: (4.9 ± 0.3) e-11 m/s
Alpha	: (0.01000)

Number of fitting models: 606

Test No. 9 at 266.33 m MD / 233.61 m TVD



INPUTPARAMETERS

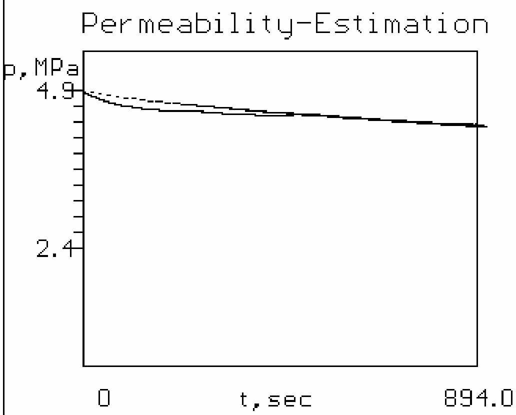
filename:	266.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.6E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	2.33
Tm (min, max), sec:	101 302
number of models:	20000
error:	7.0E-03

result (mean value of all fitting models):

Permeability : (88.3 ± 1.2) µdarcy
Kf : (8.8 ± 0.1) e-10 m/s
Alpha : (0.00010)

Number of fitting models: 132

Test No. 8 at 277.99 m MD / 243.63 m TVD



INPUTPARAMETERS

filename:	277.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	2.9E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	2.41
Tm (min, max), sec:	3046 9137
number of models:	20000
error:	1.2E-02

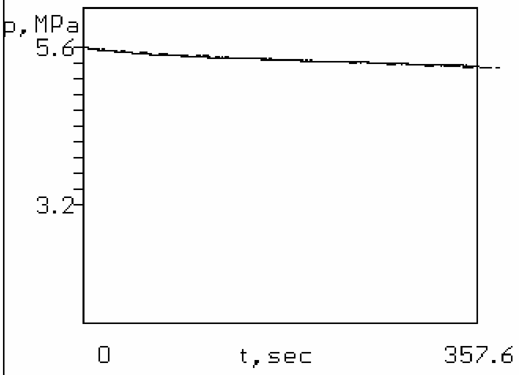
result (mean value of all fitting models):

Permeability : (4.0 ± 0.1) µdarcy
Kf : (4.0 ± 0.1) e-11 m/s
Alpha : (0.01000)

Number of fitting models: 155

Test No. 7 at 371.2 m MD / 322.95 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	371.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	3.1E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	3.20
Tm (min, max), sec:	100 6000
number of models:	20000
error:	2.5E-03

result (mean value of all fitting models):

Permeability : (4.6 ± 0.2) µdarcy

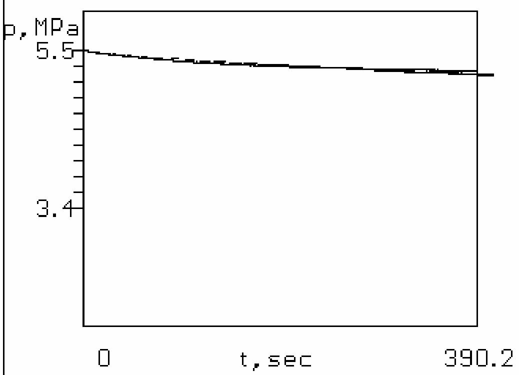
Kf : (4.6 ± 0.2) e-11 m/s

Alpha : (0.01000)

Number of fitting models: 85

Test No. 6 at 398.0 m MD / 345.30 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	398.dat
samplingrate, sec:	0.20
inv. Stiffness m³.m/Pa:	3.8E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	3.39
Tm (min, max), sec:	100 5000
number of models:	20000
error:	3.5E-03

result (mean value of all fitting models):

Permeability : (6.7 ± 0.1) µdarcy

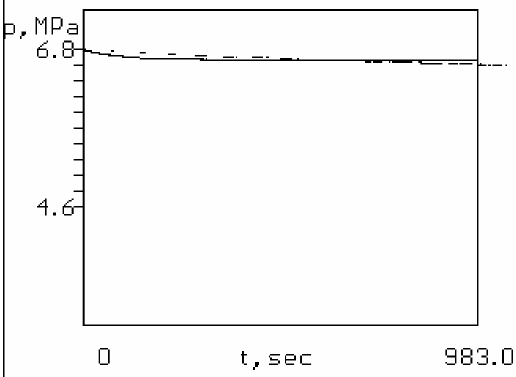
Kf : (6.7 ± 0.1) e-11 m/s

Alpha : (0.01000)

Number of fitting models: 153

Test No. 5 at 535.88 m MD / 457.03 m TVD

Permeability-Estimation



INPUTPARAMETERS

filename:	535.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	5.0E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.64
Tm (min, max), sec:	8201 24602
number of models:	20000
error:	5.5E-03

result (mean value of all fitting models):

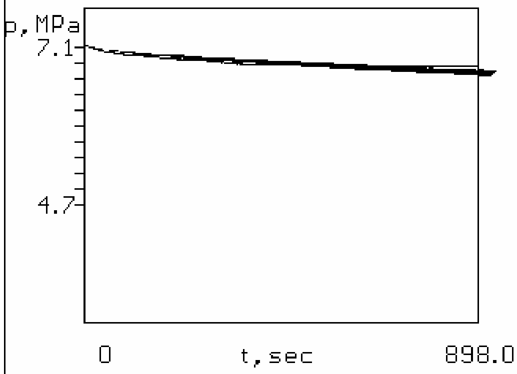
Permeability	: (1.8 ±	0.0)	µdarcy
Kf	: (1.8 ±	0.0)	e-11 m/s
Alpha	: (0.01000)		

Number of fitting models: 154

Test No. 4 at 553.90 m MD / 471.33 m TVD

prior to fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	553.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	3.1E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.68
Tm (min, max), sec:	5251 15752
number of models:	20000
error:	6.0E-03

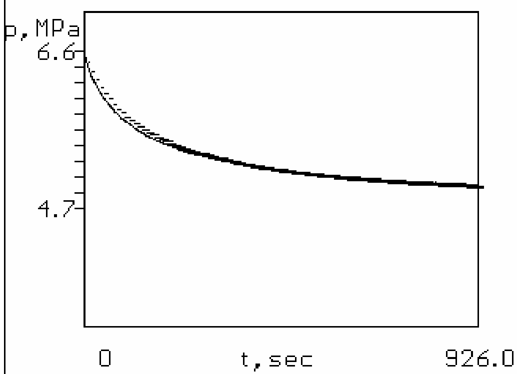
result (mean value of all fitting models):

Permeability	: (2.5 ±	0.2) µdarcy
Kf	: (2.5 ±	0.2) e-11 m/s
Alpha	: (0.01000)	

Number of fitting models: 608

after fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	553b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	3.5E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.67
Tm (min, max), sec:	151 452
number of models:	20000
error:	6.0E-03

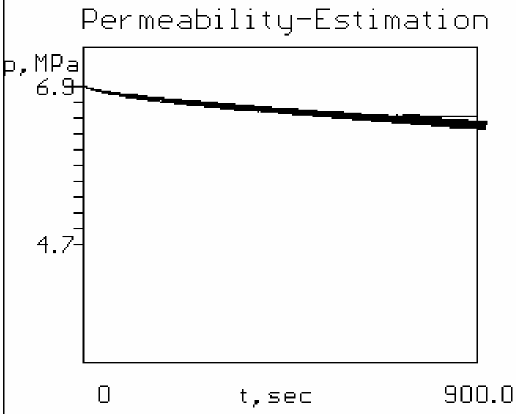
result (mean value of all fitting models):

Permeability	: (91.0 ±	2.6) µdarcy
Kf	: (9.1 ±	0.3) e-10 m/s
Alpha	: (1.00000)	

Number of fitting models: 288

Test No. 3 at 558.33 m MD / 474.84 m TVD

prior to fracturing / stimulation



INPUTPARAMETERS

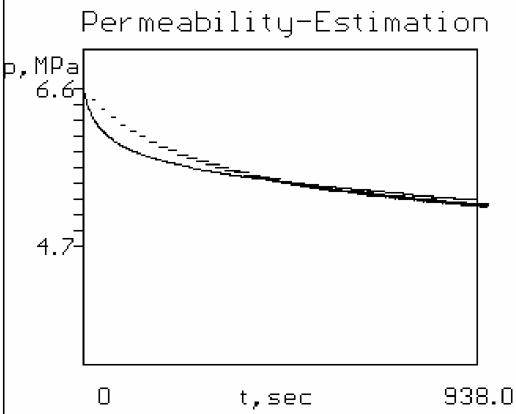
filename:	558.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	6.6E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.73
Tm (min, max), sec:	2746 8237
number of models:	20000
error:	7.0E-03

result (mean value of all fitting models):

Permeability	: (9.9 ±	0.9) µdarcy
Kf	: (9.9 ±	0.9) e-11 m/s
Alpha	: (0.01000)	

Number of fitting models: 815

after fracturing / stimulation



INPUTPARAMETERS

filename:	558b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	1.6E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.70
Tm (min, max), sec:	10 1000
number of models:	20000
error:	1.6E-02

result (mean value of all fitting models):

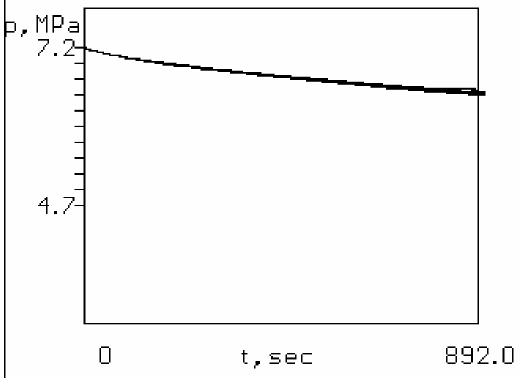
Permeability	: (17.8 ±	0.5) µdarcy
Kf	: (1.8 ±	0.0) e-10 m/s
Alpha	: (1.00000)	

Number of fitting models: 126

Test No. 2 at 564.02 m MD / 479.34 m TVD

prior to fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	564.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	4.0E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.73
Tm (min, max), sec:	2251 6752
number of models:	20000
error:	3.0E-03

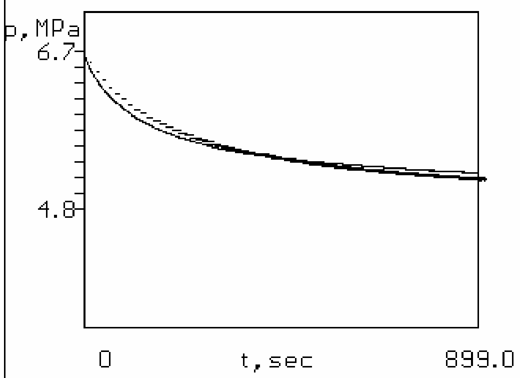
result (mean value of all fitting models):

Permeability	: (8.3 ± 0.3)	µdarcy
Kf	: (8.3 ± 0.3)	e-11 m/s
Alpha	: (0.01000)	

Number of fitting models: 241

after fracturing / stimulation

Permeability-Estimation



INPUTPARAMETERS

filename:	564b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	1.6E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	4.75
Tm (min, max), sec:	201 602
number of models:	20000
error:	1.0E-02

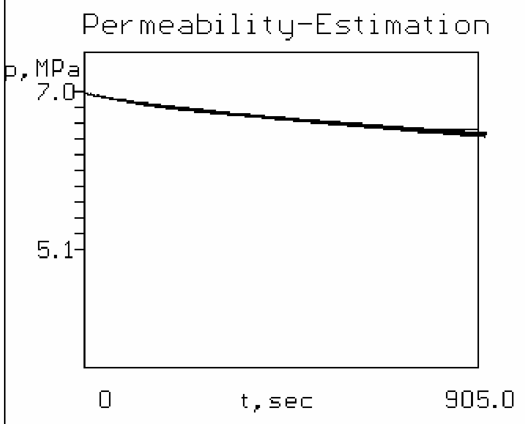
result (mean value of all fitting models):

Permeability	: (28.6 ± 0.7)	µdarcy
Kf	: (2.9 ± 0.1)	e-10 m/s
Alpha	: (1.00000)	

Number of fitting models: 207

Test No. 1 at 593.93 m MD / 502.91 m TVD

prior to fracturing / stimulation



INPUTPARAMETERS

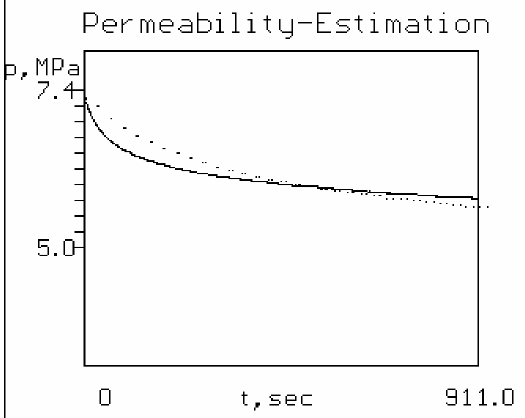
filename:	593.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	6.7E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.13
Tm (min, max), sec:	2376 7127
number of models:	20000
error:	3.0E-03

result (mean value of all fitting models):

Permeability : (12.0 ± 0.5) μdarcy
Kf : (1.2 ± 0.1) e-10 m/s
Alpha : (0.01000)

Number of fitting models: 378

after fracturing / stimulation



INPUTPARAMETERS

filename:	593b.red
samplingrate, sec:	1.00
inv. Stiffness m³.m/Pa:	1.7E-11
interval length, m:	0.60
hole diameter, mm:	77.30
Phyd, MPa:	5.00
Tm (min, max), sec:	10 1000
number of models:	20000
error:	2.1E-02

result (mean value of all fitting models):

Permeability : (14.3 ± 0.2) μdarcy
Kf : (1.4 ± 0.0) e-10 m/s
Alpha : (0.10000)

Number of fitting models: 6

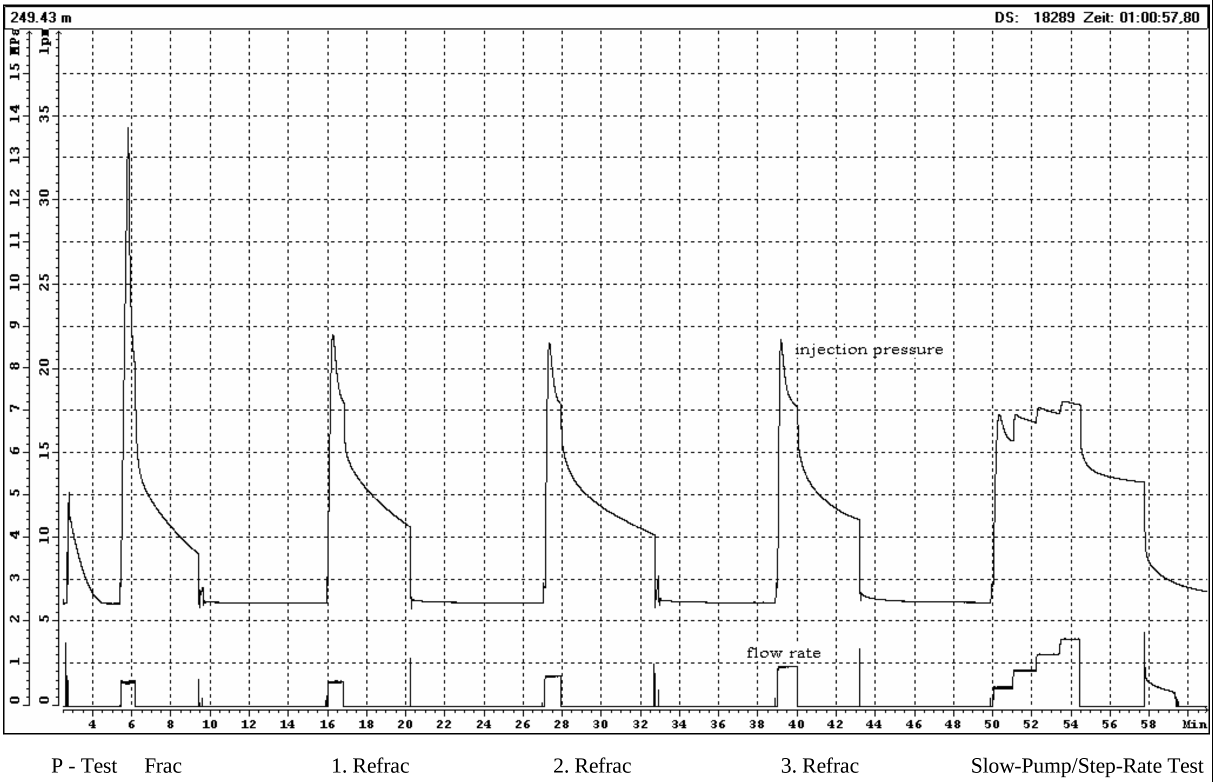
Appendix B1

Records from in-situ Hydrofrac / Hydraulic Injection Tests together with Evaluation of Characteristic Pressure Data

Borehole No. KFM01A

TEST NO. 25 AT 249.43 m MD / 247.99 m TVD

Test at 249.43 m MD : Overview - Plot



<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

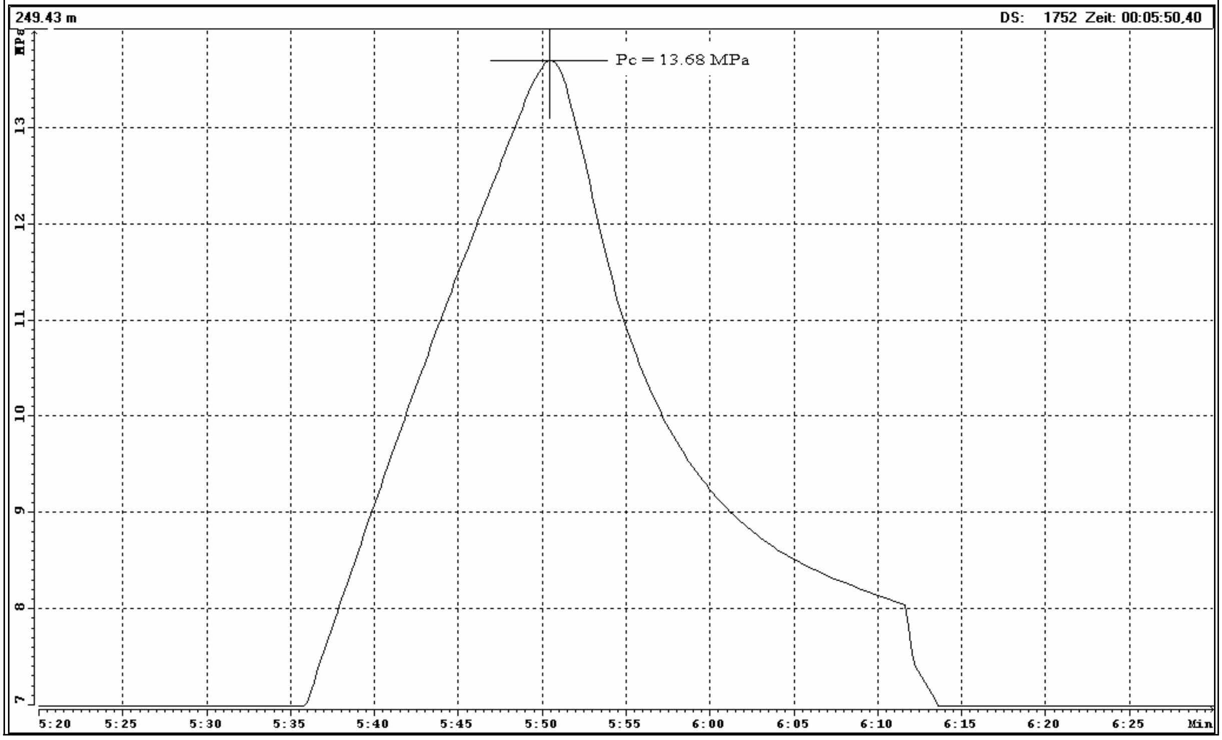
P - Test : pressure decrease: 1.93 MPa in 110 sec. (it is most likely that the significant pressure decay was caused by a small leakage of the coil tubing)

Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.0	Vr (l) = 0.15
1. Refrac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.2	Vr (l) = 0.3
2. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 1.4	Vr (l) = 0.3
3. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 2.4	Vr (l) = 0.8
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 11.4	Vr (l) = 5.5

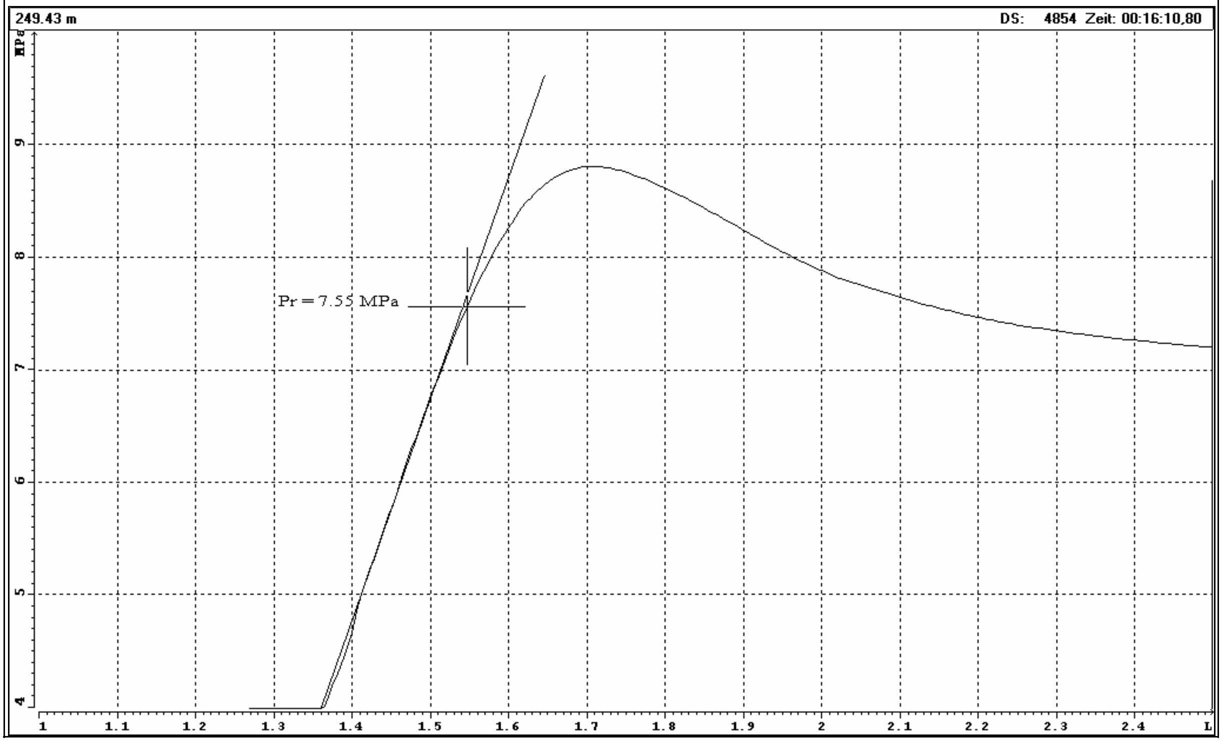
total injected volume (l): 17.4 recovered volume (l): 7.05 or 40.5 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield nearly identical fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

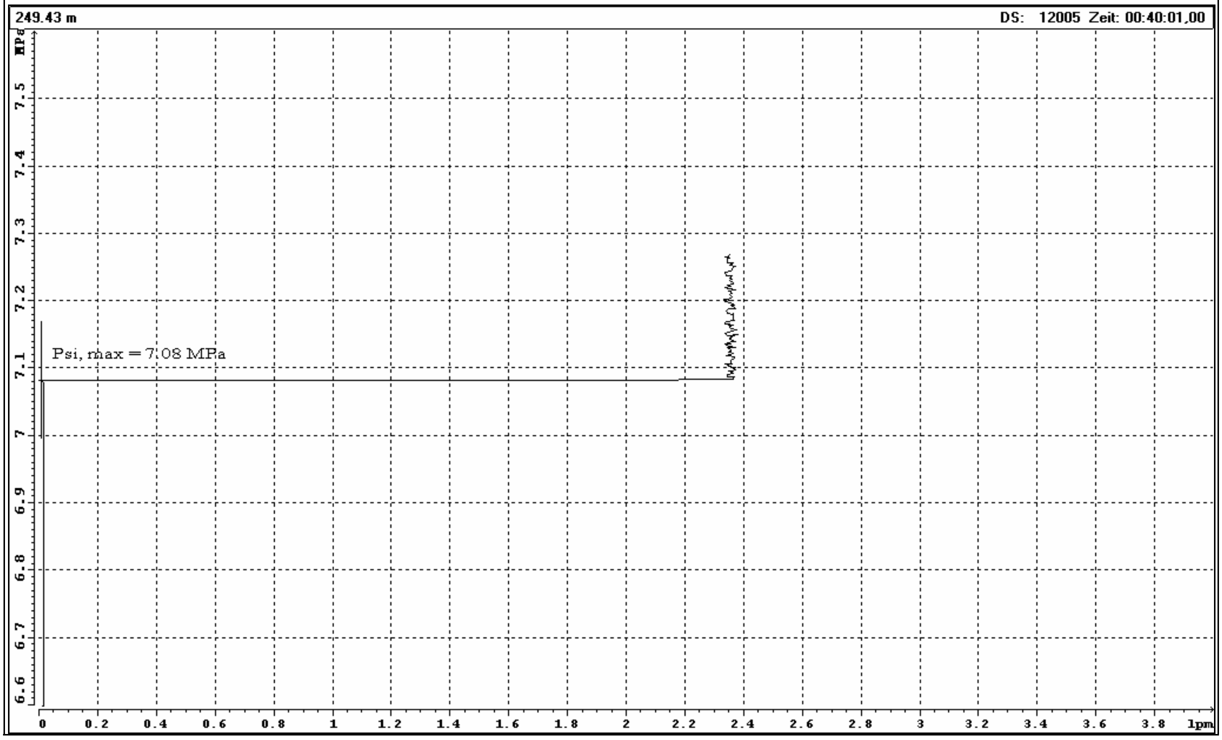
Test at 249.43 m MD: Estimation of P_c (Frac - Cycle)



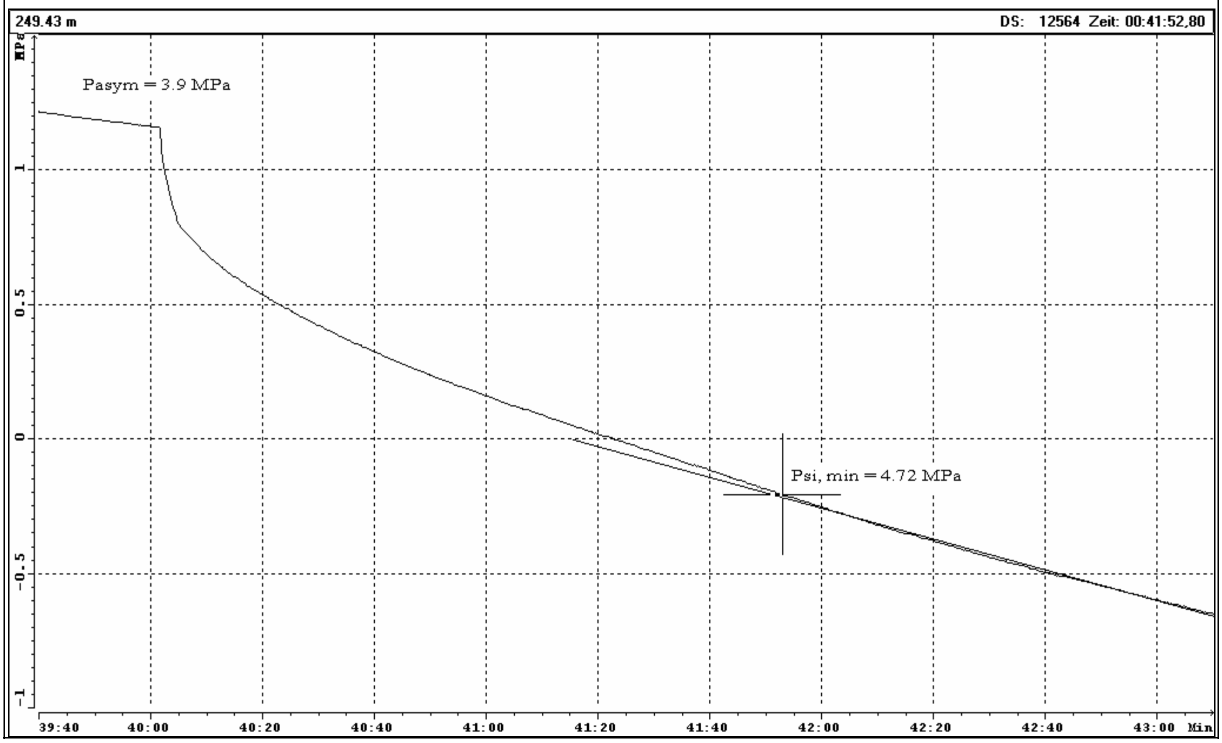
Test at 249.43 m MD: Estimation of P_r (1. Refrac - Cycle)



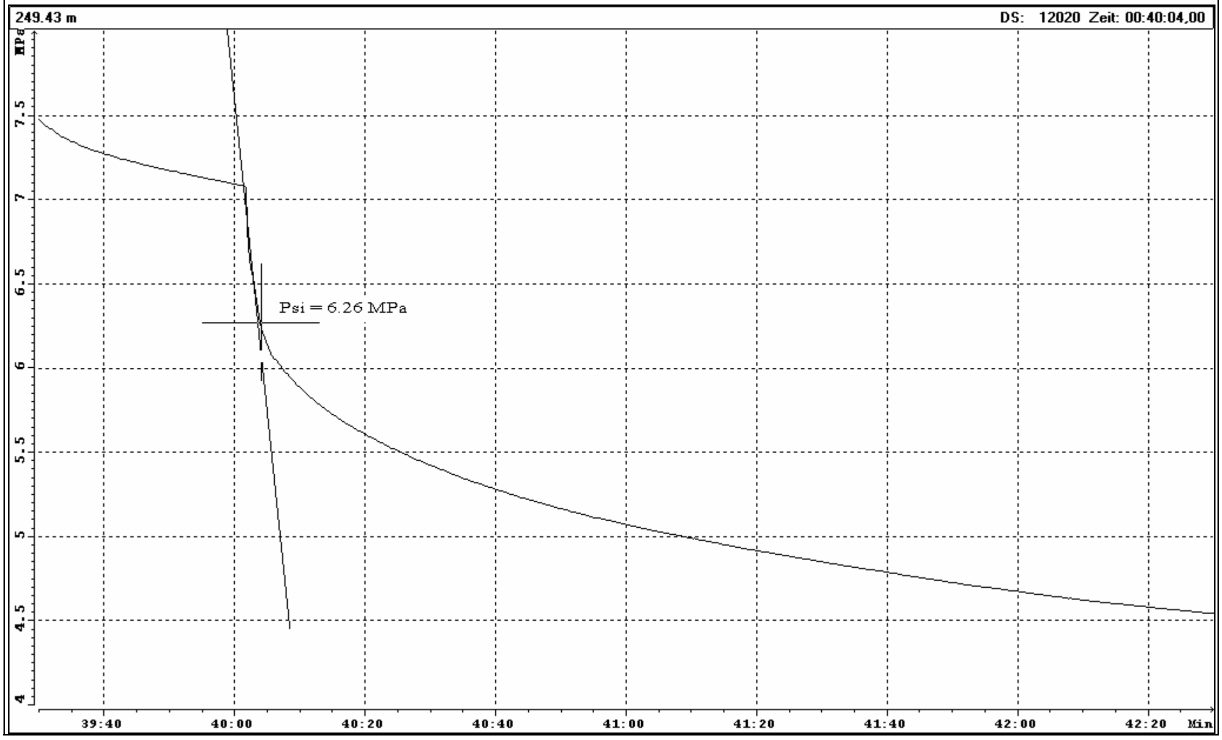
Test at 249.43 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



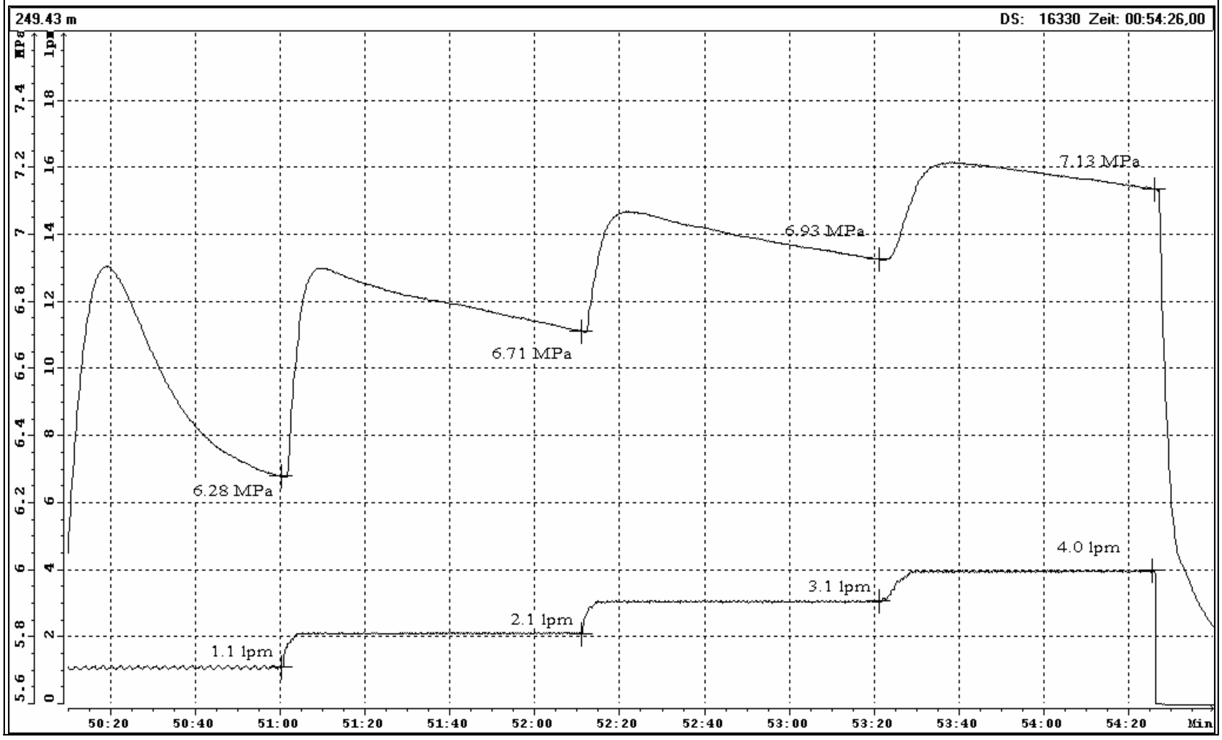
Test at 249.43 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



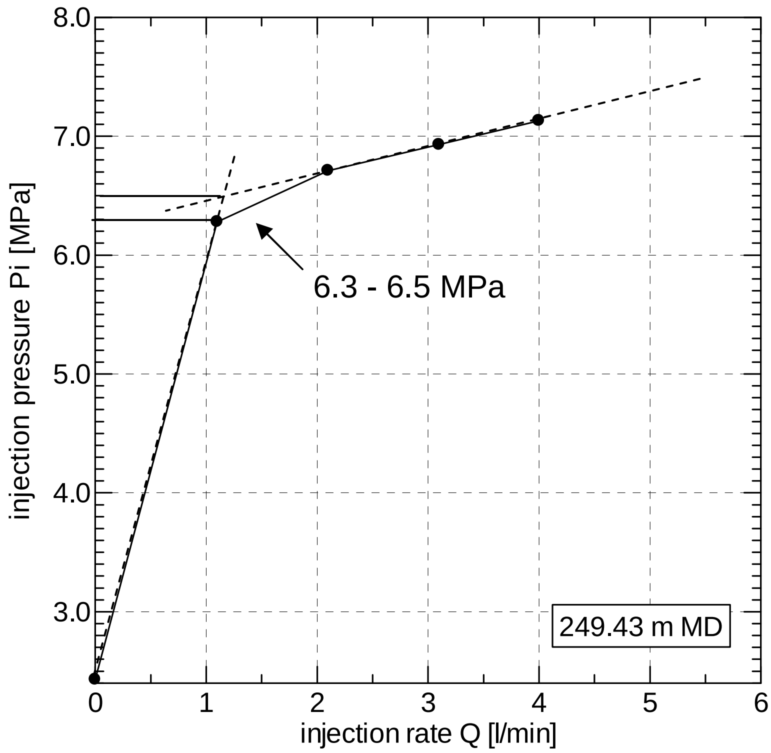
Test at 249.43 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 249.43 m MD: Analysis of Slow - Pump / Step - Rate - Test

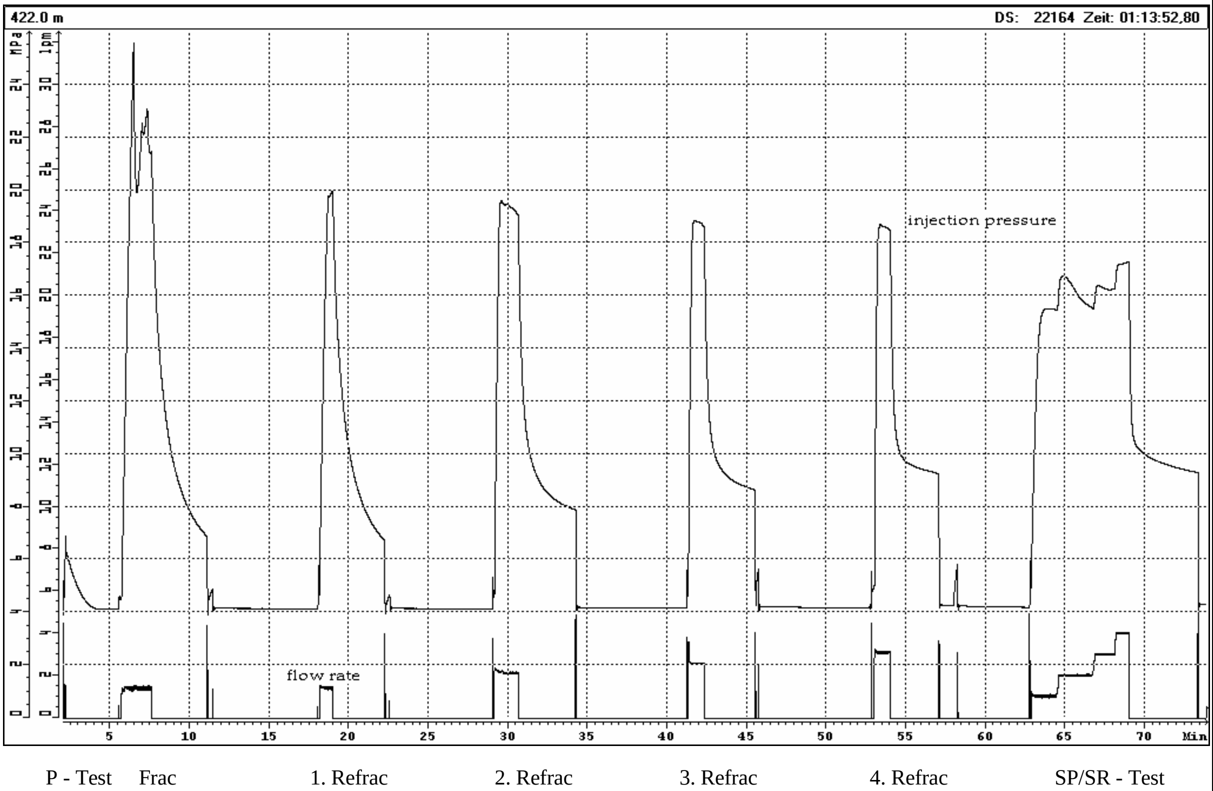


Test at 249.43 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 24 AT 422.0 m MD / 419.00 m TVD

Test at 422.0 m MD: Overview - Plot



TEST SUMMARY / ANALYSIS / REMARKS

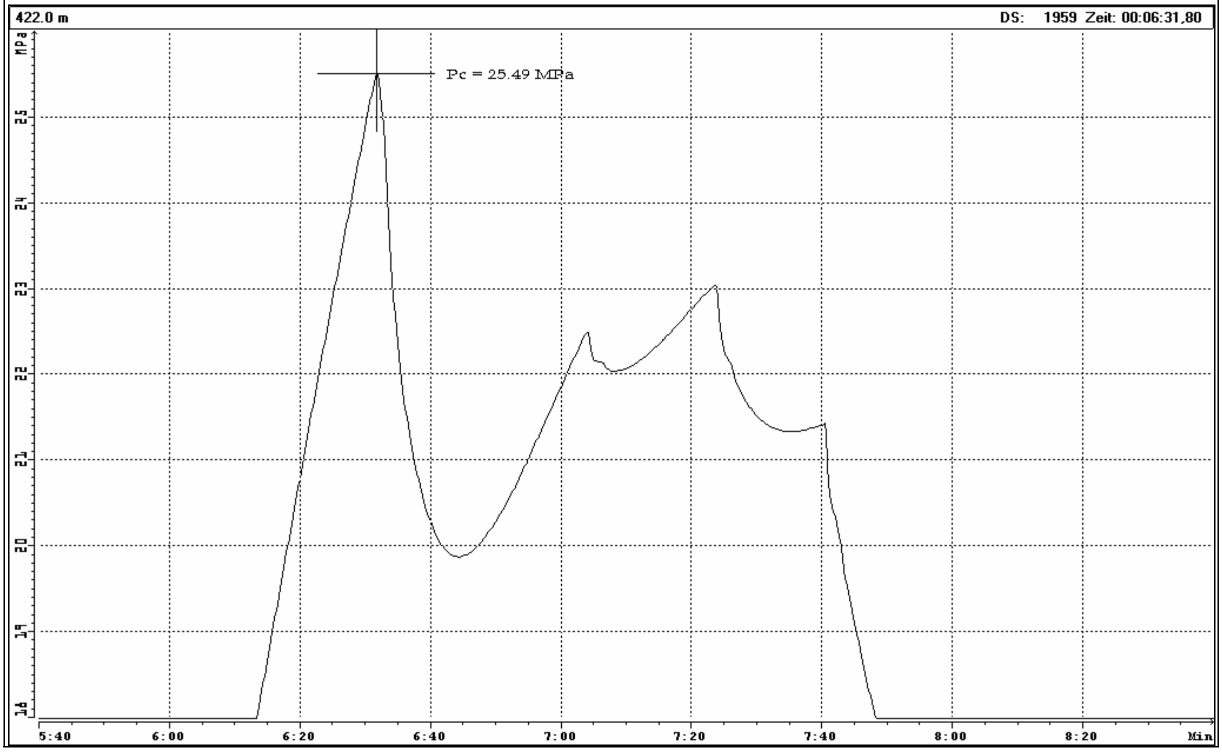
P - Test : pressure decrease: 2.15 MPa in 117 sec. (it is most likely that the significant pressure decay was caused by a small leakage of the coil tubing)

Frac - cycle	Qi (lpm) = 1,4	Vi (l) = 2,7	Vr (l) = 0,6
1. Refrac - cycle	Qi (lpm) = 1,5	Vi (l) = 1,2	Vr (l) = 0,6
2. Refrac - cycle	Qi (lpm) = 2,2	Vi (l) = 3,3	Vr (l) = 1,3
3. Refrac - cycle	Qi (lpm) = 2,6	Vi (l) = 2,7	Vr (l) = 1,6
4. Refrac - cycle	Qi (lpm) = 3,1	Vi (l) = 3,2	Vr (l) = 1,8
SP/SR - test	Qi (lpm) = 1,1-4,0	Vi (l) = 13,9	Vr (l) = 5,0

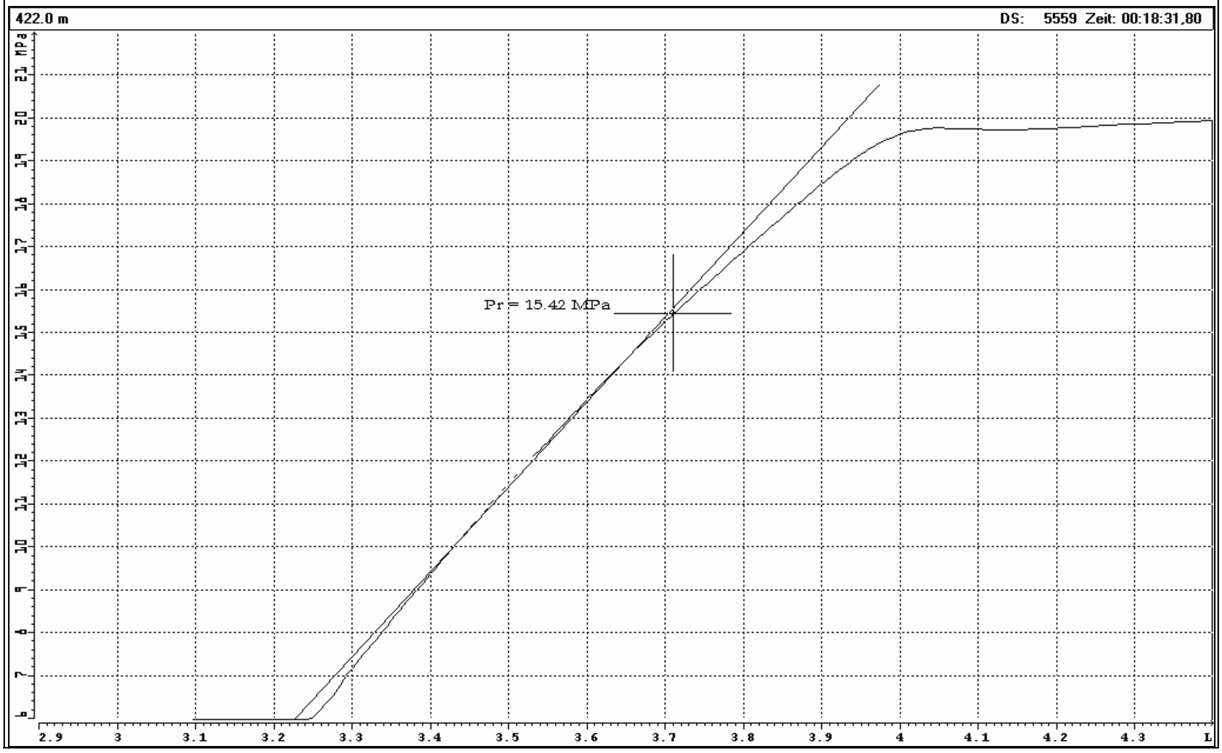
total injected volume (l): 27,0 recovered volume (l): 10,90 or 40,4 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (distinct breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 15.4 MPa, followed by a pressure increase up to about 20 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield slightly lower fracture re-opening pressure values.
- The frac - and 1. refrac - cycle yield shut-in pressures of 20.1 and 18.2 MPa, while the following refrac - cycles yield consistent shut-in pressures values of about 15.1 MPa. Therefore, the shut - in pressure of the 4. refrac - cycle was used for the stress analysis.

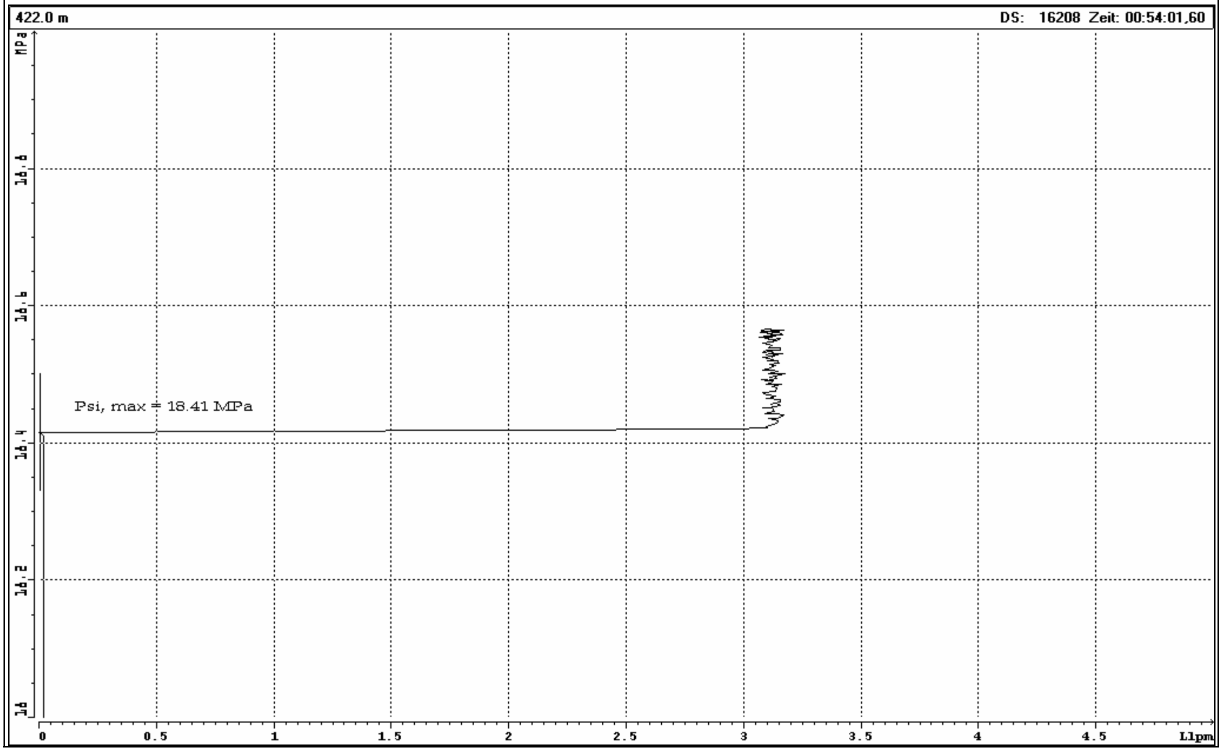
Test at 422.0 m MD: Estimation of P_c (Frac - Cycle)



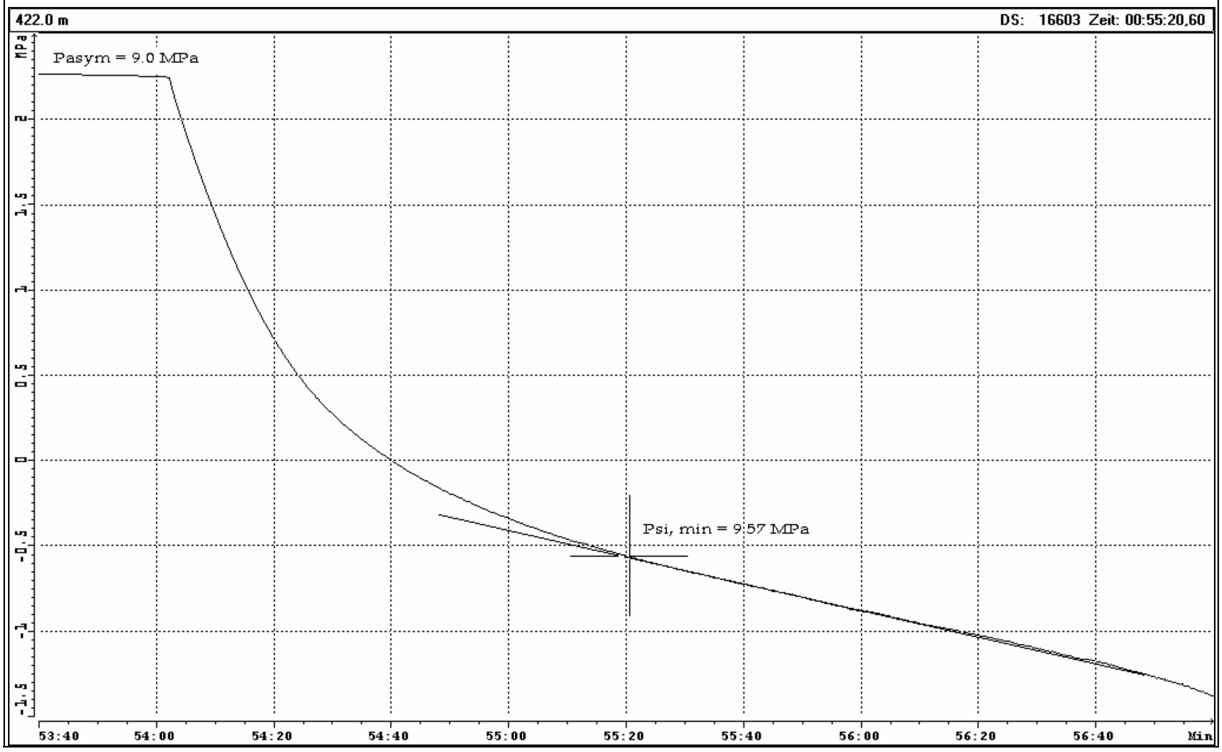
Test at 422.0 m MD: Estimation of P_r (1. Refrac - Cycle)



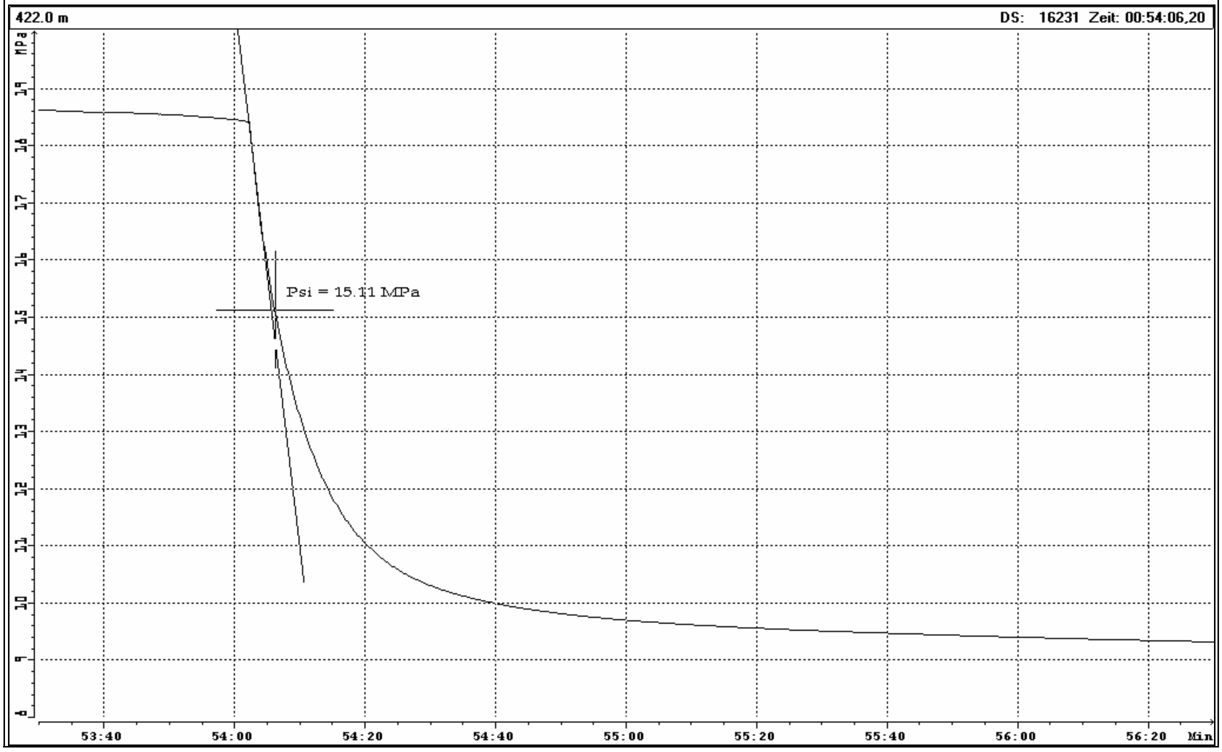
Test at 422.0 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



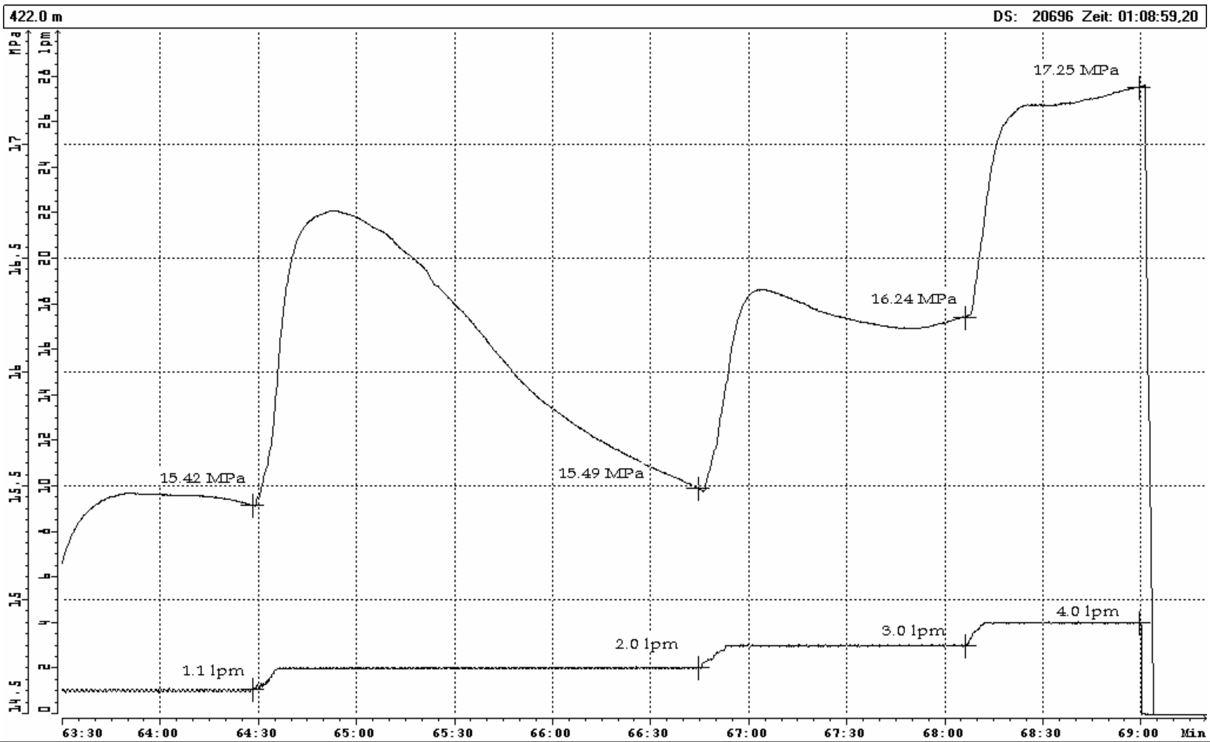
Test at 422.0 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



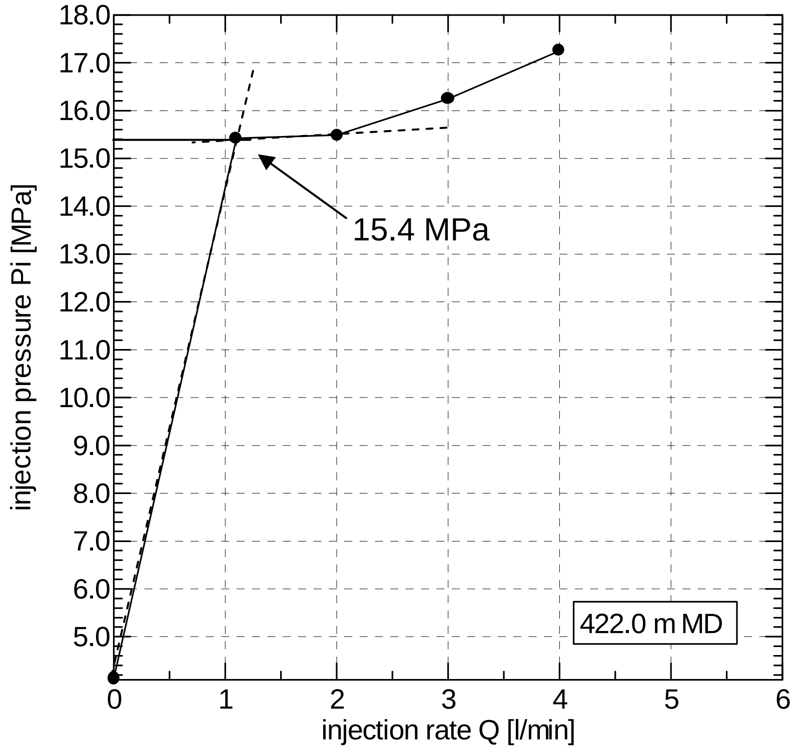
Test at 422.0 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 422.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

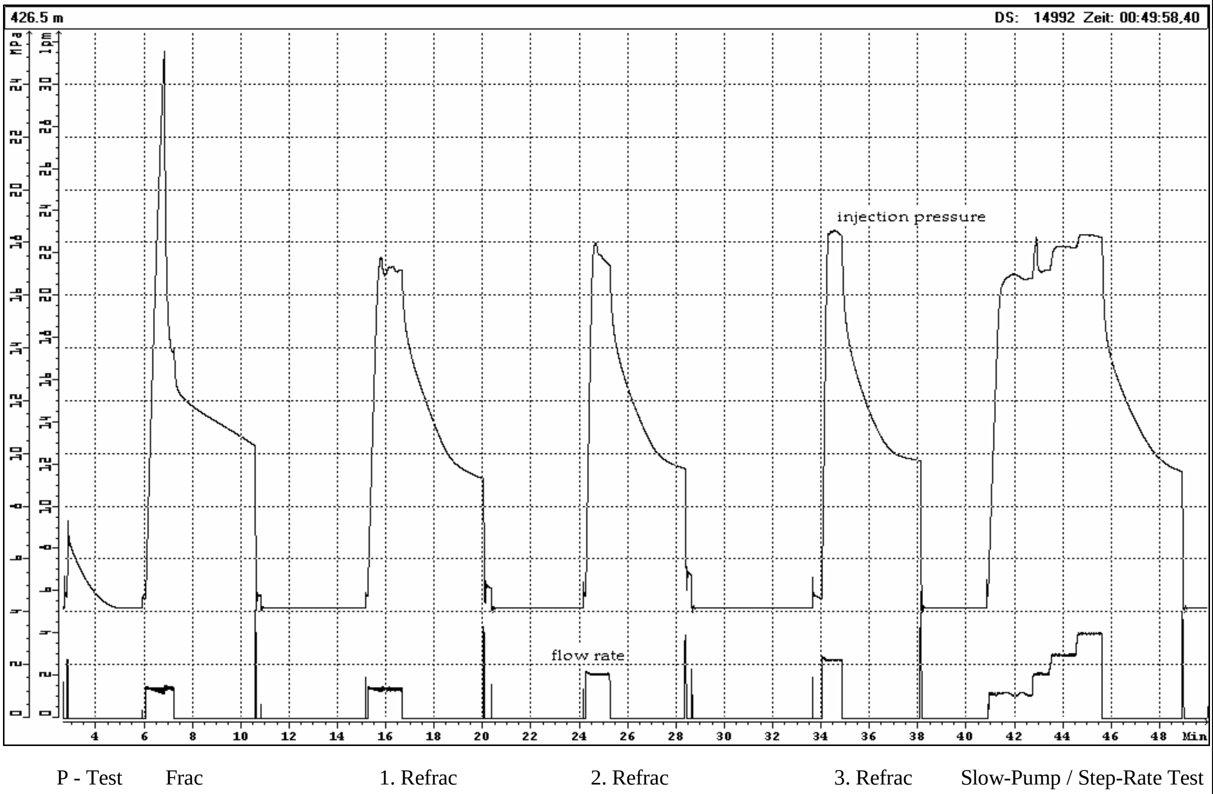


Test at 422.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 23 AT 426.5 m MD / 423.45 m TVD

Test at 426.5 m MD: Overview - Plot



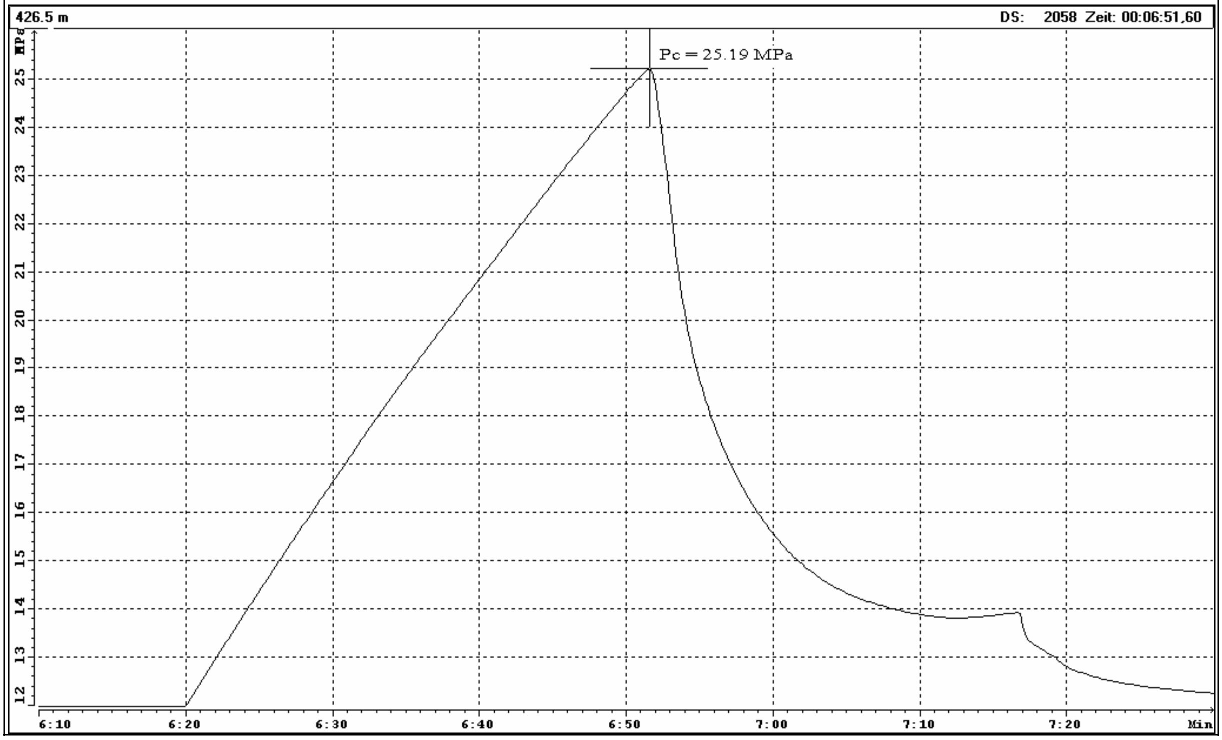
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 2.31 MPa in 119 sec. (it is most likely that the significant pressure decay was caused by a small leakage of the coil tubing)		
Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.6	Vr (l) = 0.25
1. Refrac - cycle	Qi (lpm) = 1.4	Vi (l) = 2.0	Vr (l) = 0.2
2. Refrac - cycle	Qi (lpm) = 2.1	Vi (l) = 2.1	Vr (l) = 0.2
3. Refrac - cycle	Qi (lpm) = 2.8	Vi (l) = 2.3	Vr (l) = 0.2
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 11.1	Vr (l) = 0.2

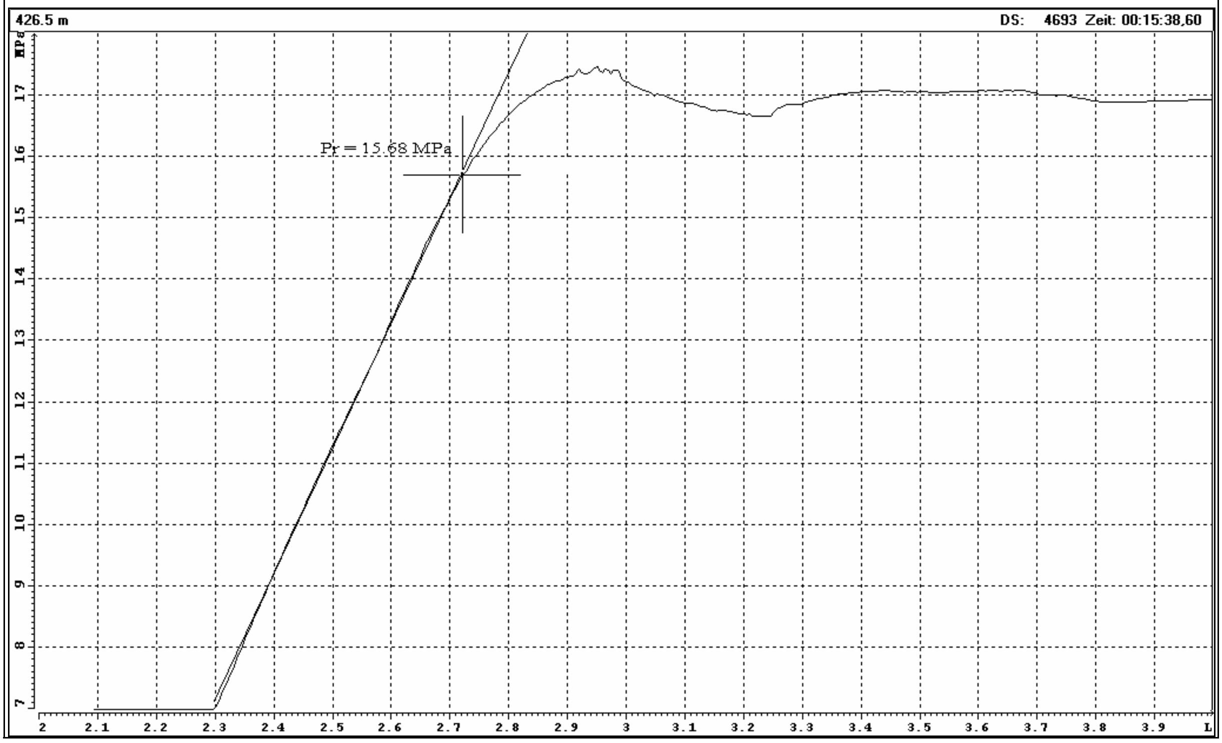
total injected volume (l): 19.1 recovered volume (l): 1.05 or 5.5 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (distinct breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield nearly identical fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

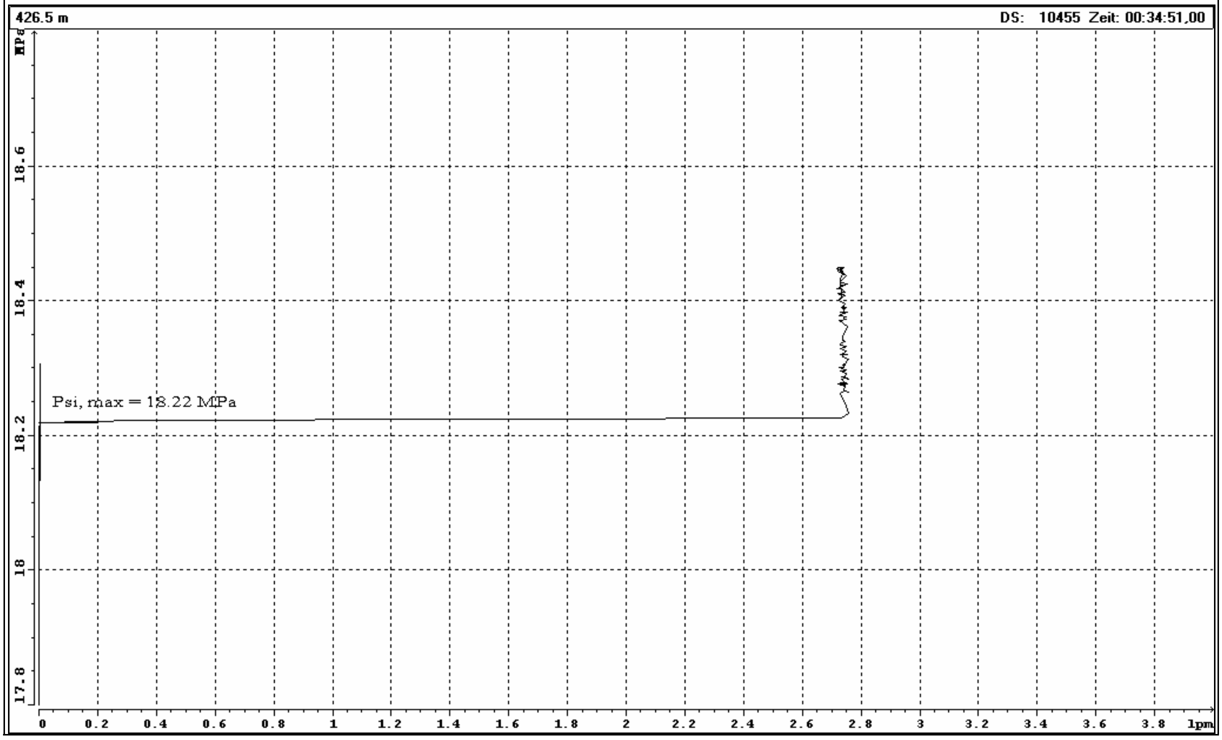
Test at 426.5 m MD: Estimation of P_c (Frac - Cycle)



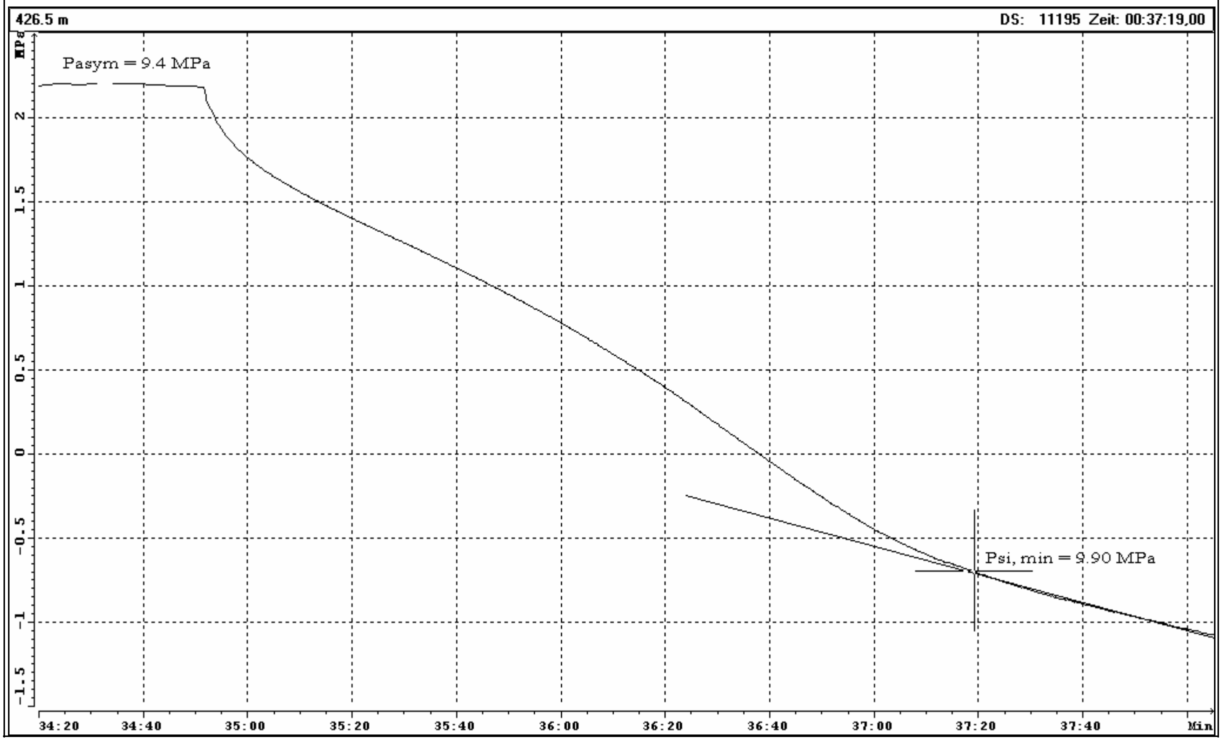
Test at 426.5 m MD: Estimation of P_r (1. Refrac - Cycle)



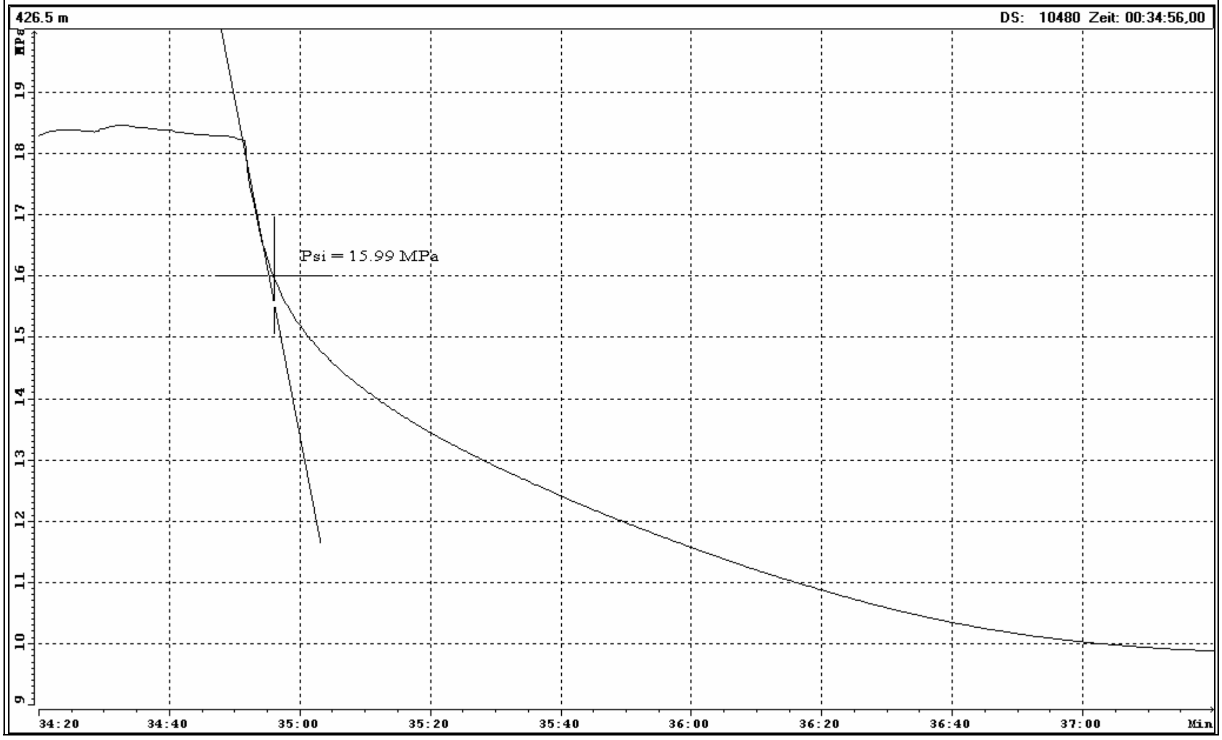
Test at 426.5 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



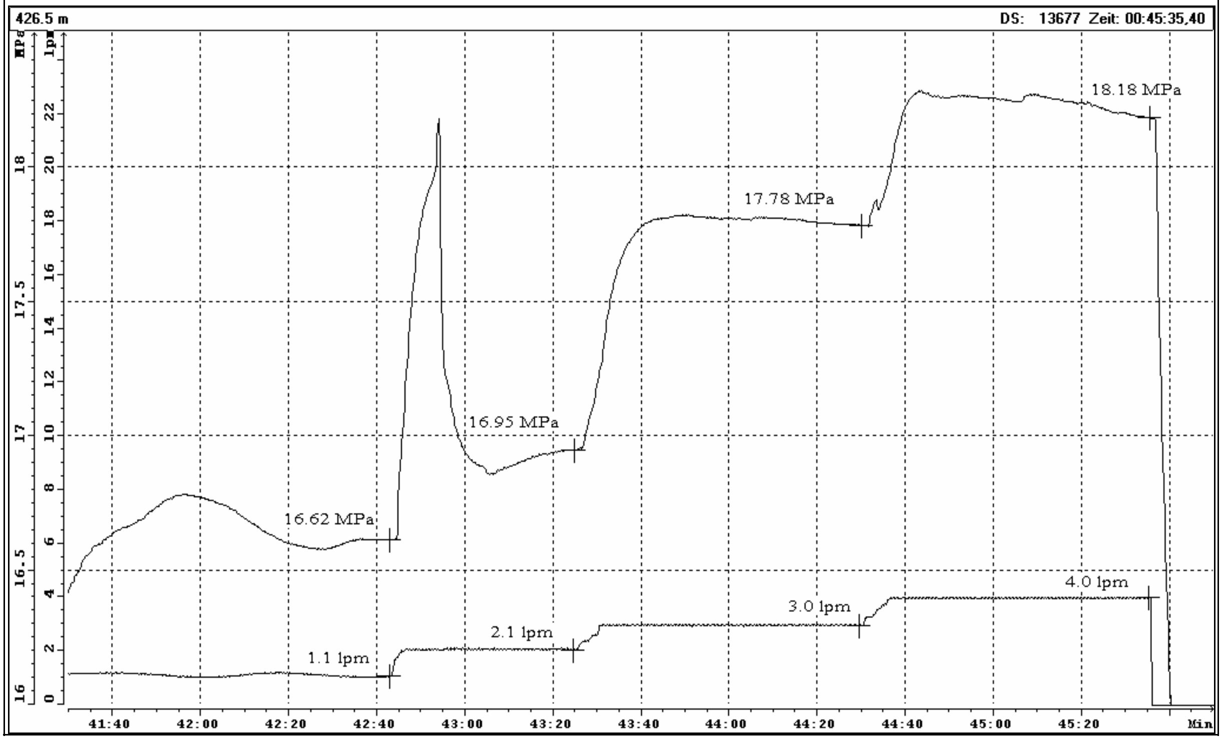
Test at 426.5 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



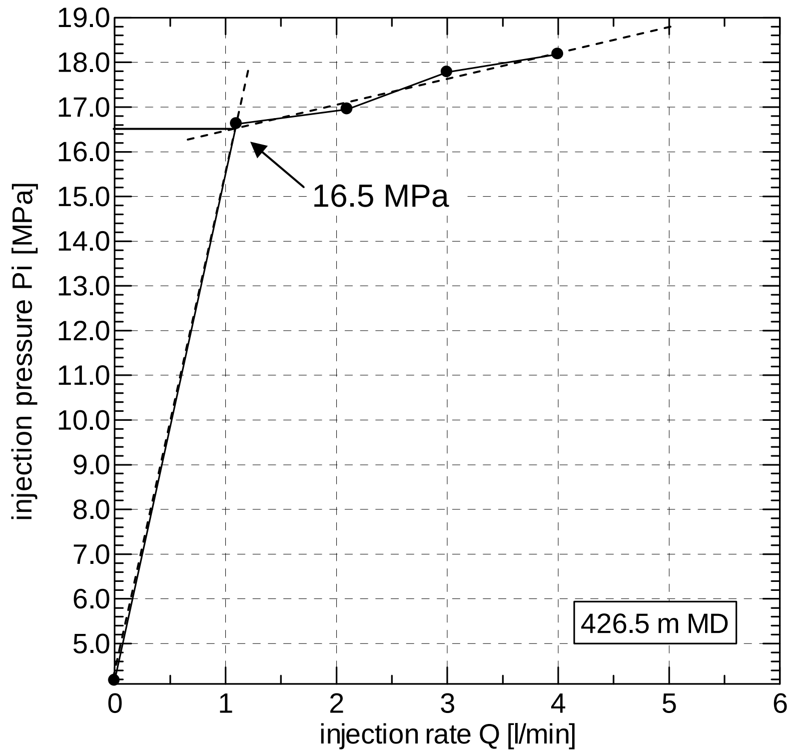
Test at 426.5 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 426.5 m MD: Analysis of Slow - Pump / Step - Rate - Test

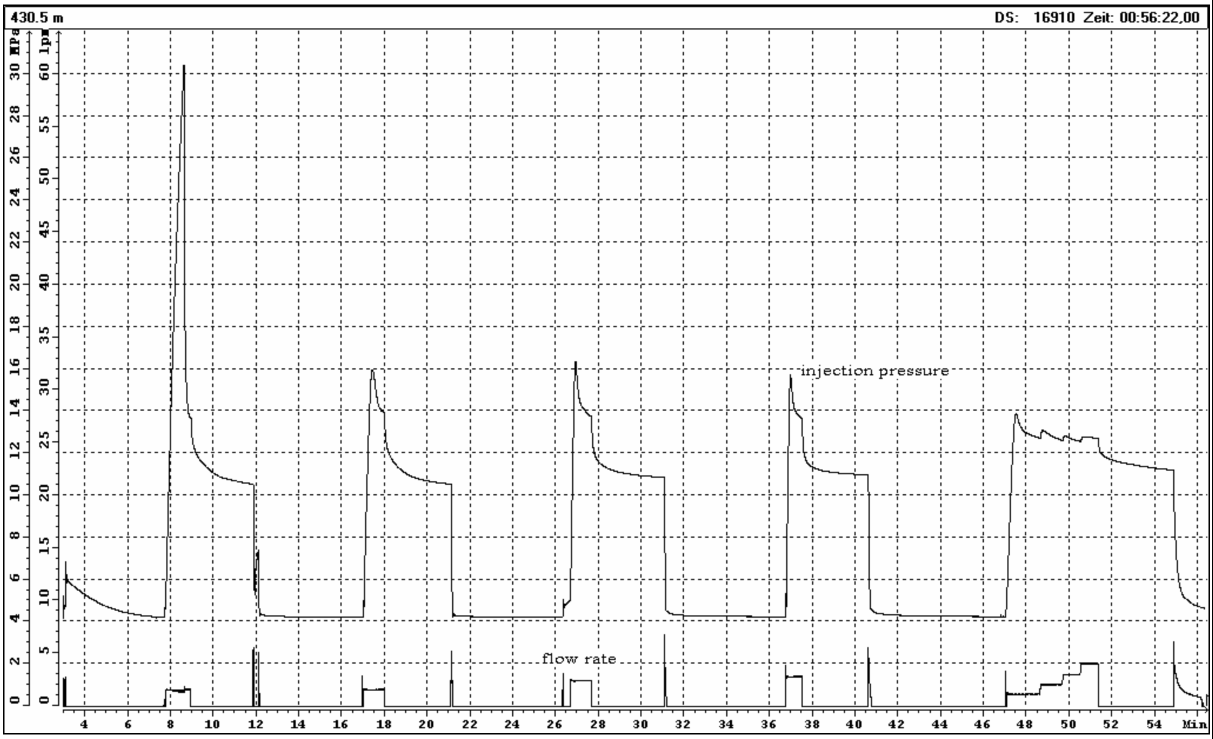


Test at 426.5 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 22 AT 430.5 m MD / 427.40 m TVD

Test at 430.5 m MD : Overview - Plot



P - Test Frac 1. Refrac 2. Refrac 3. Refrac Slow-Pump/Step-Rate Test

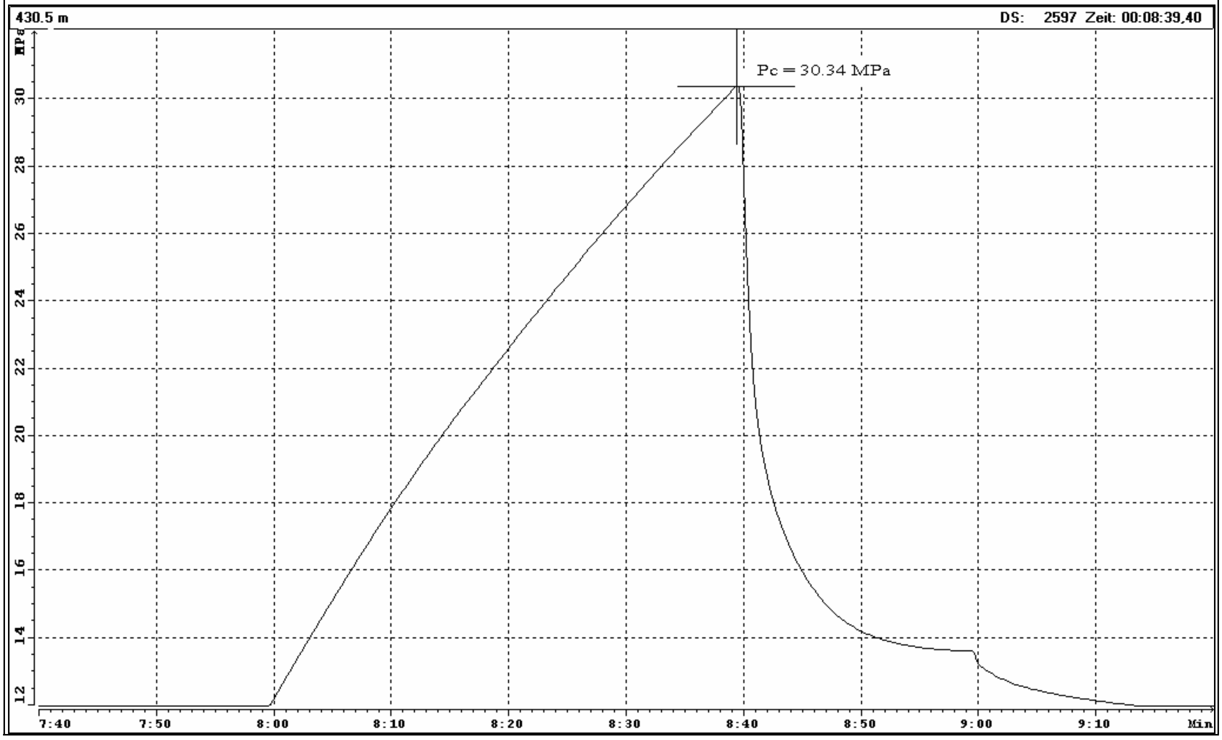
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 1.64 MPa in 243 sec. (it is most likely that the significant pressure decay was caused by a small leakage of the coil tubing)		
Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.8	Vr (l) = 0.8
1. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.5	Vr (l) = 0.8
2. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 2.4	Vr (l) = 1.6
3. Refrac - cycle	Qi (lpm) = 2.8	Vi (l) = 2.1	Vr (l) = 1.8
SP/SR - test	Qi (lpm) = 1.1-4.1	Vi (l) = 9.85	Vr (l) = 4.5

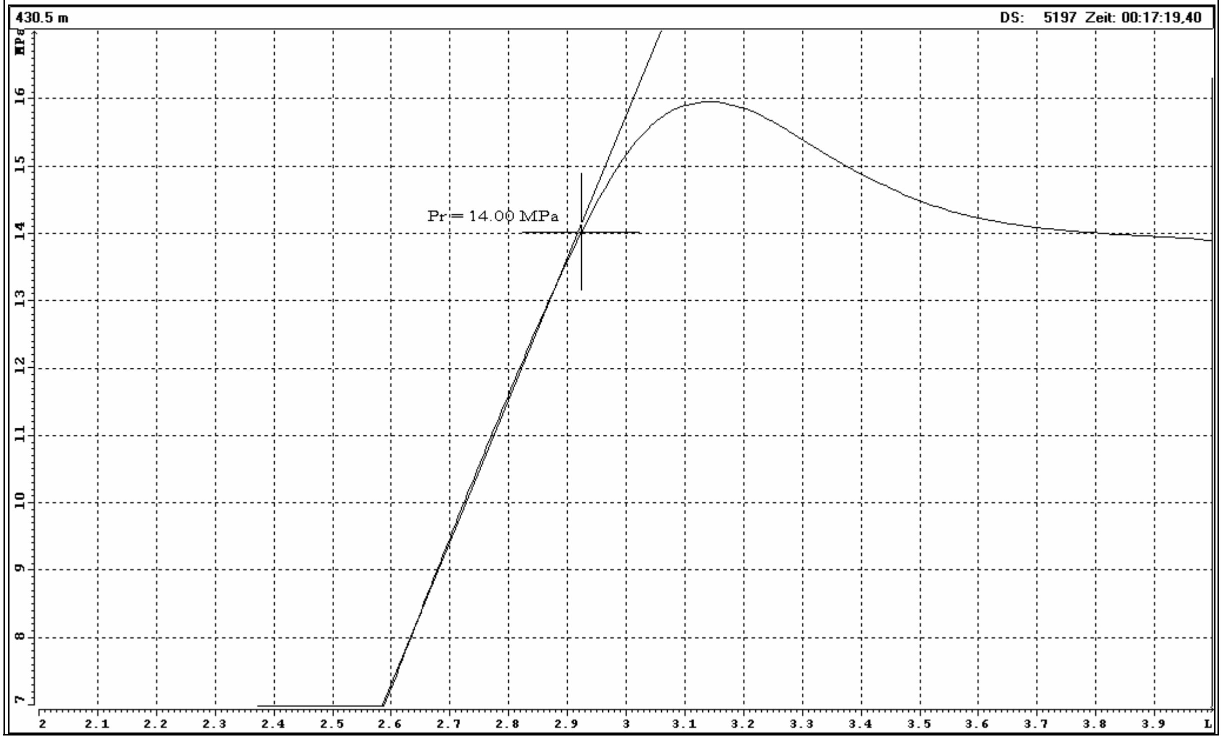
total injected volume (l): 17.65 recovered volume (l): 9.5 or 53.8 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (distinct breakdown event).
- The refrac - pressure was determined from the 1. and 2. refrac - cycle, since the later cycle with higher injection flow-rate yield a higher fracture re-opening pressure.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

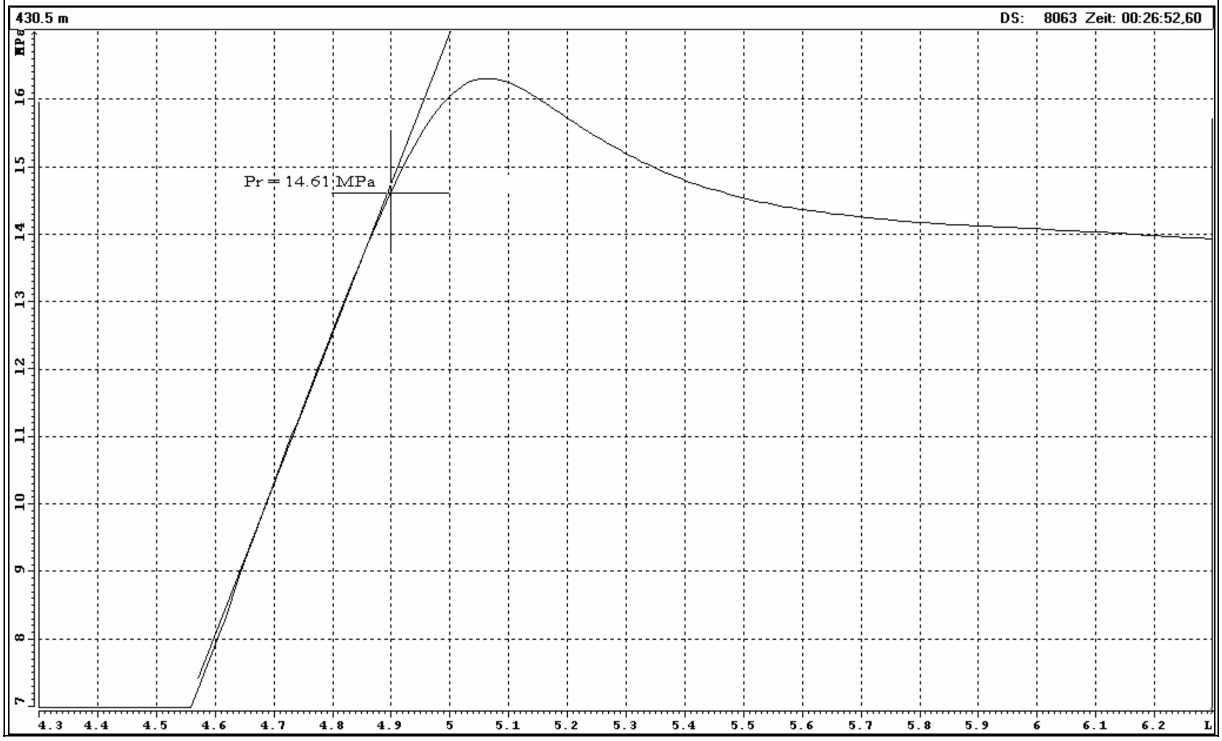
Test at 430.5 m MD: Estimation of P_c (Frac - Cycle)



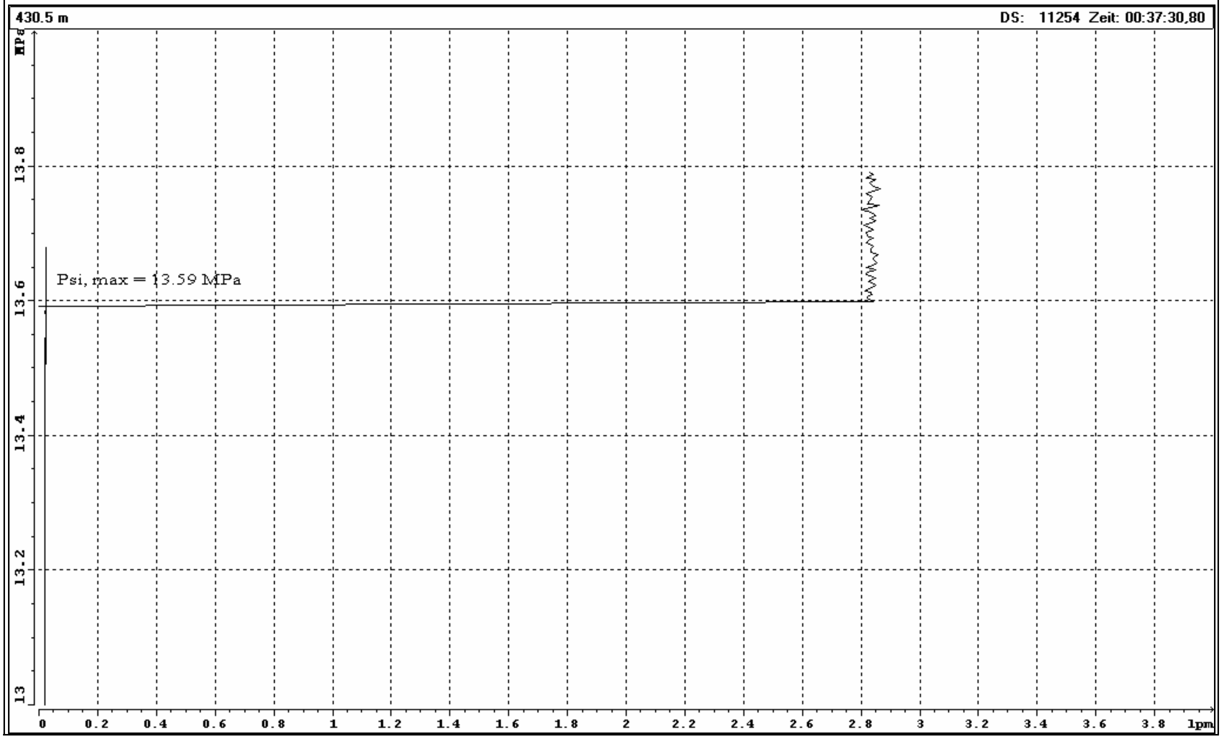
Test at 430.5 m MD: Estimation of P_r (1. Refrac) - Cycle)



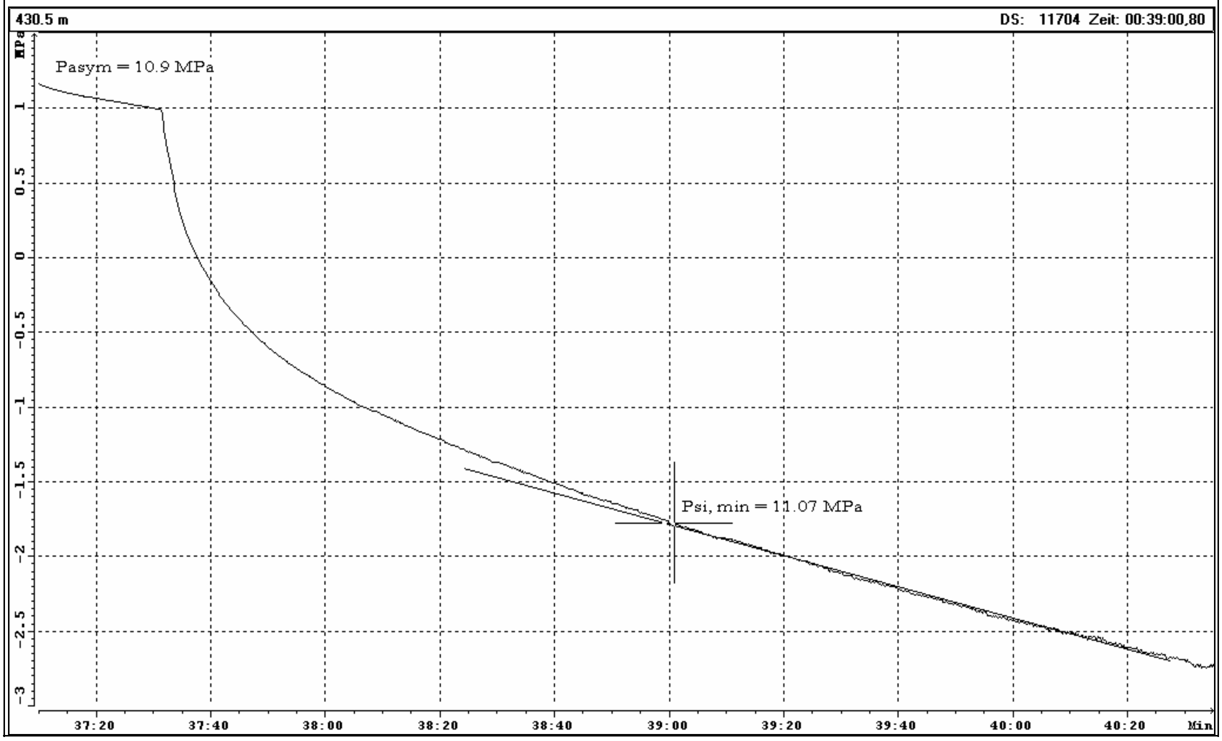
Test at 430.5 m MD: Estimation of P_r (2. Refrac - Cycle)



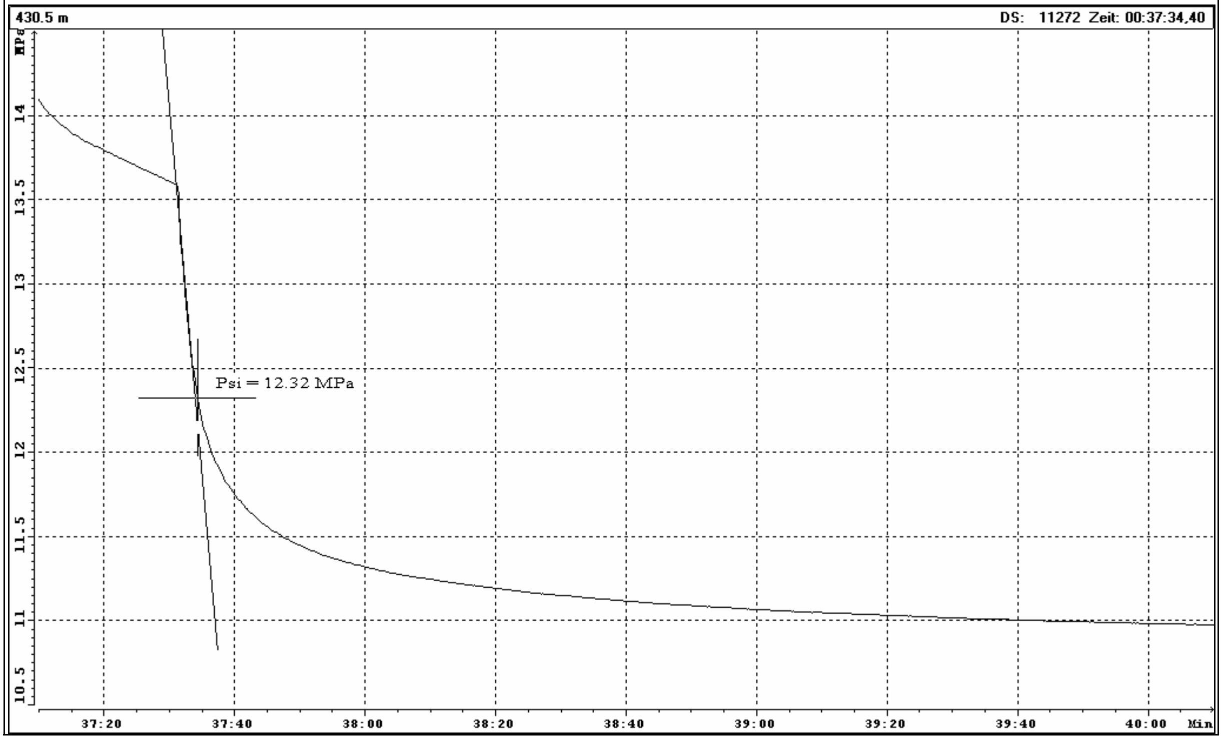
Test at 430.5 m MD: Estimation of $P_{si,\ max}$ (3. Refrac - Cycle)



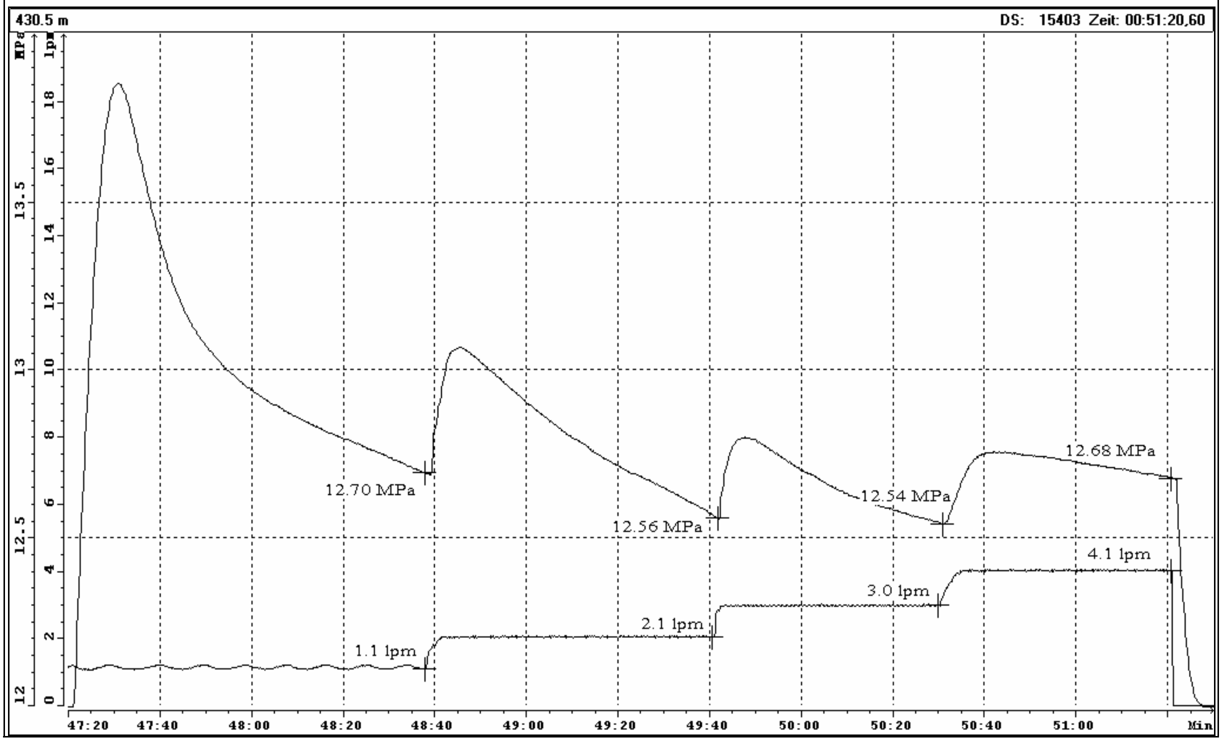
Test at 430.5 m MD: Estimation of $P_{si,\ min}$ (3. Refrac - Cycle)



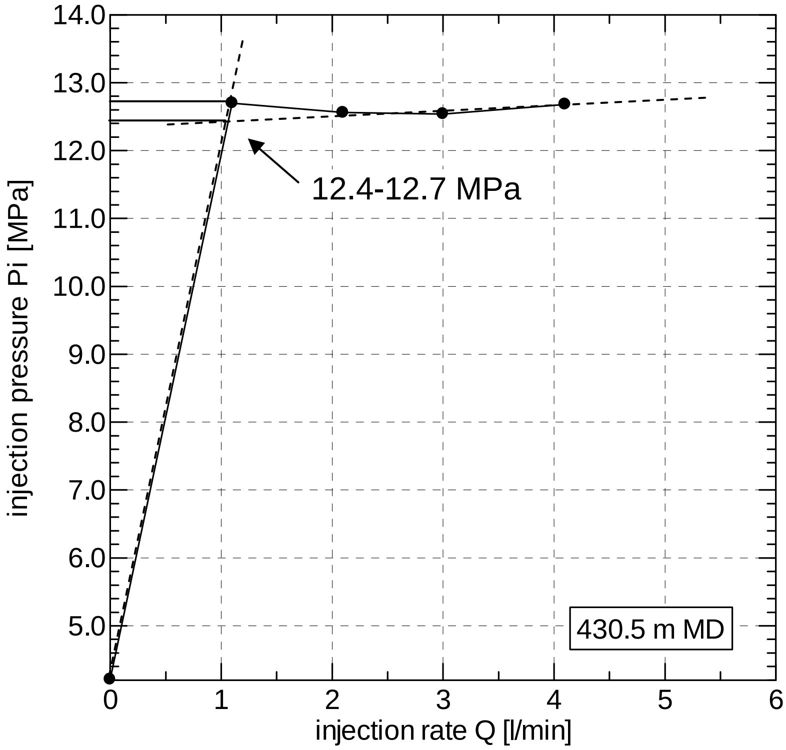
Test at 430.5 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 430.5 m MD: Analysis of Slow - Pump / Step - Rate - Test

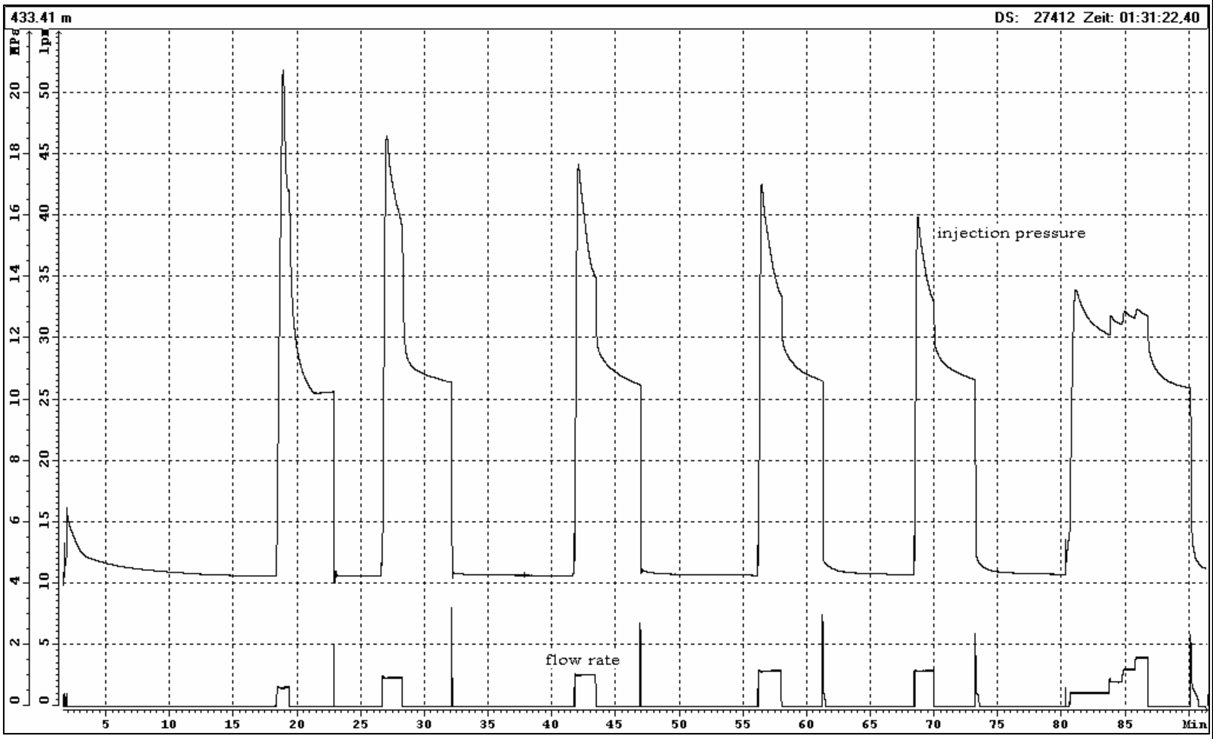


Test at 430.5 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 17 AT 433.41 m MD / 430.28 m TVD

Test at 433.41 m MD: Overview - Plot



<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

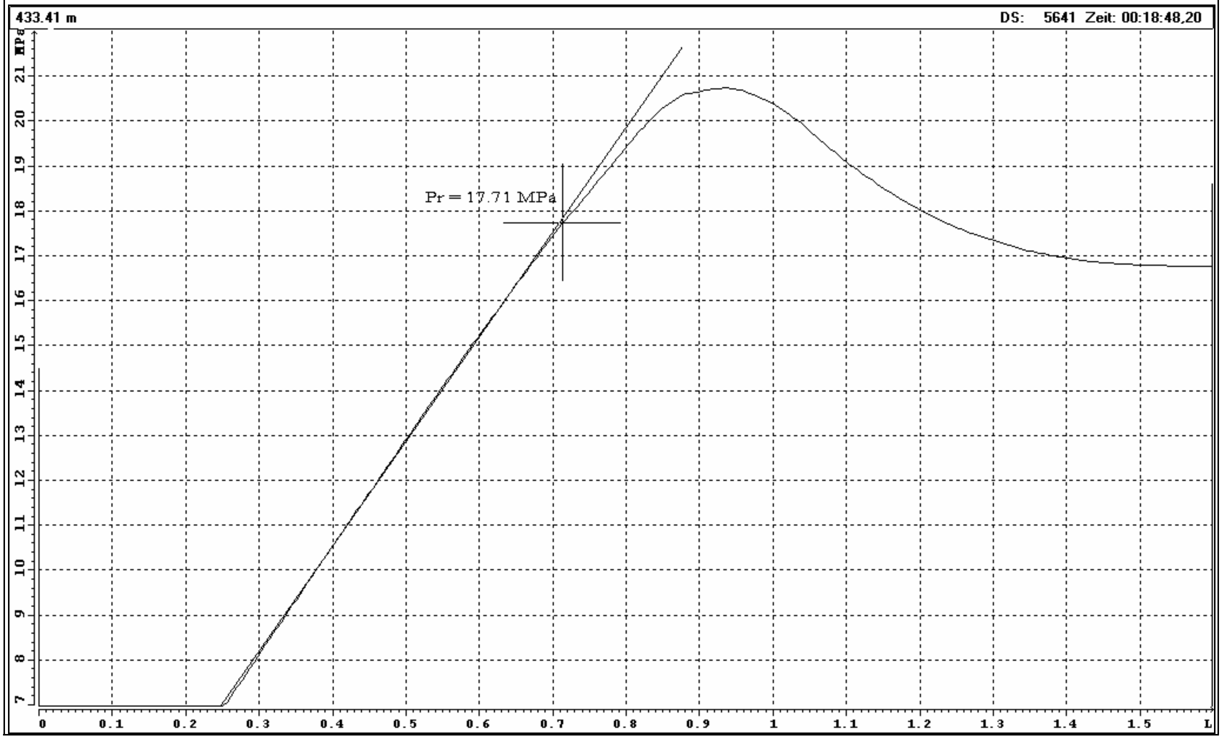
P - Test : pressure decrease: 1.75 MPa in 873 sec. (it is most likely that the significant pressure decay was caused by a small leakage of the coil tubing)

Frac (1. Refrac) - cycle	Qi (lpm) = 1.5	Vi (l) = 1.5	Vr (l) = 0.6
2. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 3.6	Vr (l) = 1.4
3. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 4.25	Vr (l) = 1.75
4. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 5.2	Vr (l) = 2.3
5. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 4.4	Vr (l) = 2.6
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 12.3	Vr (l) = 3.5

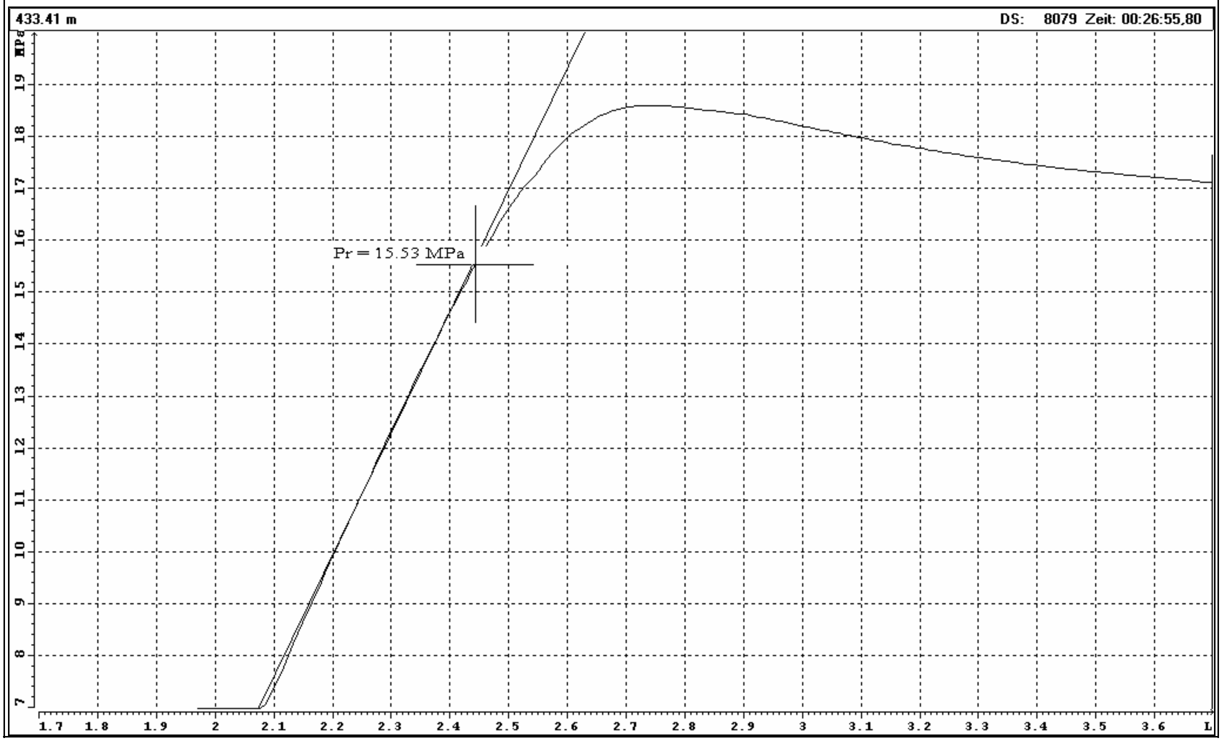
total injected volume (l): 31.25 recovered volume (l): 12.15 or 38.9 %

- Initial test type: HTPF-v
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 17.7 MPa, followed by a pressure increase up to 20.7 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield slightly lower fracture re-opening pressure values.
- The shut-in phases yield distinct shut-in pressure values which decreased from 15.7 MPa during the 1.refrac - cycle to about 12 MPa during the 3., 4. and 5. refrac - cycle . For the stress analysis, the shut - in pressure of the 5. refrac - cycle was used.

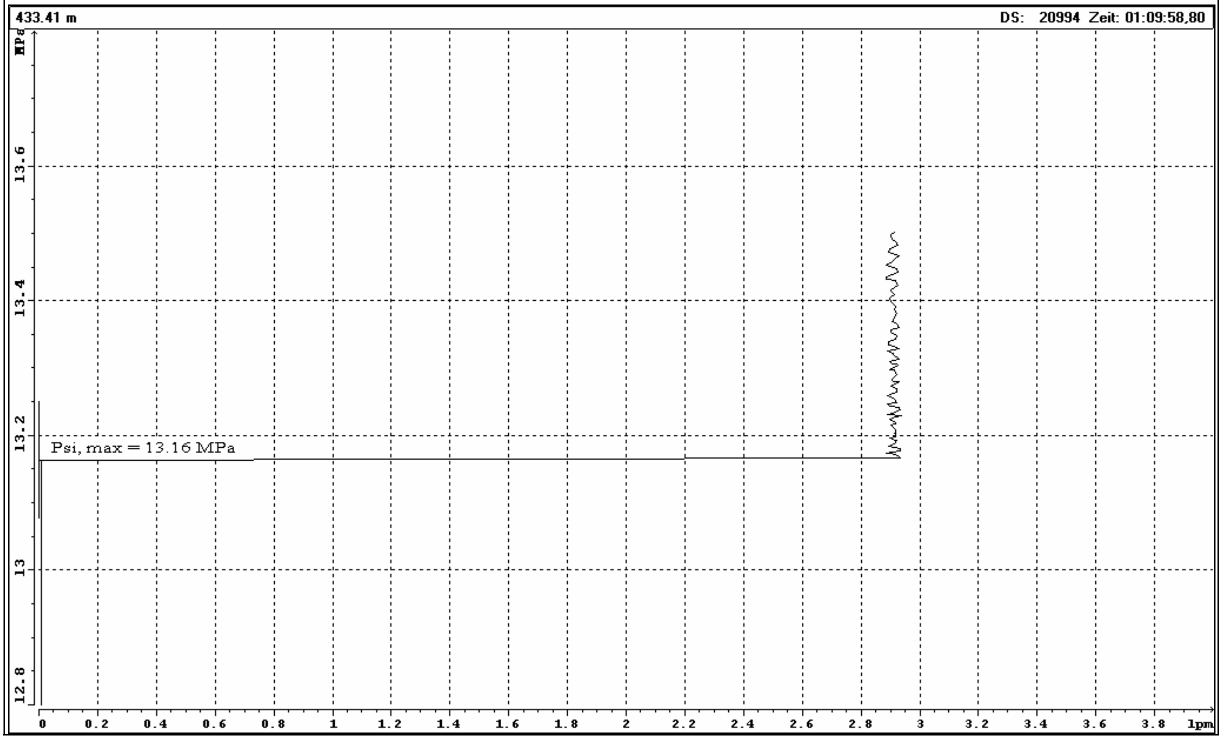
Test at 433.41 m MD: Estimation of P_r (1. Refrac - Cycle)



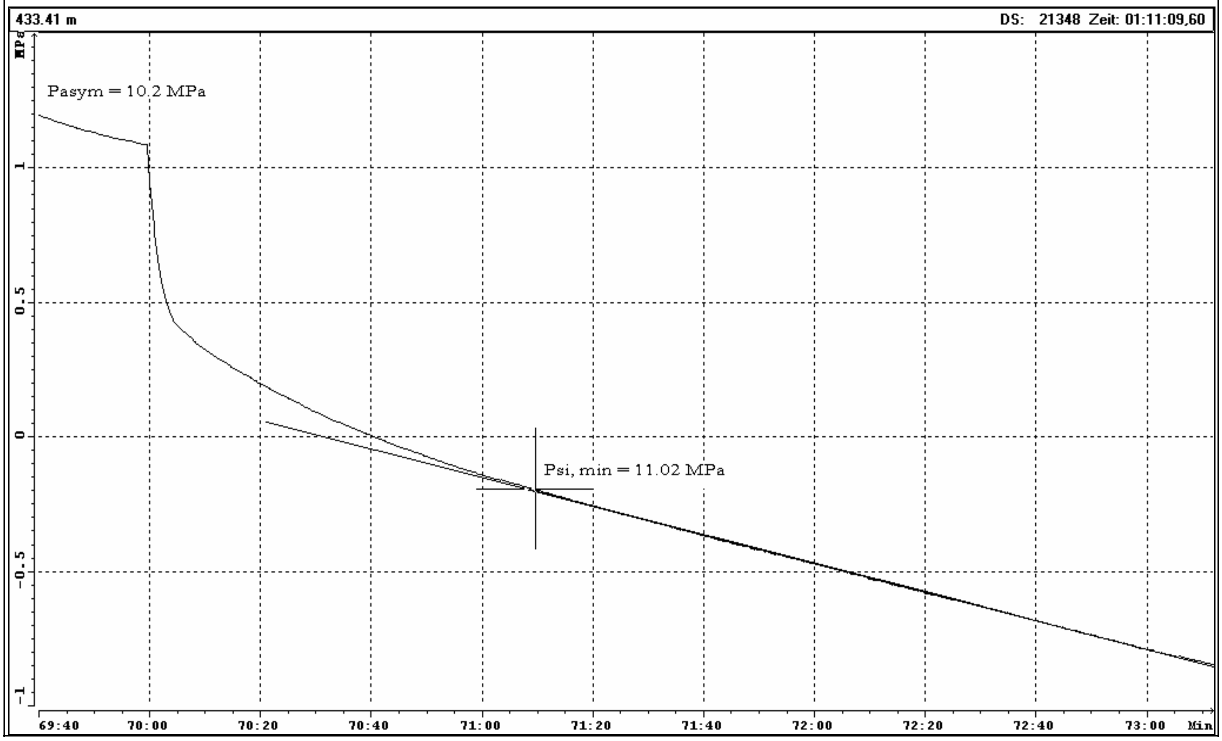
Test at 433.41 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



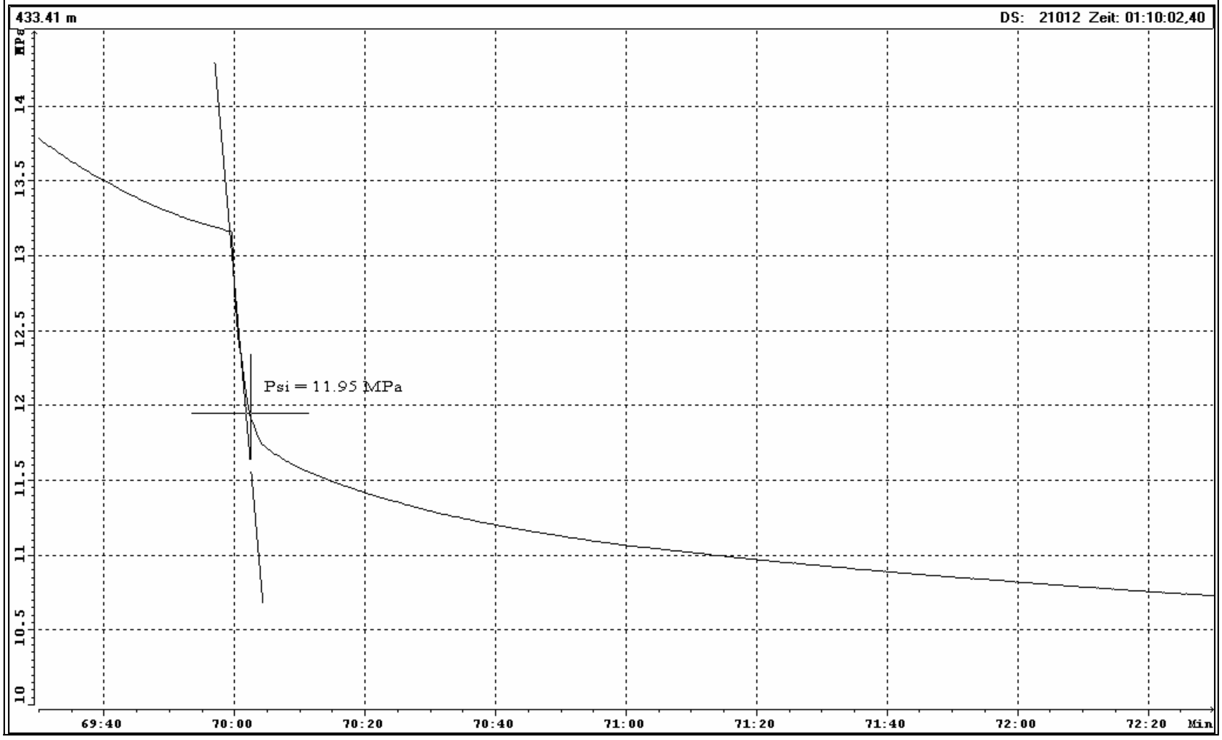
Test at 433.41 m MD: Estimation of $P_{si, max}$ (5. Refrac - Cycle)



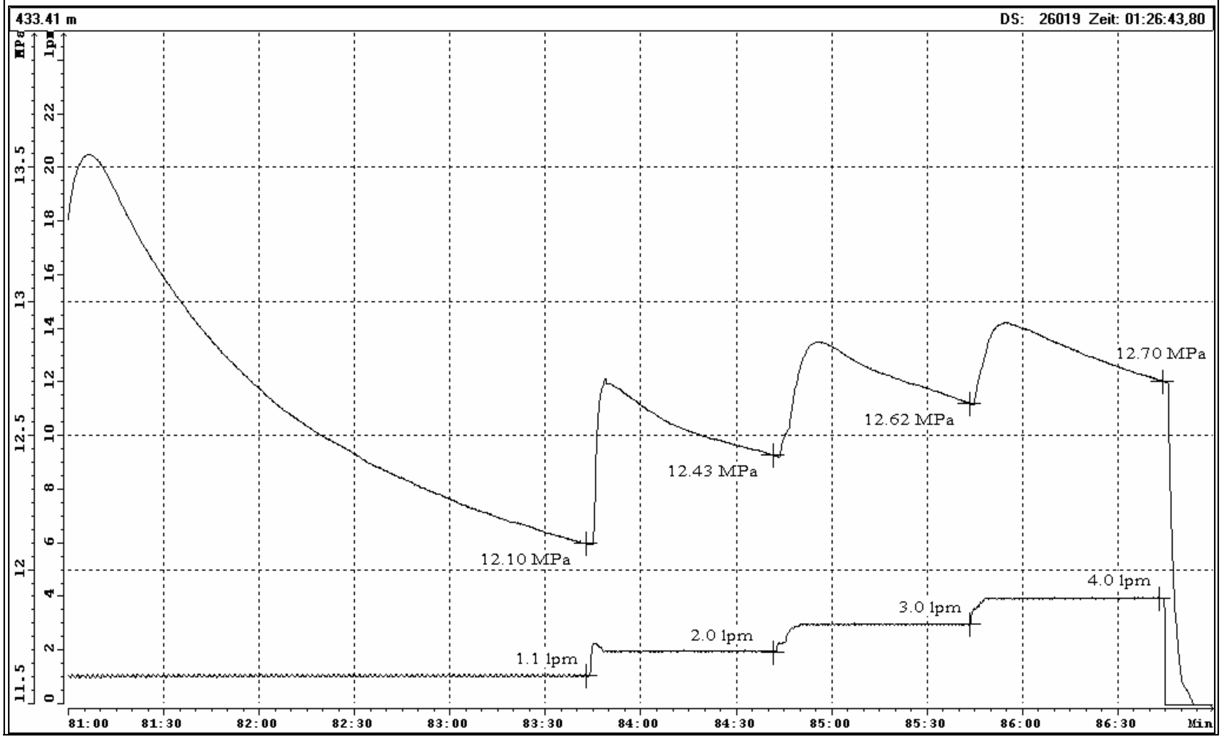
Test at 433.41 m MD: Estimation of $P_{si, min}$ (5. Refrac - Cycle)



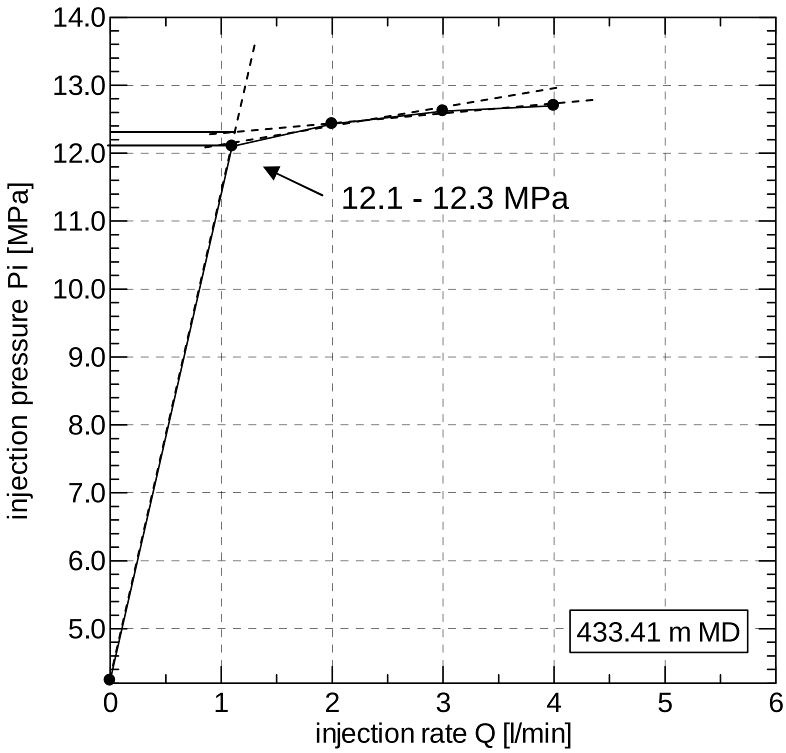
Test at 433.41 m MD: Estimation of P_{si} (5. Refrac - Cycle)



Test at 433.41 m MD: Analysis of Slow - Pump / Step - Rate - Test

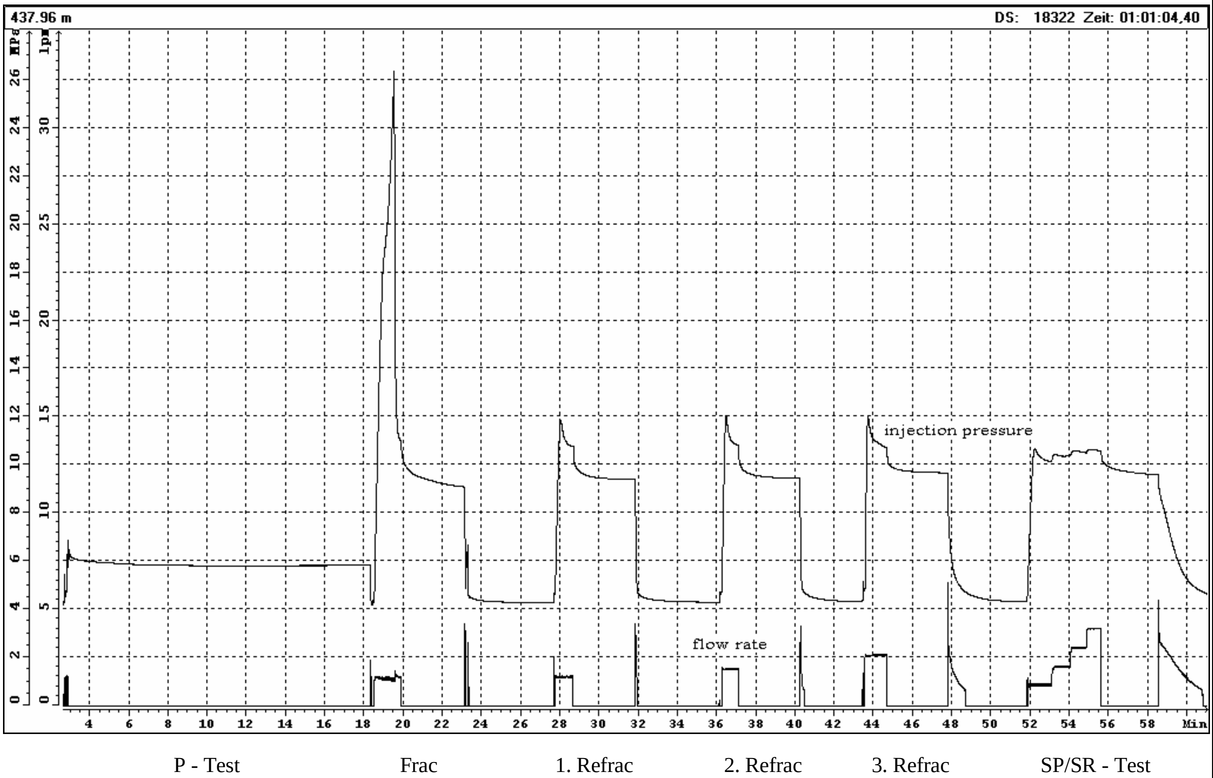


Test at 433.41 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 16 AT 437.96 m MD / 434.78 m TVD

Test at 437.96 m MD: Overview - Plot



TEST SUMMARY / ANALYSIS / REMARKS

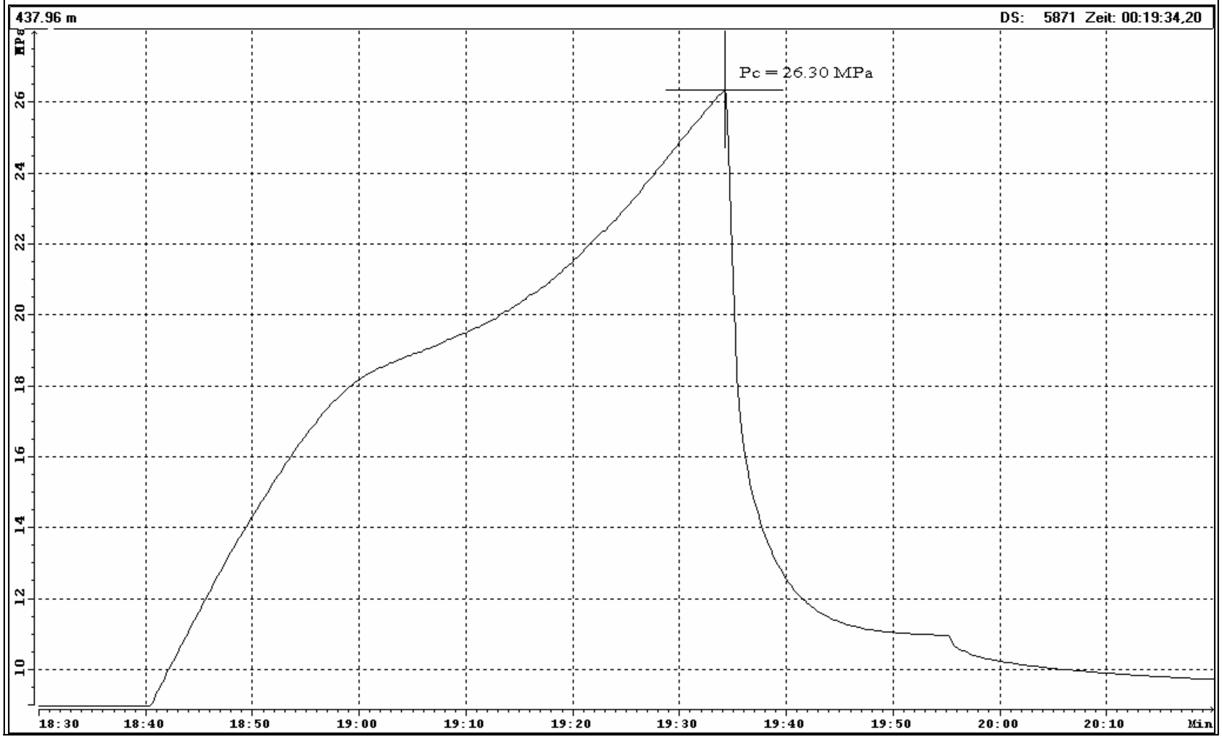
P - Test : pressure decrease: 0.37 MPa in 629 sec., followed by a minor increase of 0.04 MPa in 286 sec.

Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 2.0	Vr (l) = 0.75
1. Refrac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.4	Vr (l) = 1.25
2. Refrac - cycle	Qi (lpm) = 1.9	Vi (l) = 1.6	Vr (l) = 1.5
3. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 2.9	Vr (l) = 3.0
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 8.7	Vr (l) = 8.0

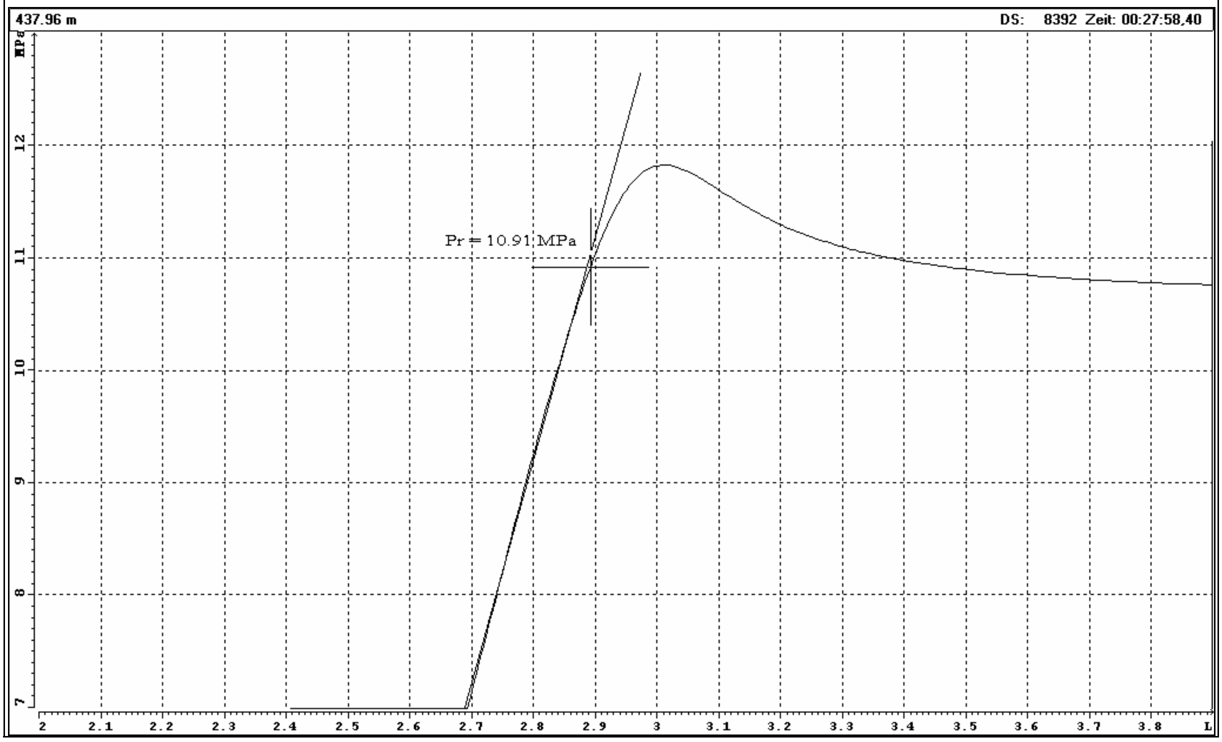
total injected volume (l): 16.6 recovered volume (l): 14.5 or 87.3 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event. However, the cycle also demonstrates a change of system stiffness dP/dV at about 15 MPa, followed by a pressure increase up to the breakdown pressure.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield nearly identical fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

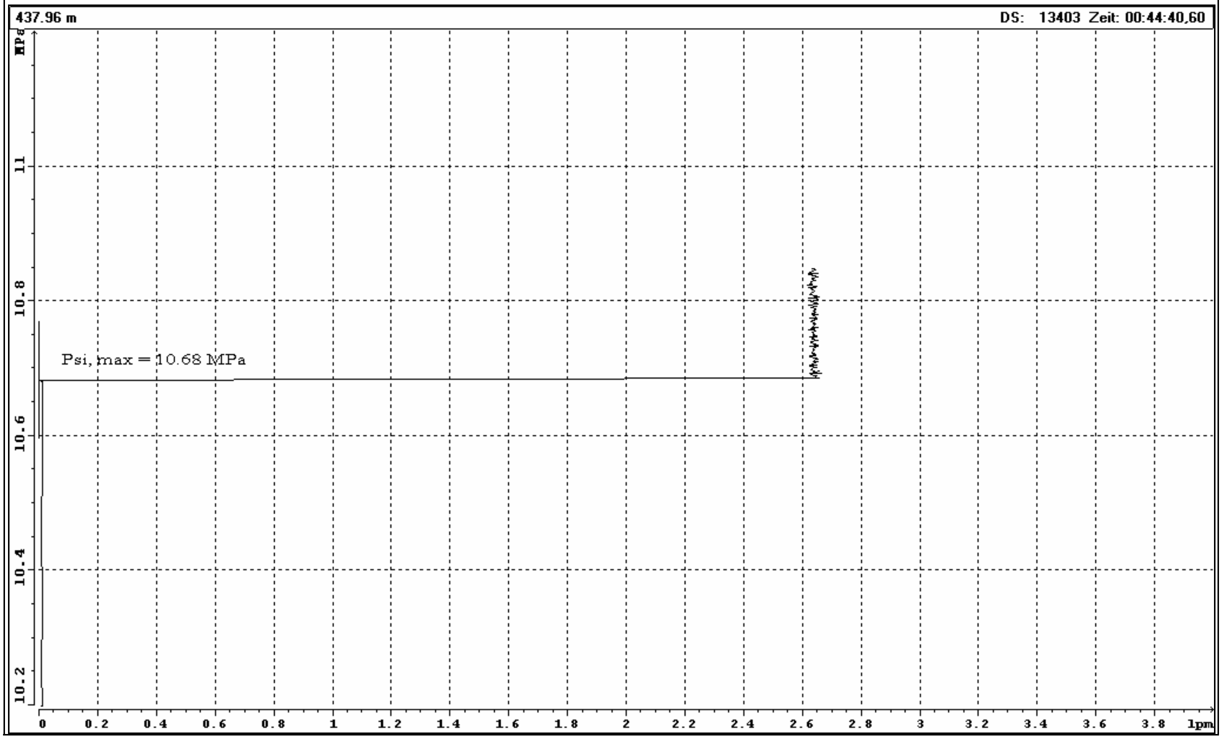
Test at 437.96 m MD: Estimation of P_c (Frac - Cycle)



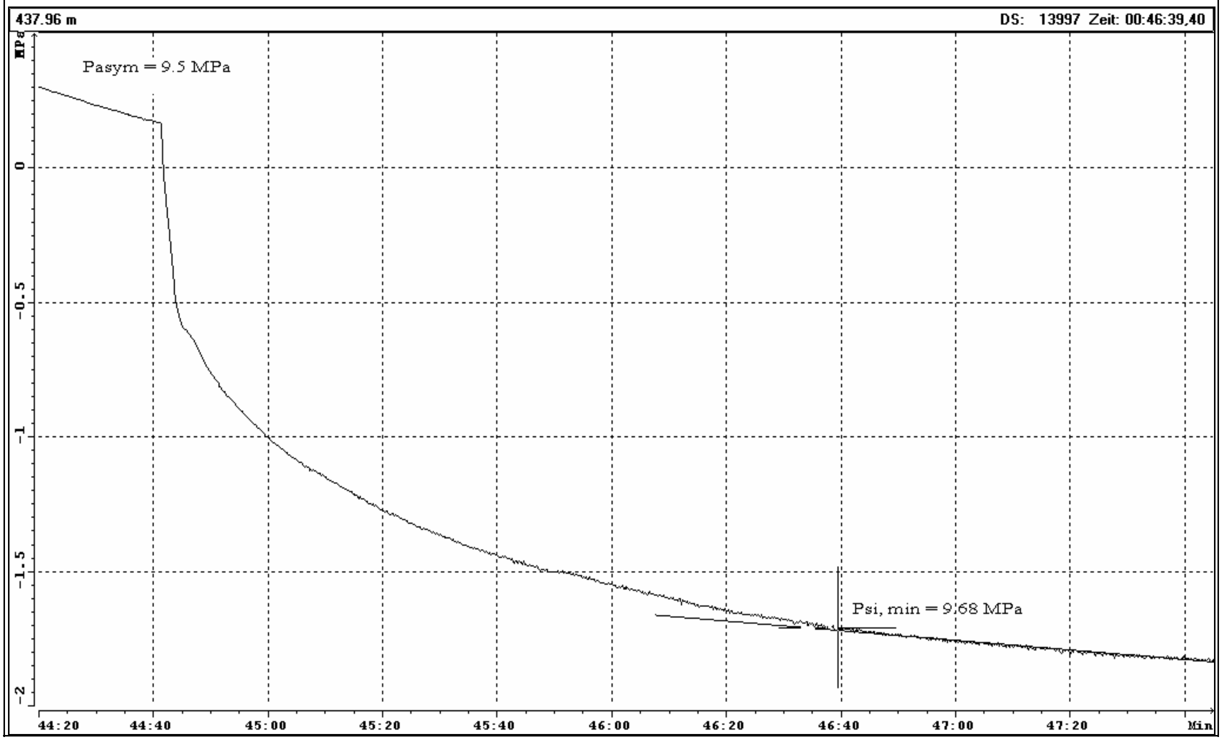
Test at 437.96 m MD: Estimation of P_r (1. Refrac - Cycle)



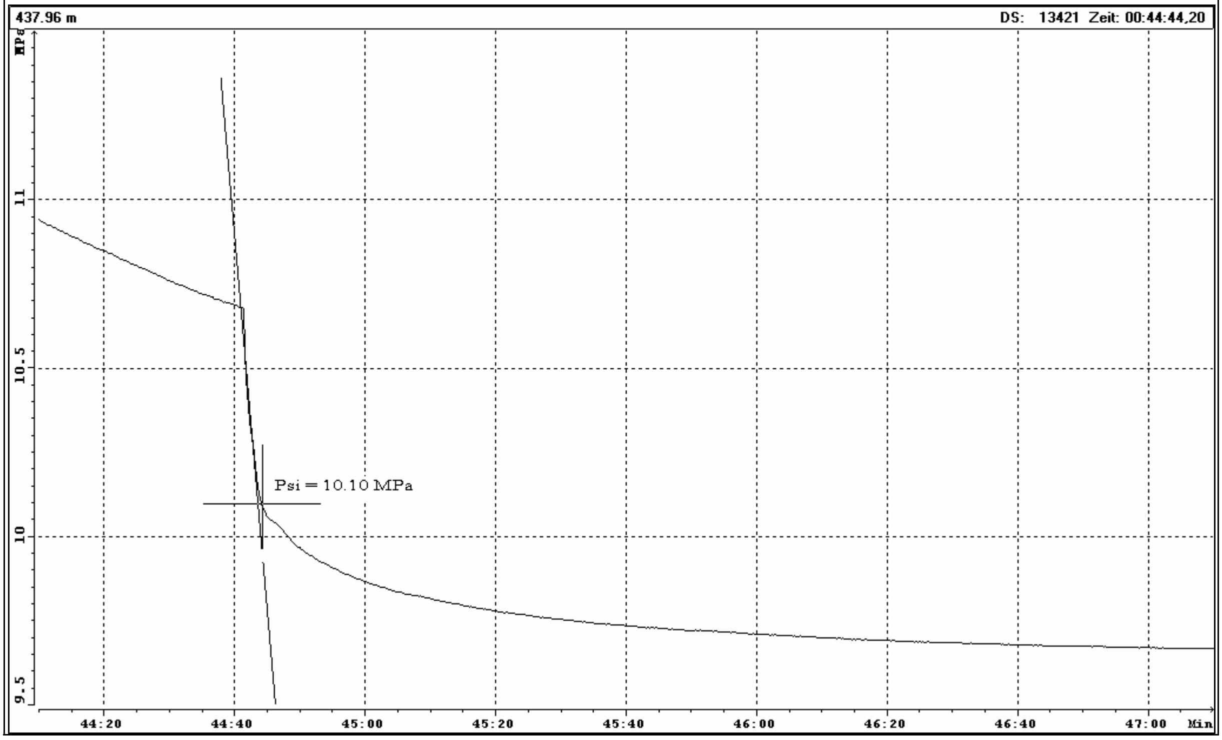
Test at 437.96 m MD: Estimation of $P_{si,\,max}$ (3. Refrac - Cycle)



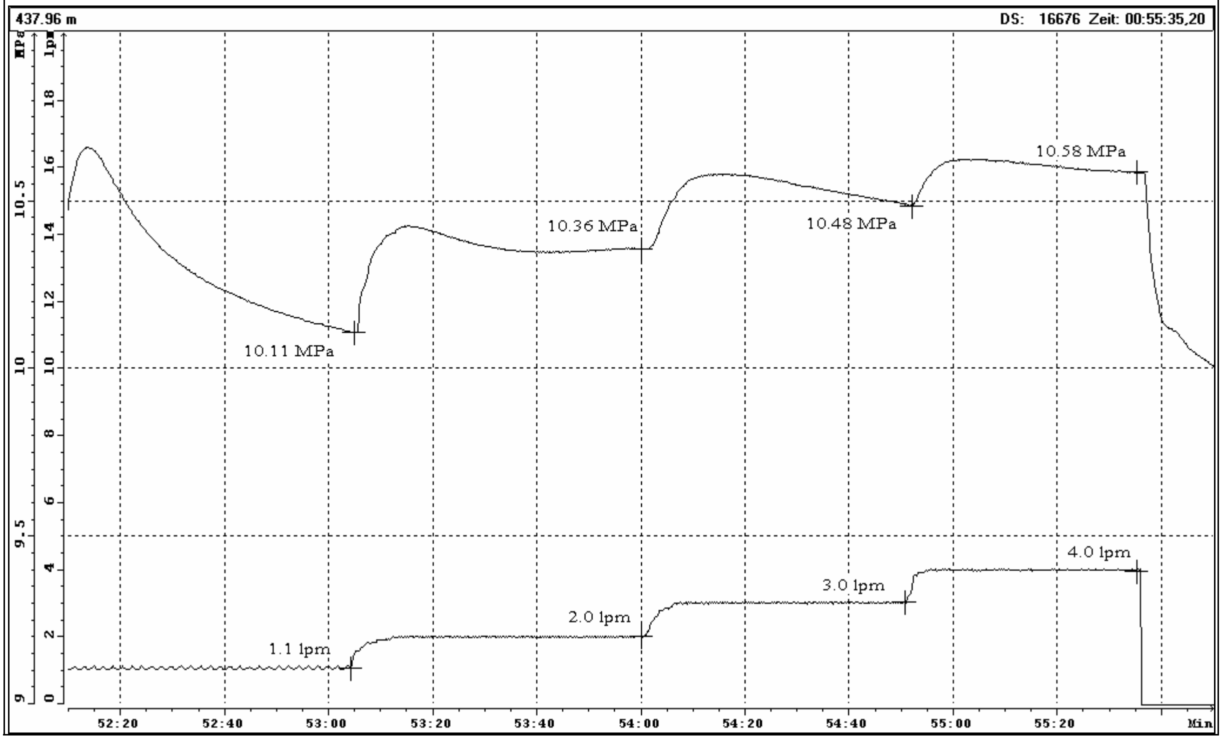
Test at 437.96 m MD: Estimation of $P_{si,\,min}$ (3. Refrac - Cycle)



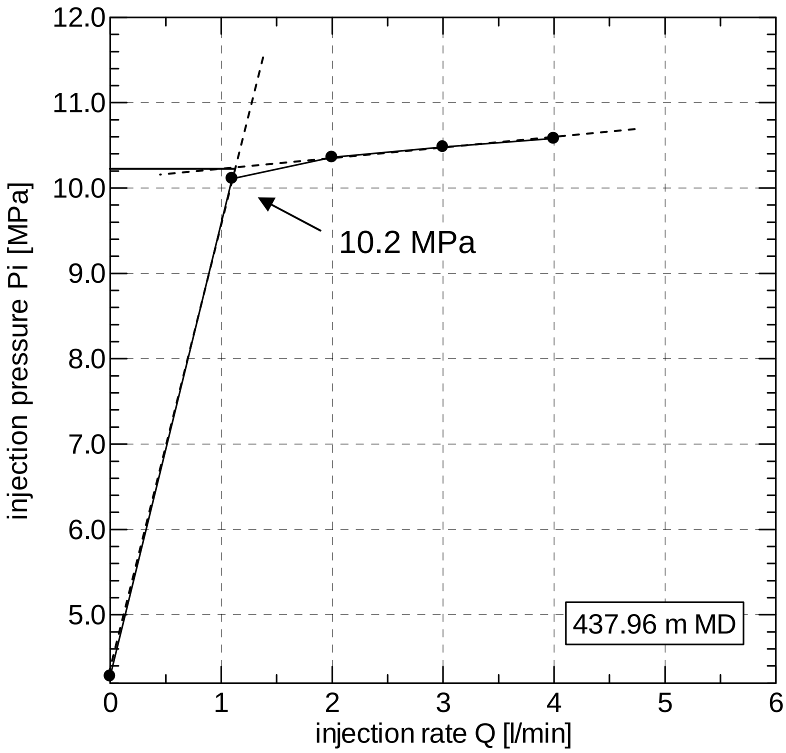
Test at 437.96 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 437.96 m MD: Analysis of Slow - Pump / Step - Rate - Test

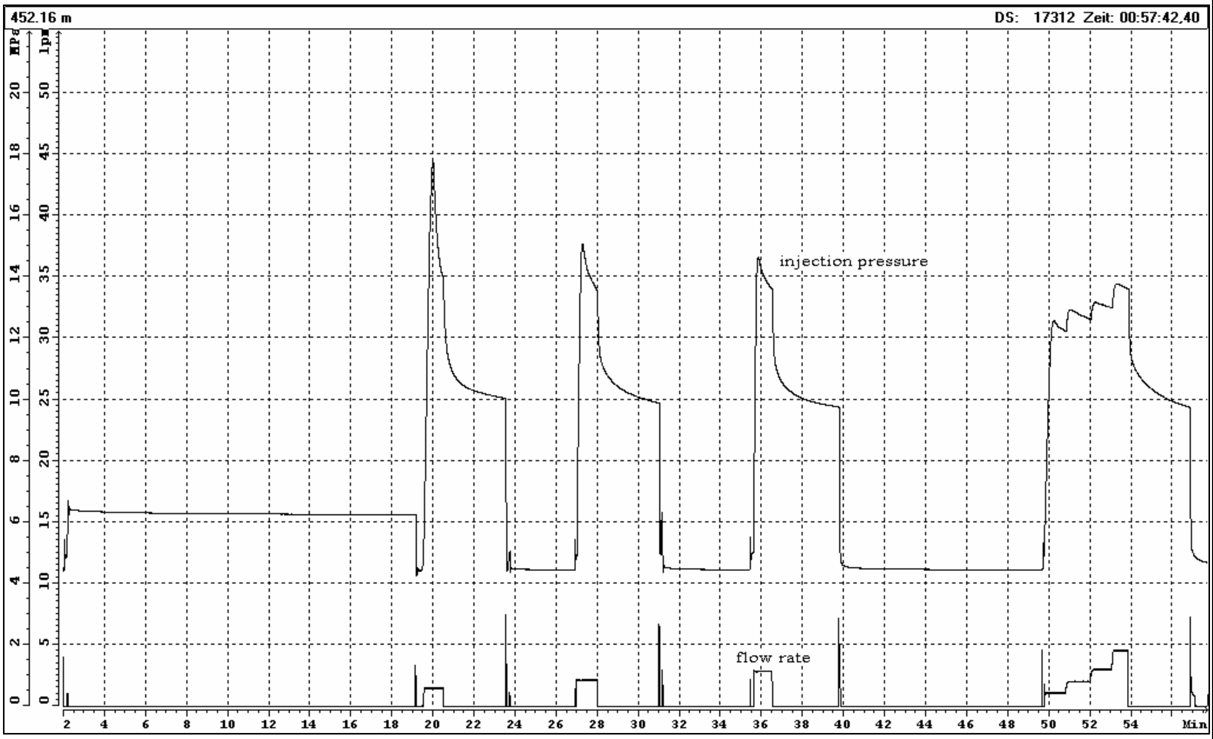


Test at 437.96 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 9 AT 452.16 m MD / 448.81 m TVD

Test at 452.16 m MD : Overview - Plot



P - Test | Frac (1. Refrac) | 2. Refrac | 3. Refrac | SP/SR - Test

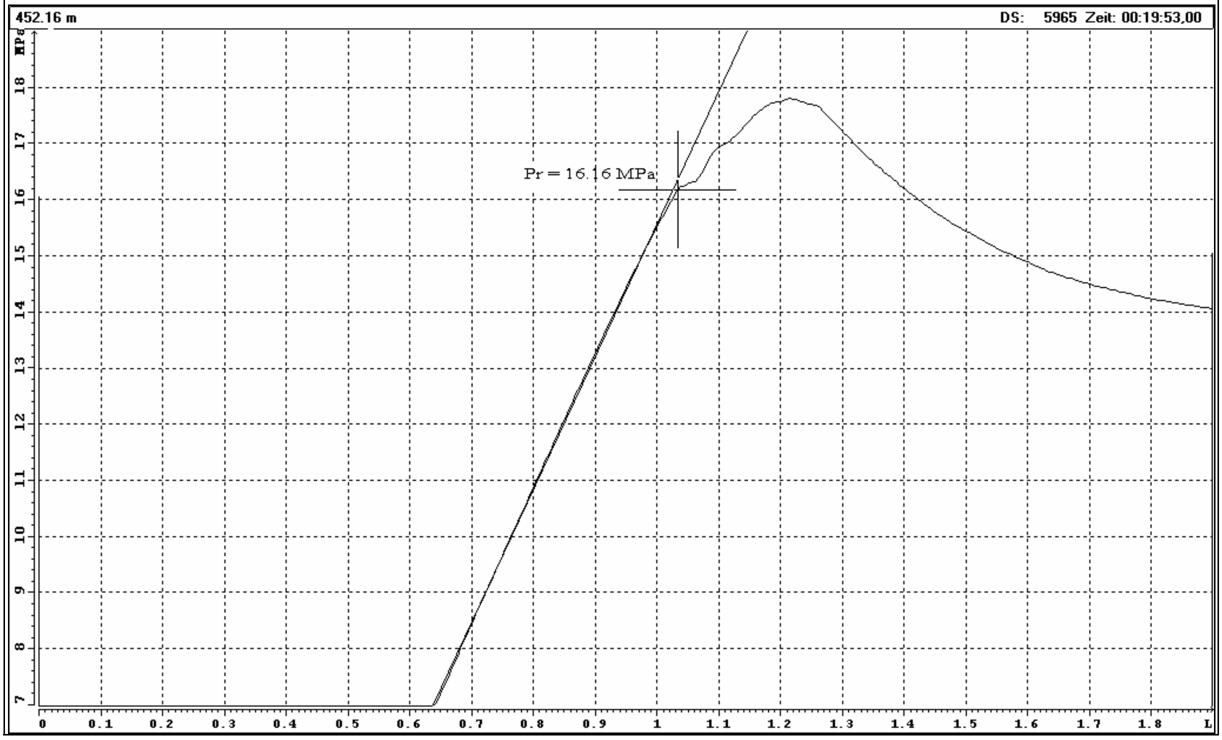
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 0.16 MPa in 1004 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.5	Vi (l) = 1.4	Vr (l) = 0.3
2. Refrac - cycle	Qi (lpm) = 2.1	Vi (l) = 2.2	Vr (l) = 0.75
3. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 2.6	Vr (l) = 1.5
SP/SR - test	Qi (lpm) = 1.1-4.5	Vi (l) = 10.3	Vr (l) = 2.0

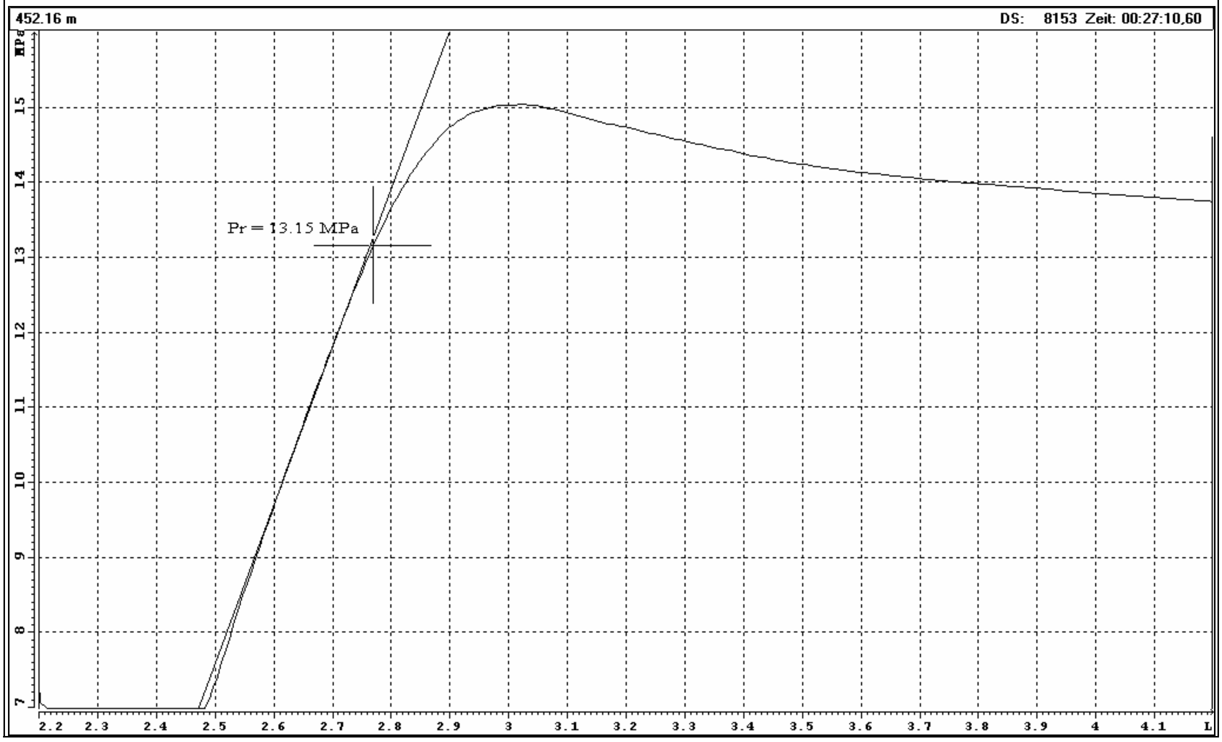
total injected volume (l): 16.5 recovered volume (l): 4.55 or 27.6 %

- Initial test type: HTPF-h
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no distinct breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 16.1 MPa, followed by a pressure increase up to 17.8 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

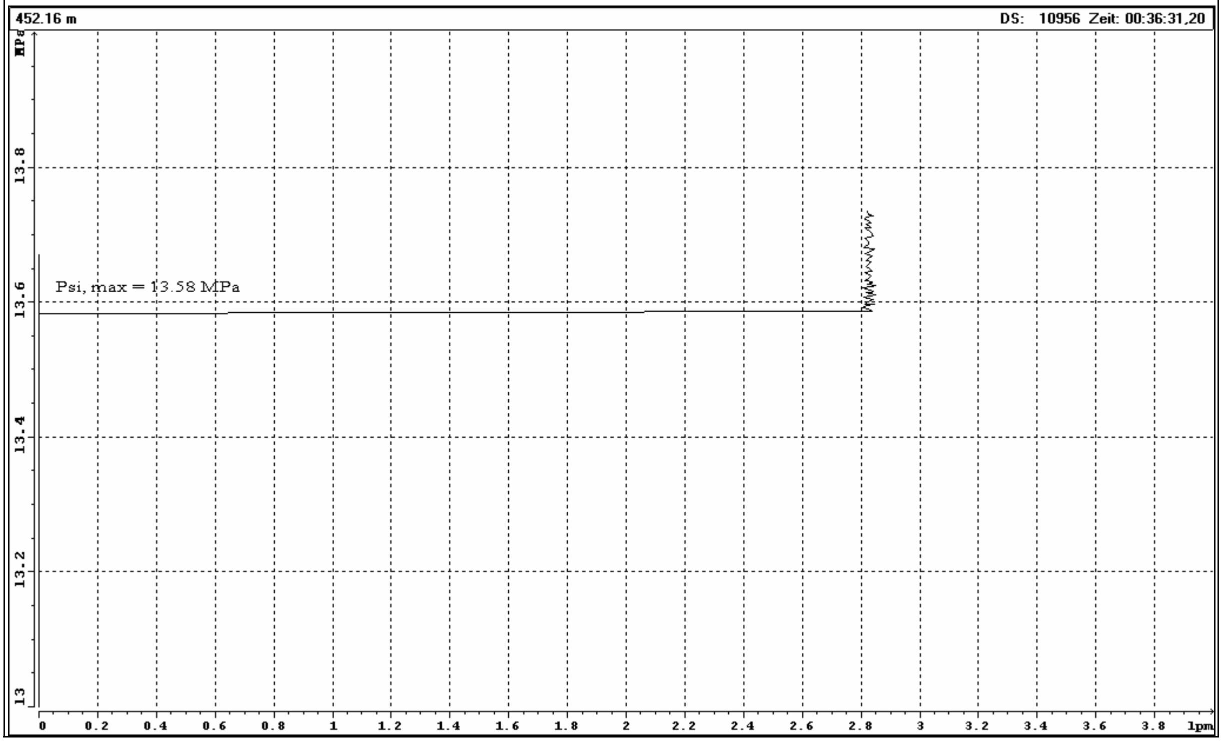
Test at 452.16 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



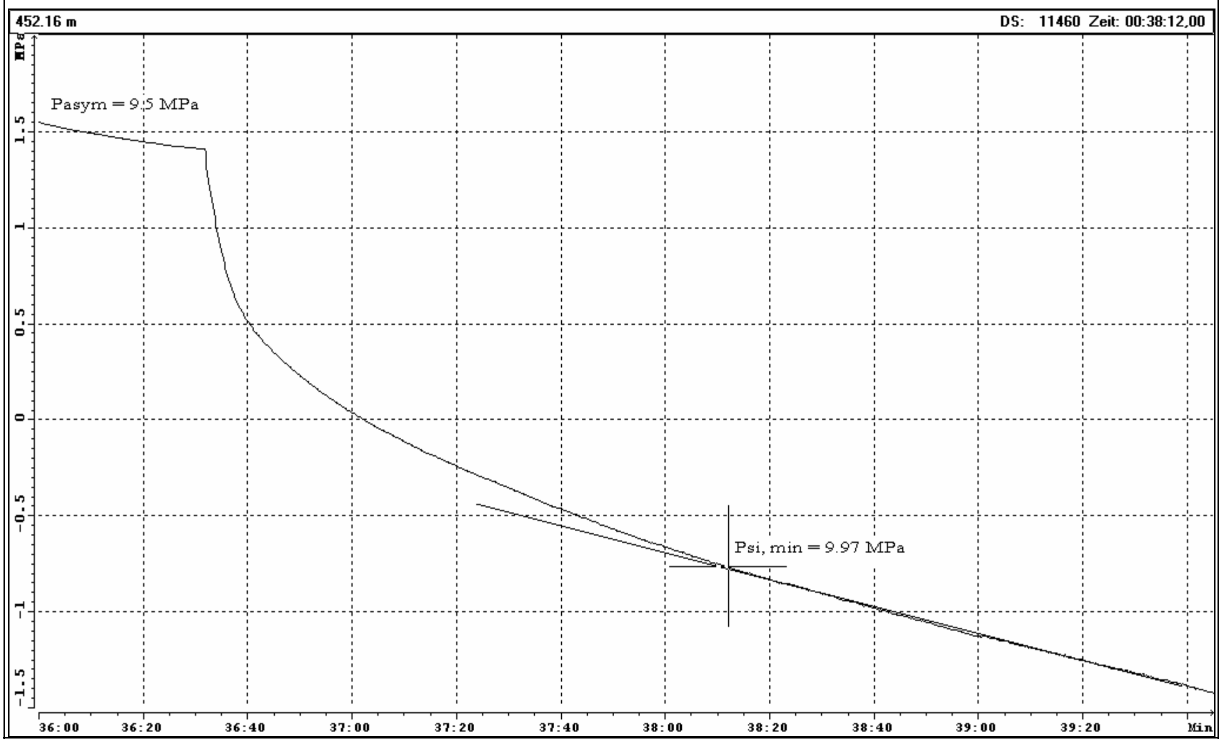
Test at 452.16 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



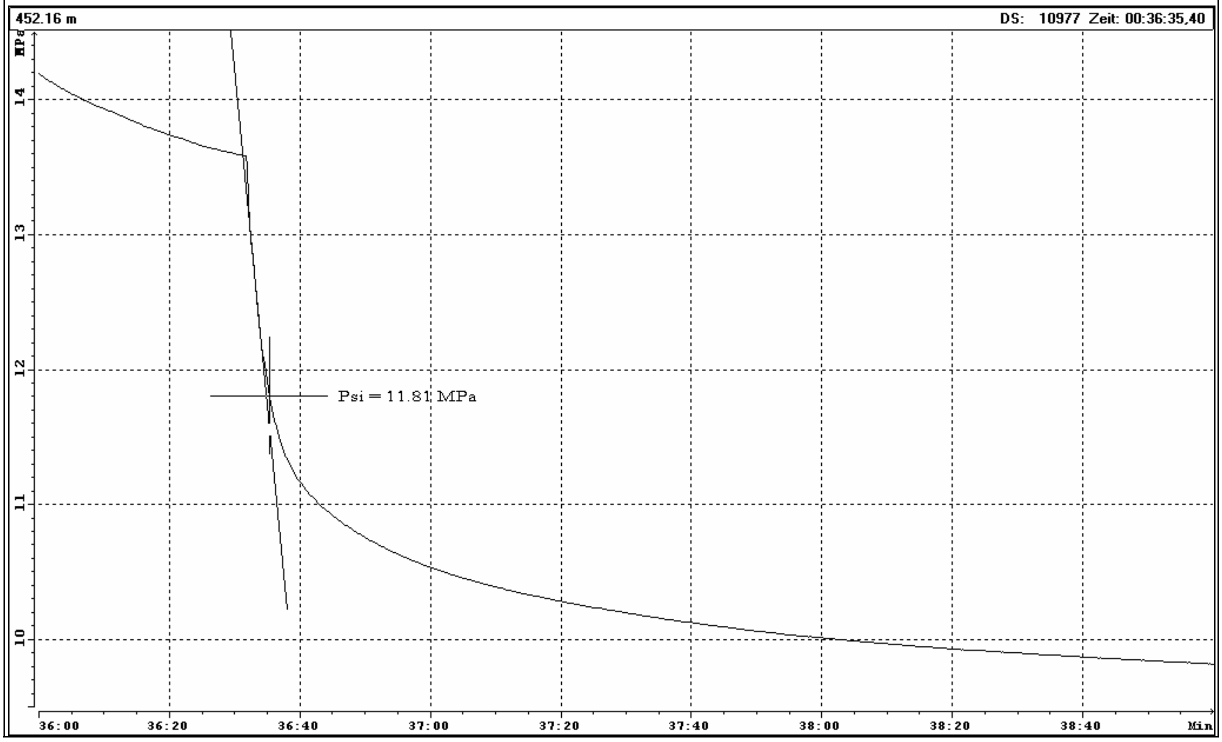
Test at 452.16 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



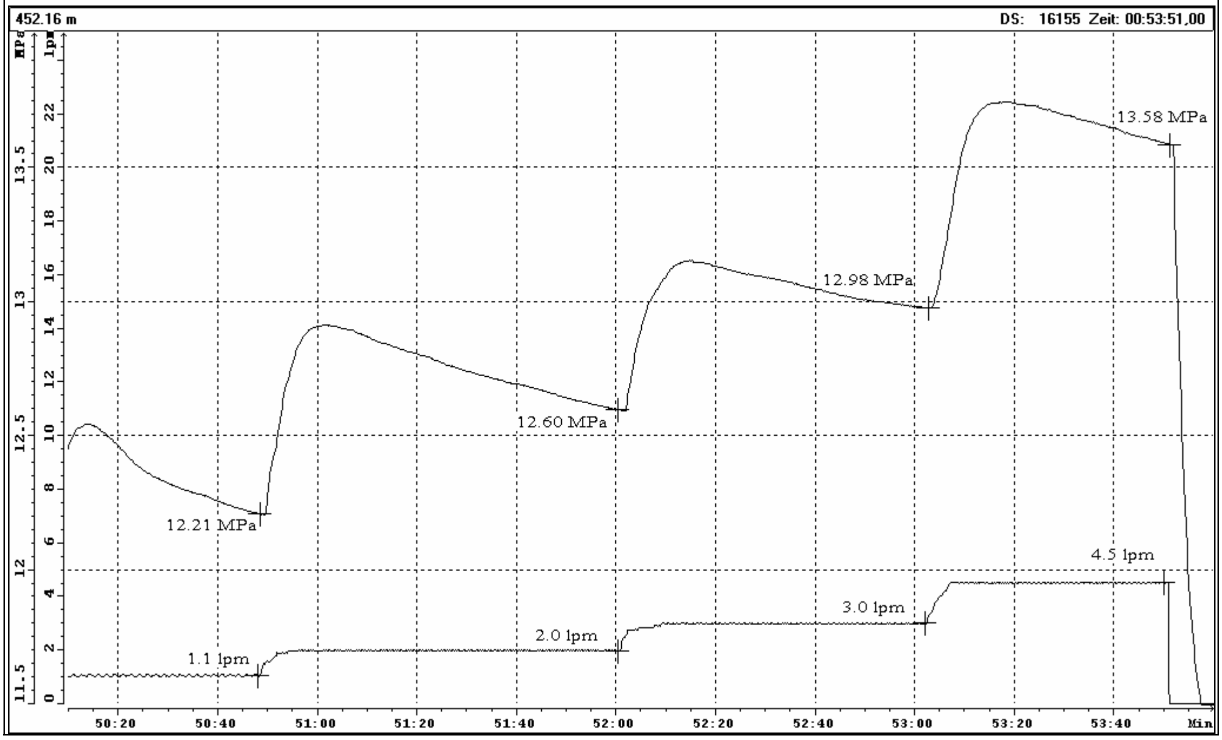
Test at 452.16 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



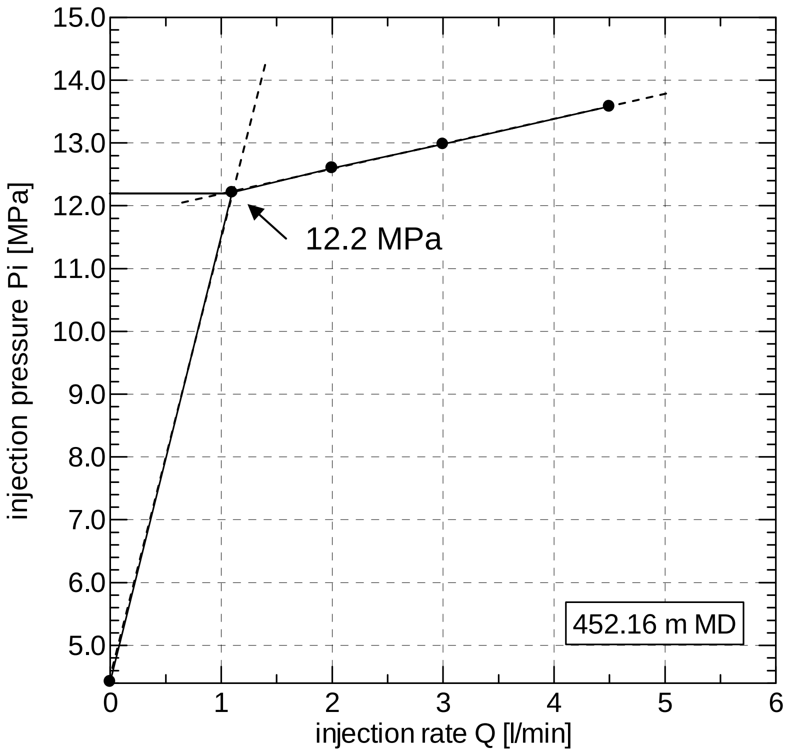
Test at 452.16 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 452.16 m MD: Analysis of Slow - Pump / Step - Rate - Test

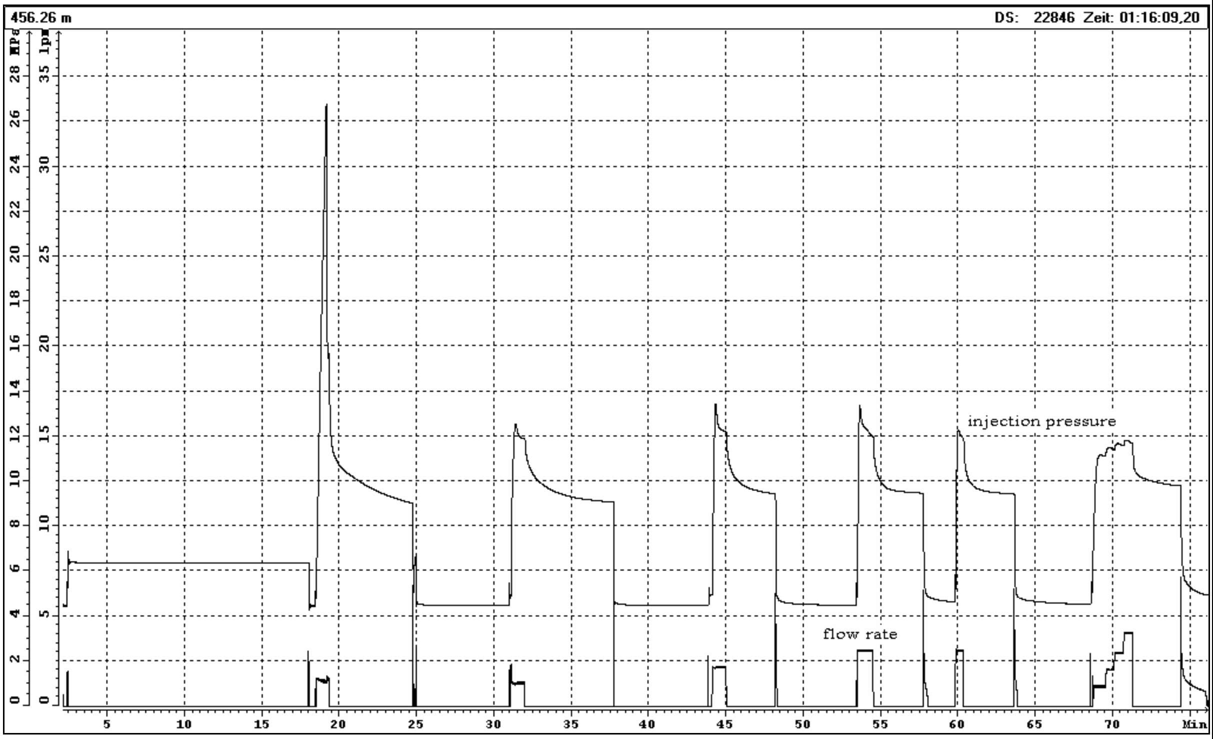


Test at 452.16 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 8 AT 456.26 m MD / 452.87 m TVD

Test at 456.26 m MD : Overview - Plot



TEST SUMMARY / ANALYSIS / REMARKS

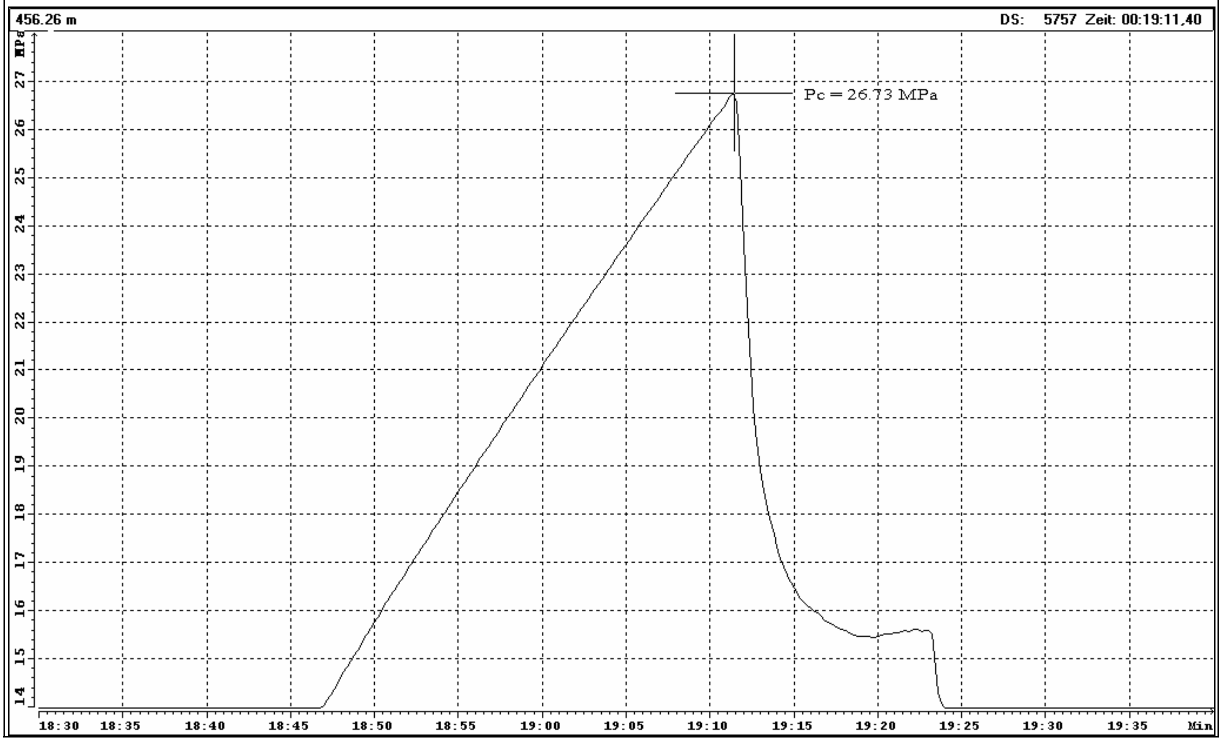
P - Test : pressure decrease: 0.03 MPa in 922 sec.

Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.25	Vr (l) = 0.6
1. Refrac - cycle	Qi (lpm) = 1.3	Vi (l) = 1.2	Vr (l) = 0.6
2. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 2.0	Vr (l) = 1.3
3. Refrac - cycle	Qi (lpm) = 3.1	Vi (l) = 3.2	Vr (l) = 1.6
4. Refrac - cycle	Qi (lpm) = 3.1	Vi (l) = 1.6	Vr (l) = 2.3
SP/SR - test	Qi (lpm) = 1.1-4.1	Vi (l) = 6.2	Vr (l) = 3.5

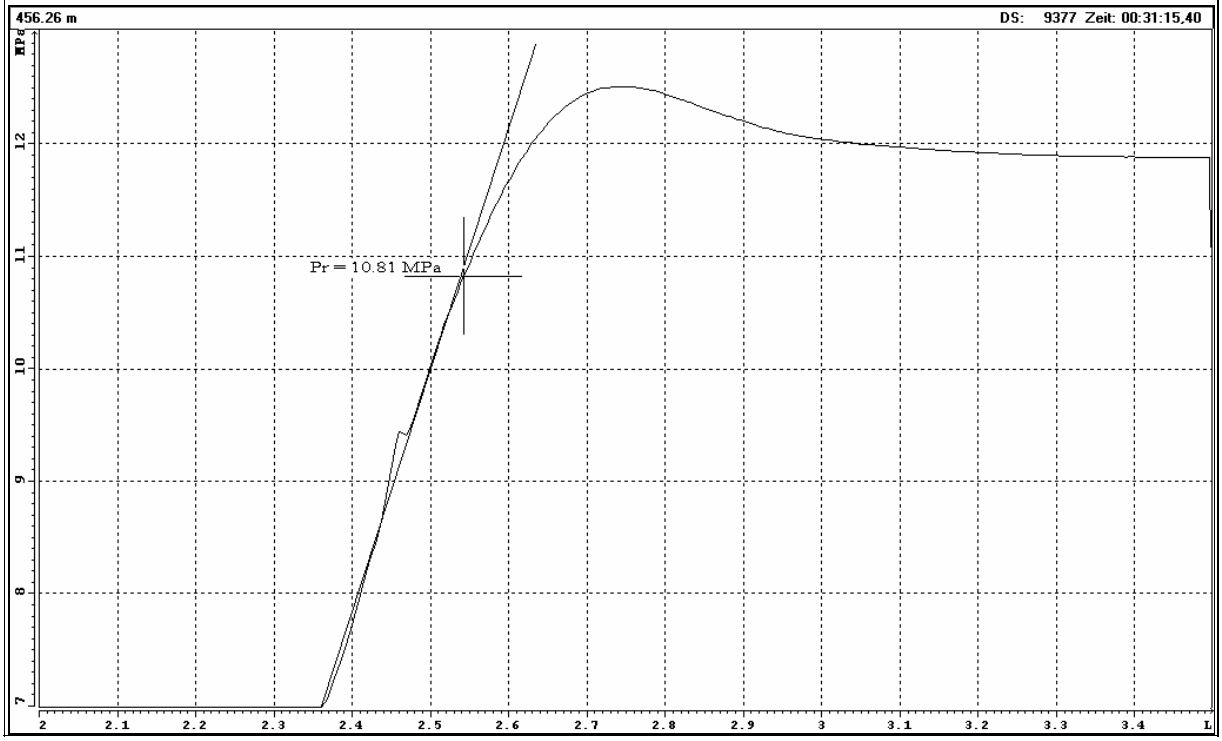
total injected volume (l): 15.45 recovered volume (l): 9.9 or 64.1 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. and 2. refrac - cycle, since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

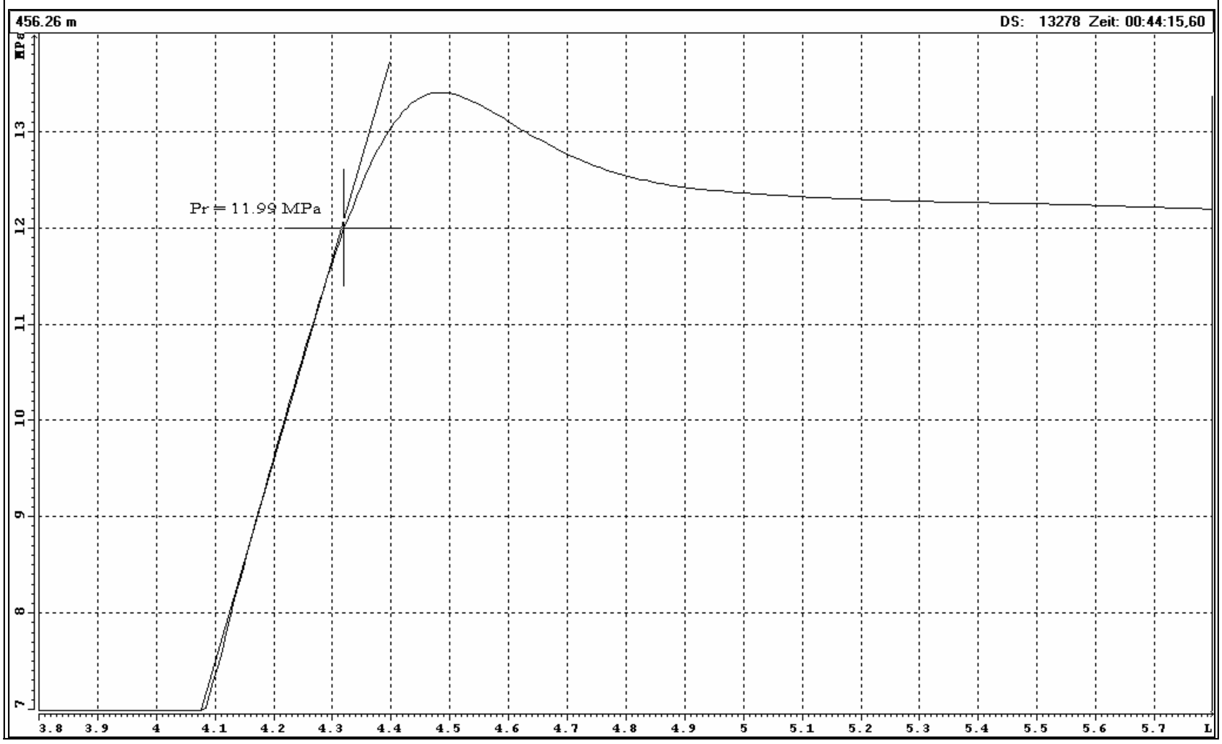
Test at 456.26 m MD: Estimation of P_c (Frac - Cycle)



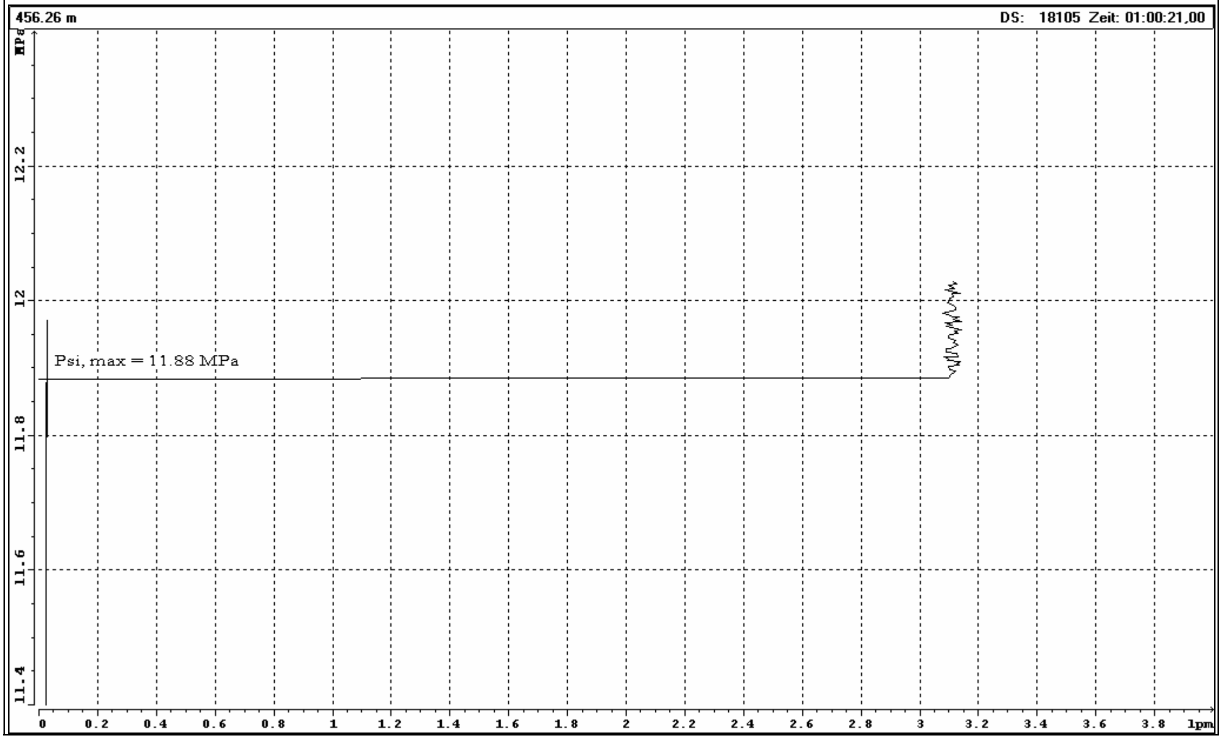
Test at 456.26 m MD: Estimation of P_r (1. Refrac - Cycle)



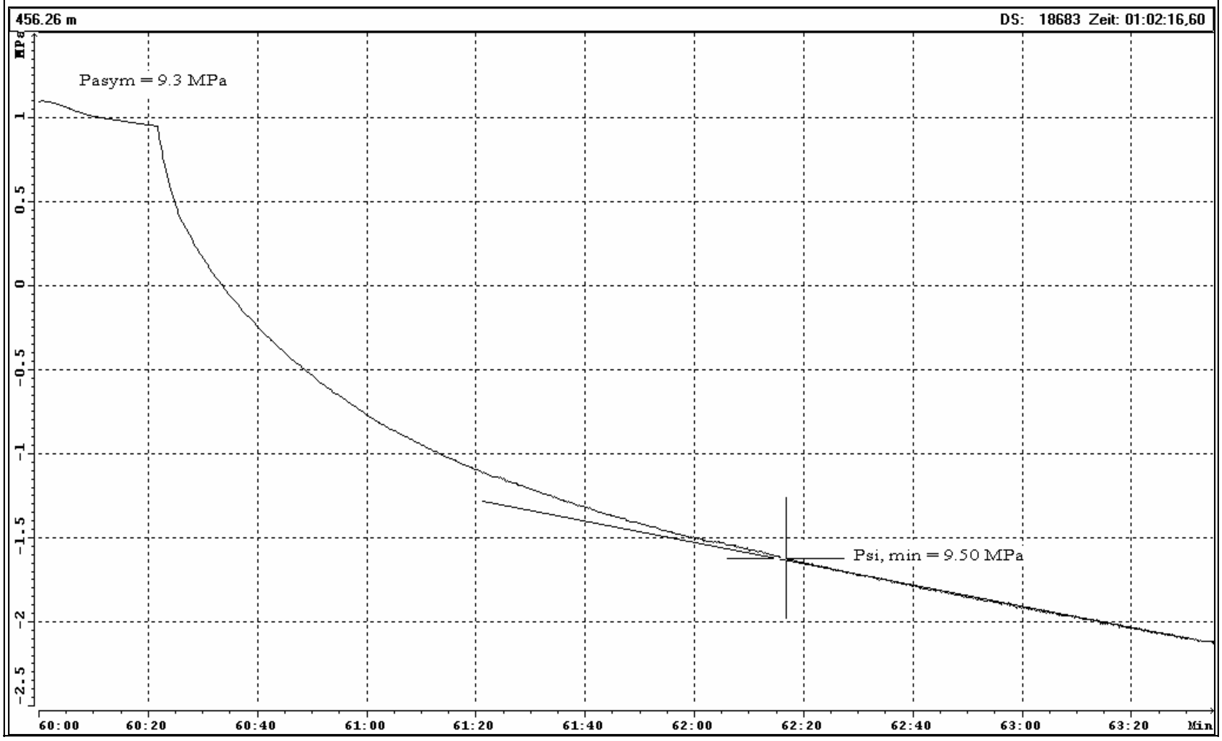
Test at 456.26 m MD: Estimation of P_r (2. Refrac - Cycle)



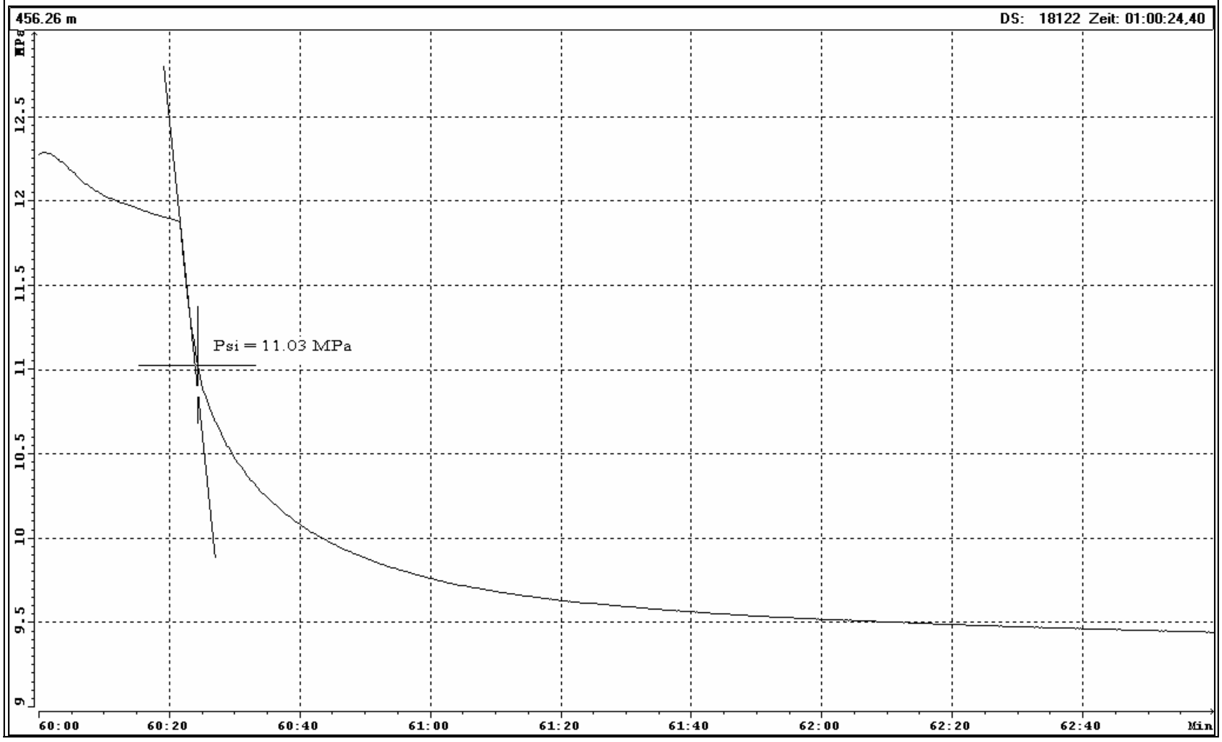
Test at 456.26 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



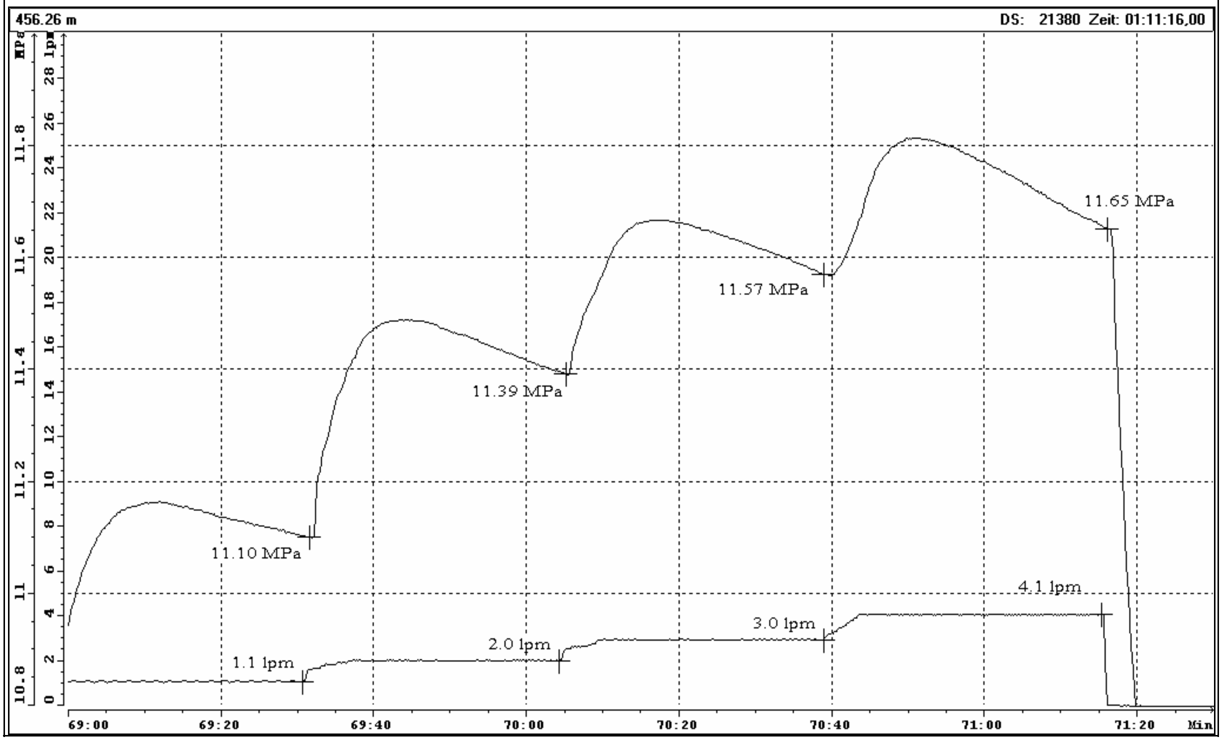
Test at 456.26 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



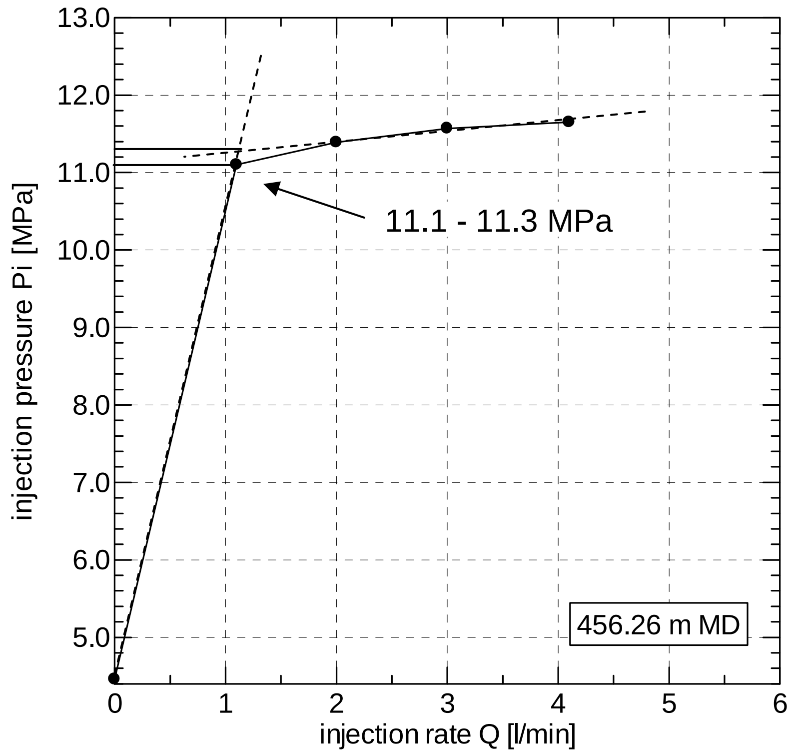
Test at 456.26 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 456.26 m MD: Analysis of Slow - Pump / Step - Rate - Test

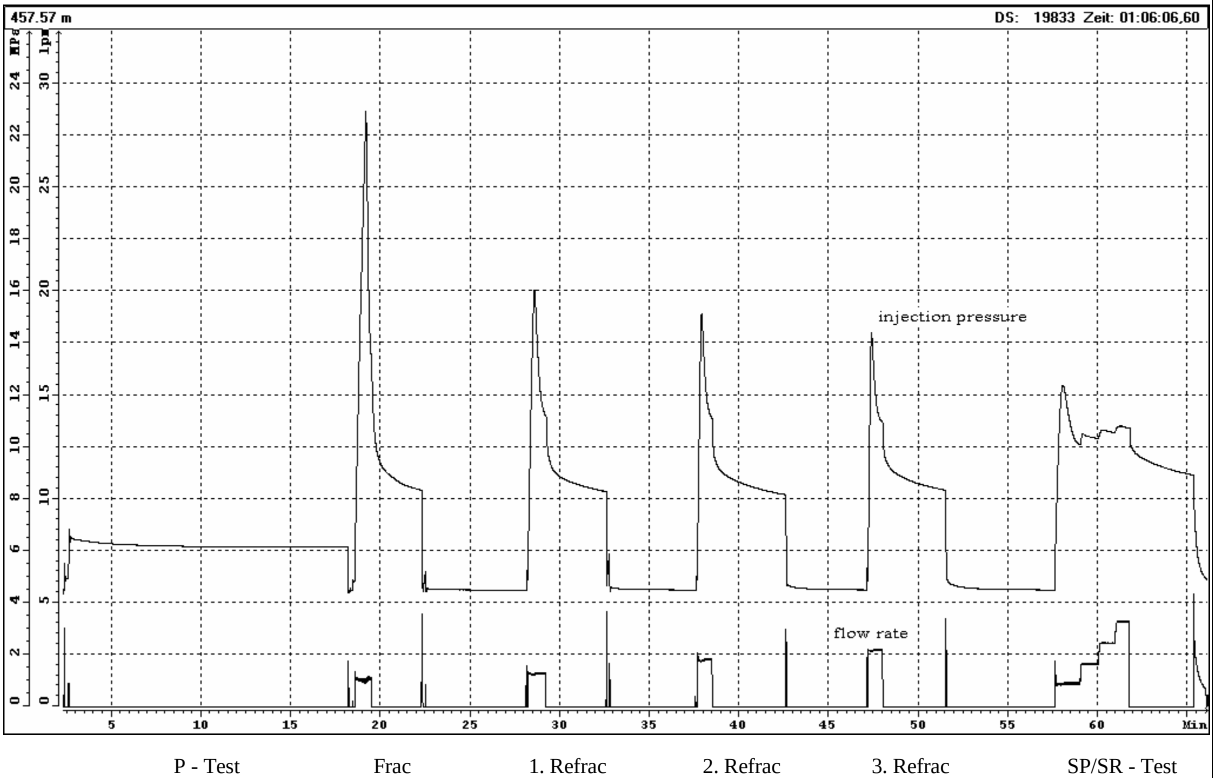


Test at 456.26 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 7 AT 457.57 m MD / 454.16 m TVD

Test at 457.57 m MD: Overview - Plot



TEST SUMMARY / ANALYSIS / REMARKS

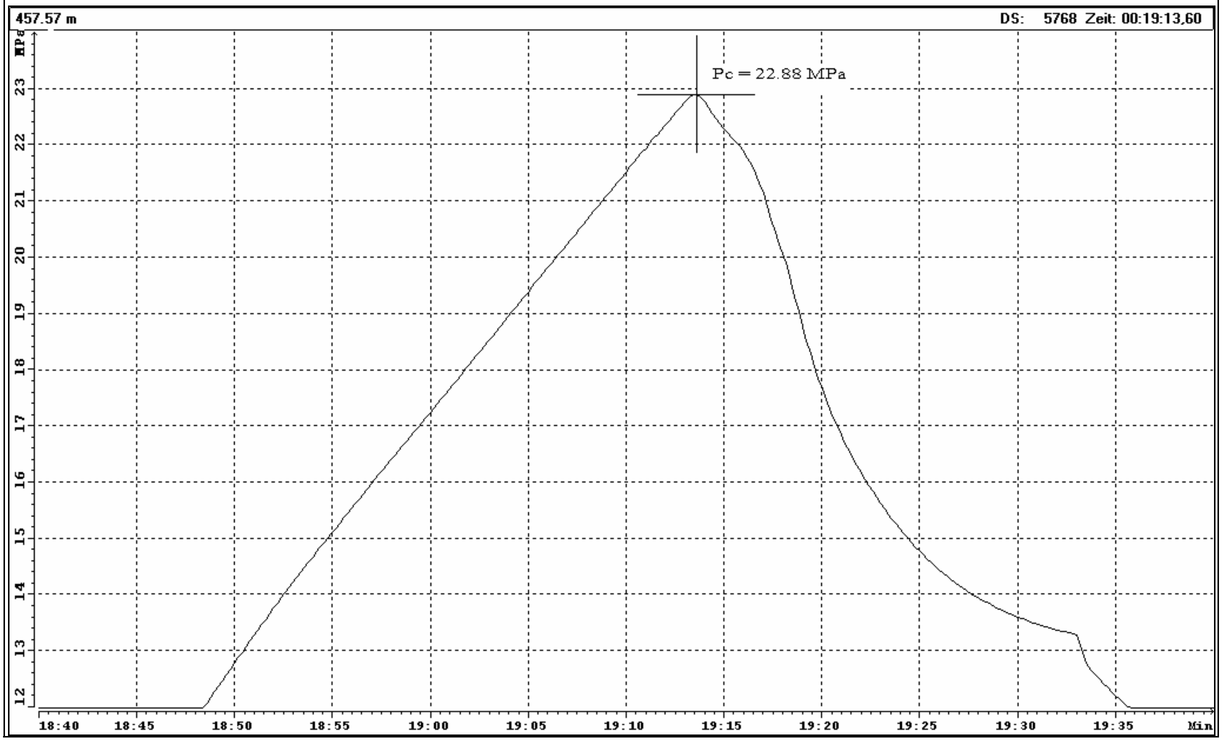
P - Test : pressure decrease: 0.31 MPa in 923 sec.

Frac - cycle	Qi (lpm) = 1.3	Vi (l) = 1.25	Vr (l) = 0.6
1. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.7	Vr (l) = 0.8
2. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 1.9	Vr (l) = 0.8
3. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 2.25	Vr (l) = 1.3
SP/SR - test	Qi (lpm) = 1.1-4.1	Vi (l) = 9.7	Vr (l) = 2.5

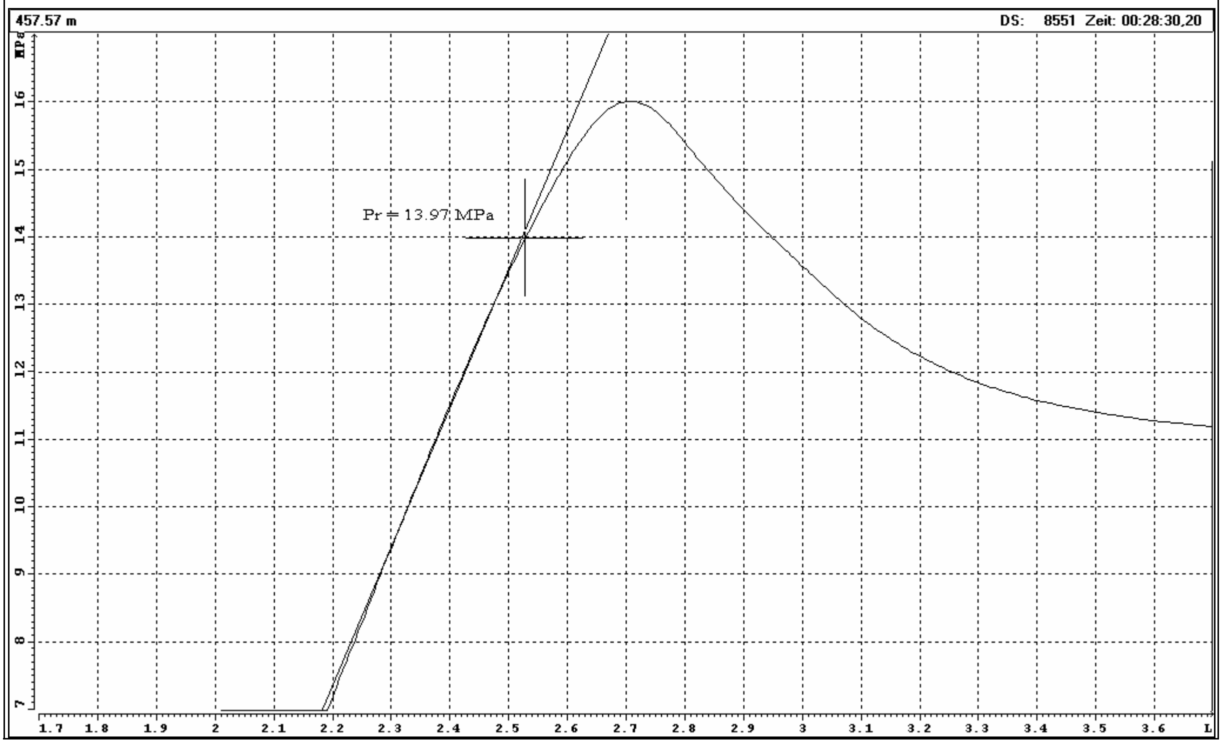
total injected volume (l): 16.8 recovered volume (l): 6.0 or 35.7 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 14 MPa, followed by a pressure increase up to 16 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the analysis, the shut - in pressure of the 3. refrac - cycle was used.

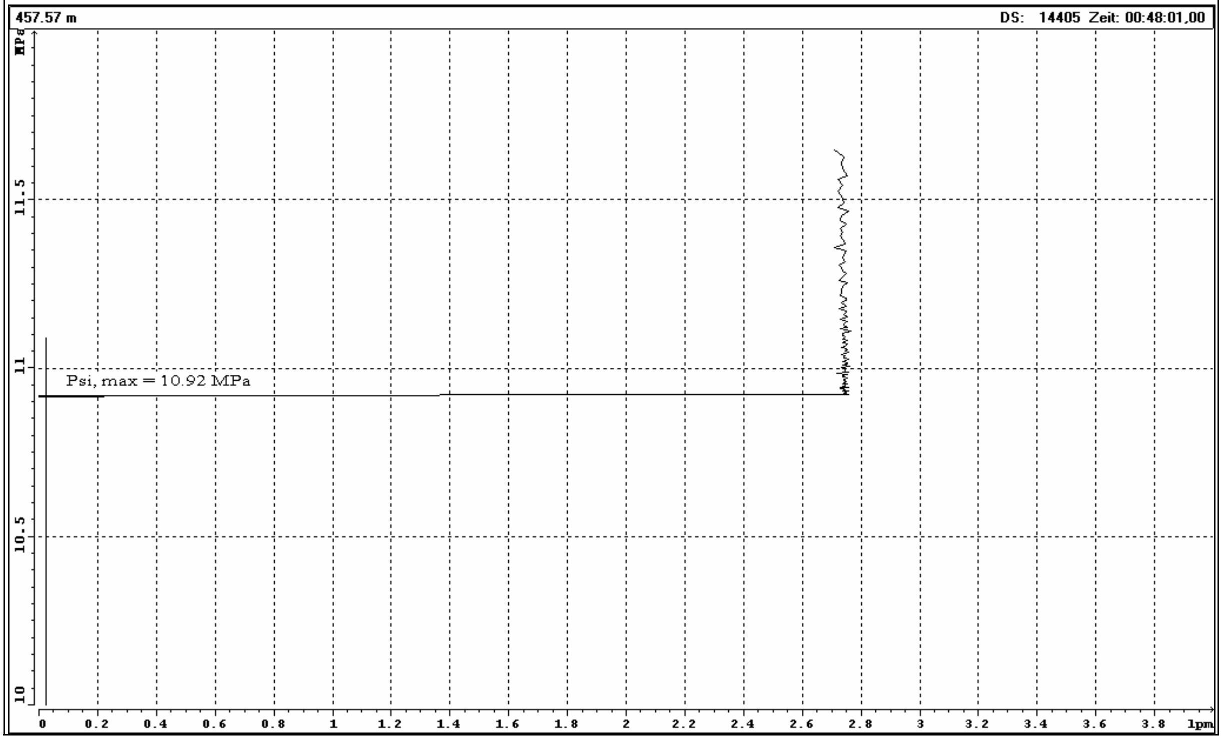
Test at 457.57 m MD: Estimation of P_c (Frac - Cycle)



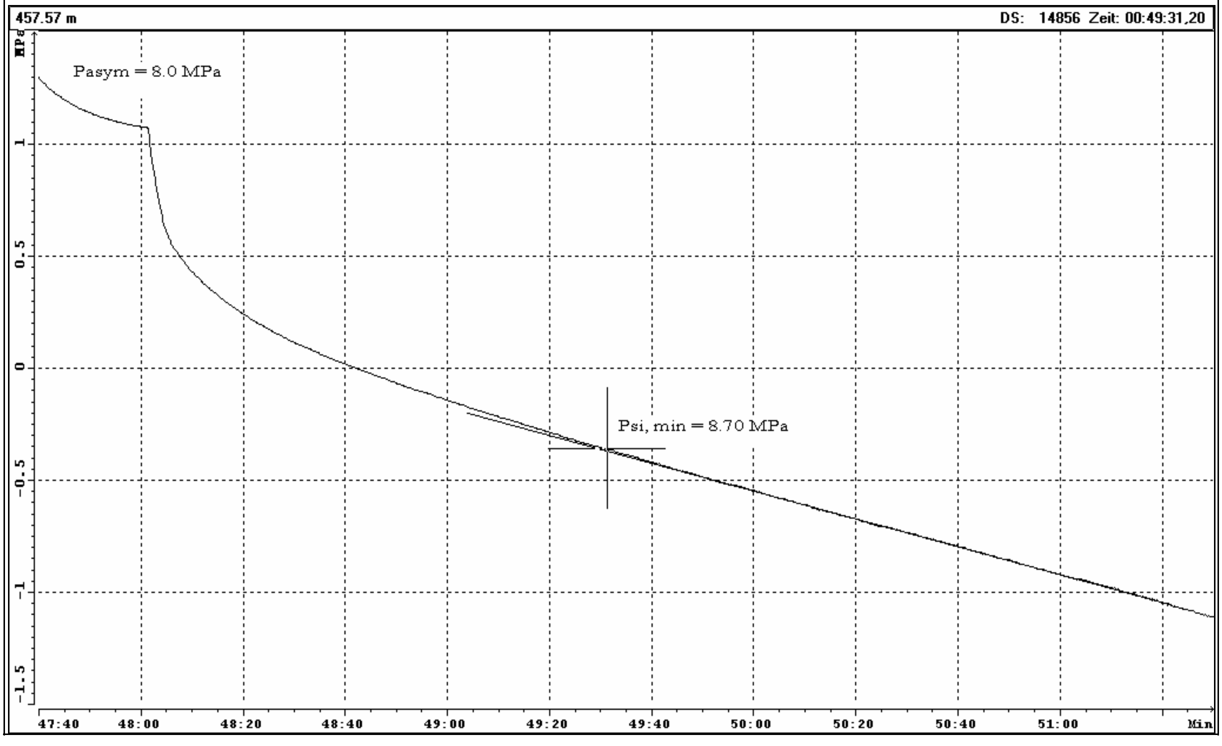
Test at 457.57 m MD: Estimation of P_r (1. Refrac - Cycle)



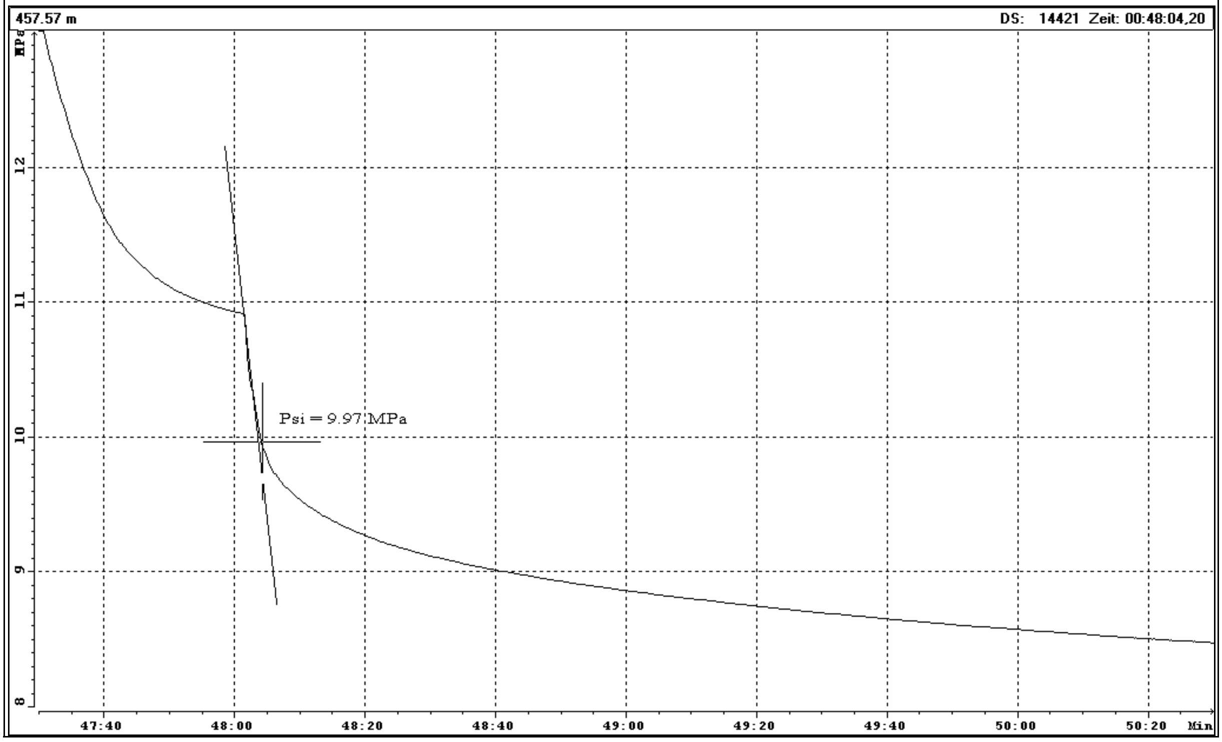
Test at 457.57 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



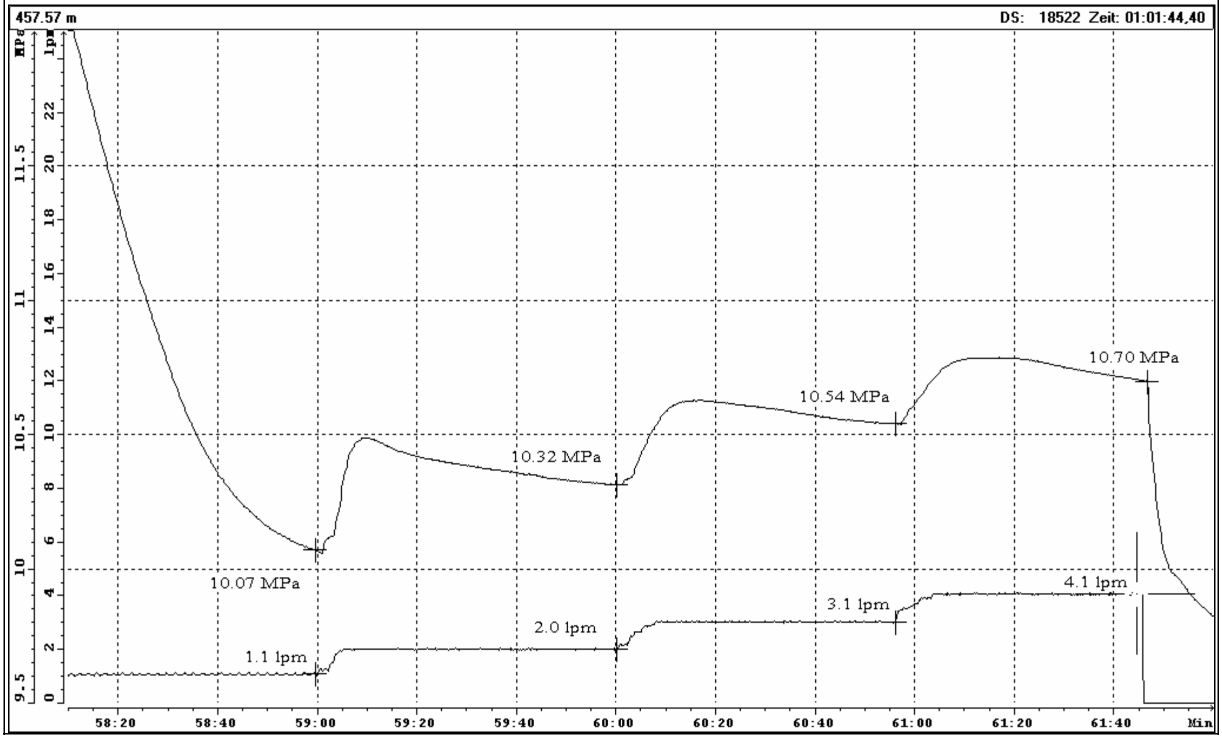
Test at 457.57 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



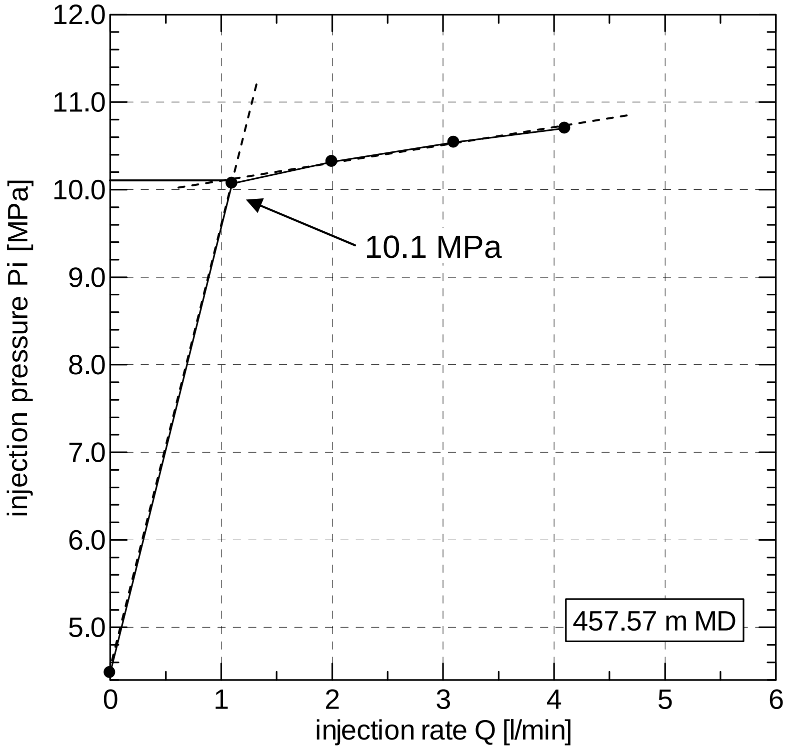
Test at 457.57 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 457.57 m MD: Analysis of Slow - Pump / Step - Rate - Test

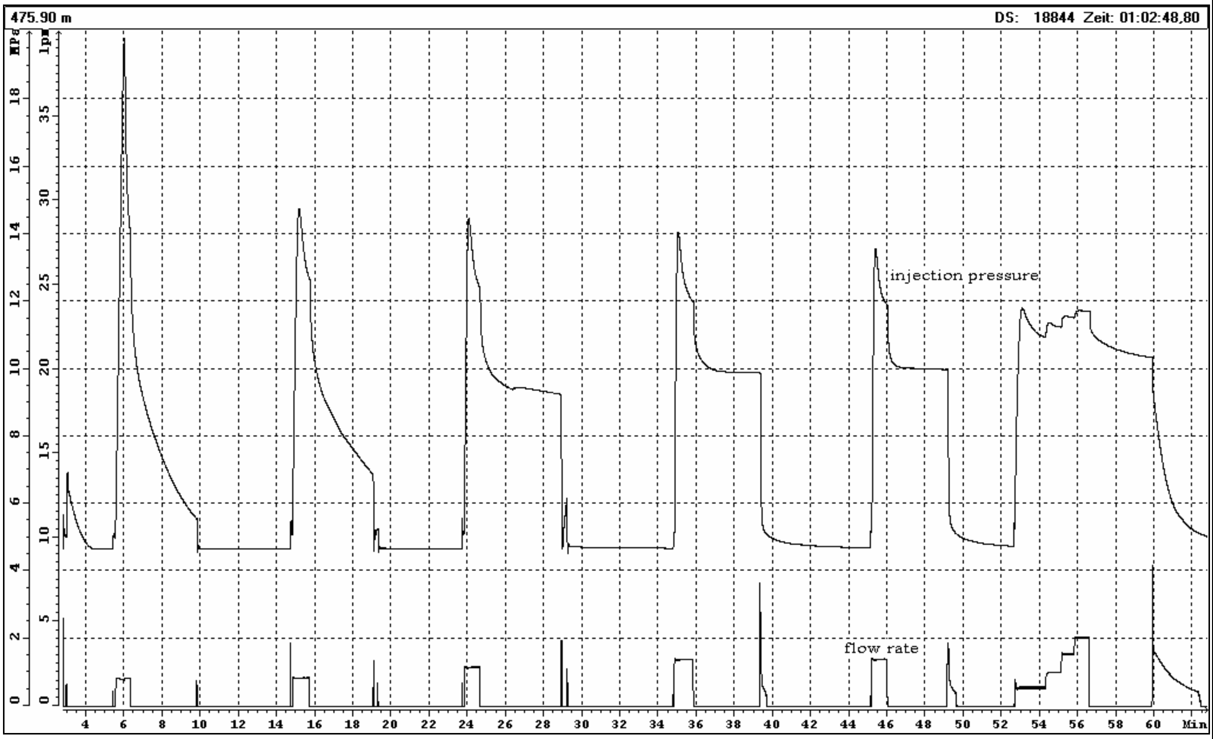


Test at 457.57 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 21 AT 475.90 m MD / 472.27 m TVD

Test at 475.90 m MD : Overview - Plot



TEST SUMMARY / ANALYSIS / REMARKS

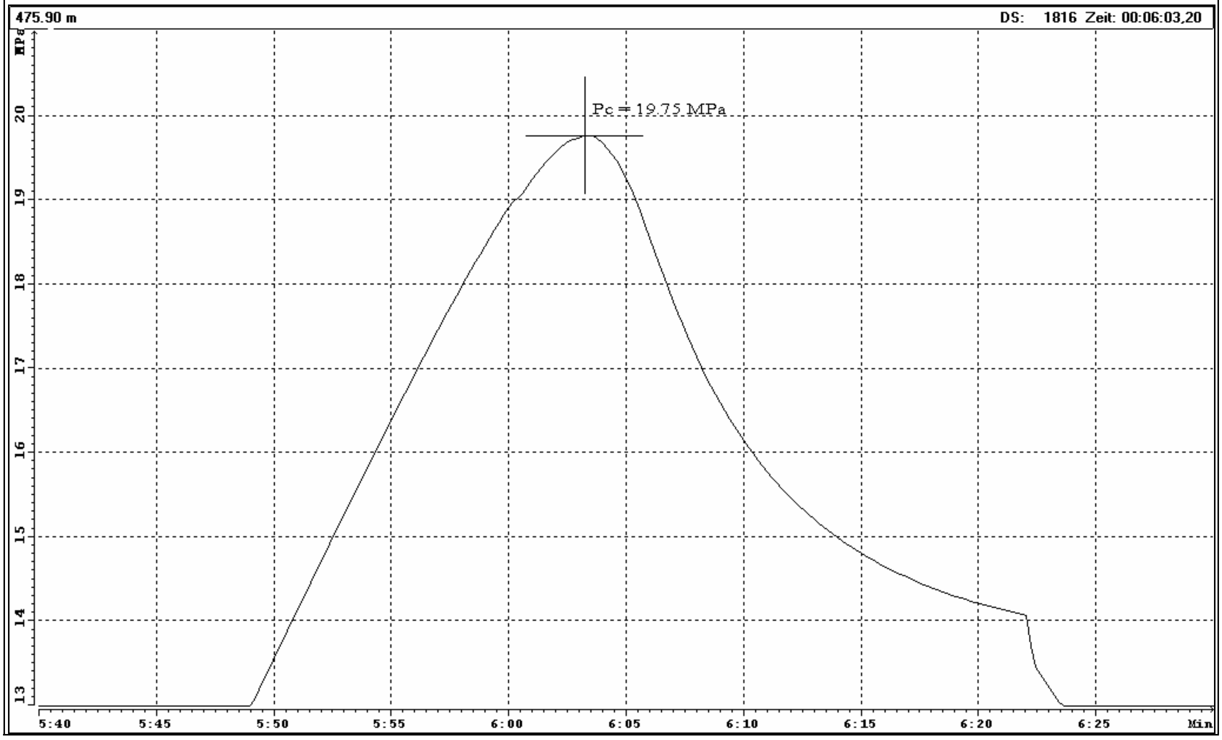
P - Test : pressure decrease: 1.60 MPa in 77 sec. (it is most likely that the significant pressure decay was caused by a small leakage of the coil tubing)

Frac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.25	Vr (l) = 0.1
1. Refrac - cycle	Qi (lpm) = 1.7	Vi (l) = 1.5	Vr (l) = 0.2
2. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 1.9	Vr (l) = 0.9
3. Refrac - cycle	Qi (lpm) = 2.8	Vi (l) = 2.8	Vr (l) = 2.25
4. Refrac - cycle	Qi (lpm) = 2.8	Vi (l) = 2.3	Vr (l) = 3.0
SP/SR - test	Qi (lpm) = 1.1-4.1	Vi (l) = 8.8	Vr (l) = 7.0

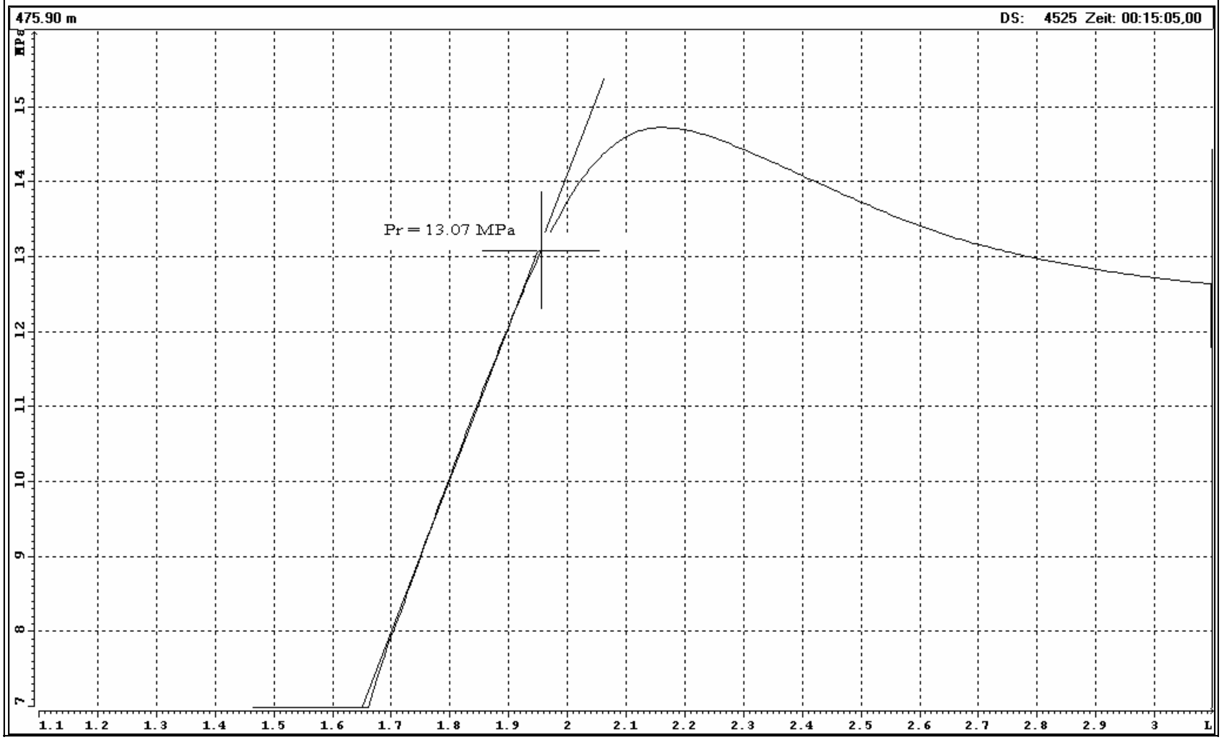
total injected volume (l): 18.55 recovered volume (l): 13.45 or 72.5 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- A significant decrease of the pressure fall-off during the shut-in phases associated with an increase of the fluid recovery rate was observed after the 1. refrac - cycles.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

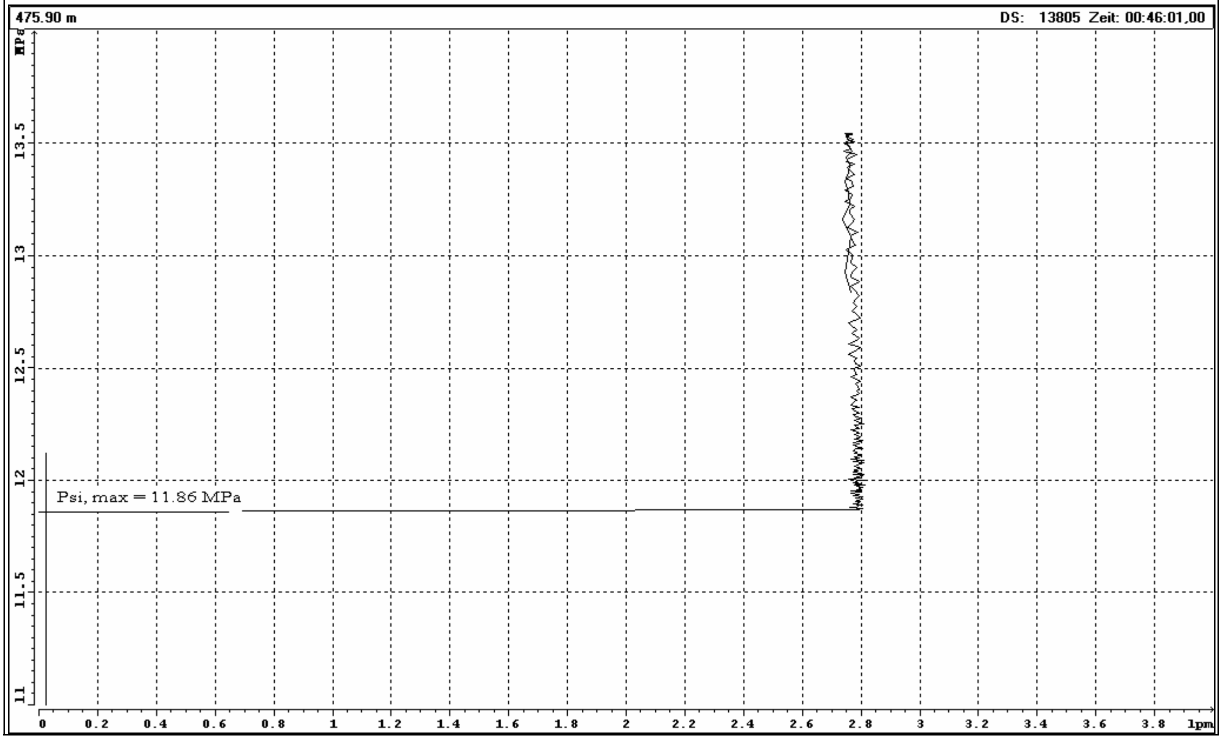
Test at 475.90 m MD: Estimation of P_c (Frac - Cycle)



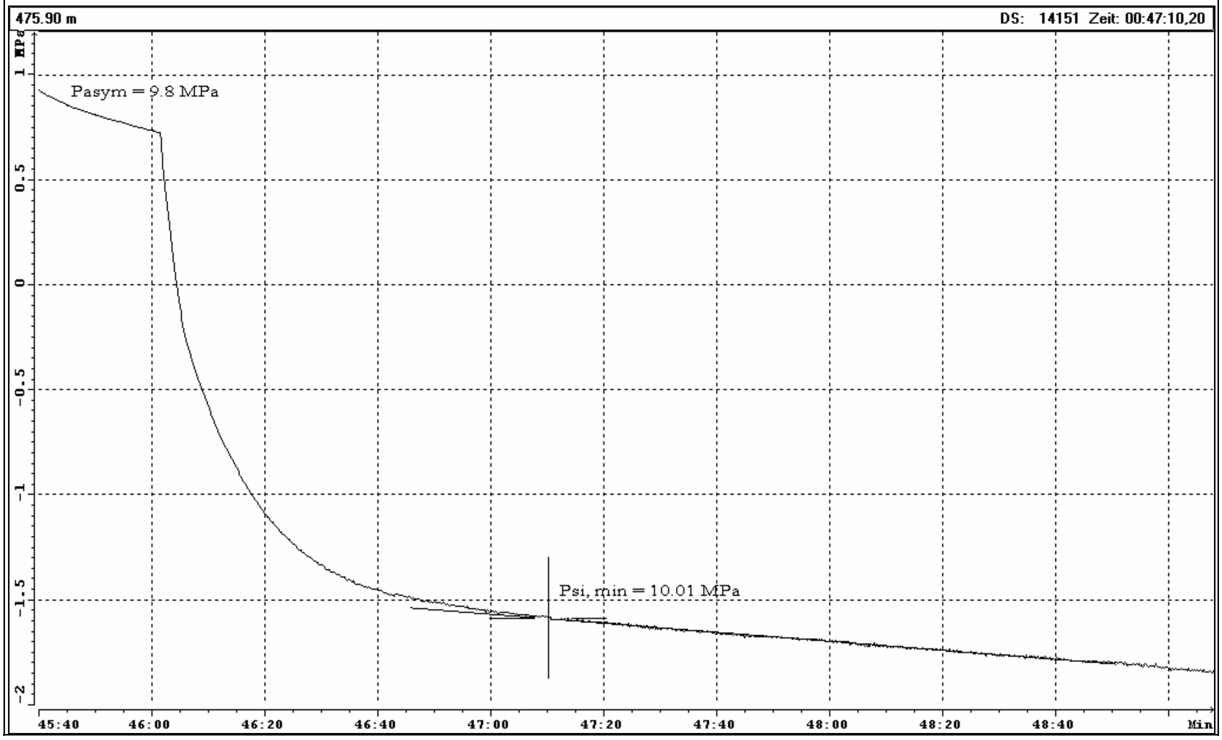
Test at 475.90 m MD: Estimation of P_r (1. Refrac - Cycle)



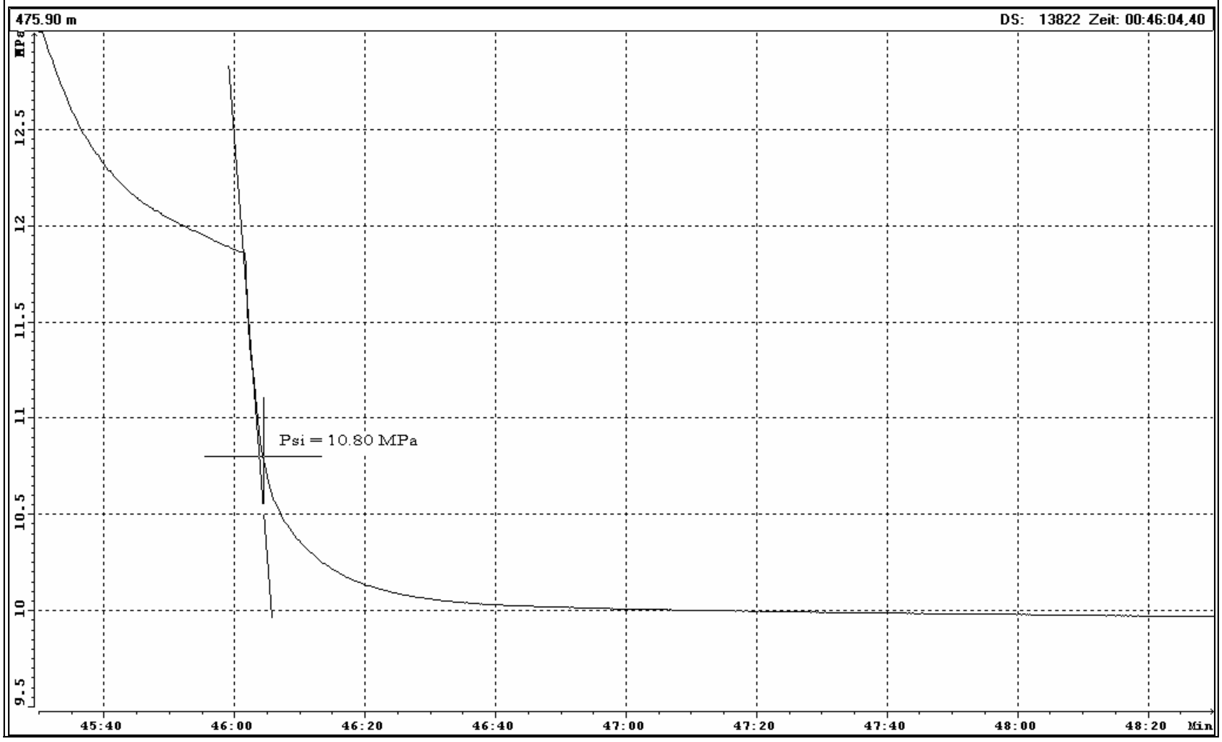
Test at 475.90 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



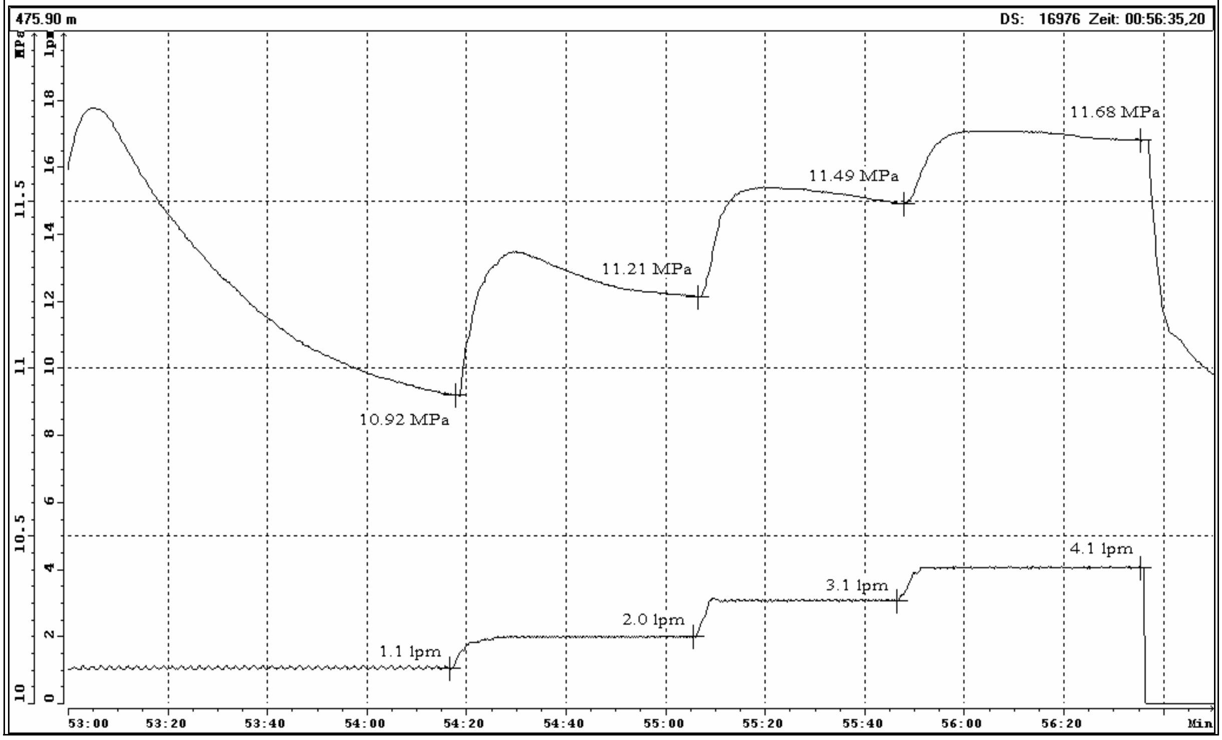
Test at 475.90 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



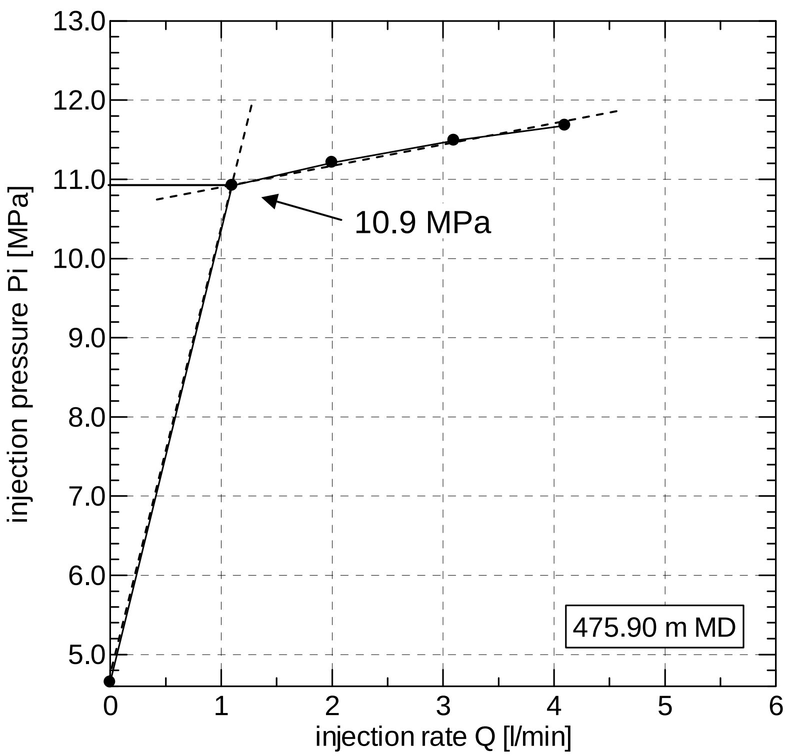
Test at 475.90 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 475.90 m MD: Analysis of Slow - Pump / Step - Rate - Test

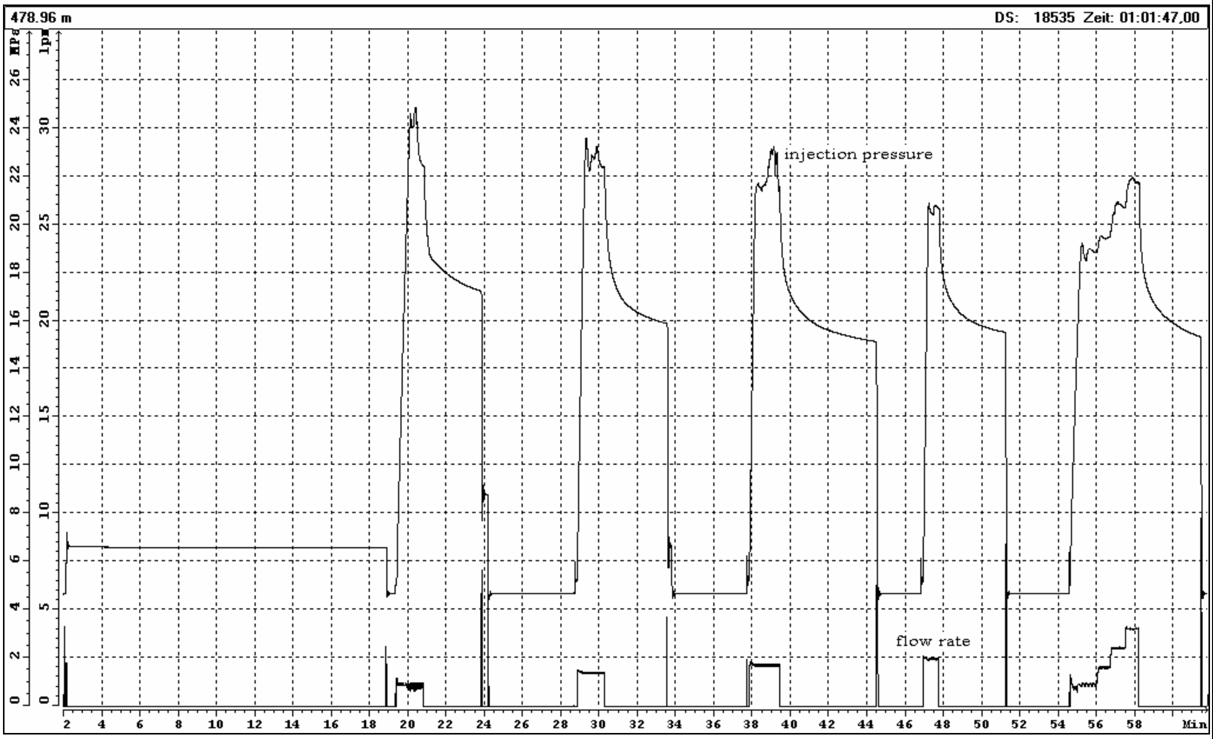


Test at 475.90 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 6 AT 478.96 m MD / 475.29 m TVD

Test at 478.96 m MD: Overview - Plot



P - Test Frac (1. Refrac) 2. Refrac 3. Refrac 4. Refrac SP/SR - Test

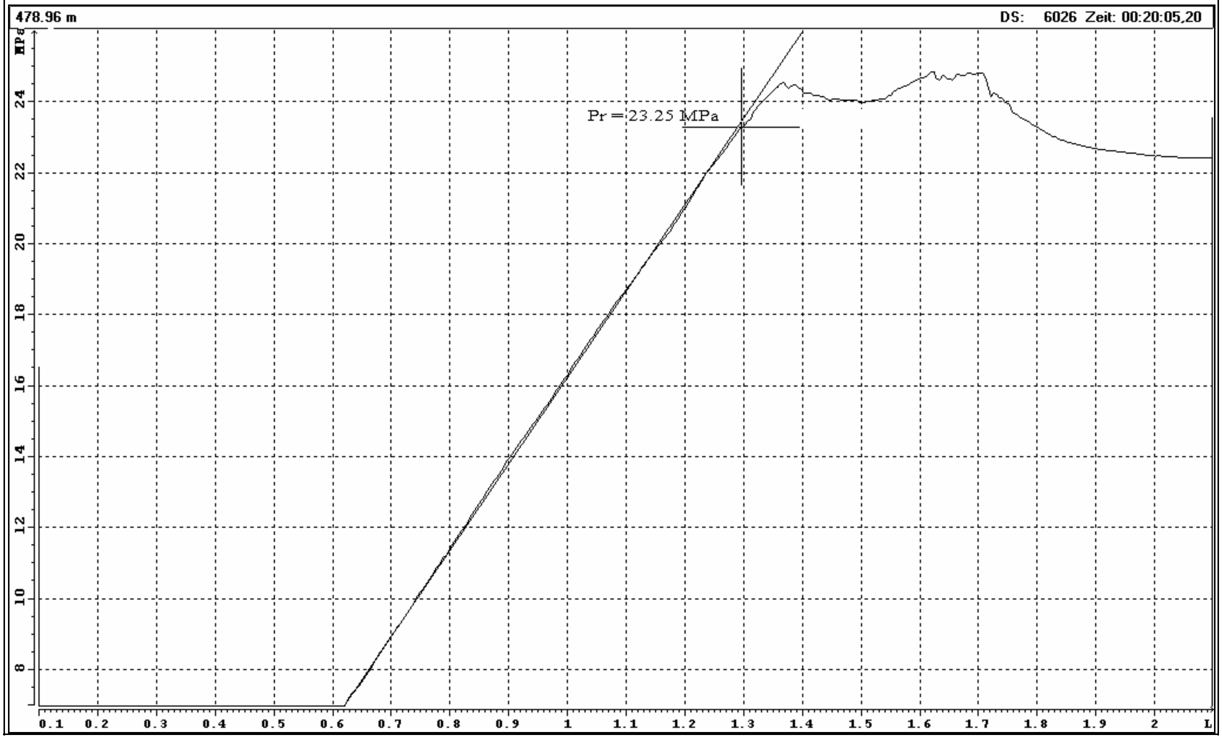
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.07 MPa in 990 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.2	Vi (l) = 1.6	Vr (l) = 0.5
2. Refrac - cycle	Qi (lpm) = 1.7	Vi (l) = 2.5	Vr (l) = 0.4
3. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 3.4	Vr (l) = 0.4
4. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 2.0	Vr (l) = 0.4
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 8.2	Vr (l) = 0.4

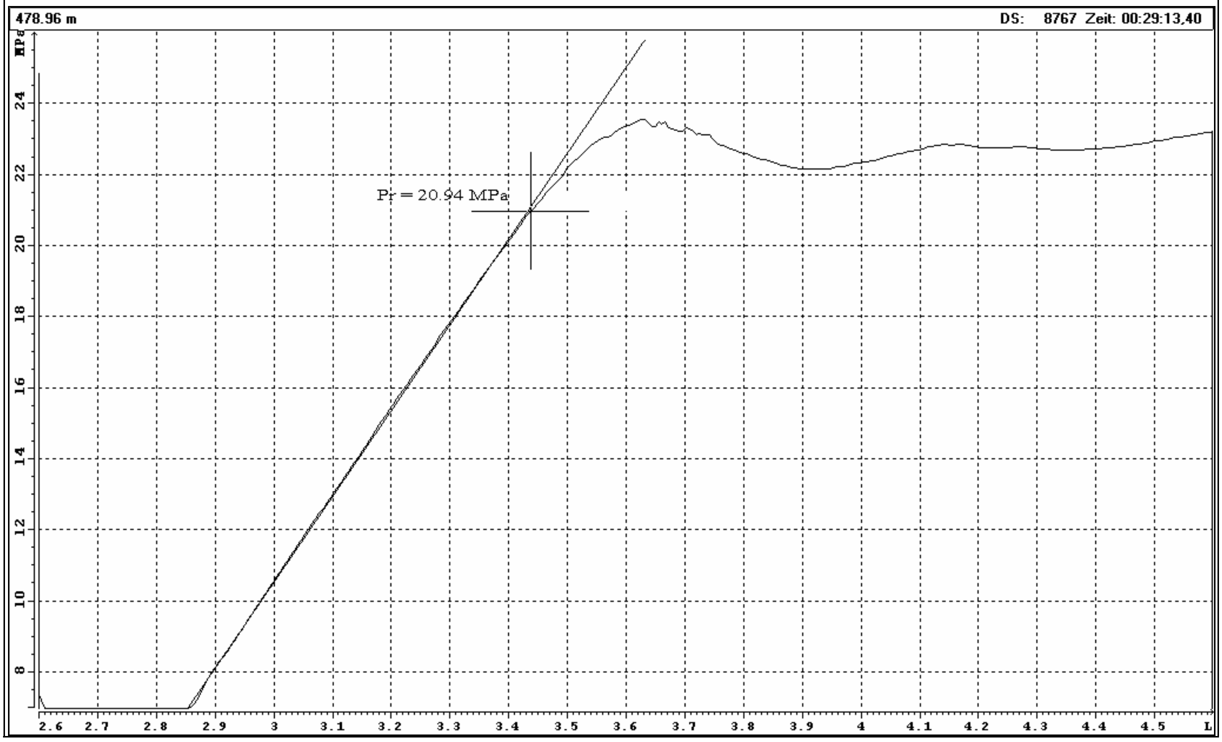
total injected volume (l): 17.7 recovered volume (l): 2.1 or 11.9 %

- Initial test type: HTPF-h
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no distinct breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

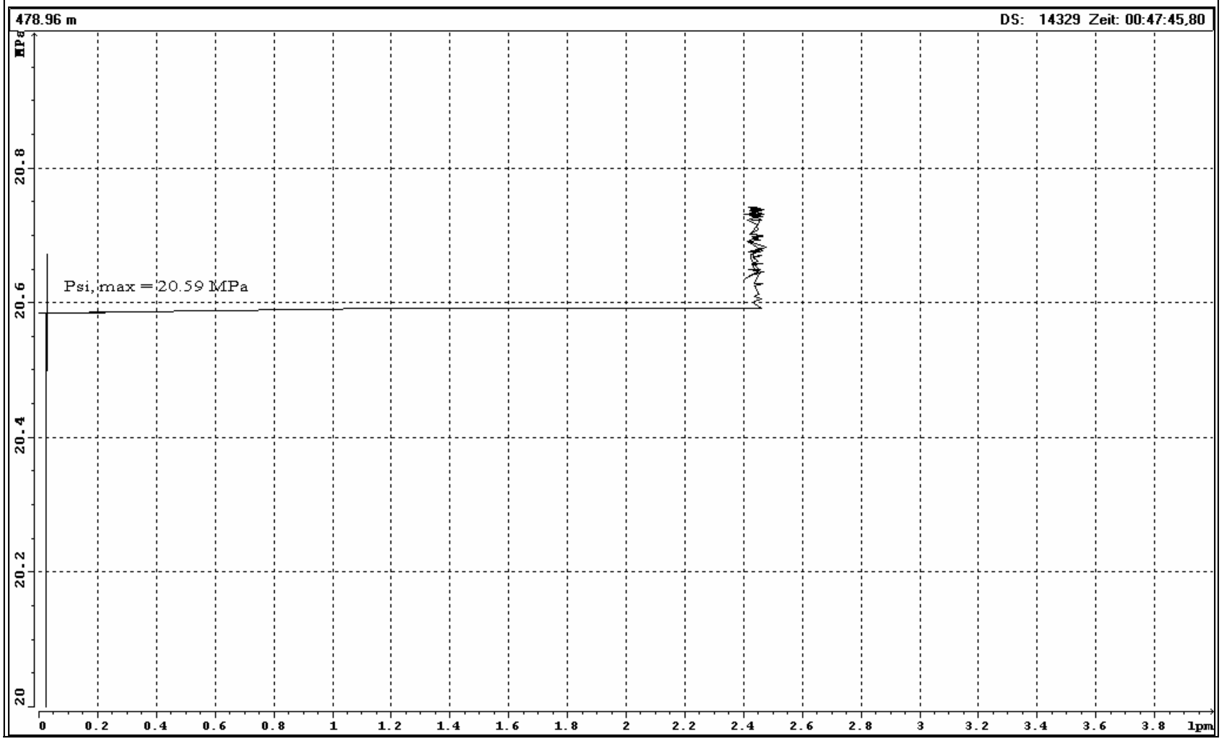
Test at 478.96 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



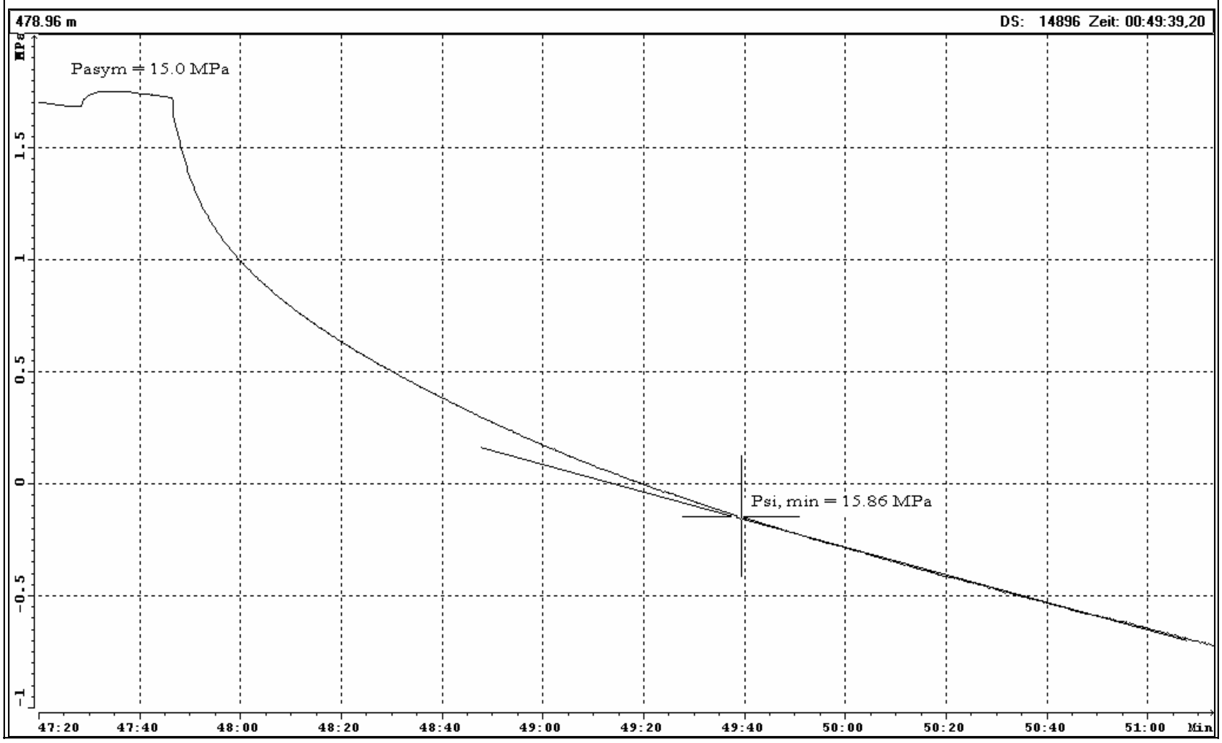
Test at 478.96 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



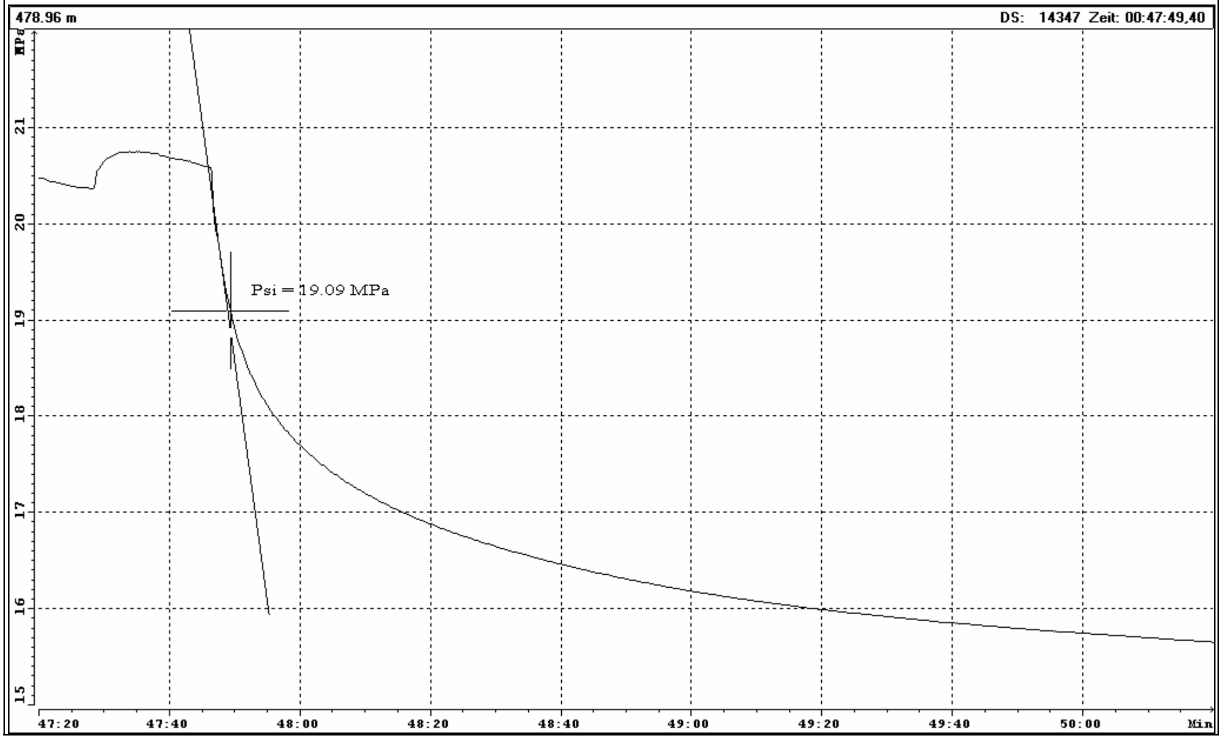
Test at 478.96 m MD: Estimation of $P_{si,\,max}$ (4. Refrac - Cycle)



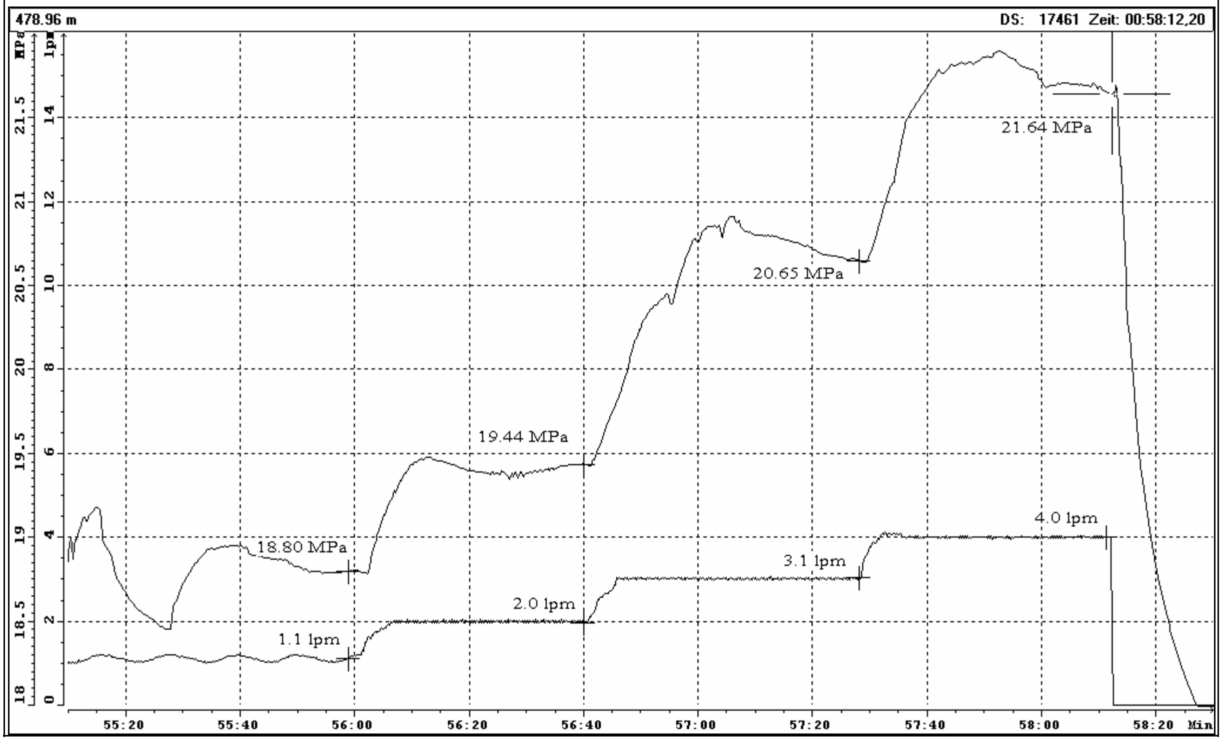
Test at 478.96 m MD: Estimation of $P_{si,\,min}$ (4. Refrac - Cycle)



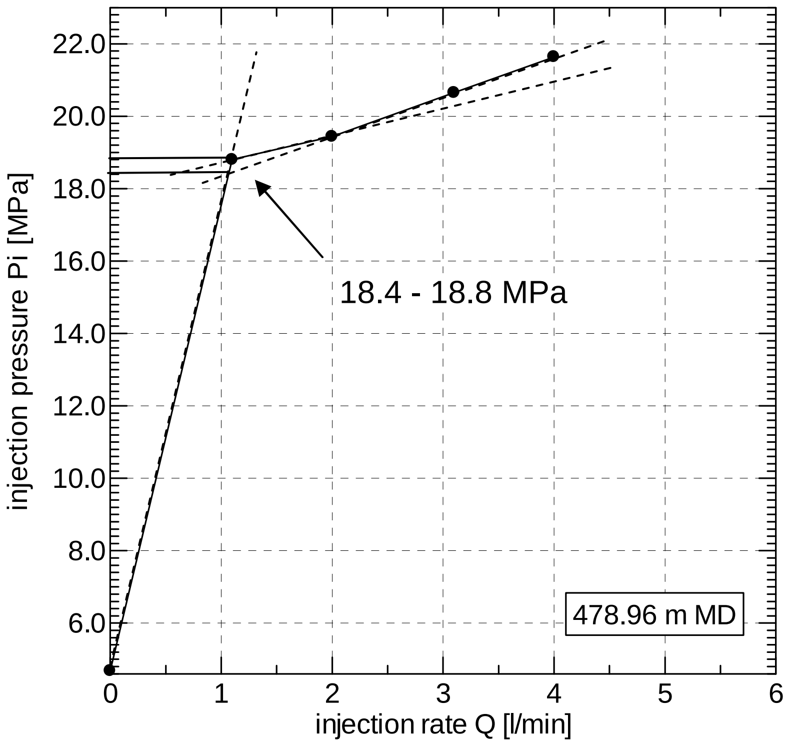
Test at 478.96 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 478.96 m MD: Analysis of Slow - Pump / Step - Rate - Test

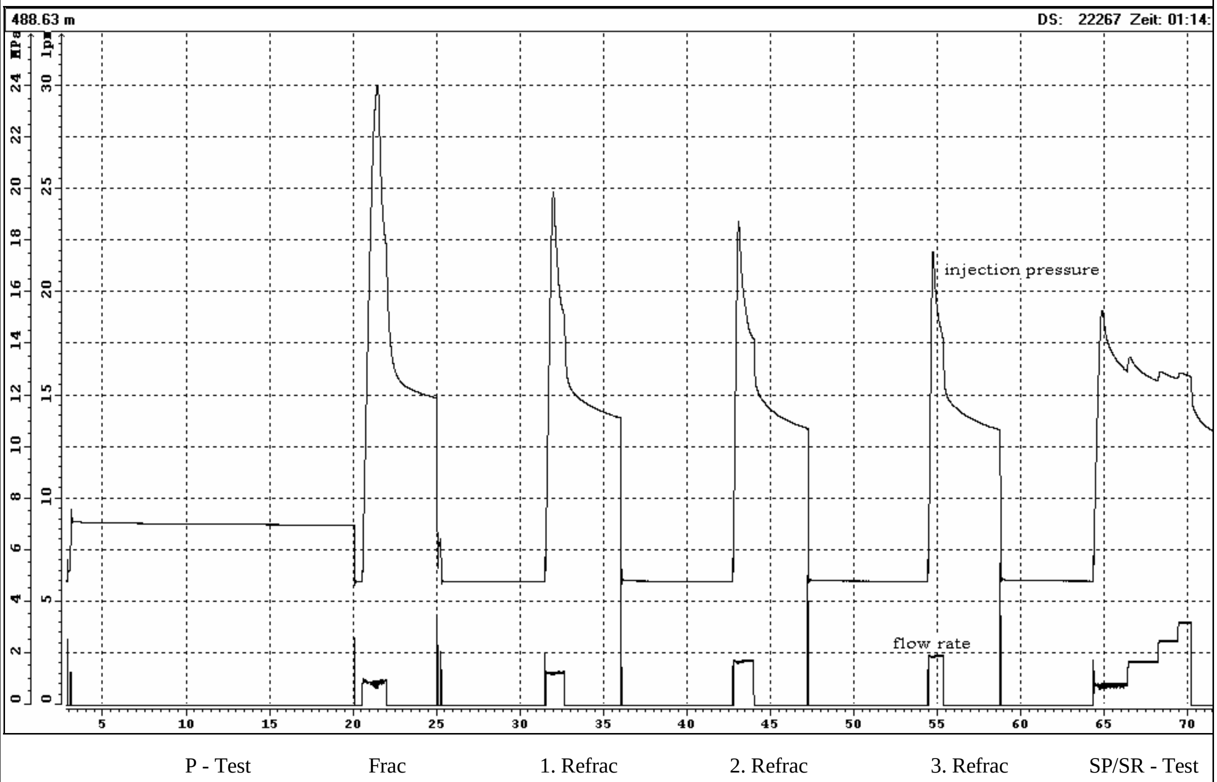


Test at 478.96 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 5 AT 488.63 m MD / 484.84 m TVD

Test at 488.63 m MD : Overview - Plot



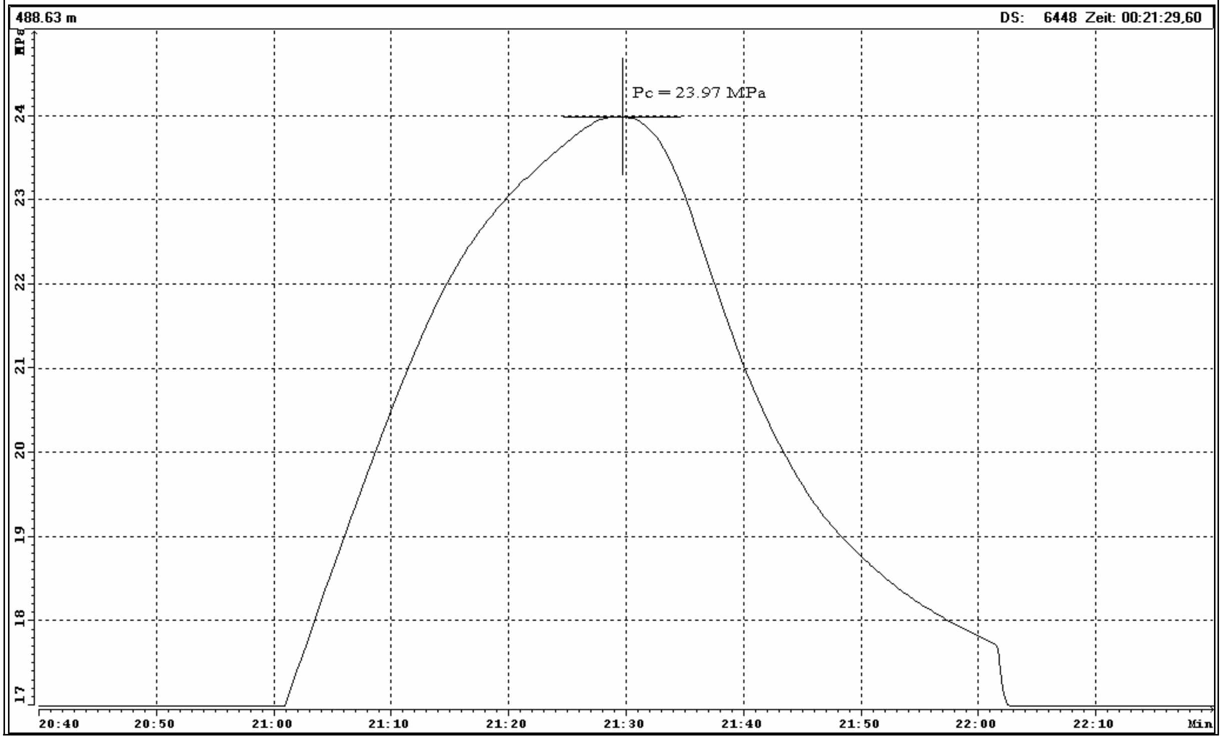
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.14 MPa in 1008 sec.		
Frac - cycle	Qi (lpm) = 1.1	Vi (l) = 1.6	Vr (l) = 0.4
1. Refrac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.8	Vr (l) = 0.75
2. Refrac - cycle	Qi (lpm) = 2.1	Vi (l) = 2.6	Vr (l) = 0.9
3. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 2.1	Vr (l) = 1.0
SP/SR - test	Qi (lpm) = 1.0-4.0	Vi (l) = 12.65	Vr (l) = 2.5

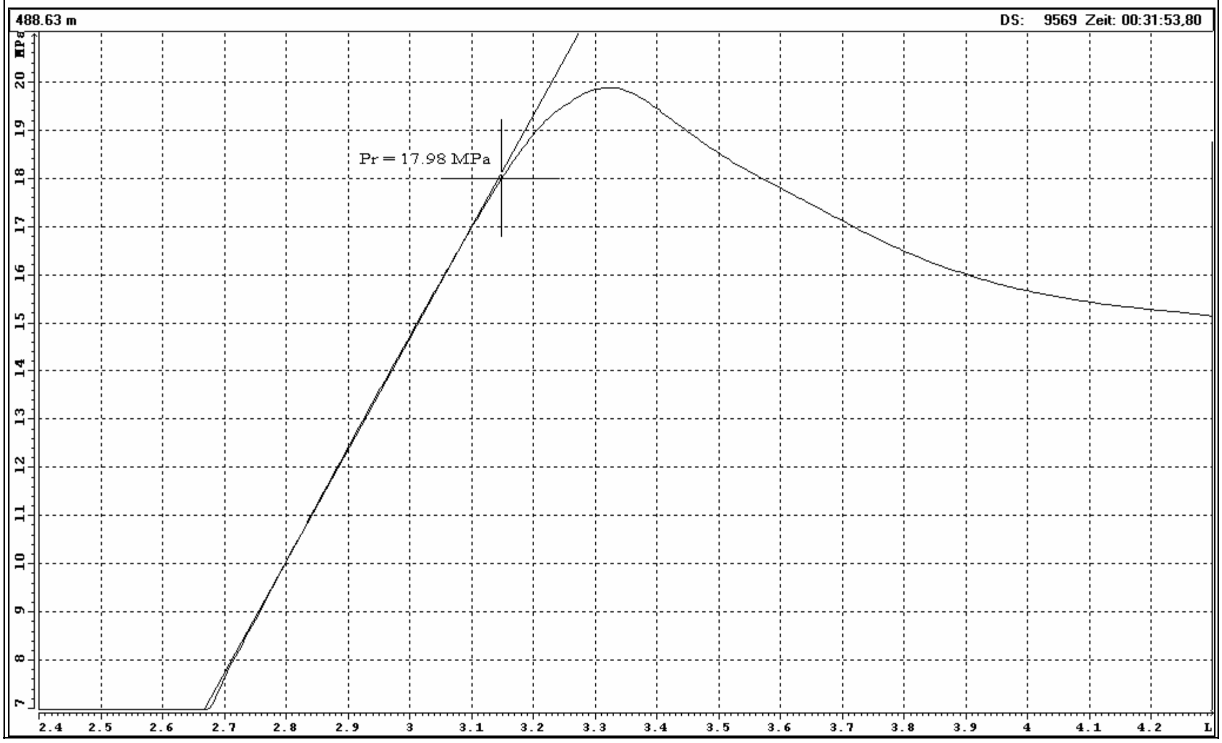
total injected volume (l): 20.75 recovered volume (l): 5.55 or 26.7 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a weak breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

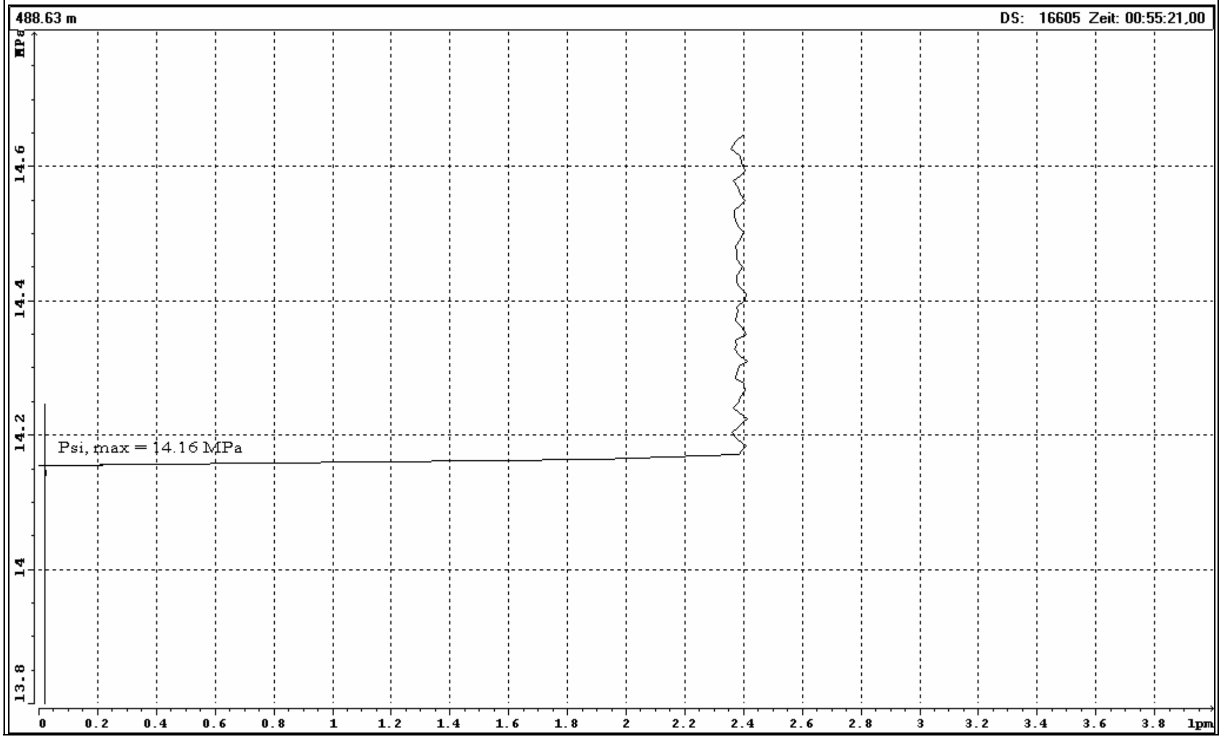
Test at 488.63 m MD: Estimation of P_c (Frac - Cycle)



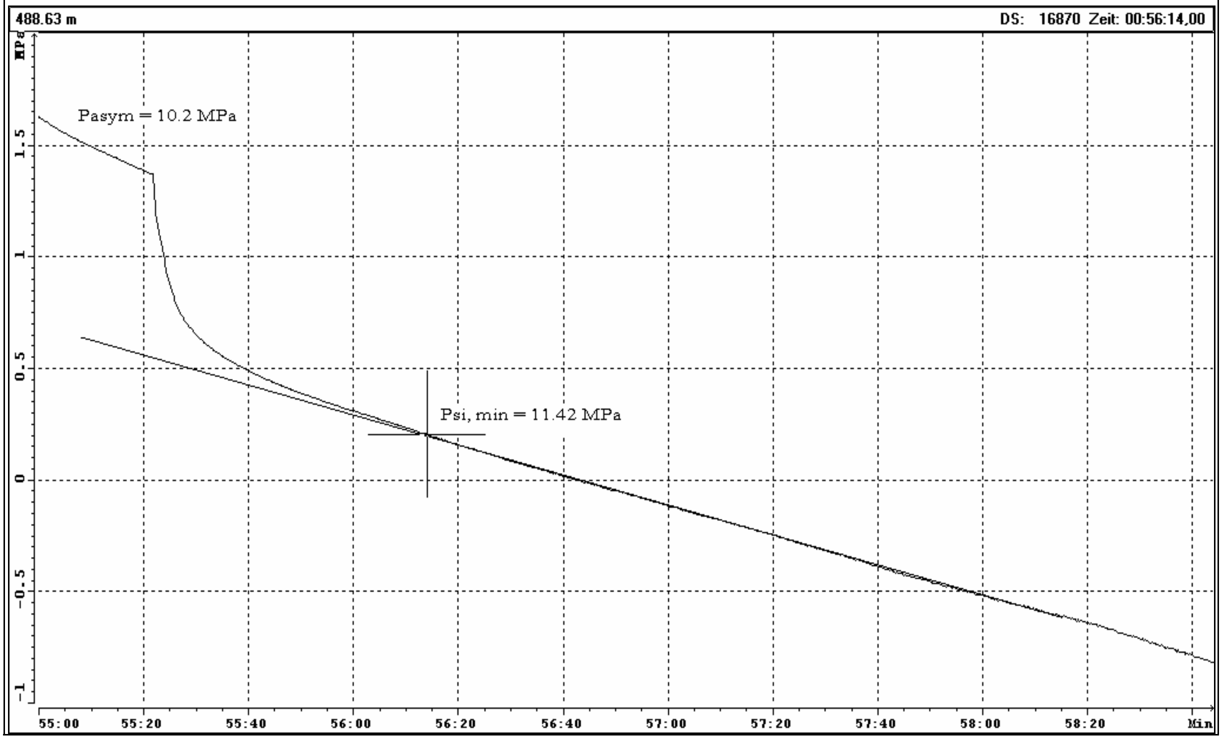
Test at 488.63 m MD: Estimation of P_r (1. Refrac - Cycle)



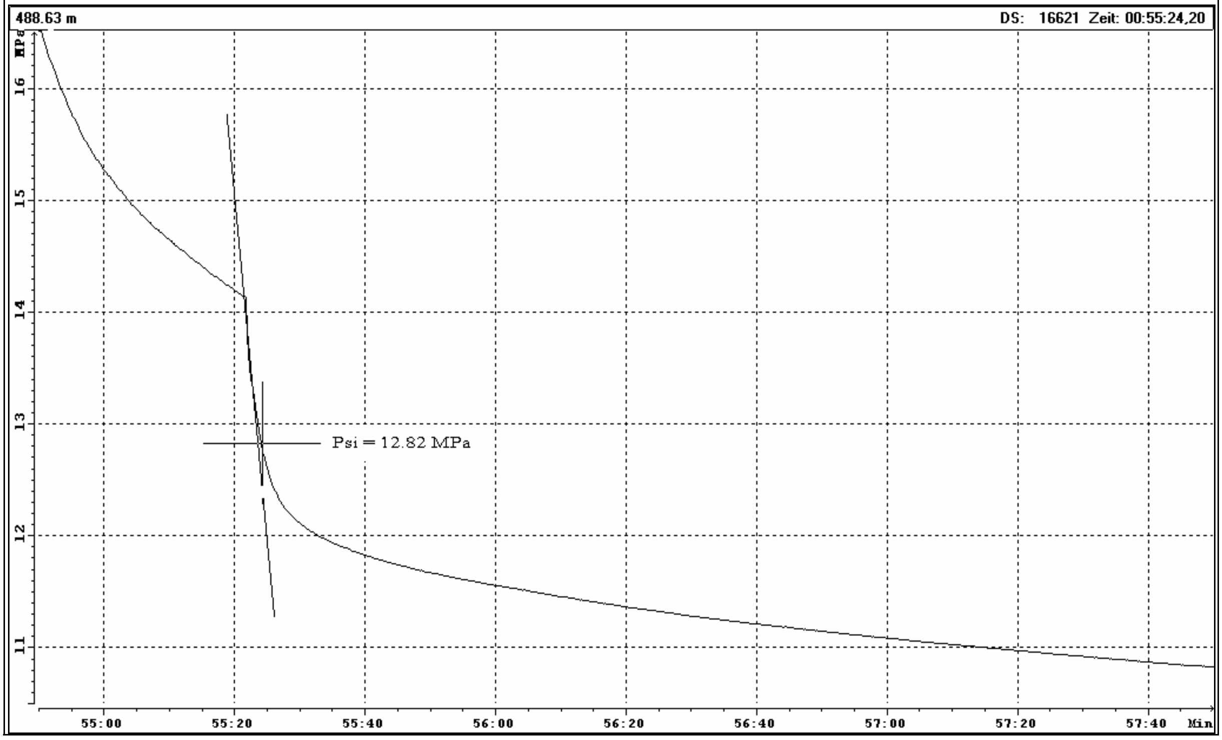
Test at 488.63 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



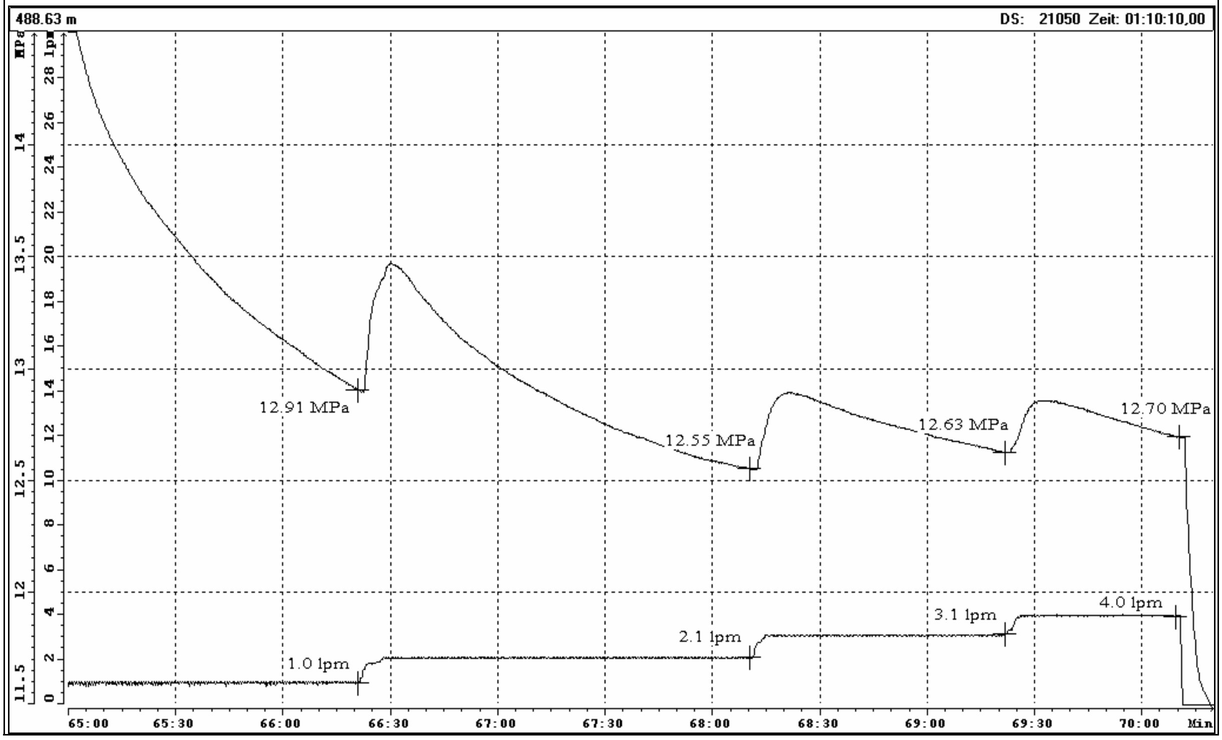
Test at 488.63 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



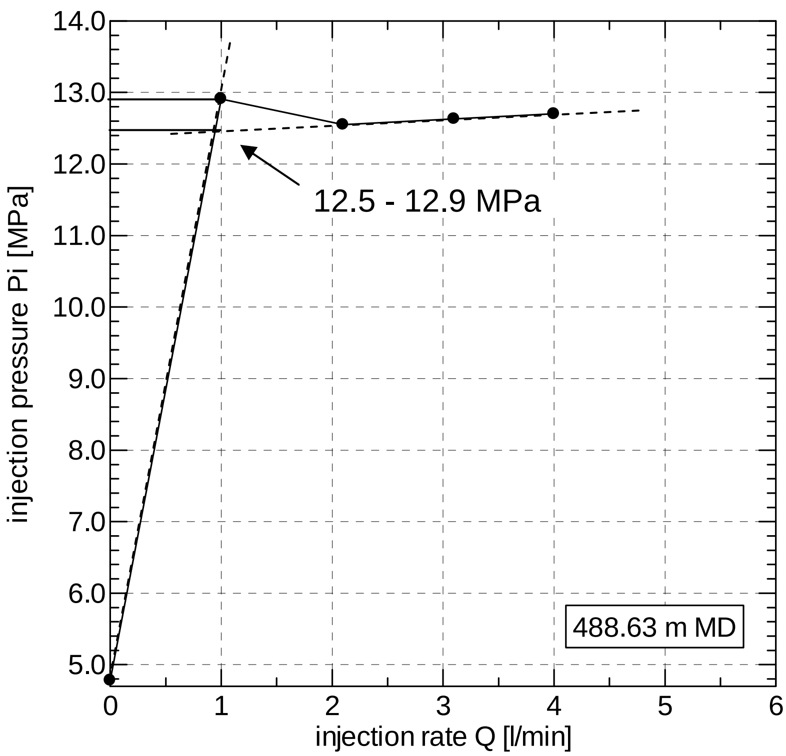
Test at 488.63 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 488.63 m MD: Analysis of Slow - Pump / Step - Rate - Test

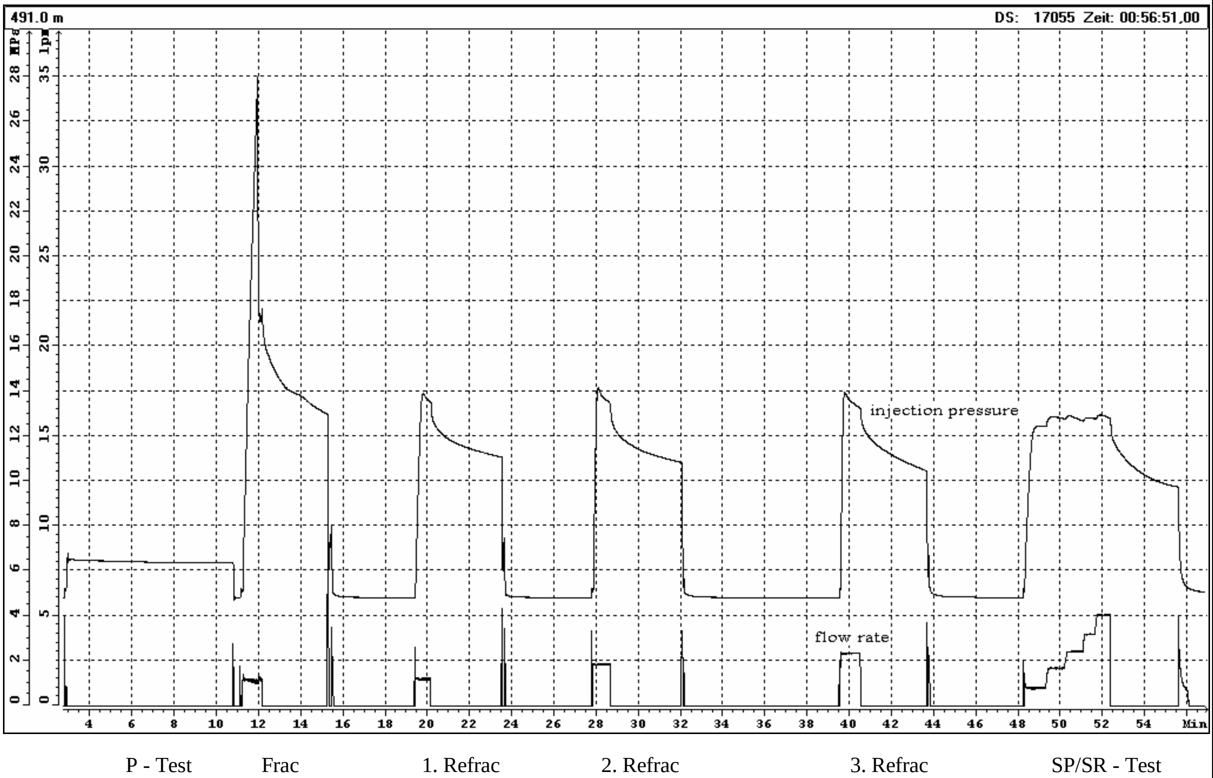


Test at 488.63 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 4 AT 491.0 m MD / 487.17 m TVD

Test at 491.0 m MD : Overview - Plot



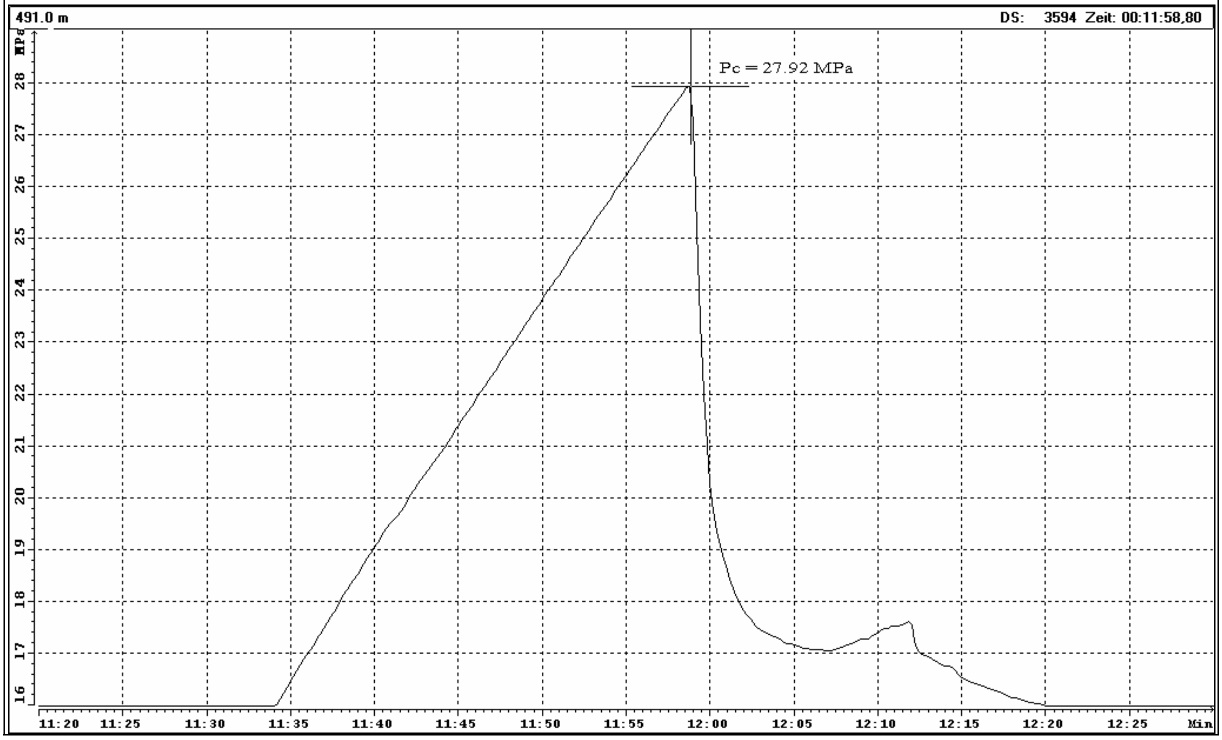
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.16 MPa in 463 sec.		
Frac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.4	Vr (l) = 0.8
1. Refrac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.2	Vr (l) = 0.6
2. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 1.95	Vr (l) = 0.75
3. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 2.8	Vr (l) = 1.0
SP/SR - test	Qi (lpm) = 1.0-5.0	Vi (l) = 11.3	Vr (l) = 3.2

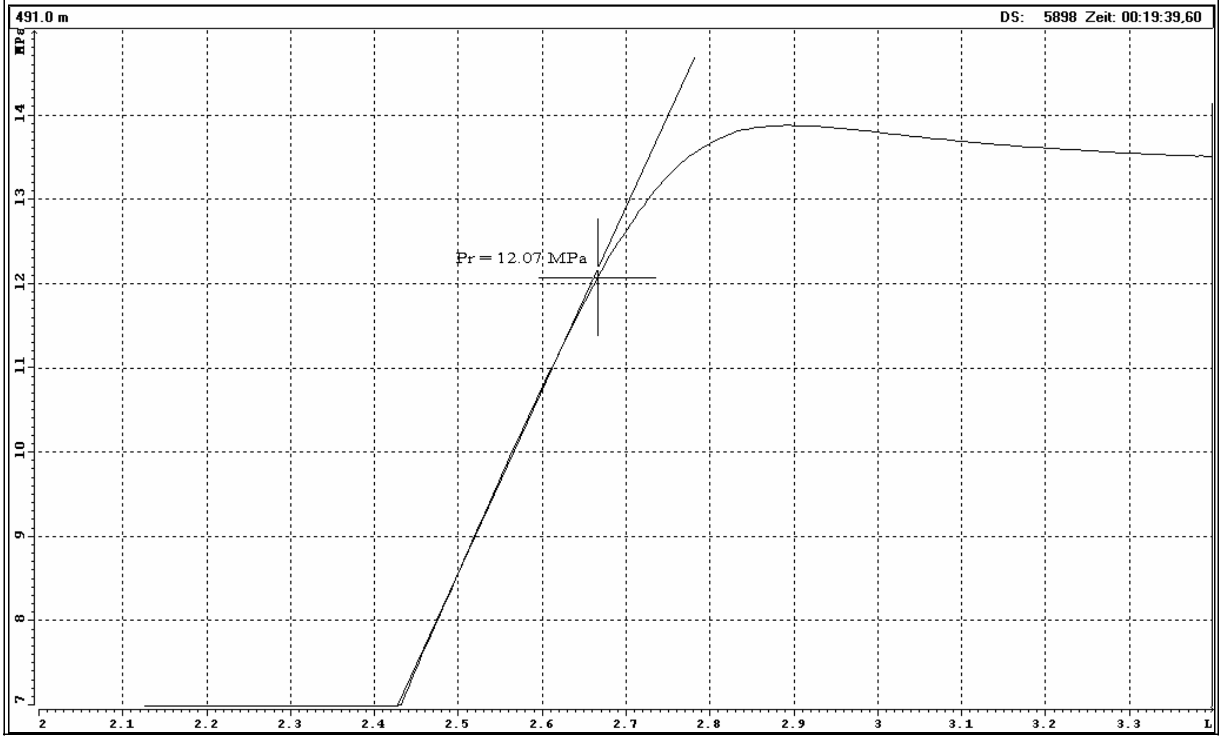
total injected volume (l): 18.65 recovered volume (l): 6.35 or 34.0 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (distinct breakdown event).
- The refrac - pressure was determined from the 1. and 2. refrac - cycle, since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

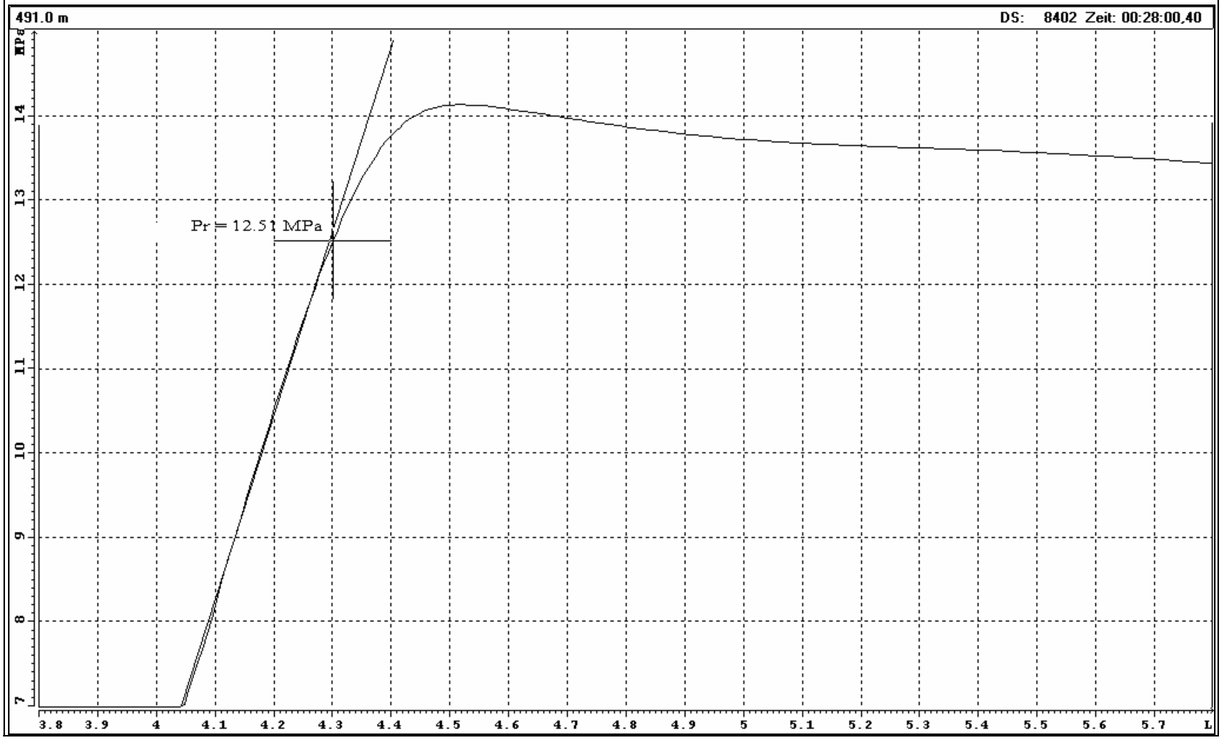
Test at 491.0 m MD: Estimation of P_c (Frac - Cycle)



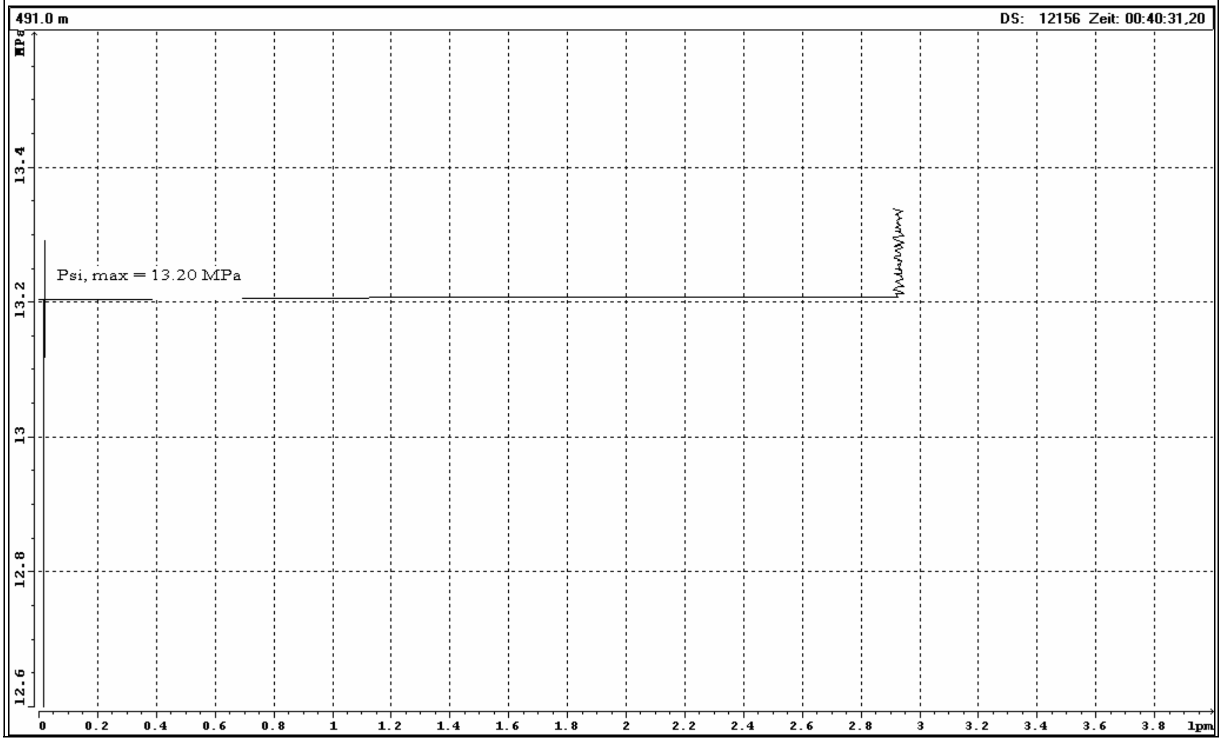
Test at 491.0 m MD: Estimation of P_r (1. Refrac - Cycle)



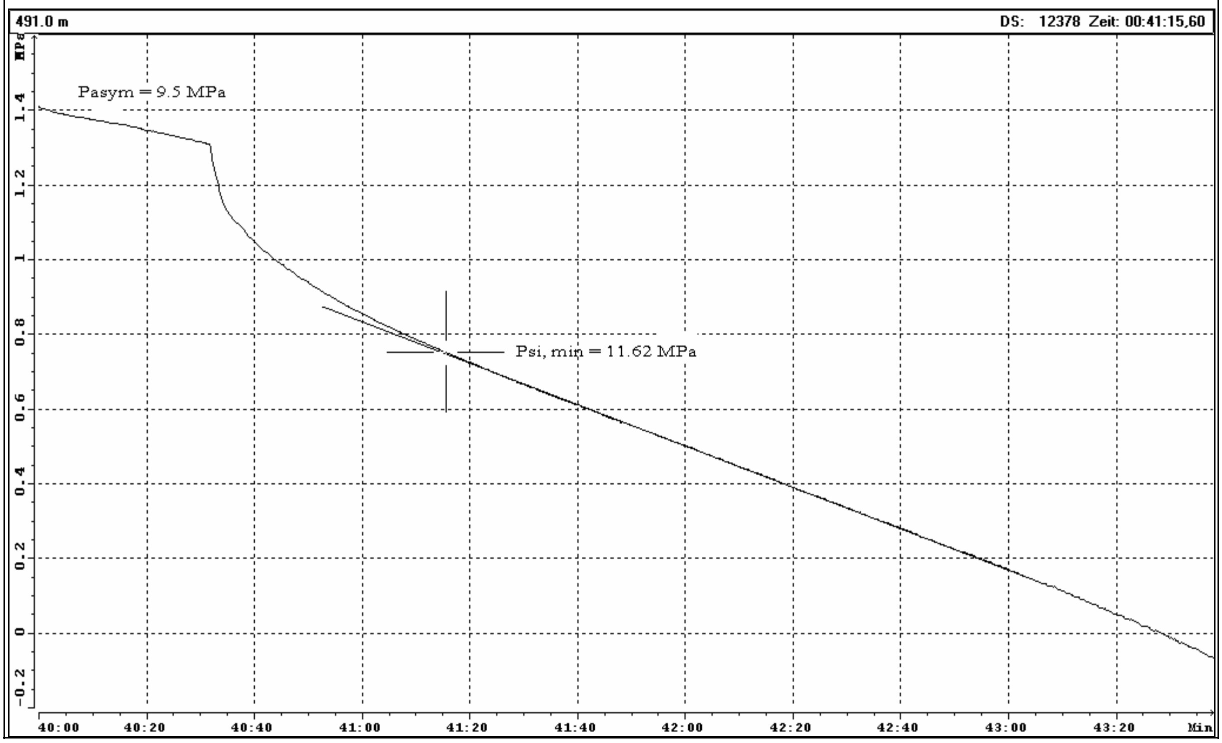
Test at 491.0 m MD: Estimation of P_r (2. Refrac - Cycle)



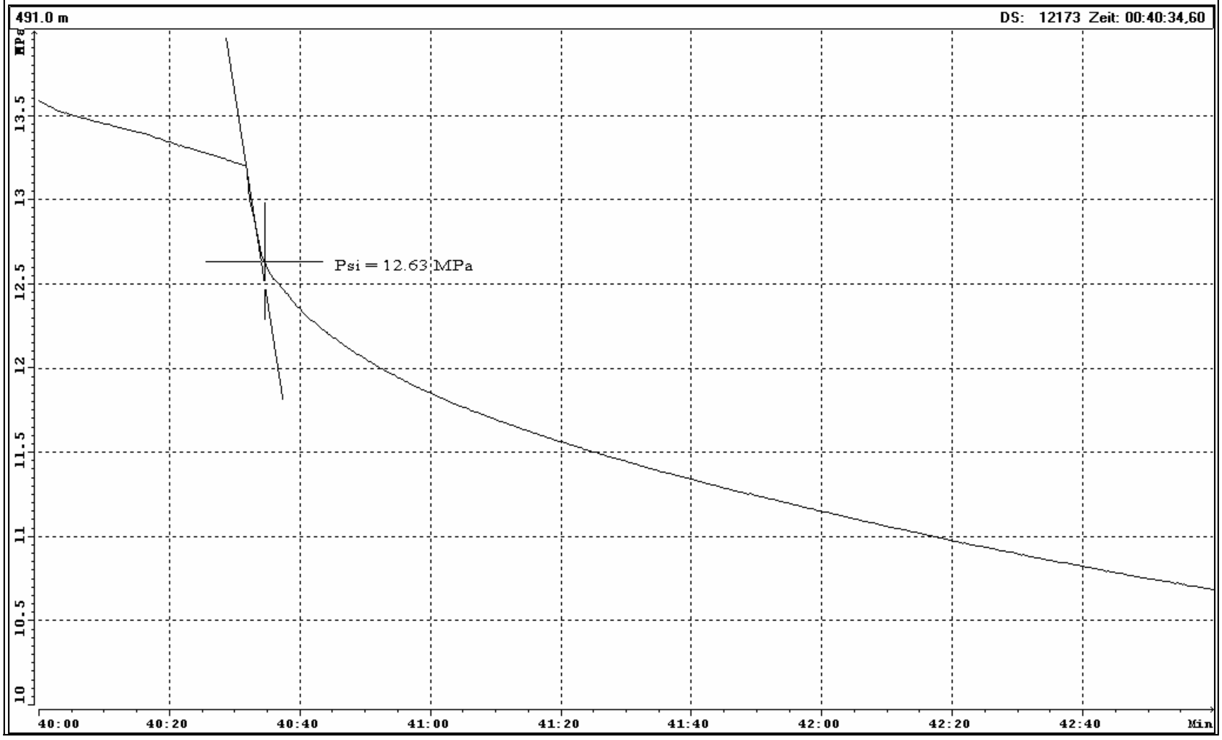
Test at 491.0 m MD: Estimation of $P_{si,\,max}$ (3. Refrac - Cycle)



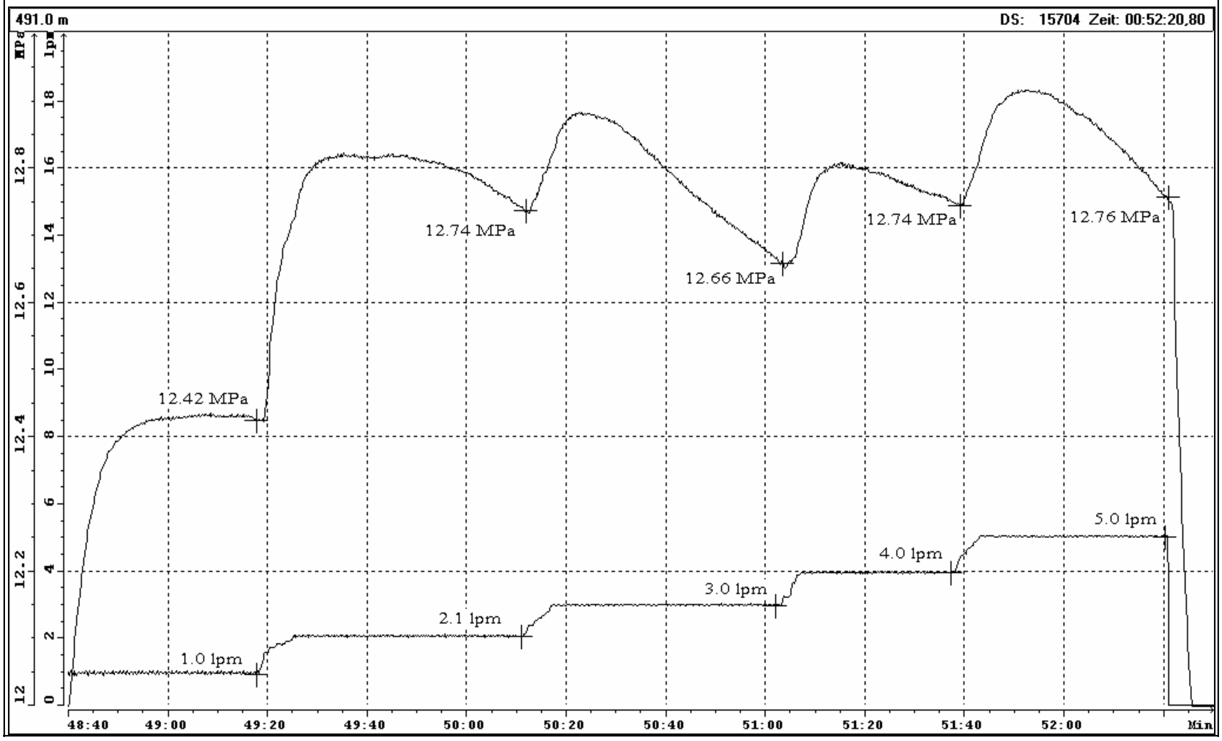
Test at 491.0 m MD: Estimation of $P_{si,\,min}$ (3. Refrac - Cycle)



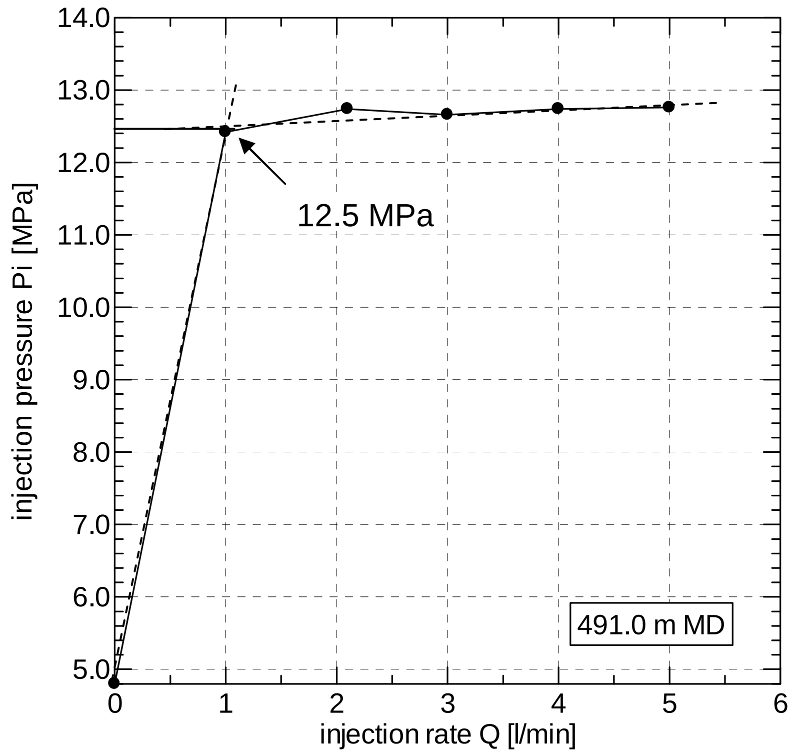
Test at 491.0 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 491.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

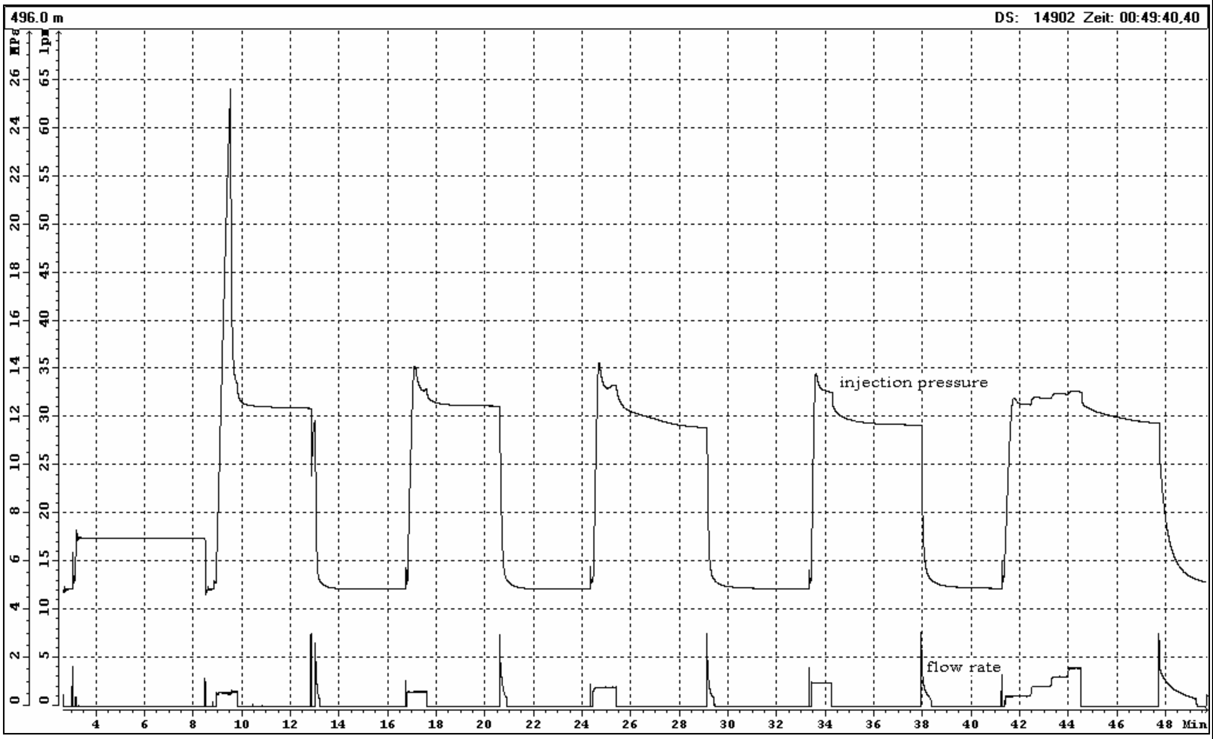


Test at 491.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 3 AT 496.0 m MD / 492.11 m TVD

Test at 496.0 m MD: Overview - Plot



P - Test Frac 1. Refrac 2. Refrac 3. Refrac Slow-Pump/Step-Rate - Test

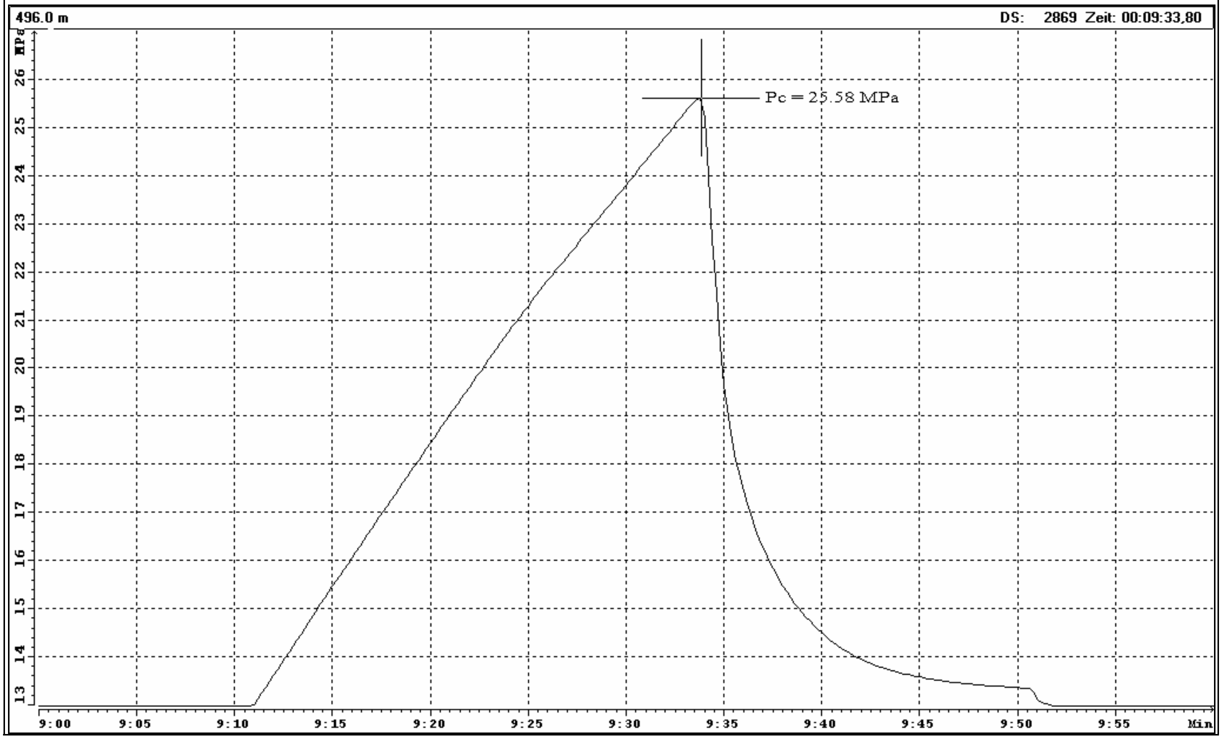
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 0.0 MPa in 304 sec.		
Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.2	Vr (l) = 1.1
1. Refrac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.2	Vr (l) = 1.0
2. Refrac - cycle	Qi (lpm) = 2.0	Vi (l) = 1.9	Vr (l) = 1.5
3. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 2.1	Vr (l) = 1.5
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 7.15	Vr (l) = 4.7

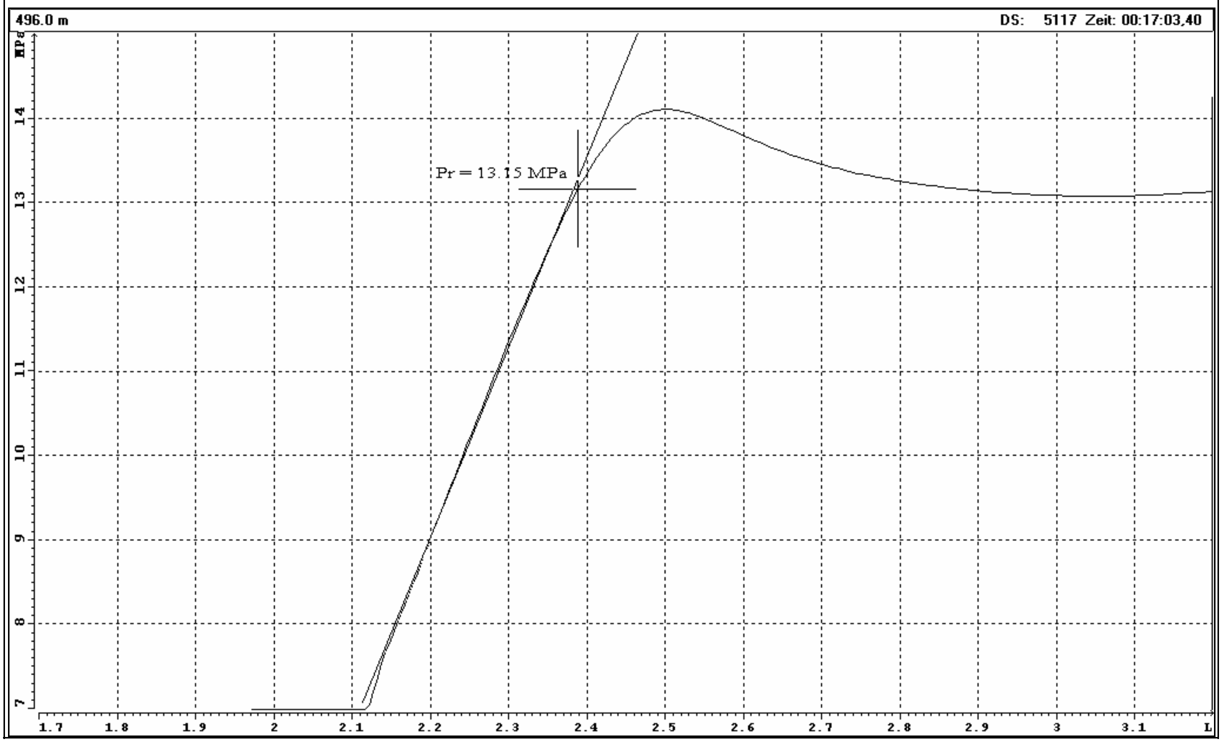
total injected volume (l): 13.55 recovered volume (l): 9.8 or 72.3 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (distinct breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield nearly identical fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

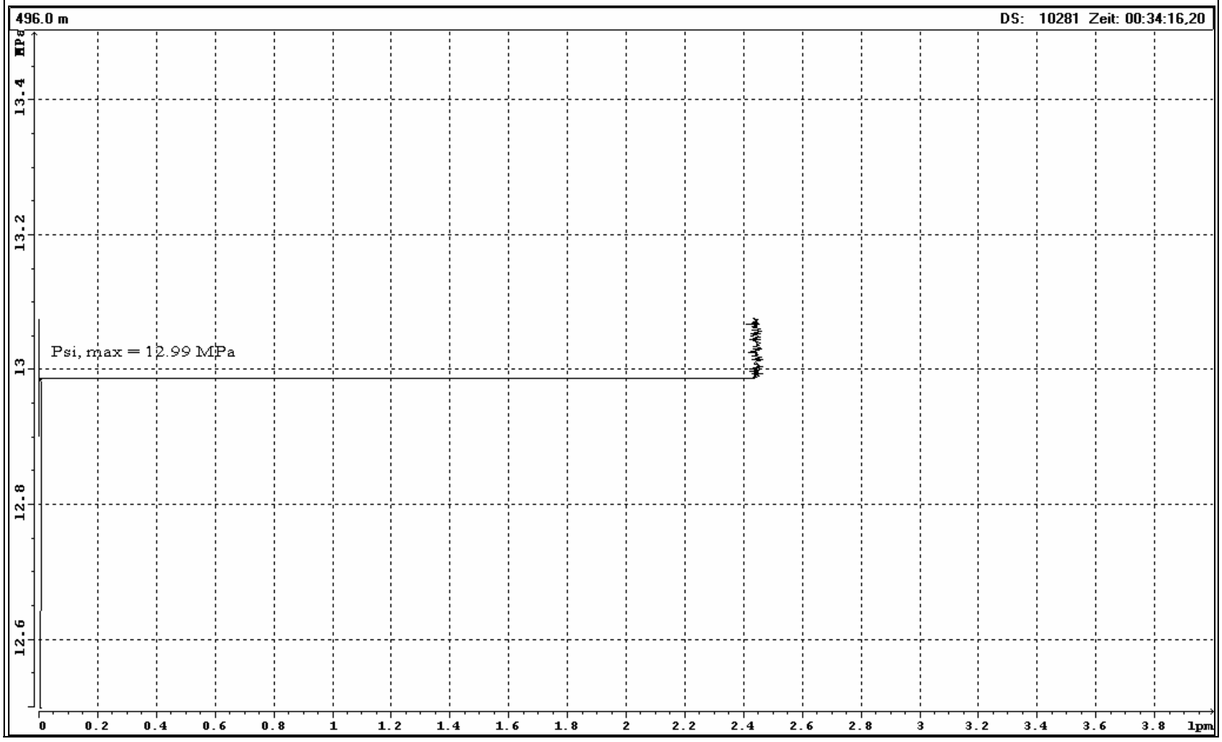
Test at 496.0 m MD: Estimation of P_c (Frac - Cycle)



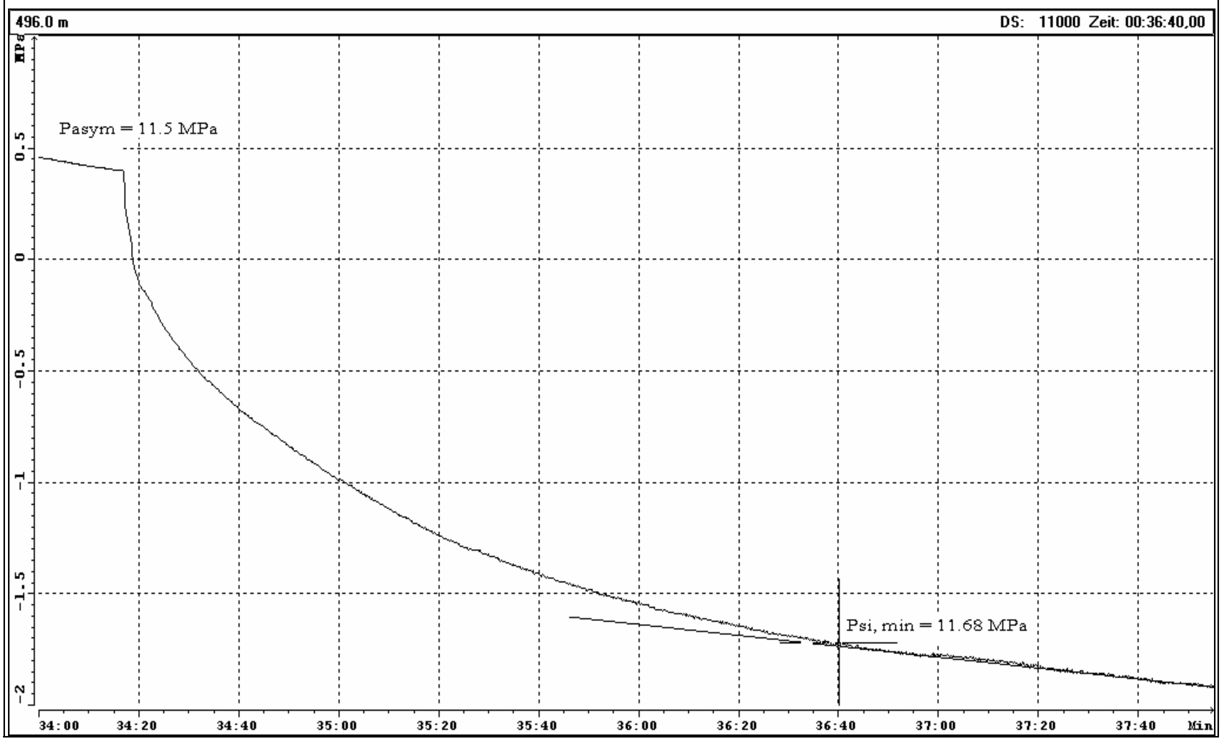
Test at 496.0 m MD: Estimation of P_r (1. Refrac - Cycle)



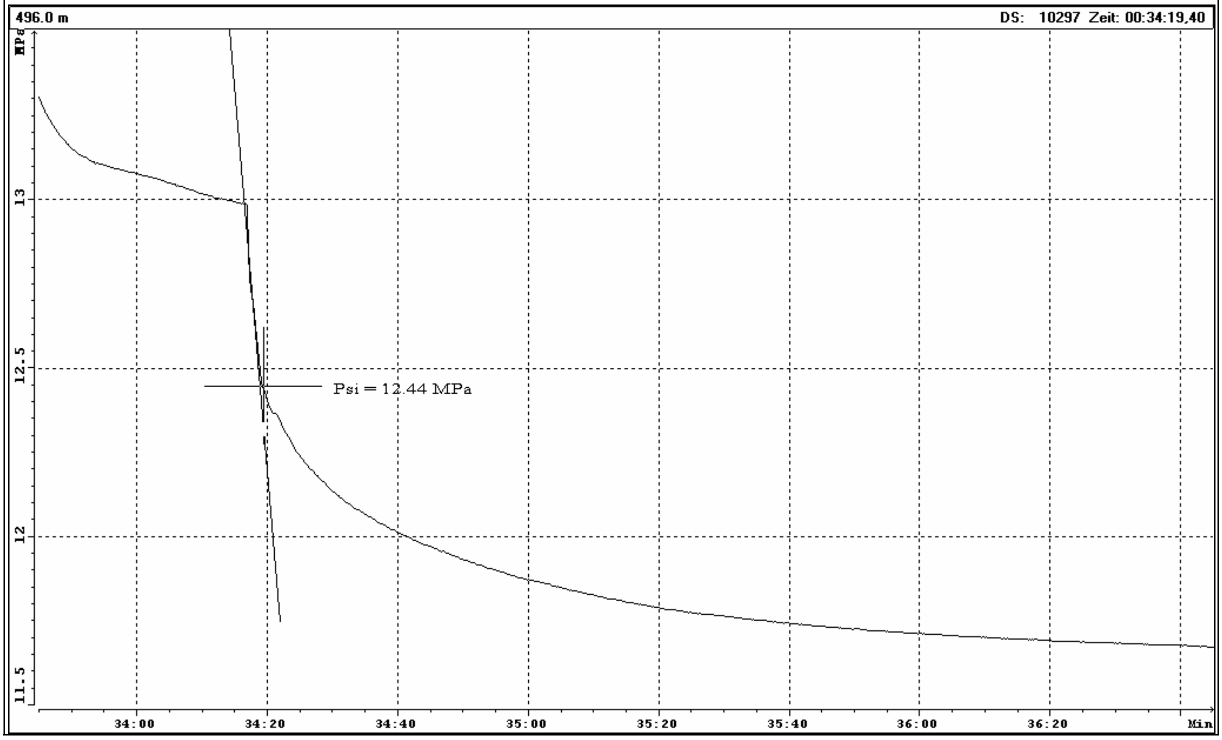
Test at 496.0 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



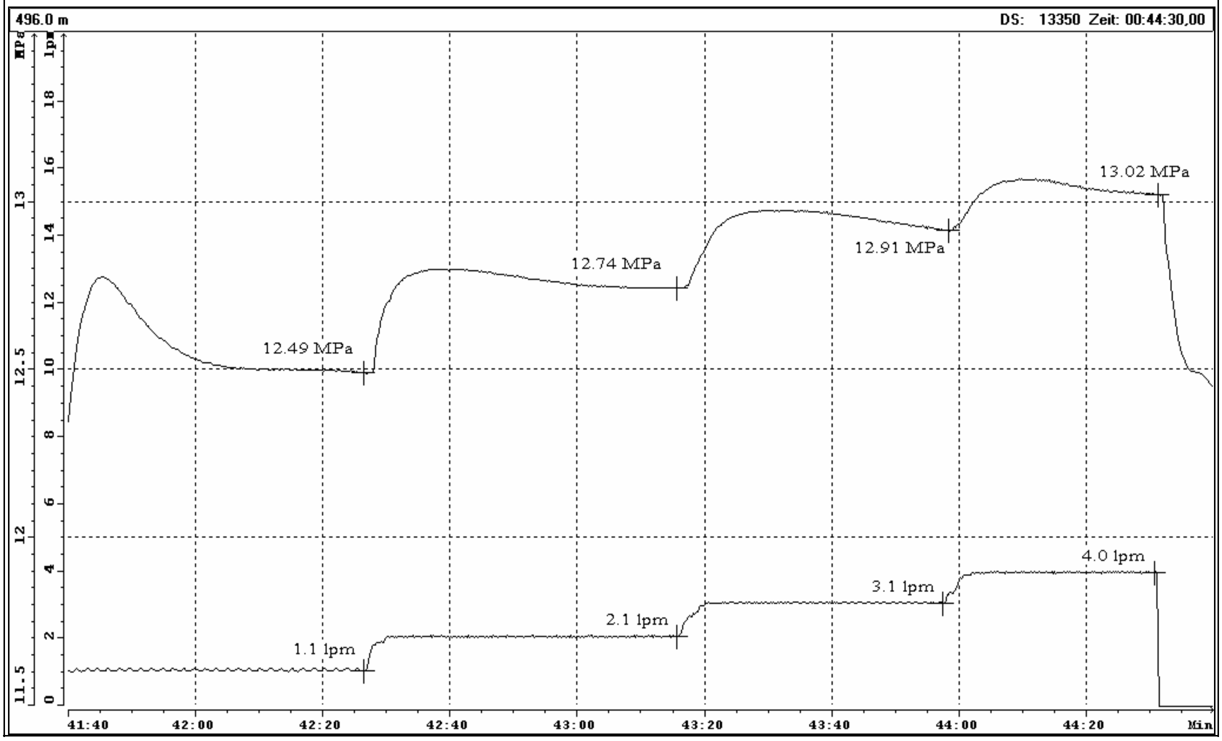
Test at 496.0 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



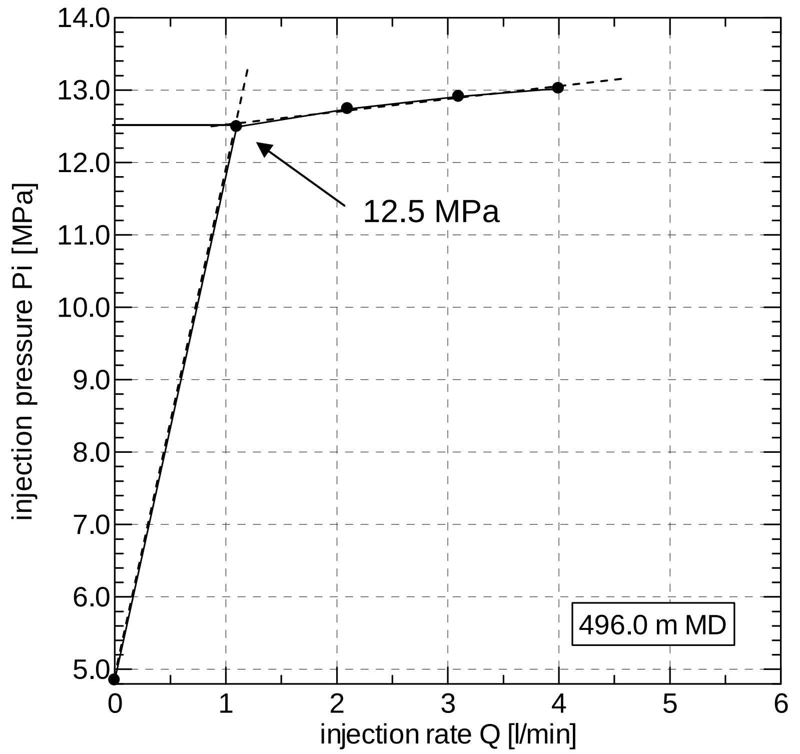
Test at 496.0 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 496.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

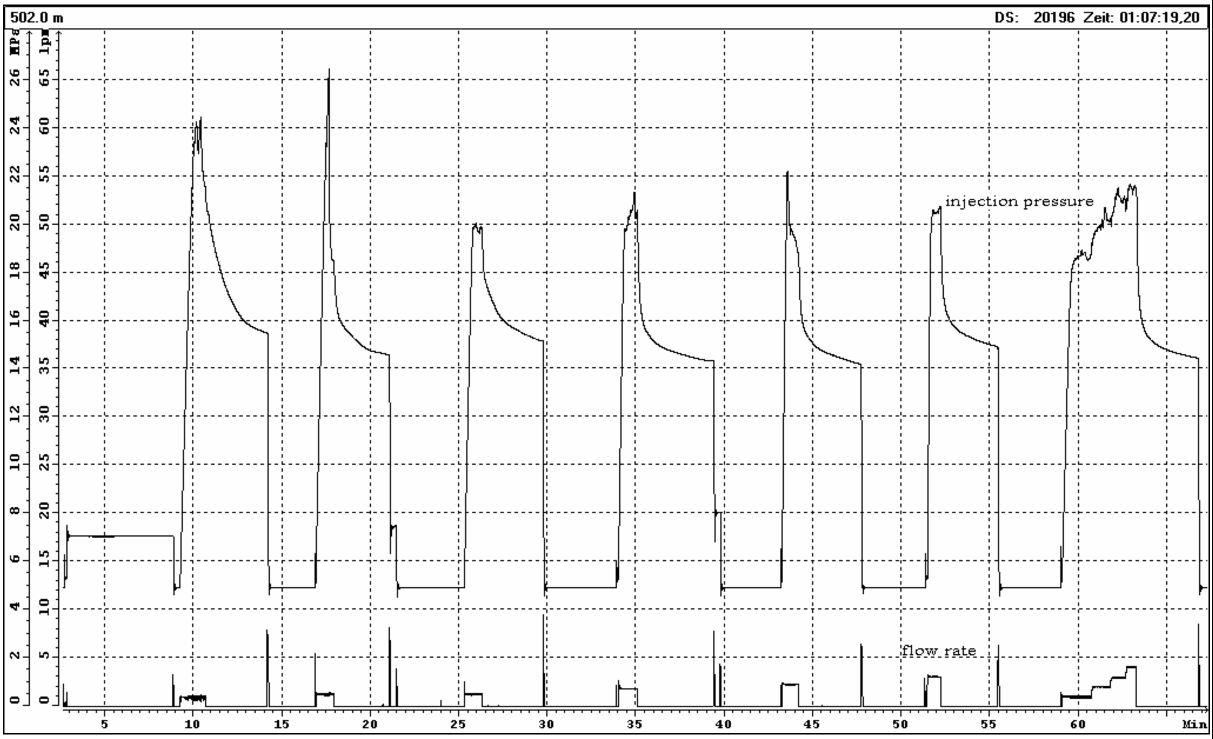


Test at 496.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 2 AT 502.0 m MD / 498.03 m TVD

Test at 502.0 m MD: Overview - Plot



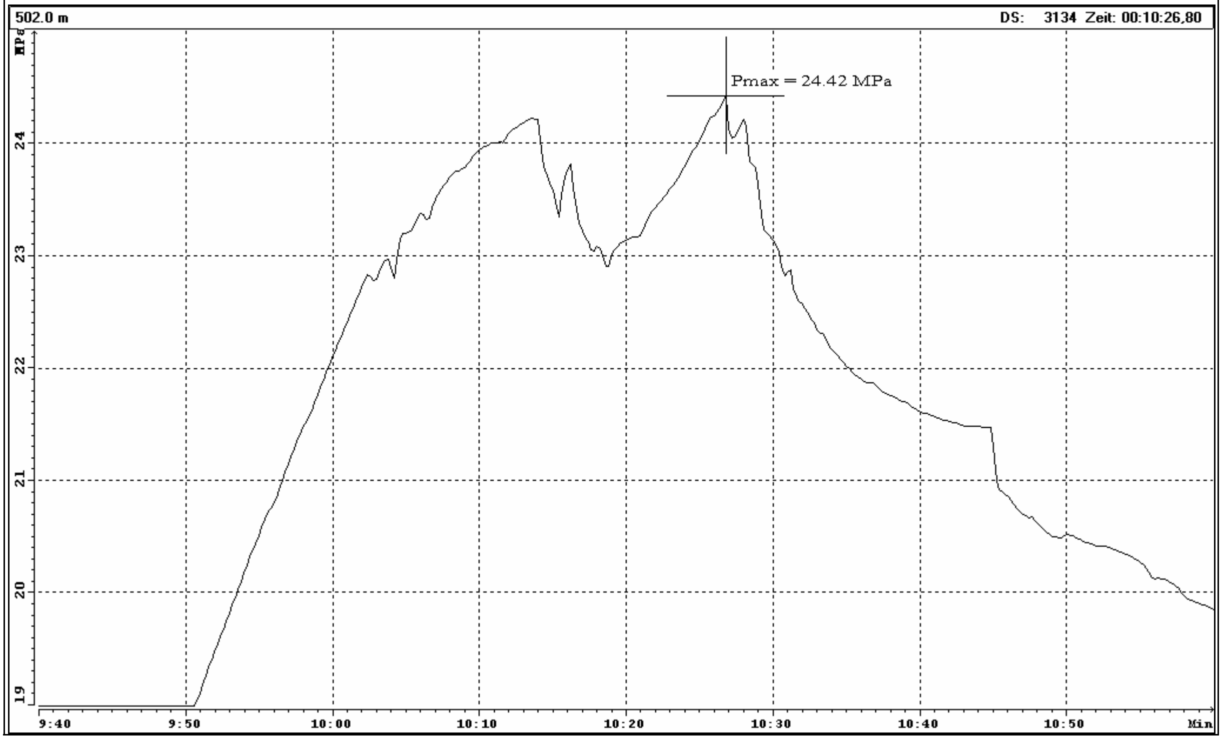
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 0.0 MPa in 345 sec.		
1. Frac - cycle	Qi (lpm) = 1.1	Vi (l) = 1.35	Vr (l) = 0.4
2. Frac - cycle	Qi (lpm) = 1.1	Vi (l) = 1.3	Vr (l) = 0.4
1. Refrac - cycle	Qi (lpm) = 1.3	Vi (l) = 1.3	Vr (l) = 0.35
2. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 2.0	Vr (l) = 0.4
3. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 2.2	Vr (l) = 0.4
4. Refrac - cycle	Qi (lpm) = 3.1	Vi (l) = 2.3	Vr (l) = 0.4
SP/SR - test	Qi (lpm) = 1.0-4.1	Vi (l) = 8.9	Vr (l) = 0.4

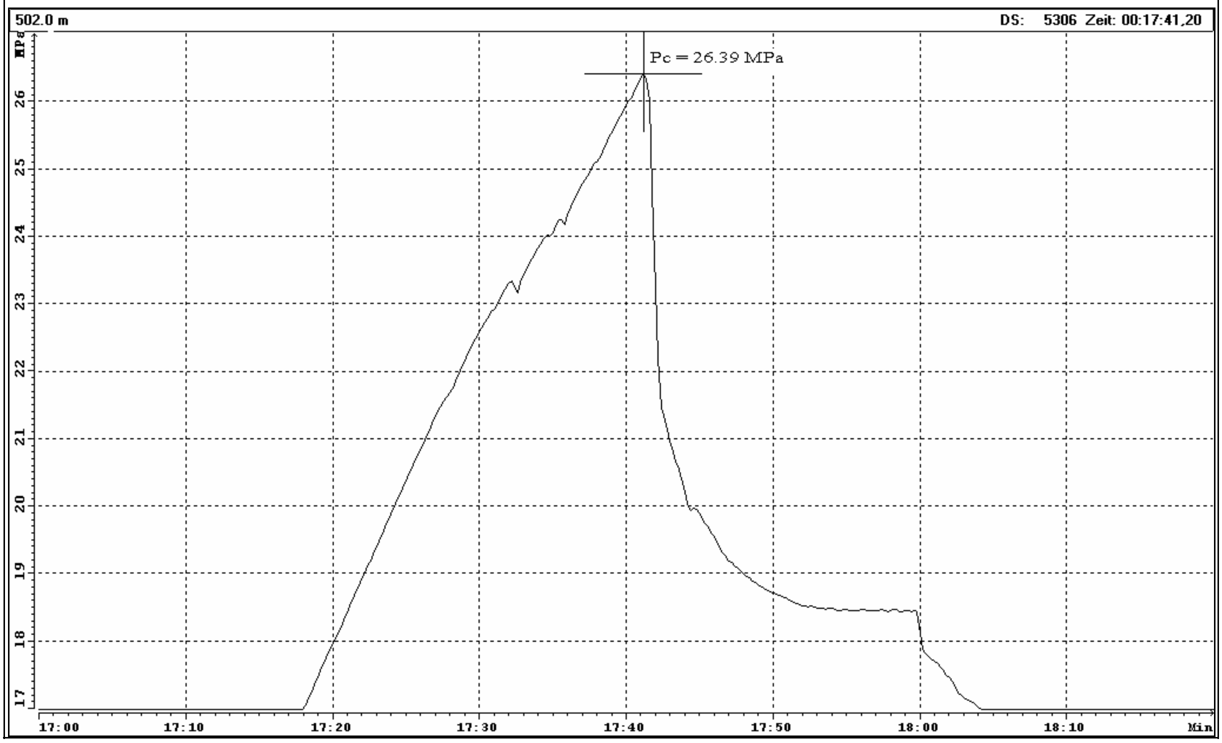
total injected volume (l): 19.35 recovered volume (l): 2.75 or 14.2 %

- Initial test type: HF
- During the 1. frac - cycle, a maximum pressure of 24.4 MPa without a distinct breakdown event was observed (sawtooth shape of the pressure vs. time record). The 2. frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event at 26.4 MPa.
- The refrac - pressure was determined from the 1. and 3. refrac - cycle. The analysis of the fracture opening phases show a decrease of system stiffness dP/dV already at 17.8 and 17.9 MPa, followed by a pressure increase up to 20 and 22.1 MPa, respectively. In comparison, the 2. and 4. refrac - cycle yield lower fracture re-opening pressures.
- The shut-in phases yield distinct shut-in pressure values, which increased from 17.2 MPa during the 3. refrac - cycle to 18.4 MPa during the 4. refrac - cycle. Therefore, the shut - in pressure of the 3. refrac - cycle was used for the stress analysis.
- The final slow-pump / step - rate test is characterized by various pressure variations.

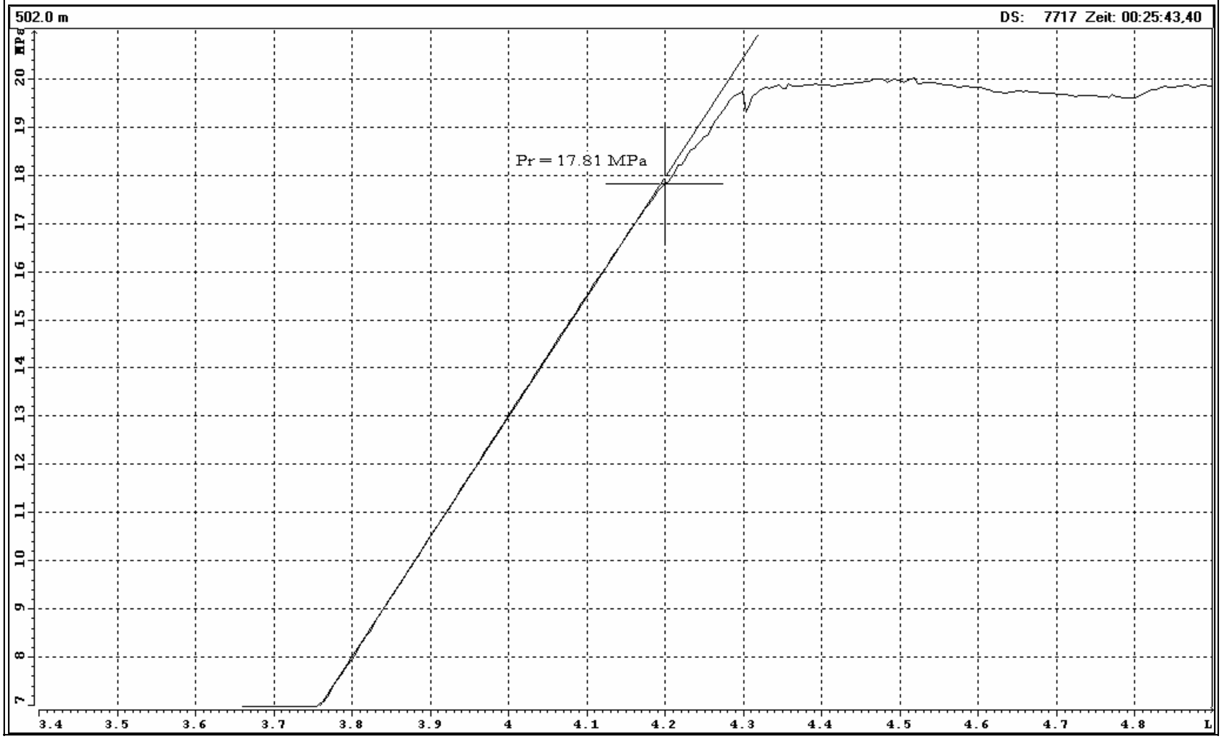
Test at 502.0 m MD: Estimation of P_{max}(1. Frac - Cycle)



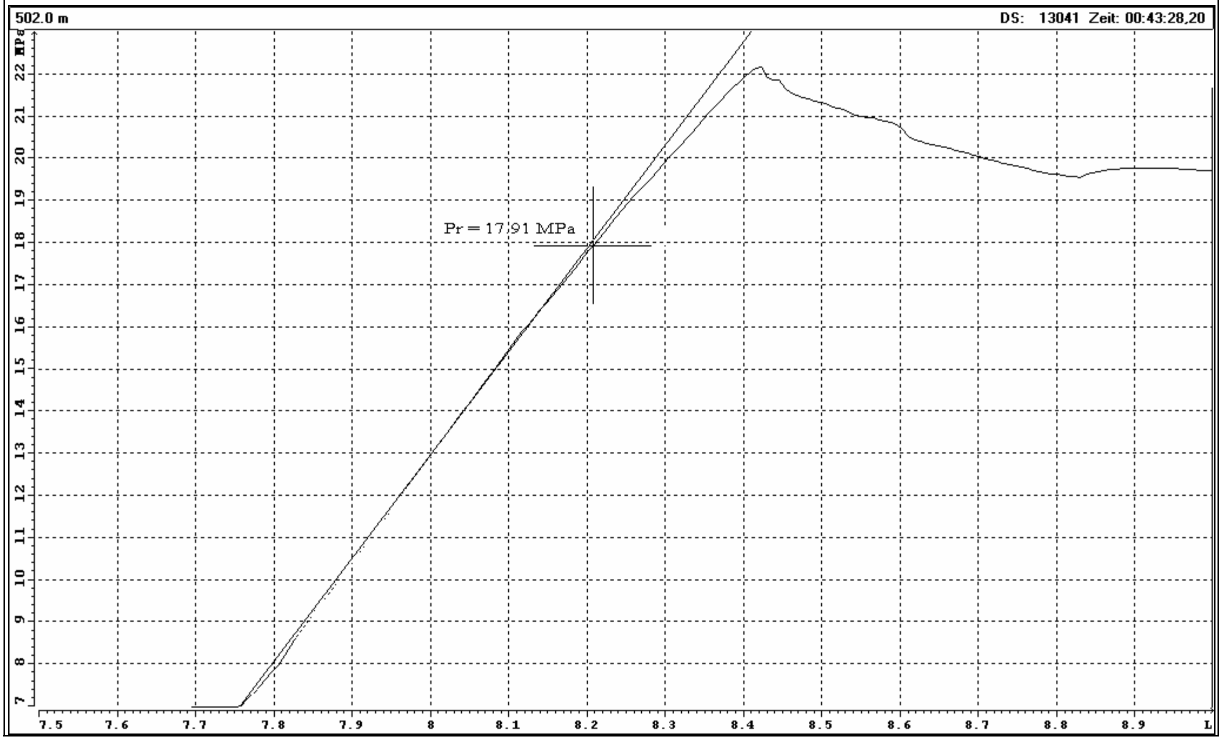
Test at 502.0 m MD: Estimation of P_c (2. Frac - Cycle)



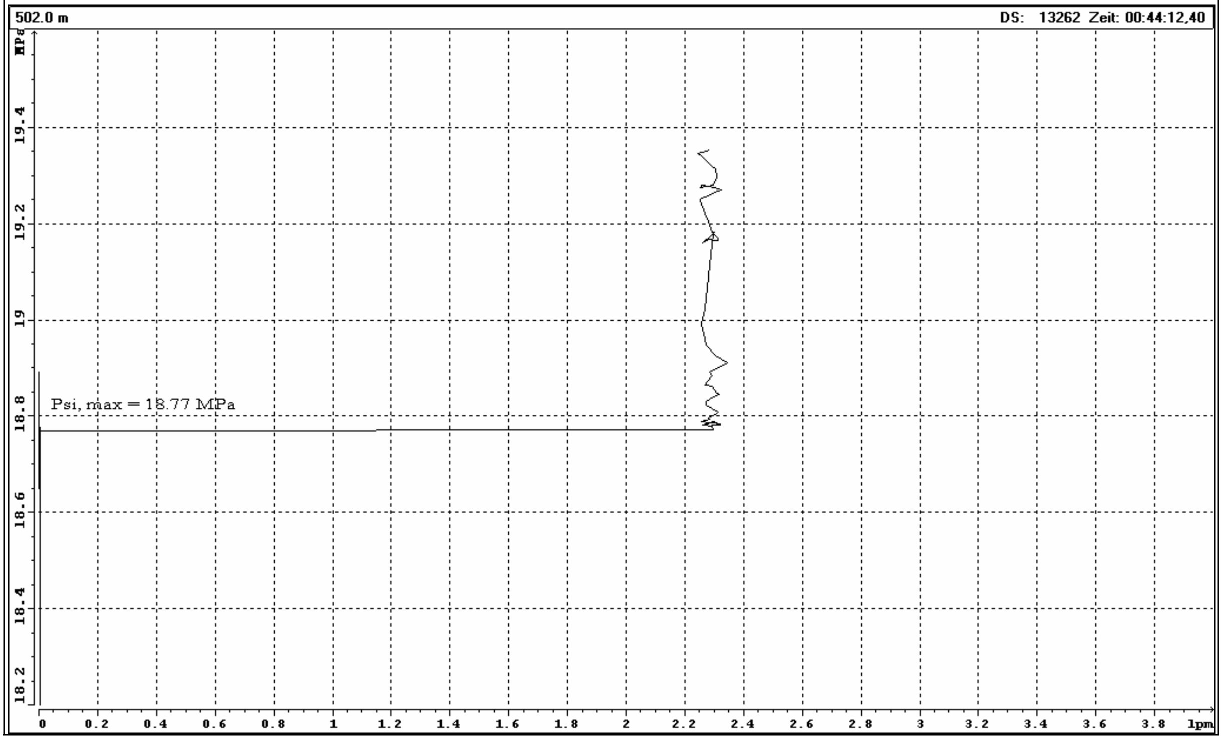
Test at 502.0 m MD: Estimation of P_r (1. Refrac - Cycle)



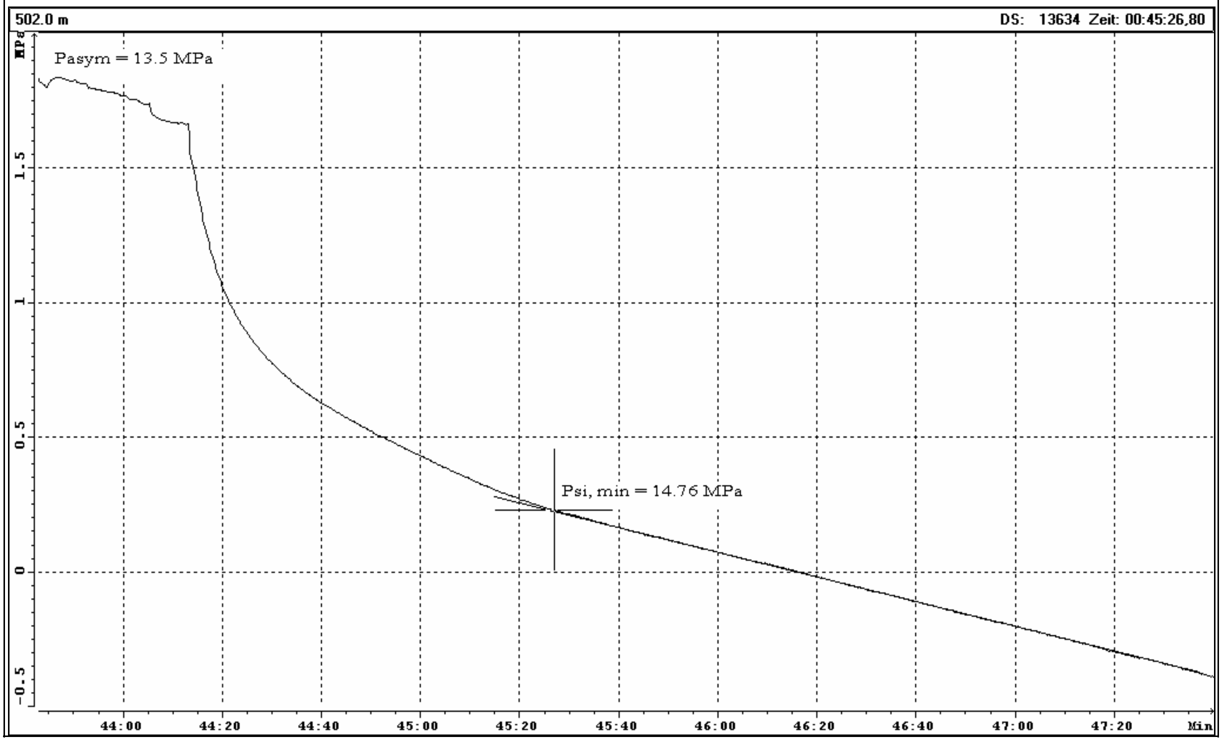
Test at 502.0 m MD: Estimation of P_r (3. Refrac - Cycle)



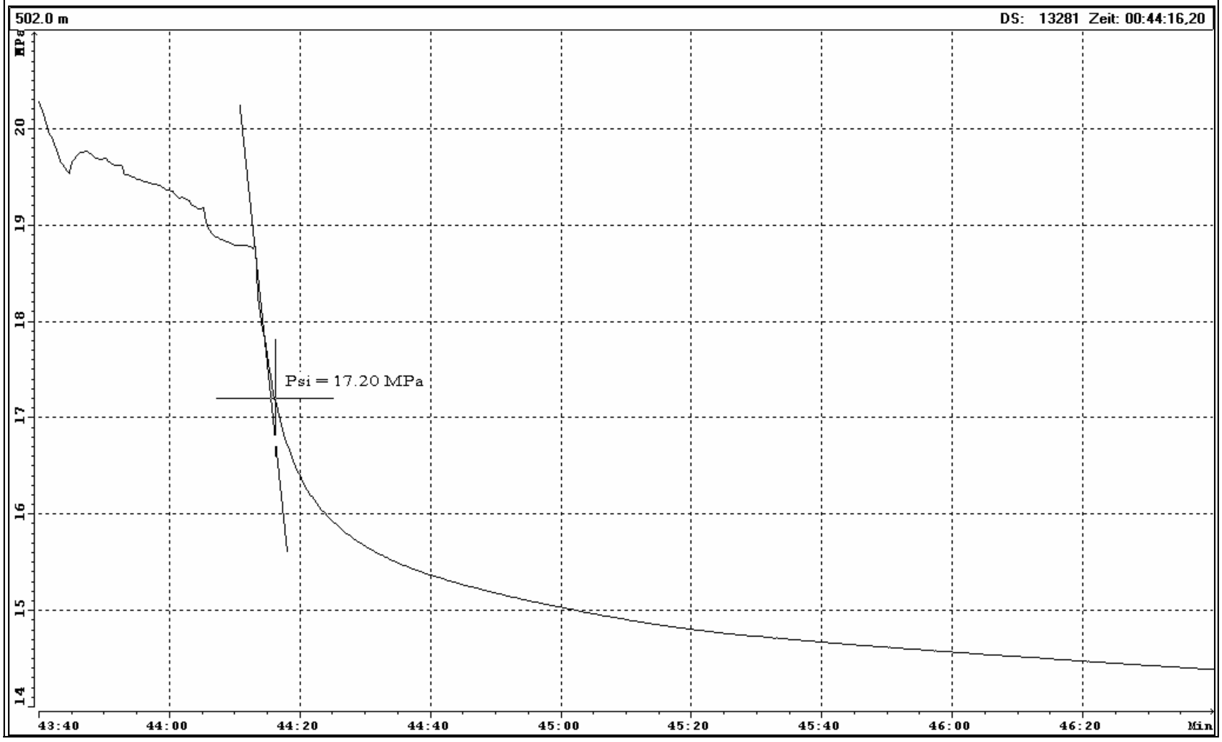
Test at 502.0 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



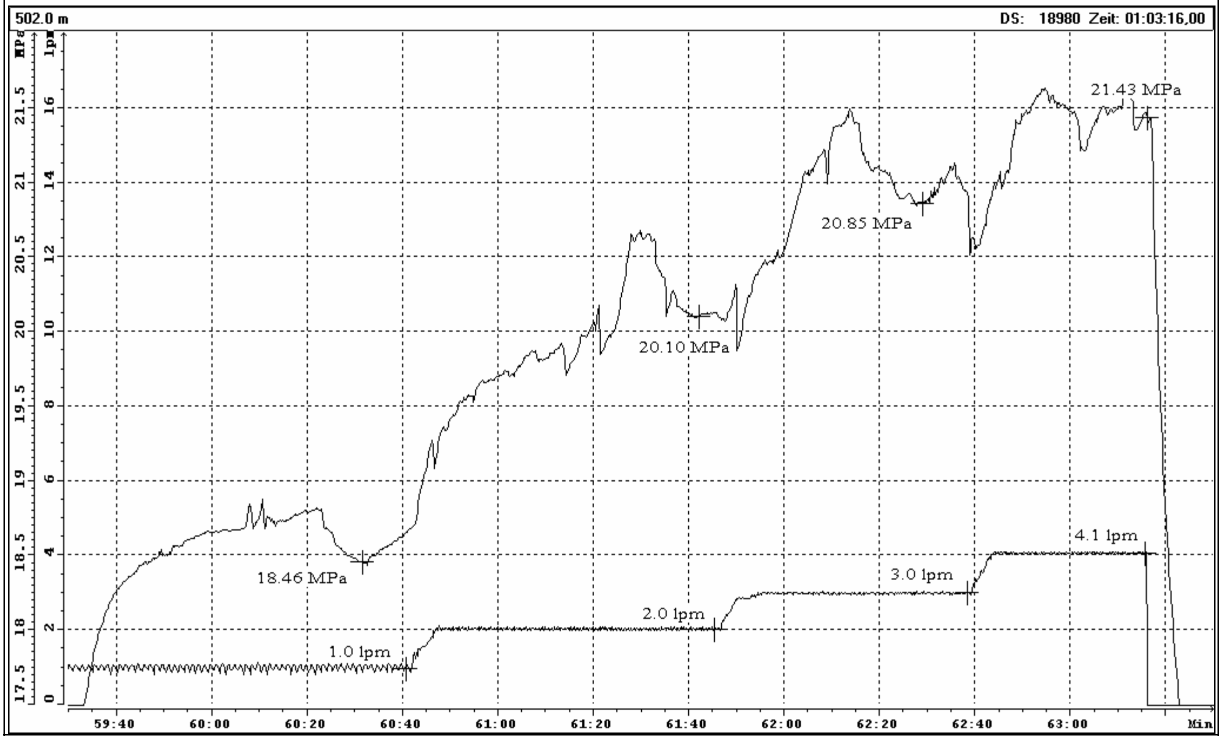
Test at 502.0 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



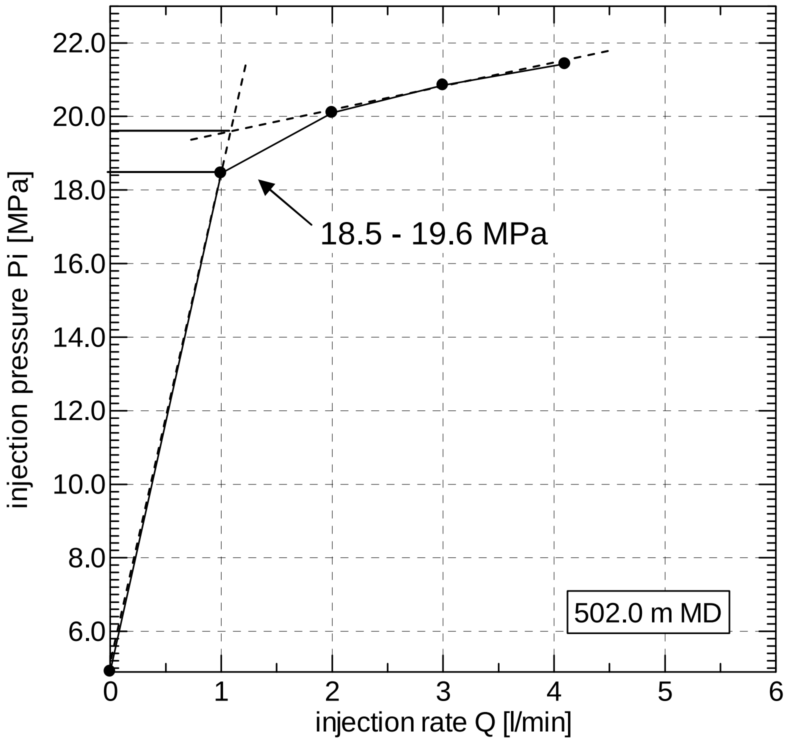
Test at 502.0 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 502.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

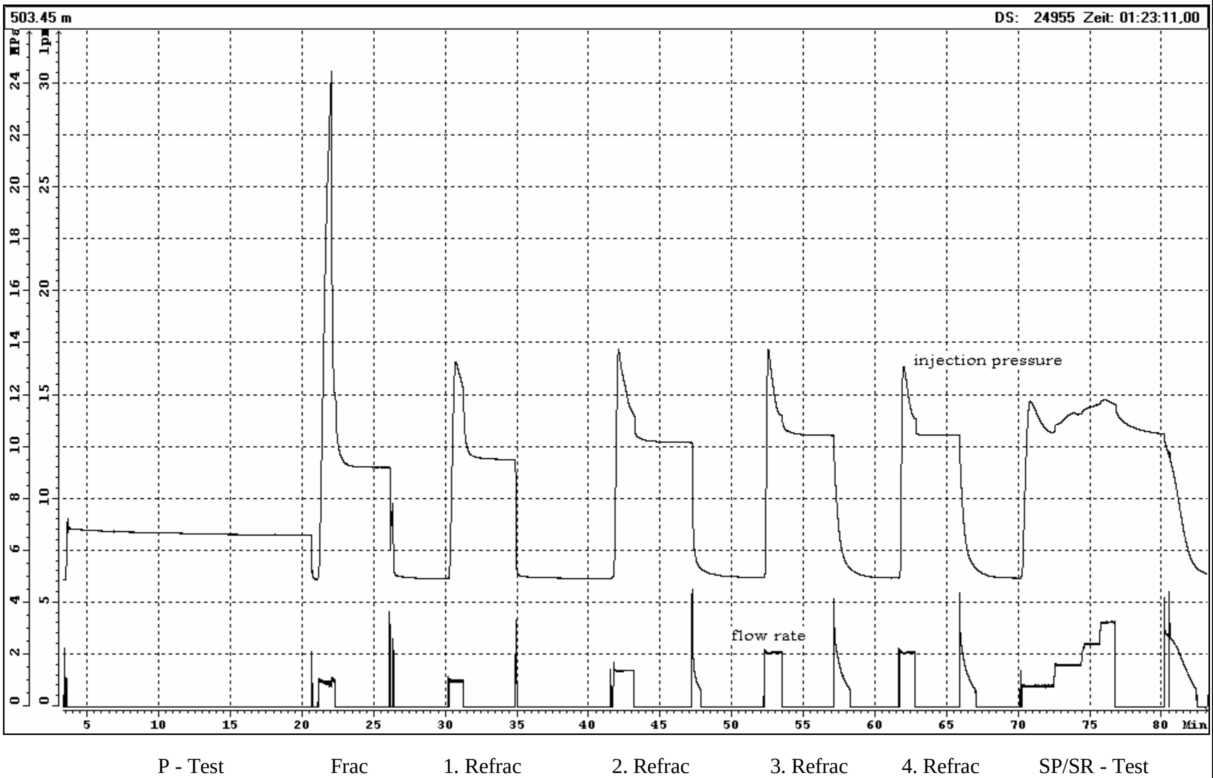


Test at 502.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 1 AT 503.45 m MD / 499.46 m TVD

Test at 503.45 m MD : Overview - Plot



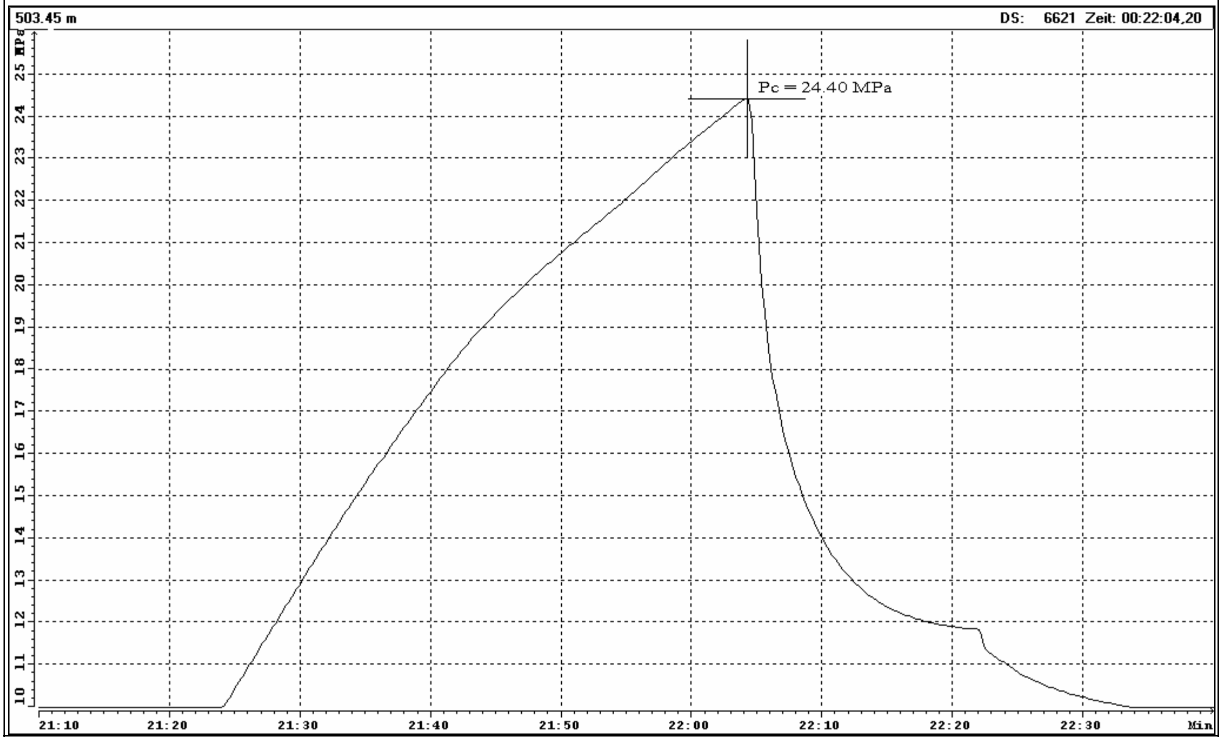
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.24 MPa in 1011 sec.		
Frac - cycle	Qi (lpm) = 1.2	Vi (l) = 1.45	Vr (l) = 1.1
1. Refrac - cycle	Qi (lpm) = 1.2	Vi (l) = 1.3	Vr (l) = 1.3
2. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 2.6	Vr (l) = 2.0
3. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 3.25	Vr (l) = 2.9
4. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 2.9	Vr (l) = 2.9
SP/SR - test	Qi (lpm) = 1.0-4.1	Vi (l) = 14.3	Vr (l) = 9.0

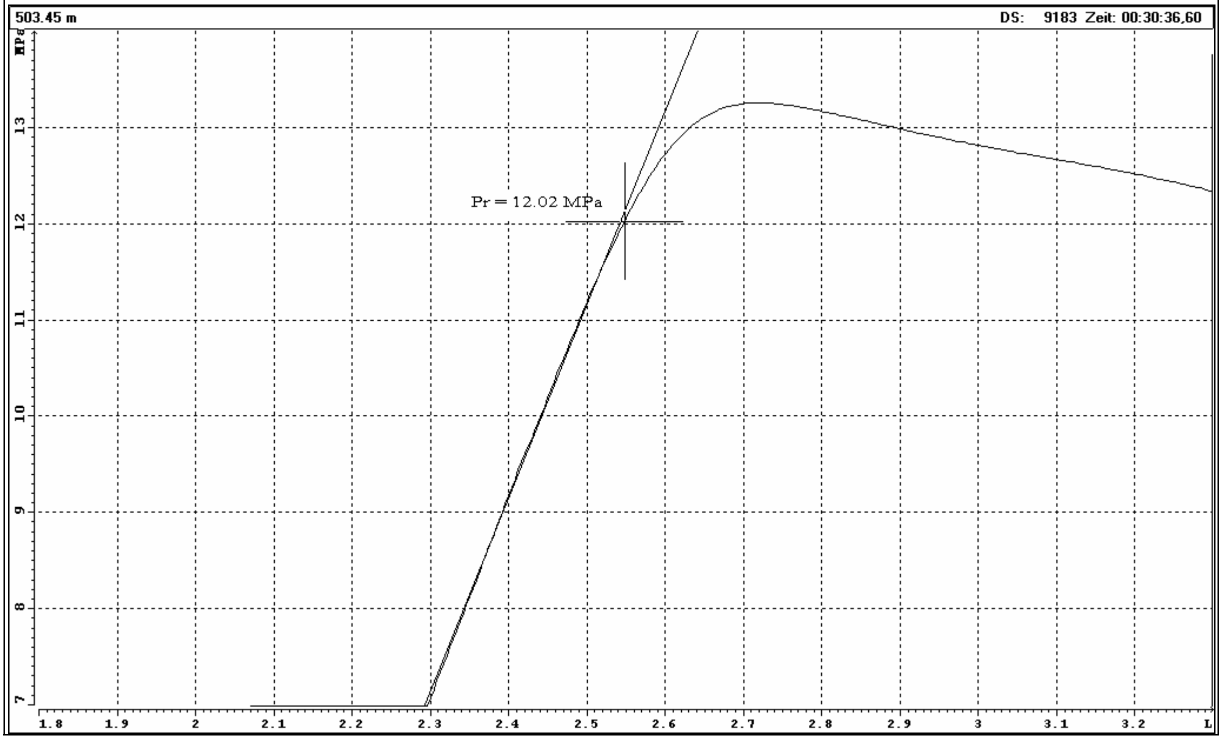
total injected volume (l): 25.8 recovered volume (l): 19.2 or 74.4 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. and 2. refrac - cycle, since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- The shut-in phases yield rather distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

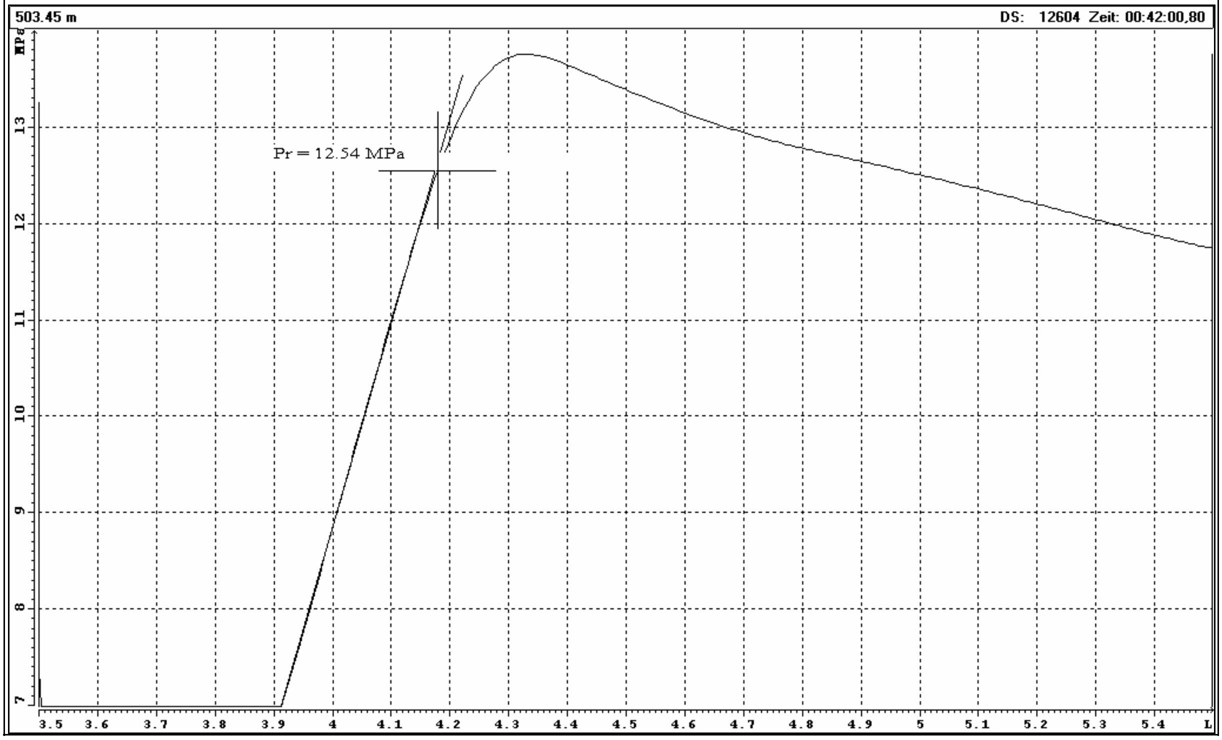
Test at 503.45 m MD: Estimation of P_c (Frac - Cycle)



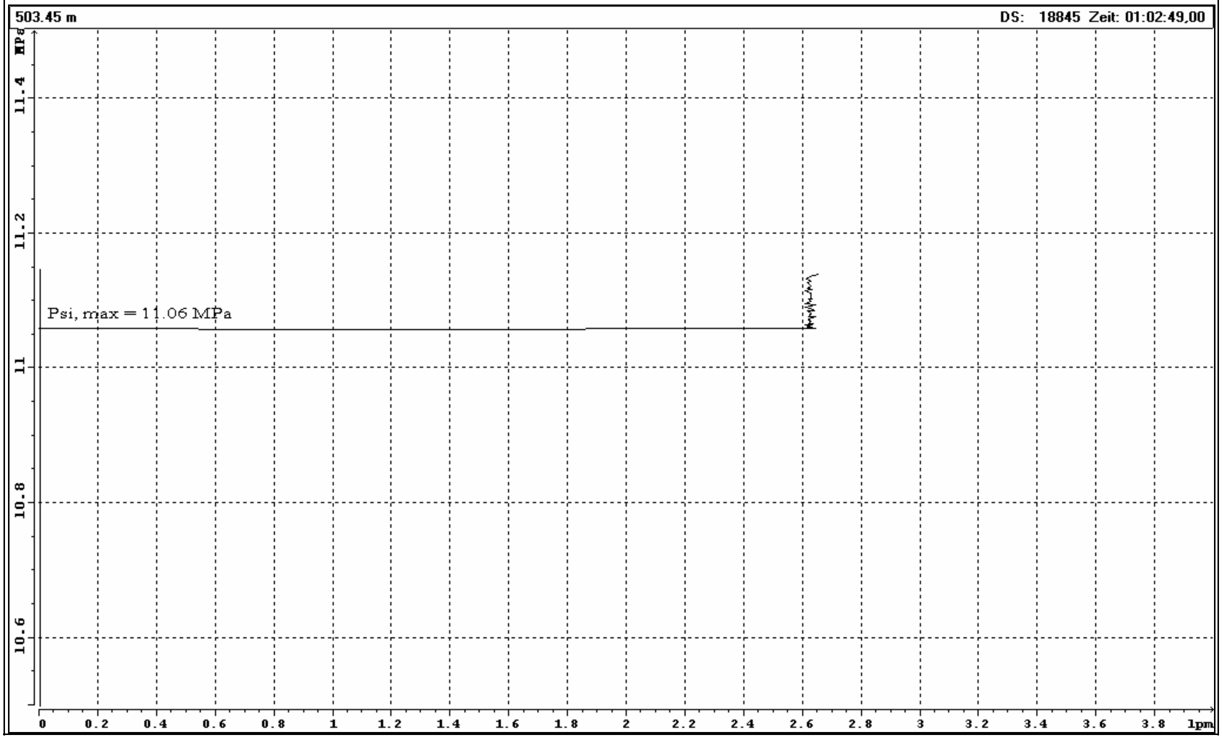
Test at 503.45 m MD: Estimation of P_r (1. Refrac) - Cycle)



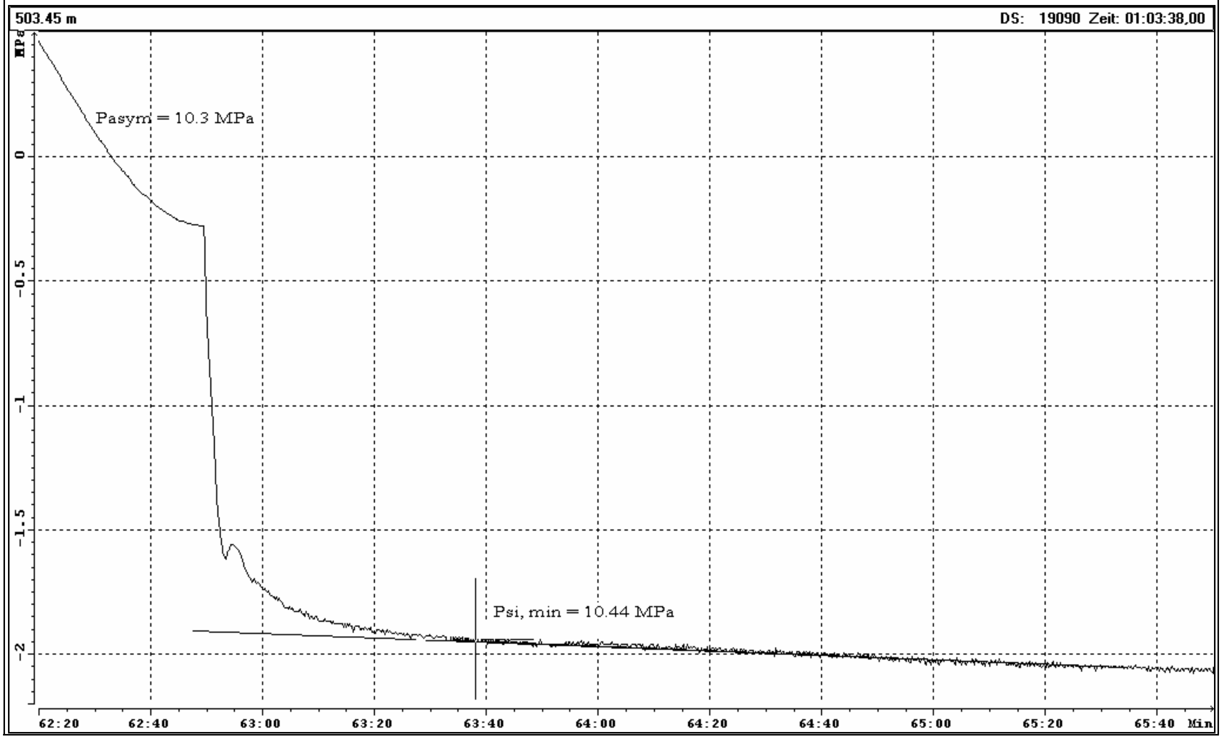
Test at 503.45 m MD: Estimation of P_r (2. Refrac - Cycle)



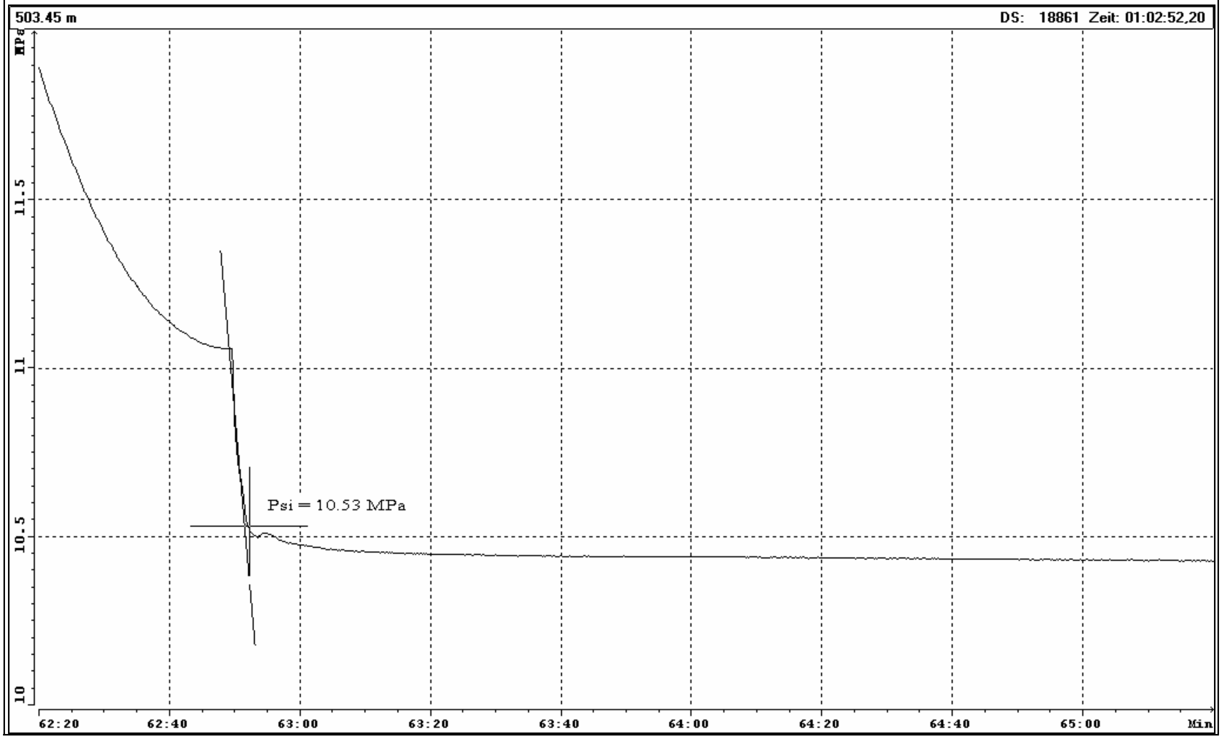
Test at 503.45 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



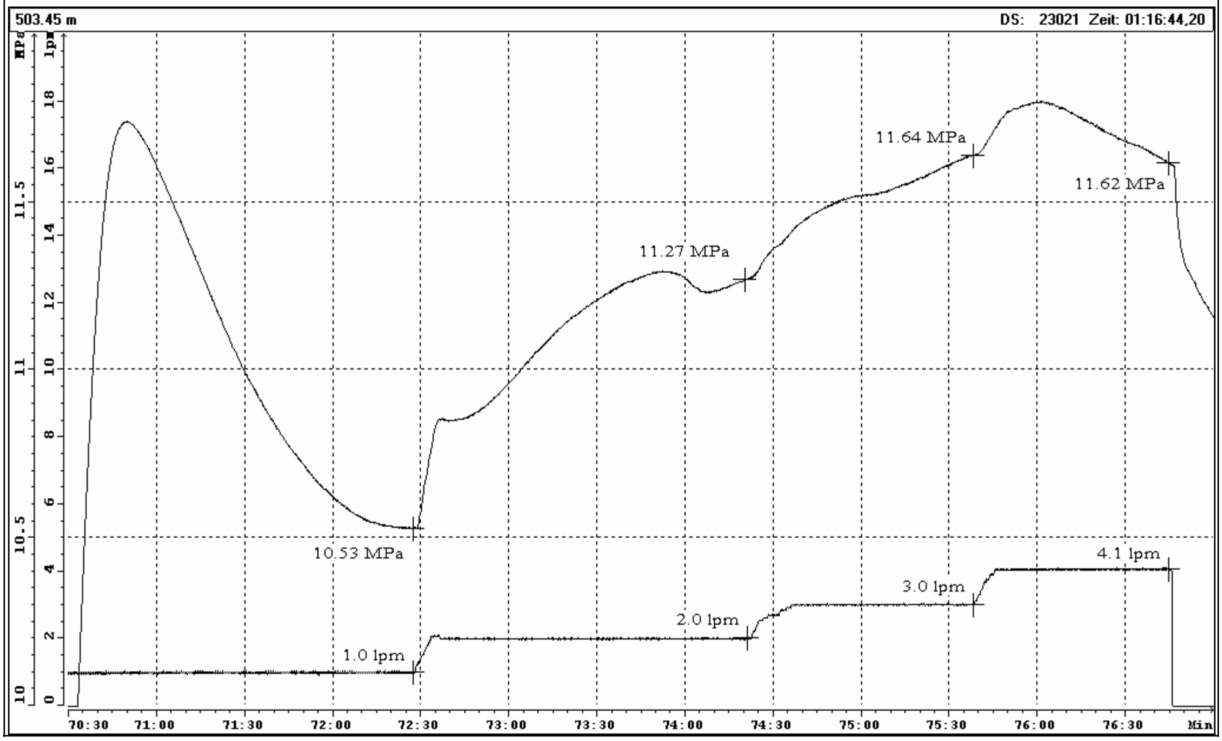
Test at 503.45 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



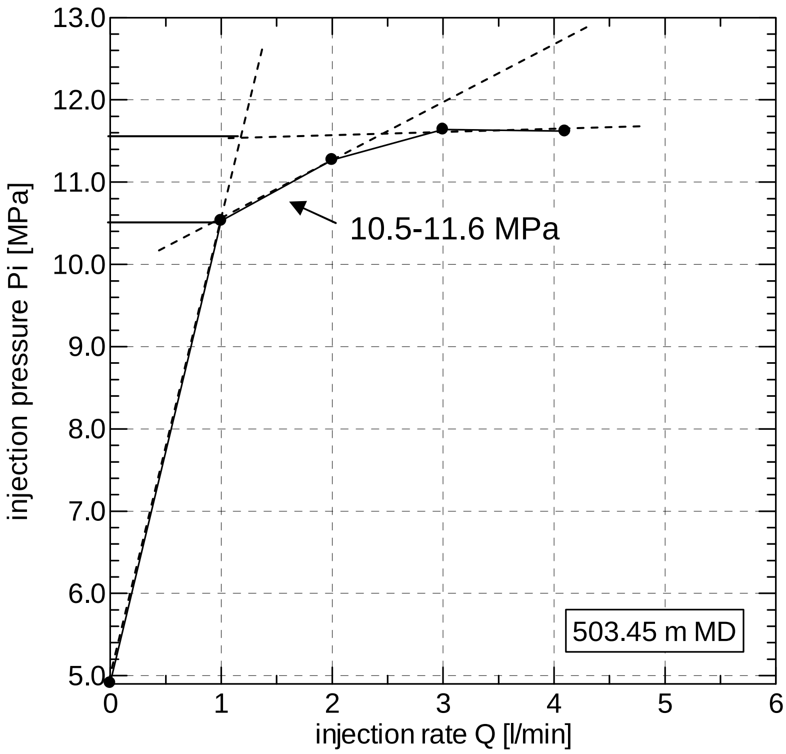
Test at 503.45 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 503.45 m MD: Analysis of Slow - Pump / Step - Rate - Test

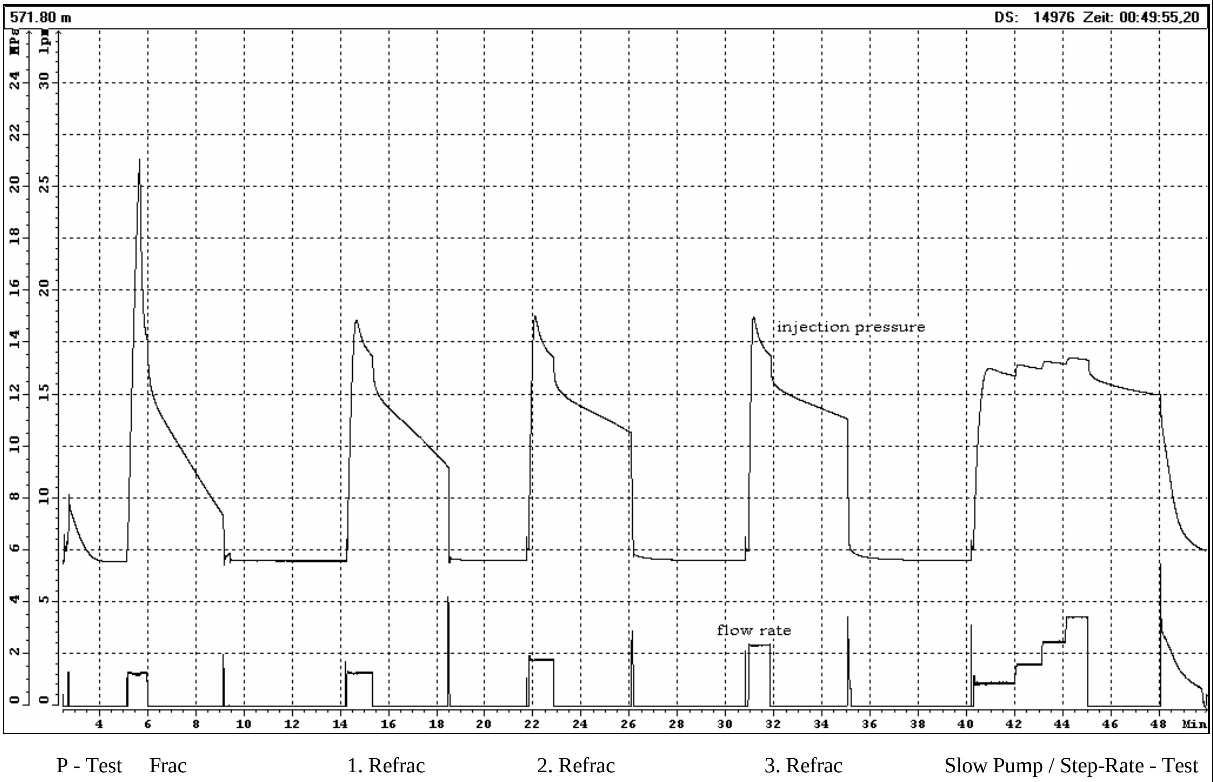


Test at 503.45 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 20 AT 571.80 m MD / 566.74 m TVD

Test at 571.80 m MD: Overview - Plot



<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

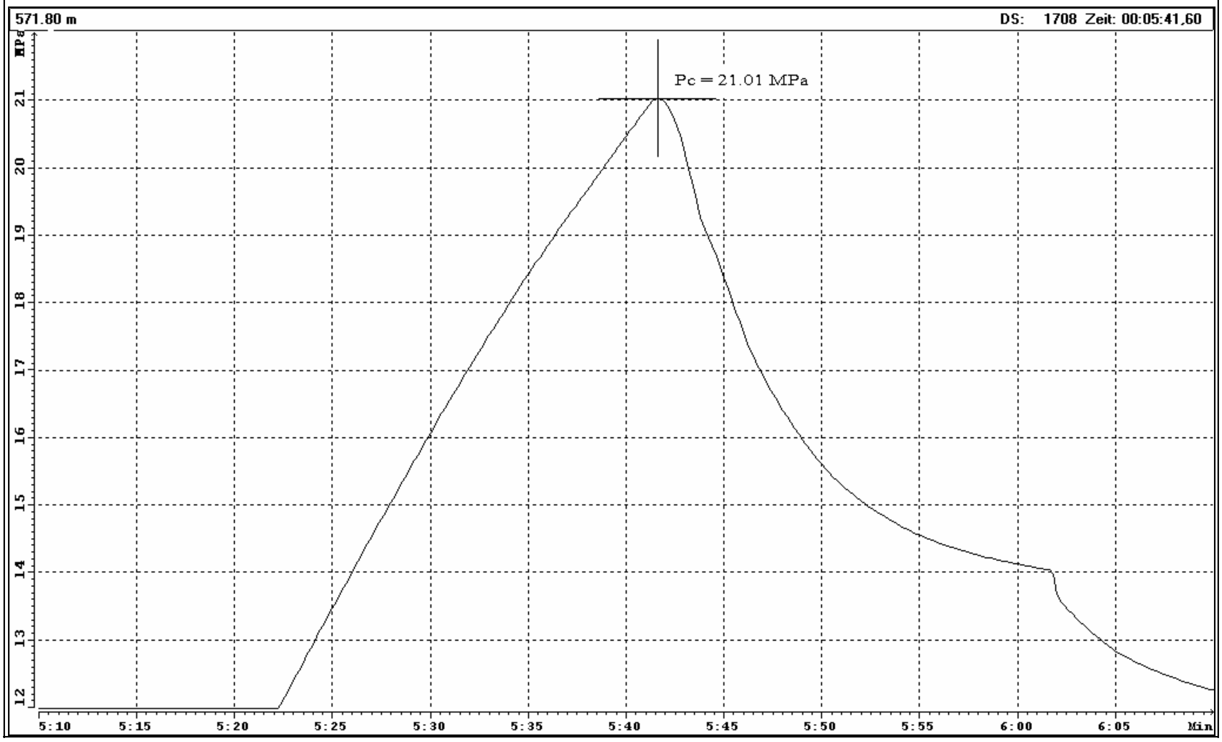
P - Test : pressure decrease: 1.89 MPa in 75 sec. (it is most likely that the significant pressure decay was caused by a small leakage of the coil tubing)

Frac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.3	Vr (l) = 0.15
1. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.7	Vr (l) = 0.3
2. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 2.3	Vr (l) = 0.9
3. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 2.7	Vr (l) = 1.3
SP/SR - test	Qi (lpm) = 1.1-4.3	Vi (l) = 11.2	Vr (l) = 6.0

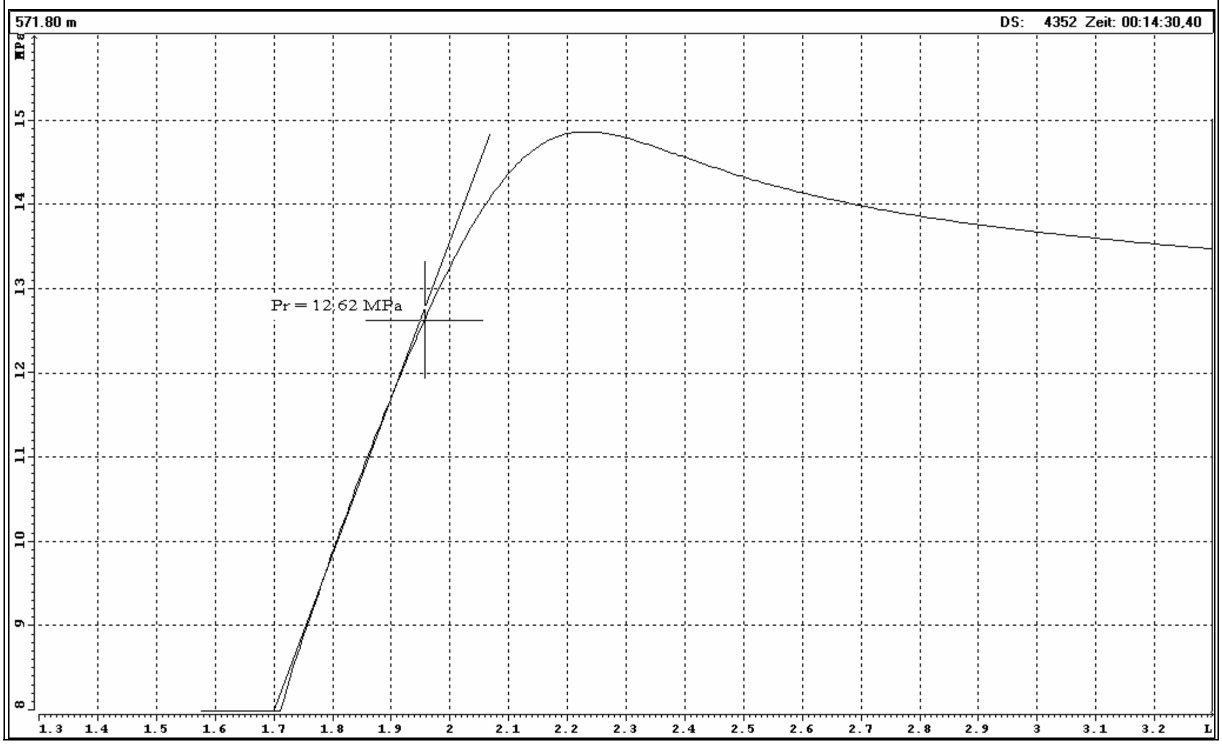
total injected volume (l): 19.2 recovered volume (l): 8.65 or 45.1 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 12.6 MPa, followed by a pressure increase up to about 15 MPa. The subsequent refrac - cycles yield nearly identical fracture re-opening pressure values.
- A decrease of the pressure fall-off during the shut-in phases associated with an increase of the fluid recovery rate was observed after the 1. refrac - cycles.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

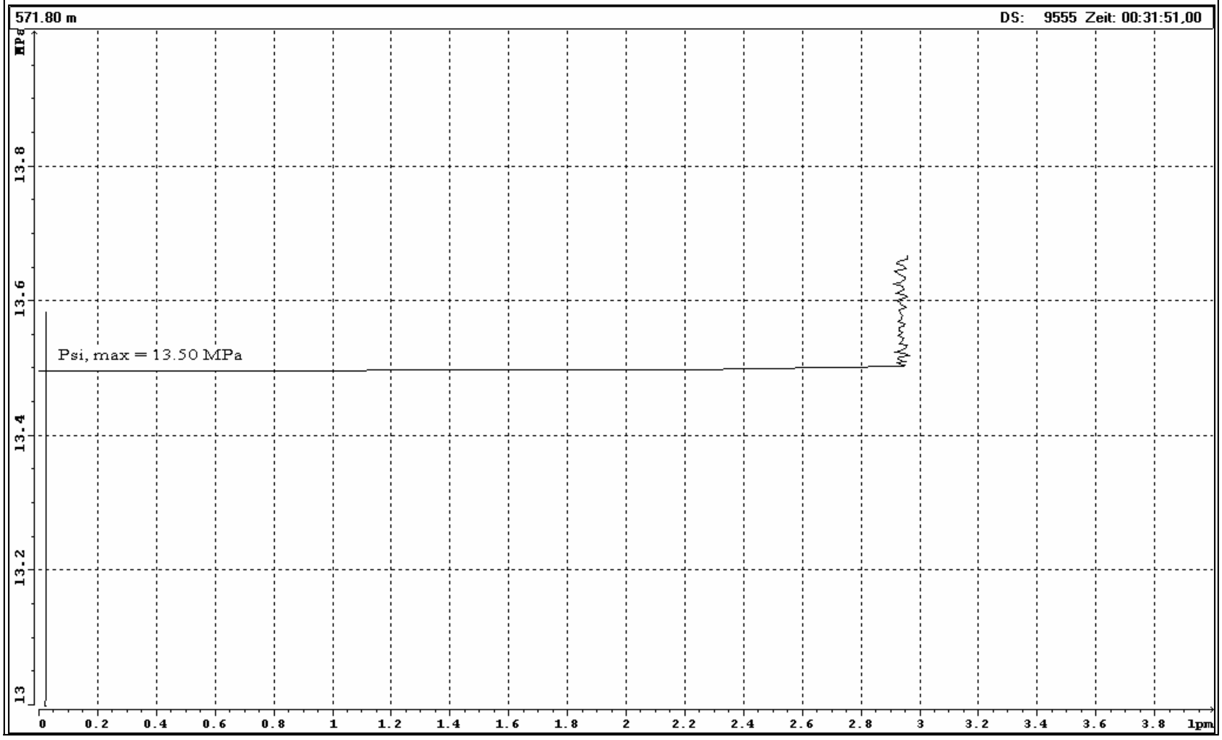
Test at 571.80 m MD: Estimation of P_c (1. Frac - Cycle)



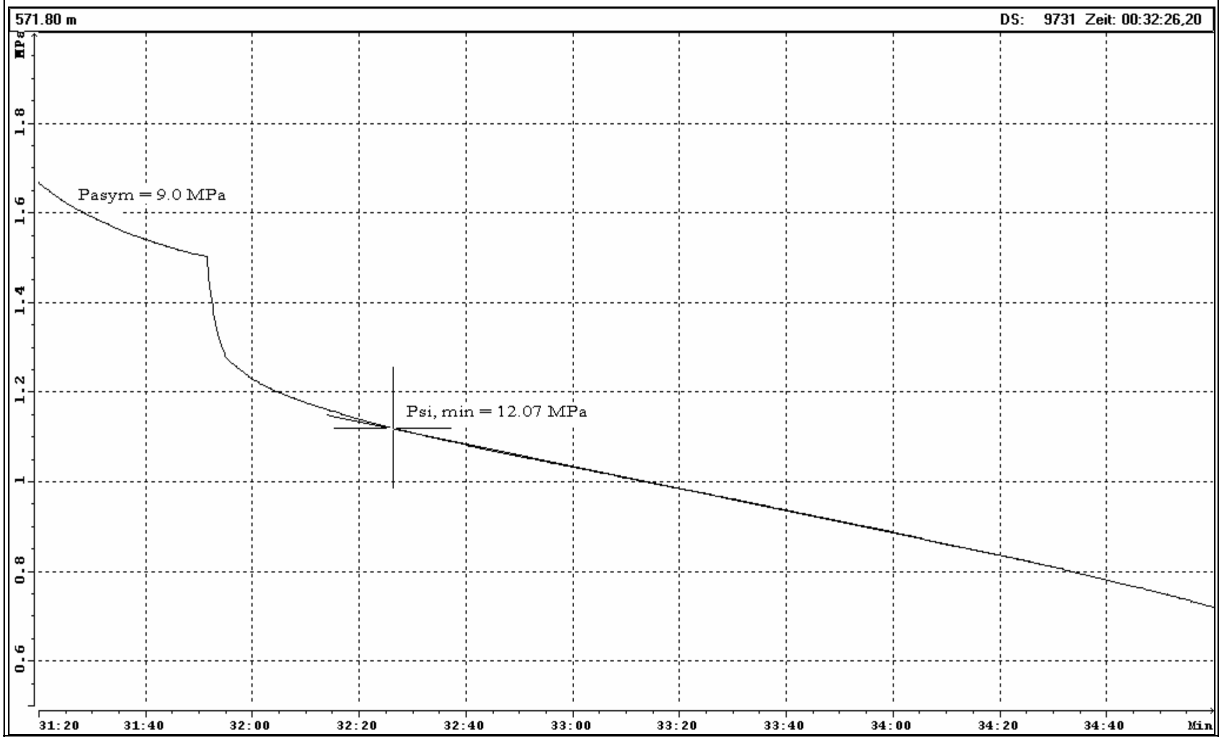
Test at 571.80 m MD: Estimation of P_r (1. Refrac - Cycle)



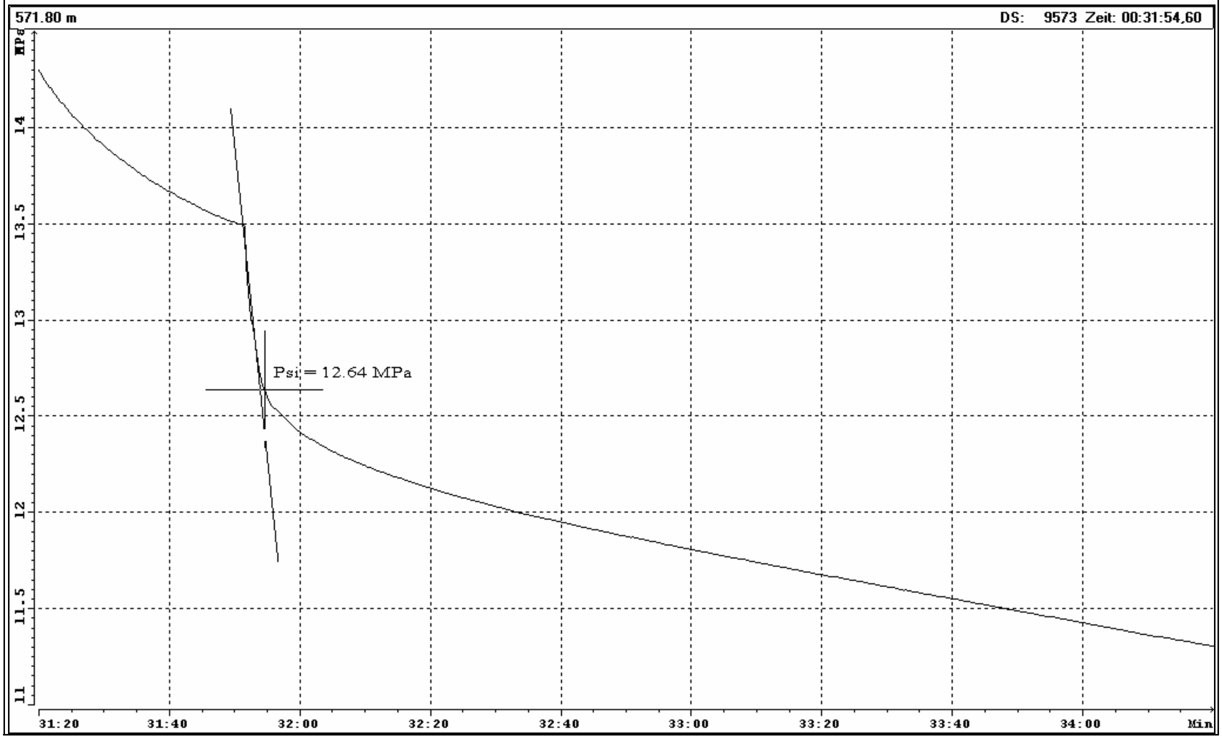
Test at 571.80 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



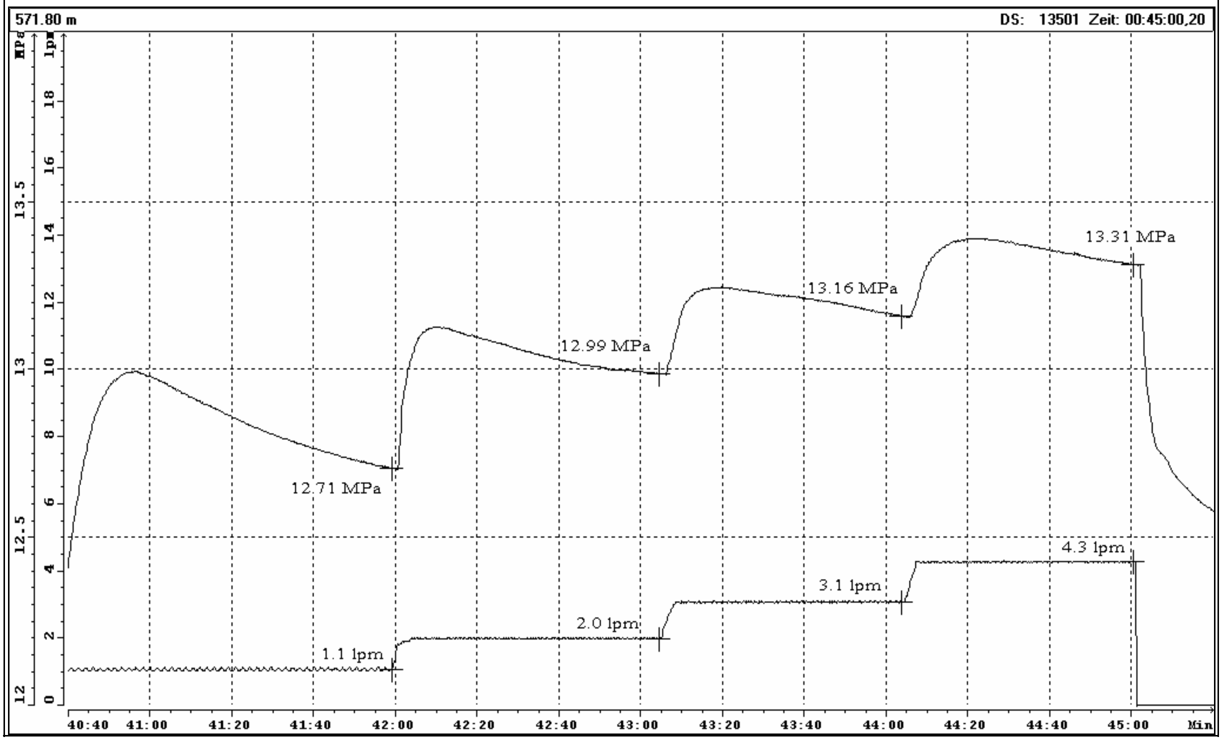
Test at 571.80 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



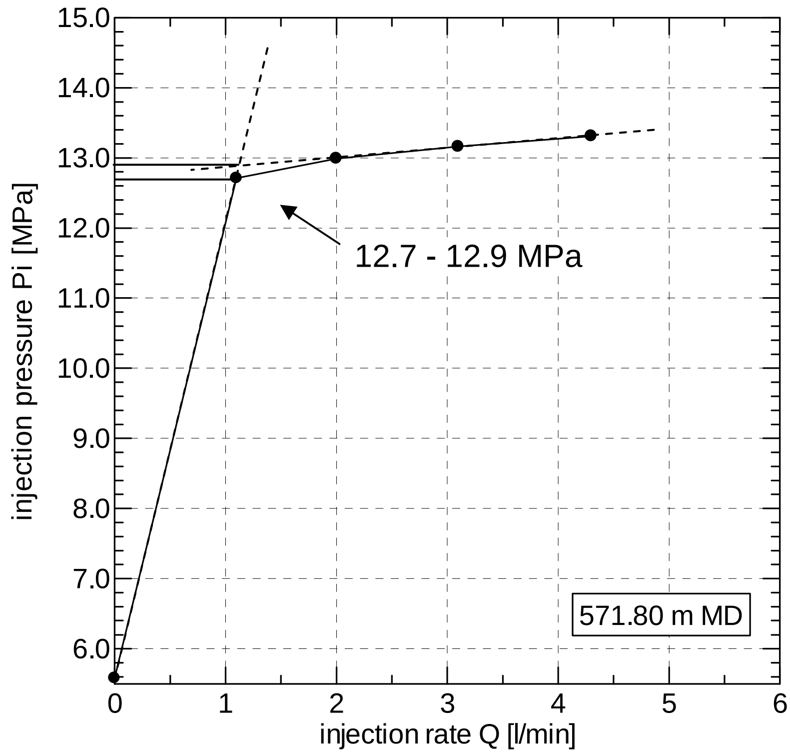
Test at 571.80 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 571.80 m MD: Analysis of Slow - Pump / Step - Rate - Test

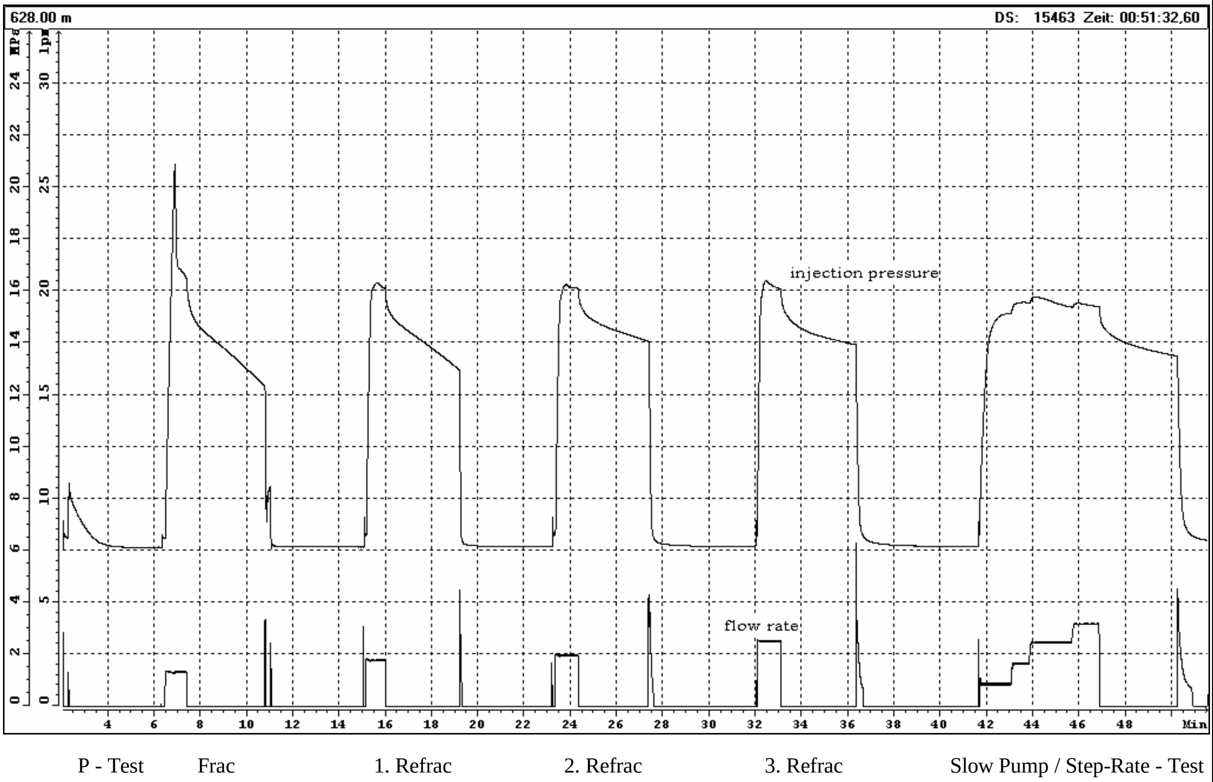


Test at 571.80 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 19 AT 628.00 m MD / 621.90 m TVD

Test at 628.00 m MD: Overview - Plot



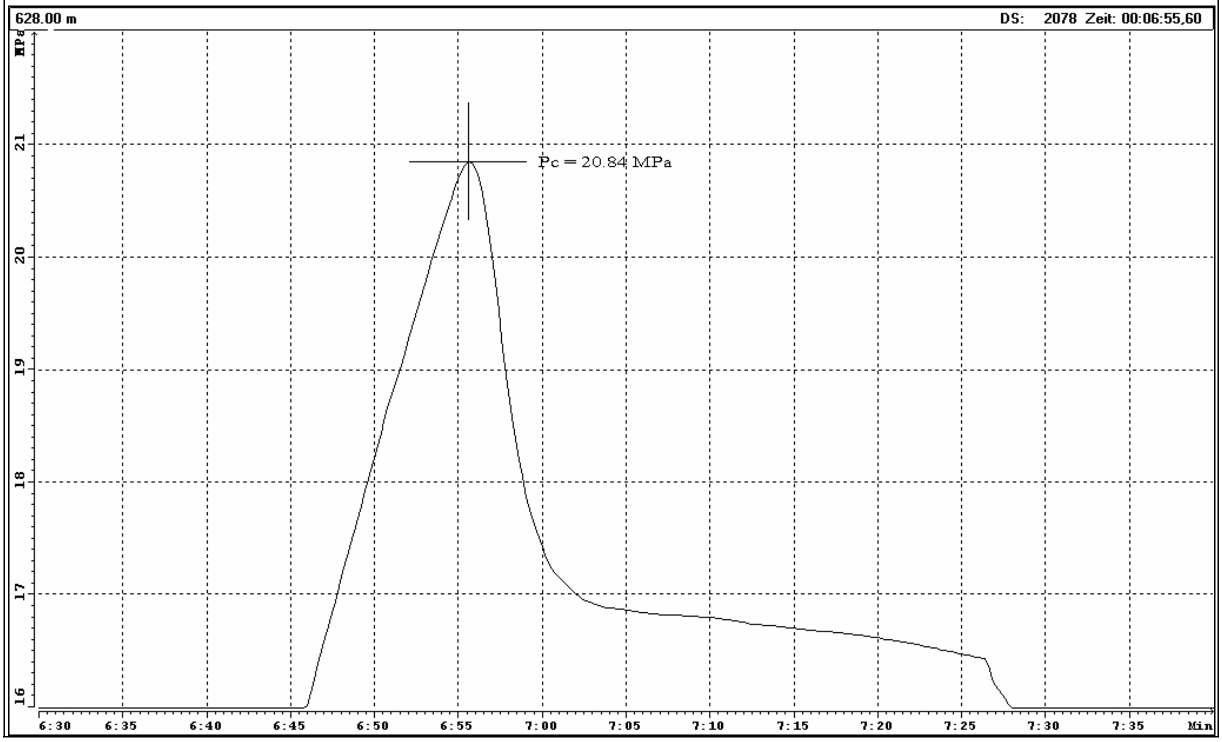
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 1.91 MPa in 138 sec. (it is most likely that the significant pressure decay was caused by a small leakage of the coil tubing)		
Frac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.5	Vr (l) = 0.5
1. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 1.9	Vr (l) = 0.7
2. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 2.4	Vr (l) = 1.4
3. Refrac - cycle	Qi (lpm) = 3.1	Vi (l) = 3.2	Vr (l) = 1.75
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 13.4	Vr (l) = 3.0

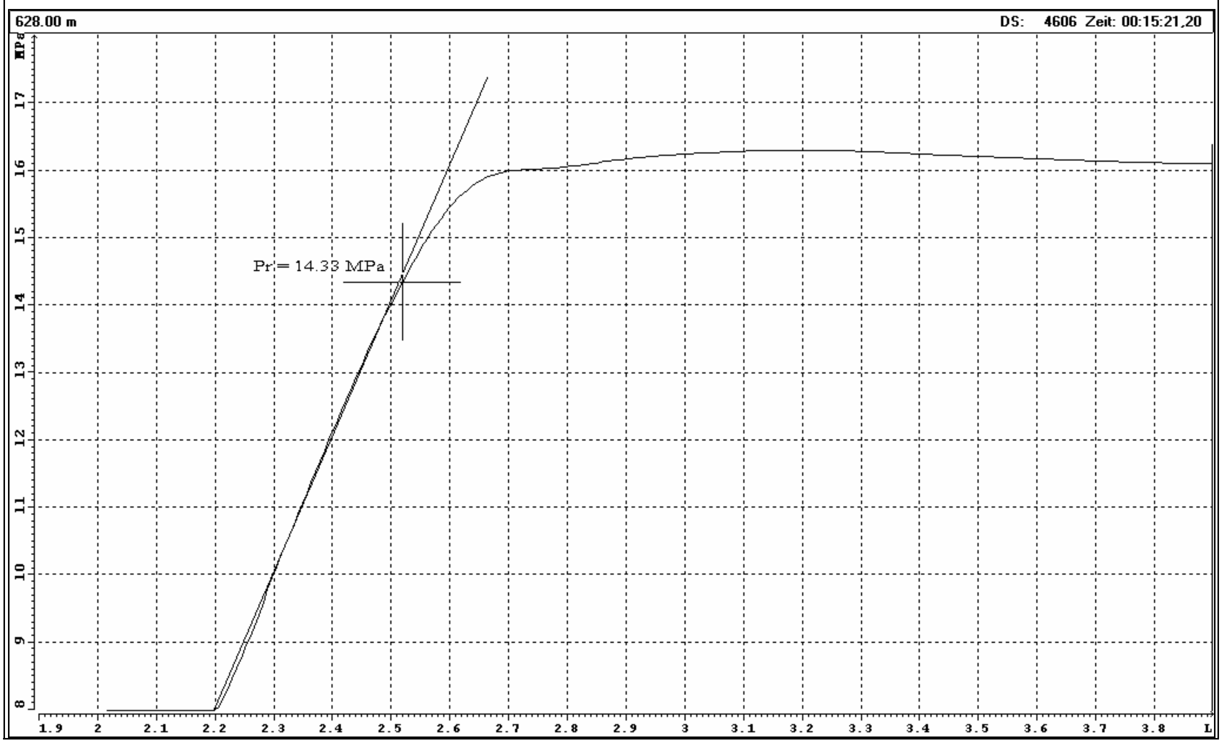
total injected volume (l): 22.4 recovered volume (l): 7.35 or 32.8 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 14.3, followed by a pressure increase up to 16.3 MPa. The subsequent refrac - cycles yield lower fracture re-opening pressure values.
- A decrease of the pressure fall-off during the shut-in phases associated with an increase of the fluid recovery rate was observed after the 1. refrac - cycles.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

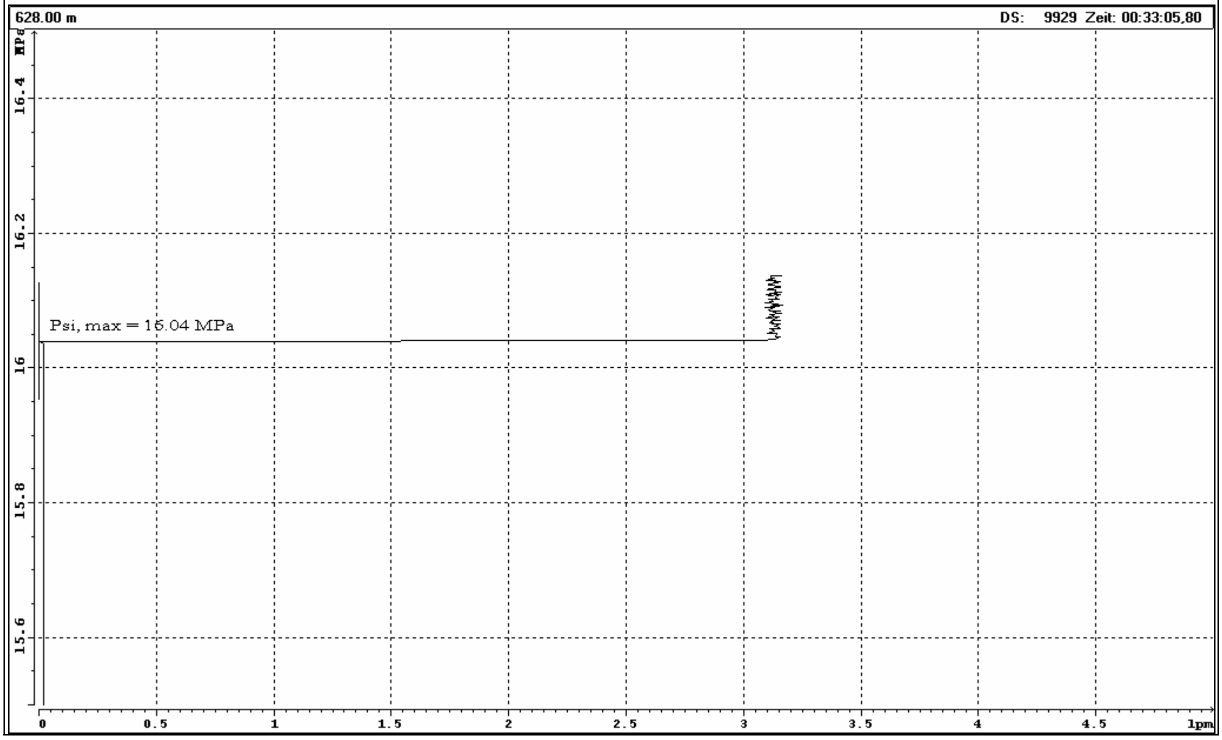
Test at 628.00 m MD: Estimation of P_c (Frac - Cycle)



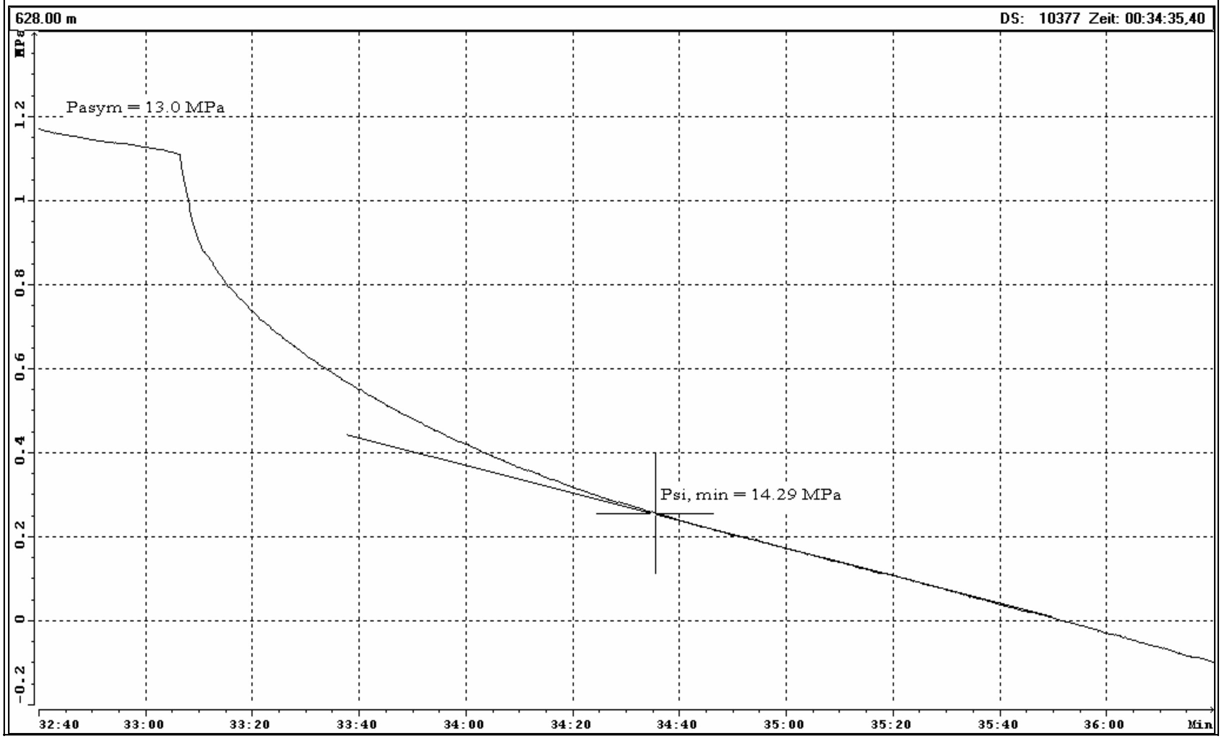
Test at 628.00 m MD: Estimation of P_r (1. Refrac - Cycle)



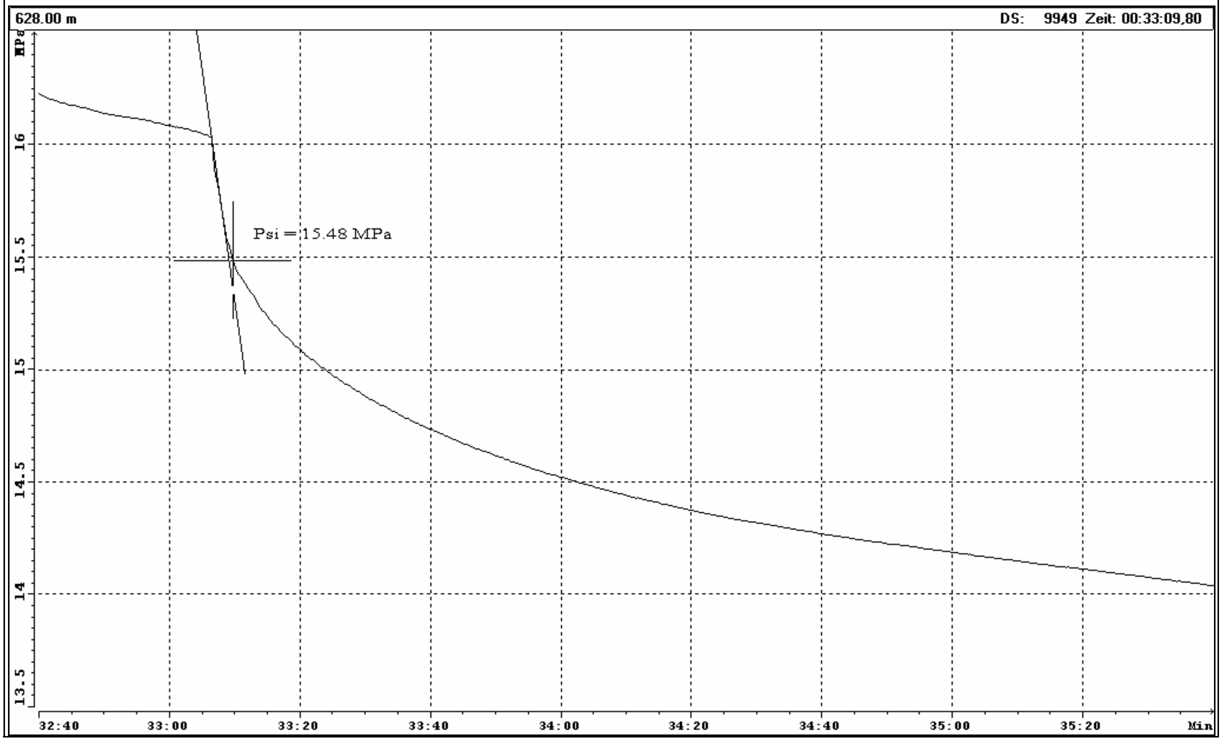
Test at 628.00 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



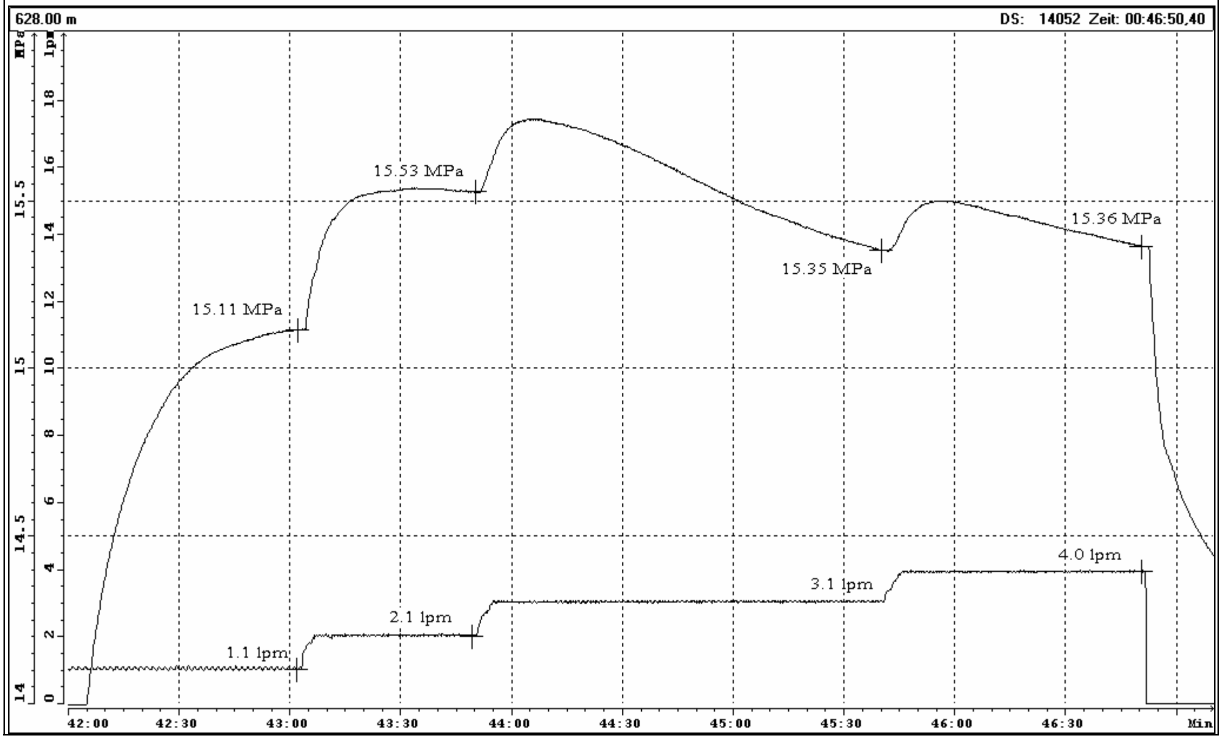
Test at 628.00 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



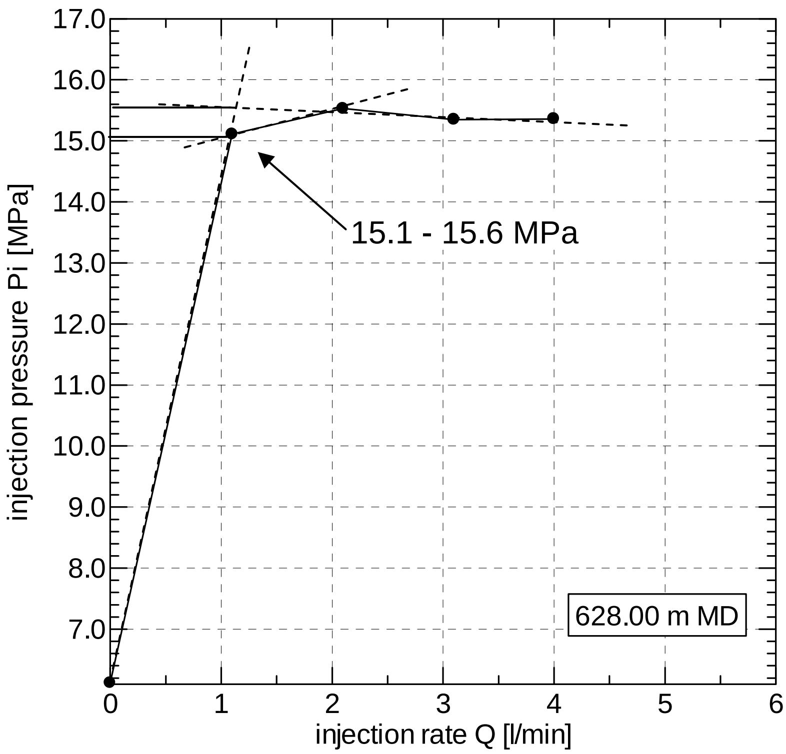
Test at 628.00 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 628.00 m MD: Analysis of Slow - Pump / Step - Rate - Test

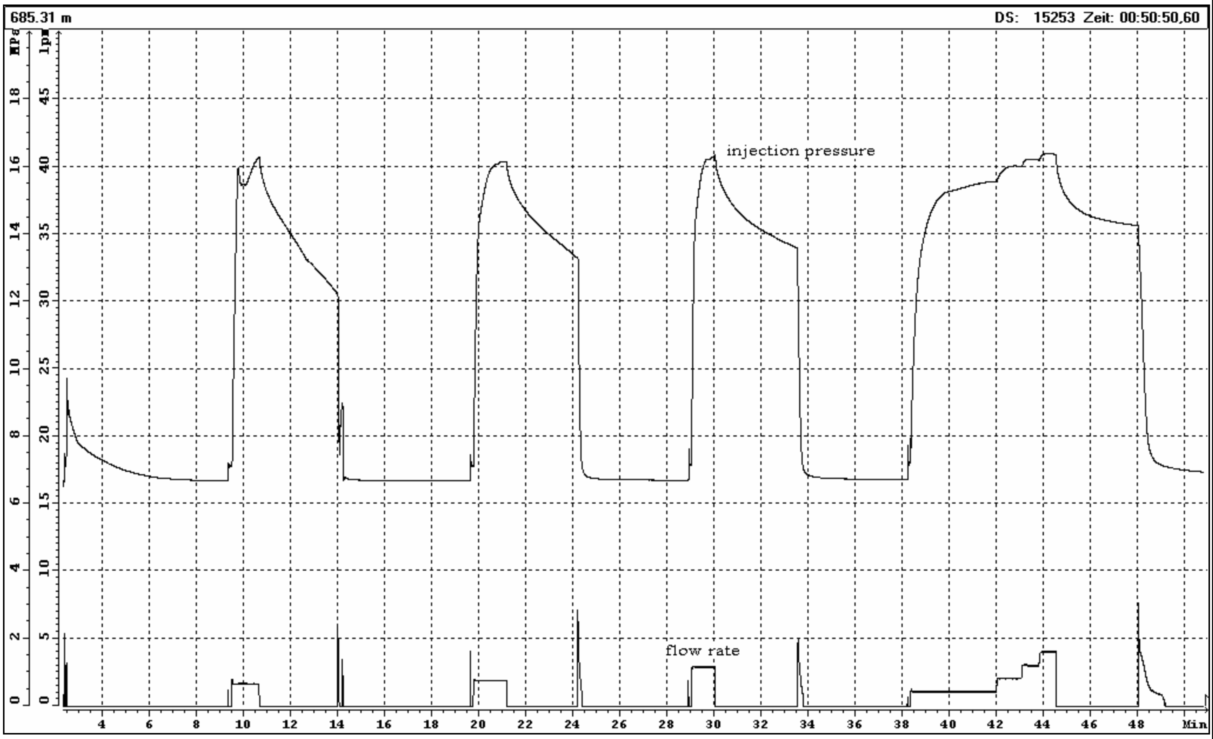


Test at 628.00 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 18 AT 685.31 m MD / 678.02 m TVD

Test at 685.31 m MD : Overview - Plot



P - Test Frac (1. Refrac) 2. Refrac 3. Refrac Slow Pump / Step-Rate - Test

<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

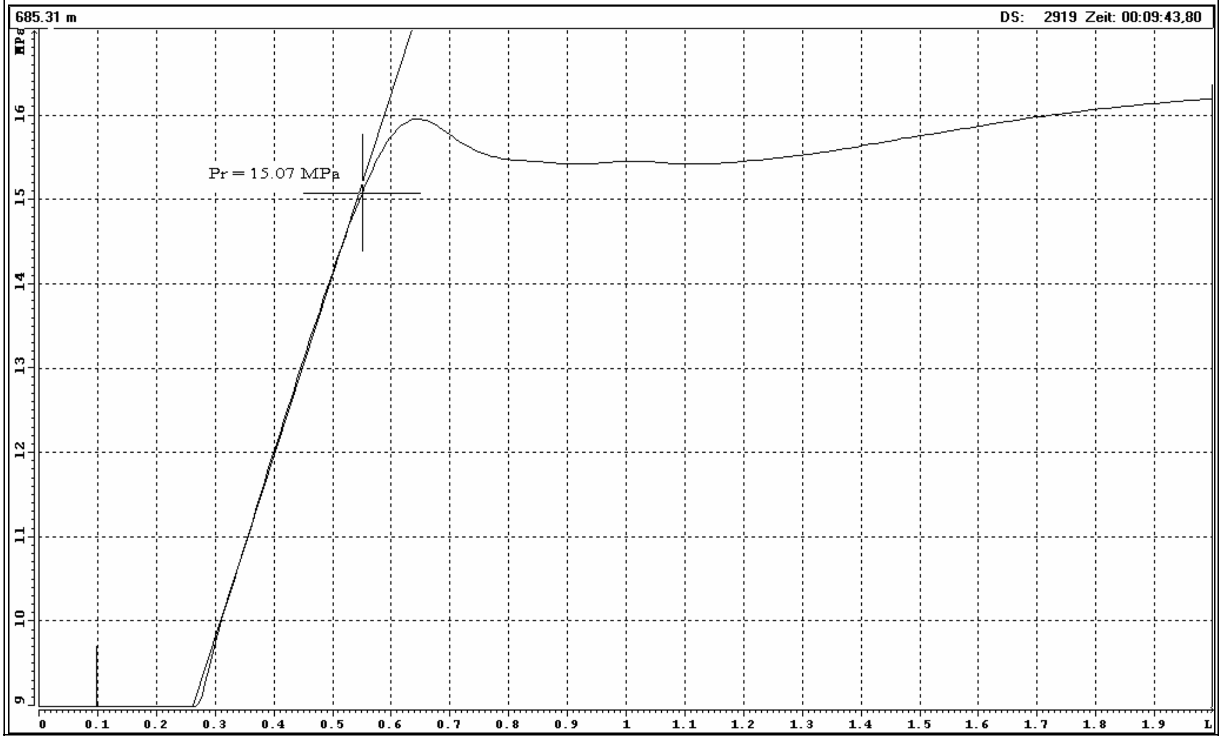
P - Test : pressure decrease: 0.21 MPa in 356 sec. (it is most likely that the significant pressure decay was caused by a small leakage of the coil tubing)

Frac (1. Refrac) - cycle	Qi (lpm) = 1.7	Vi (l) = 2.0	Vr (l) = 0.5
2. Refrac - cycle	Qi (lpm) = 1.9	Vi (l) = 2.7	Vr (l) = 1.1
3. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 2.9	Vr (l) = 1.6
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 11.2	Vr (l) = 4.5

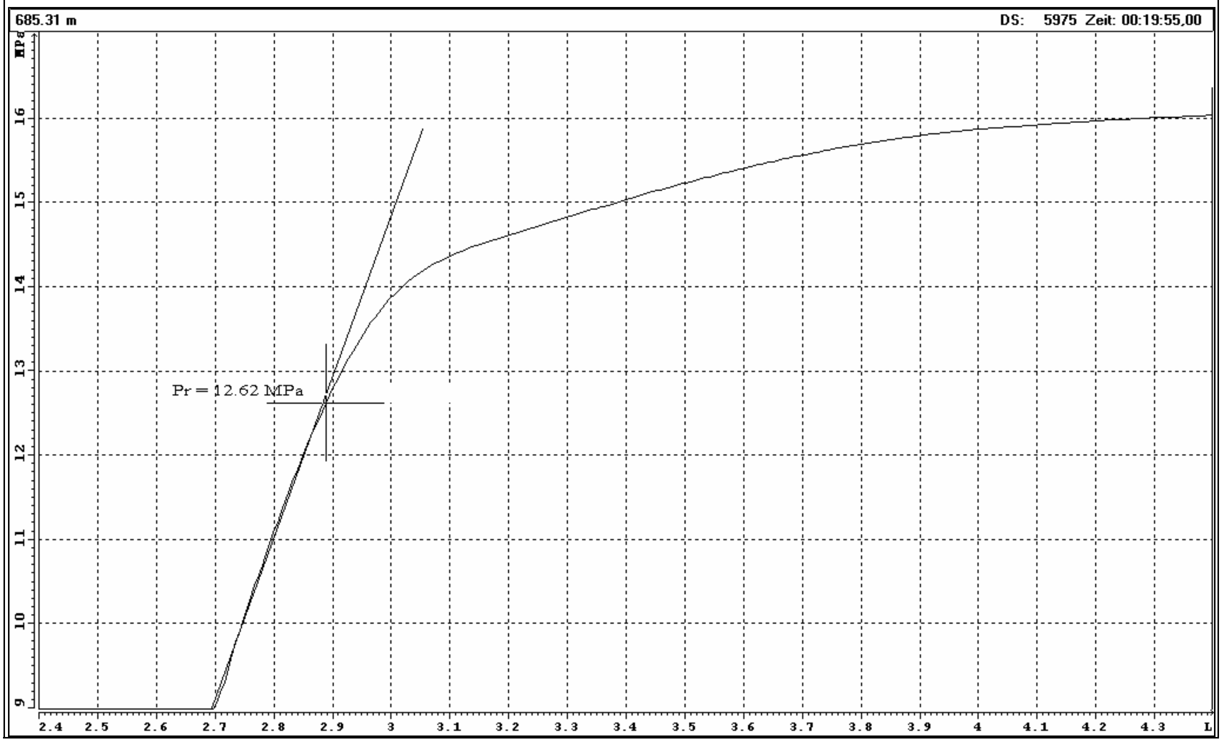
total injected volume (l): 18.8 recovered volume (l): 7.7 or 41.0 %

- Initial test type: HTPF-h
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

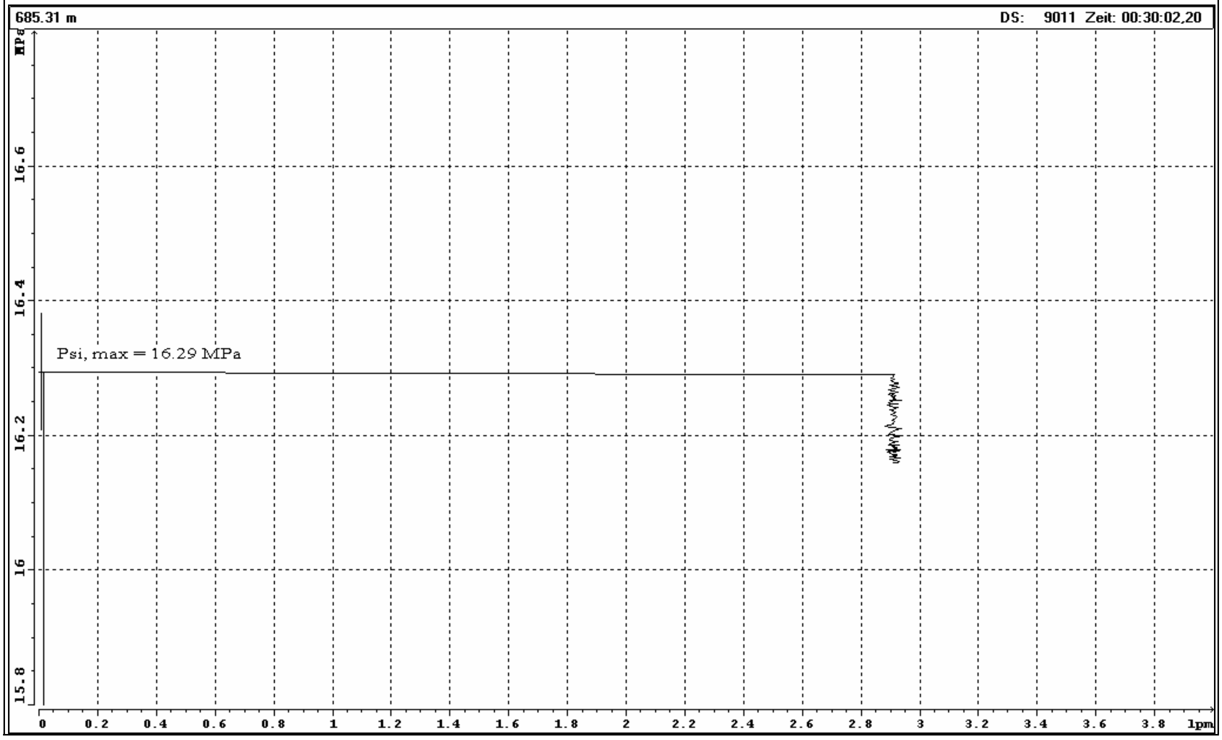
Test at 685.31 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



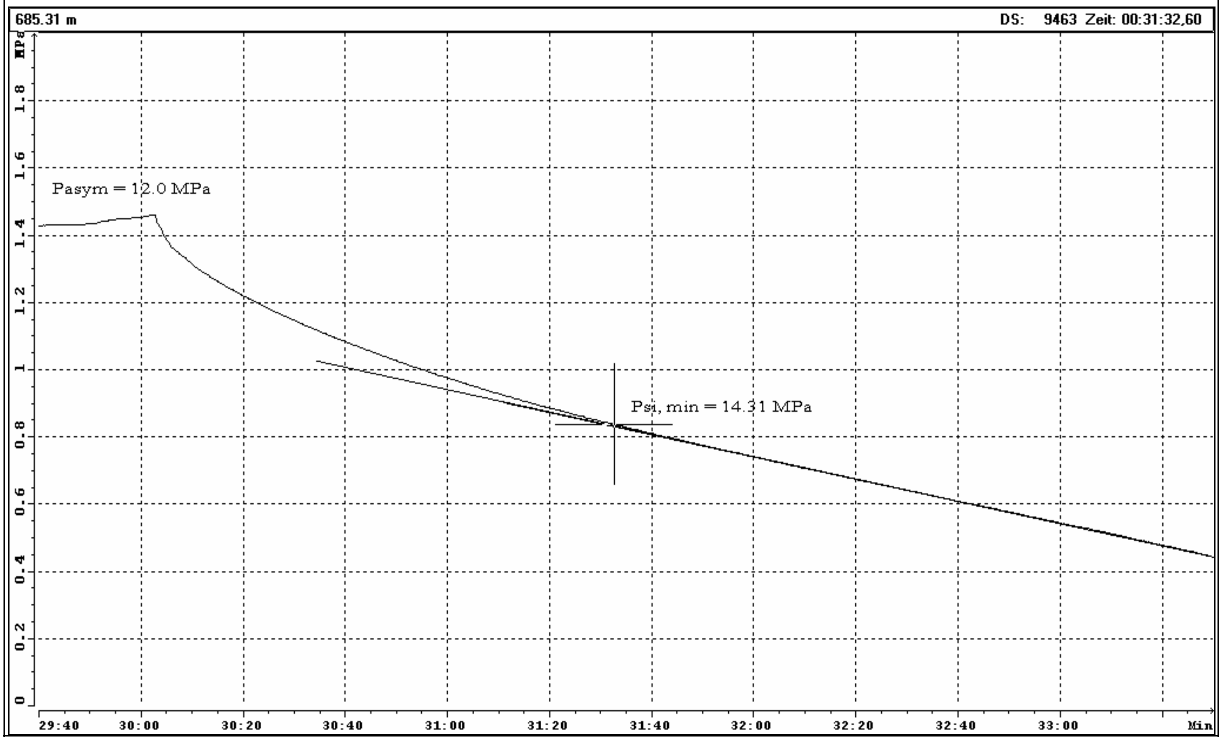
Test at 685.31 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



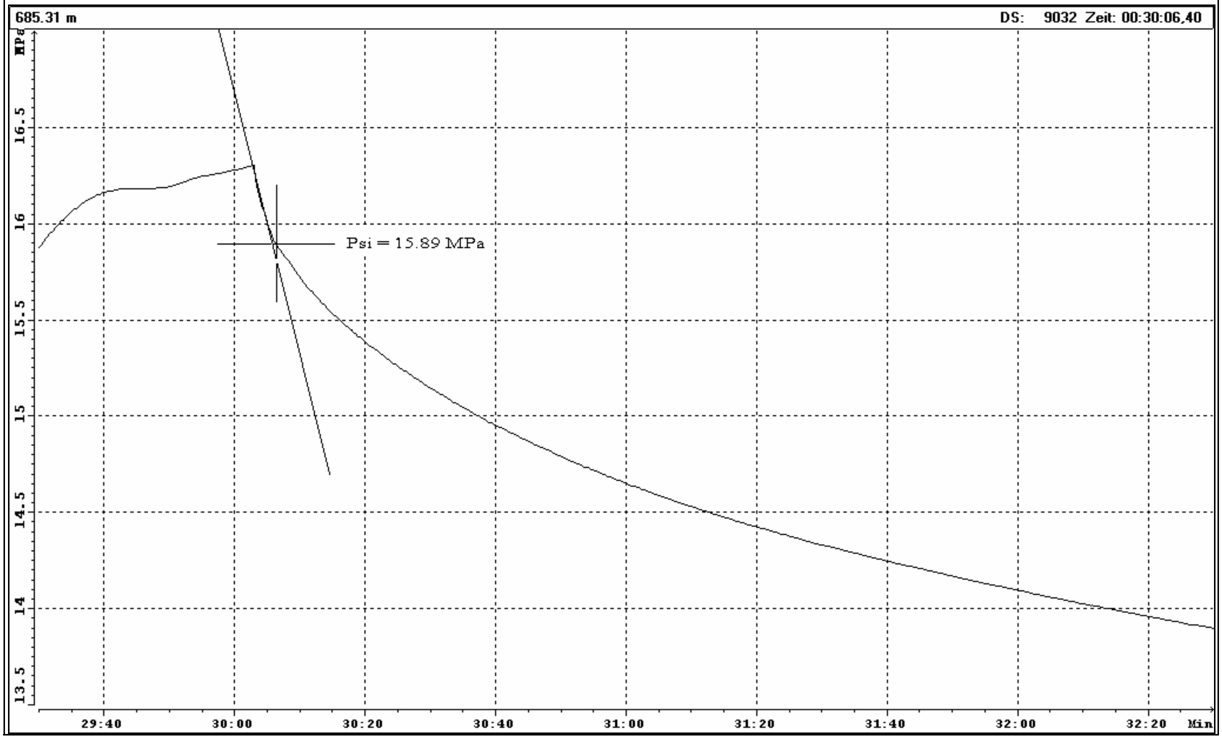
Test at 685.31 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



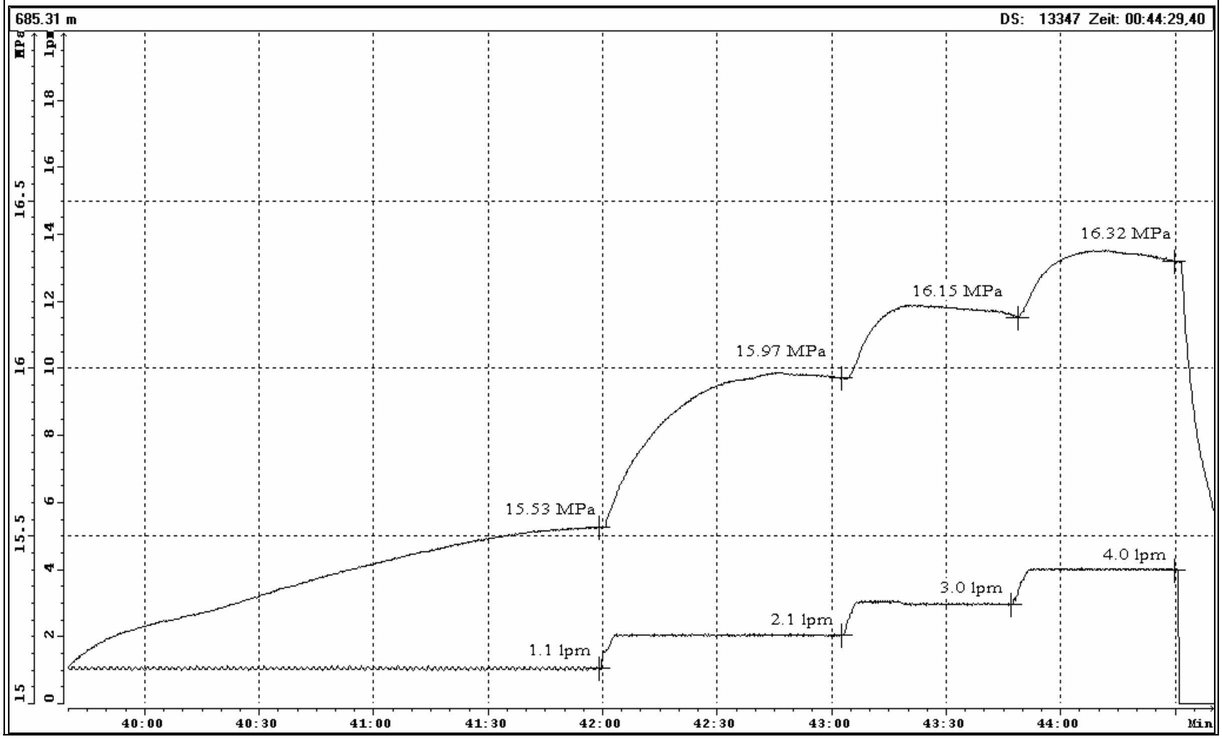
Test at 685.31 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



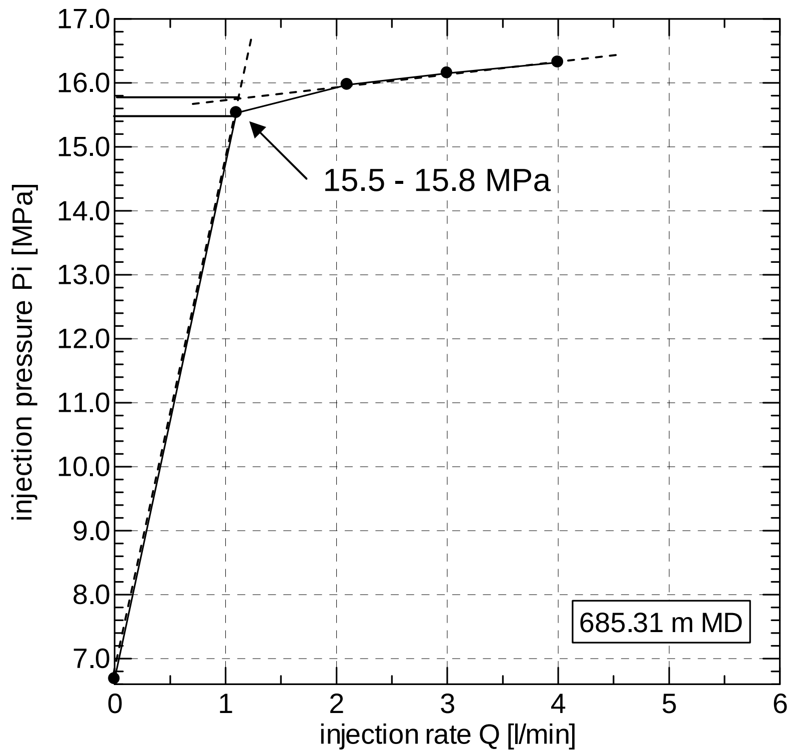
Test at 685.31 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 685.31 m MD: Analysis of Slow - Pump / Step - Rate - Test

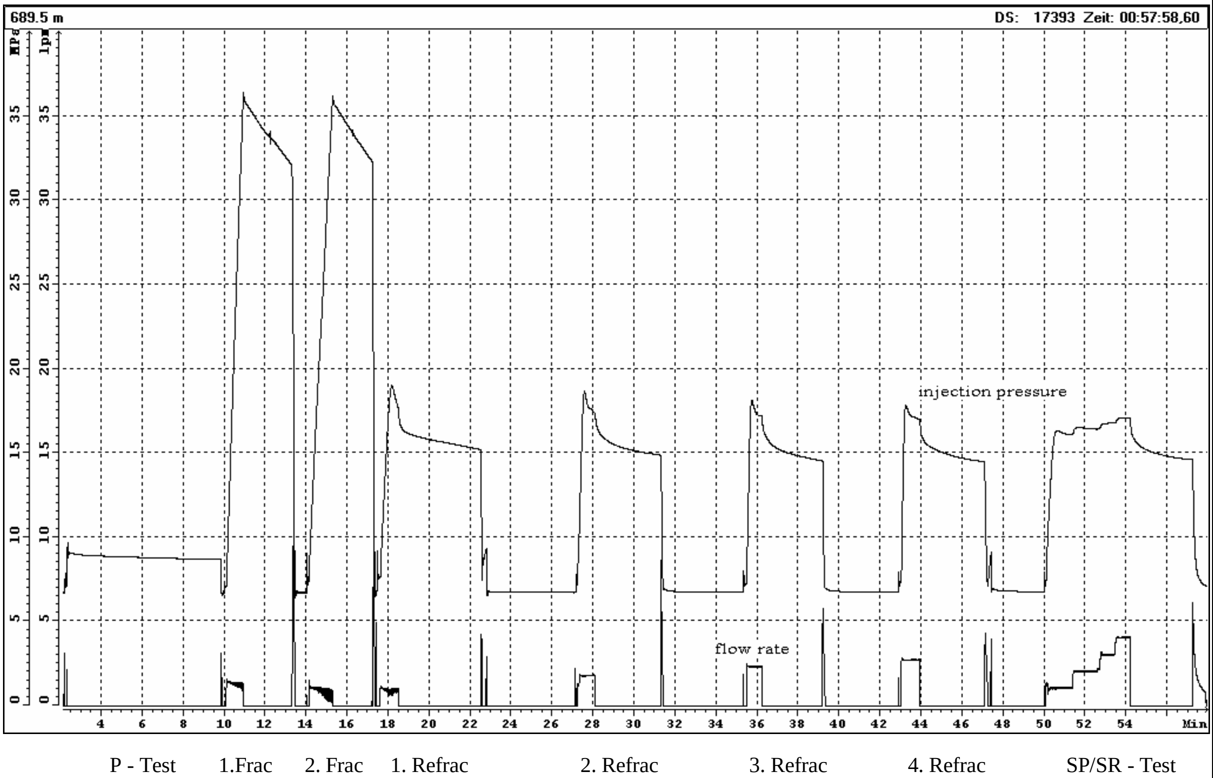


Test at 685.31 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 15 AT 689.5 m MD / 682.13 m TVD

Test at 689.5 m MD : Overview - Plot



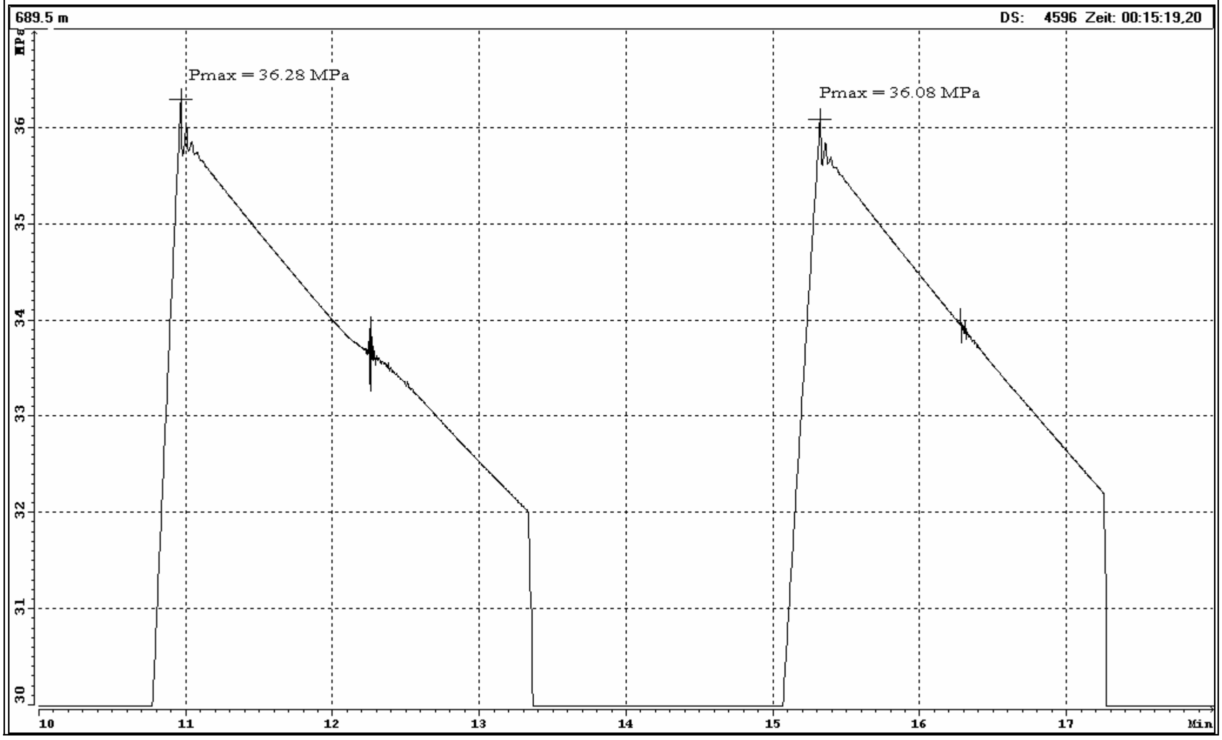
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 0.37 MPa in 437 sec.		
1. Frac - cycle	Qi (lpm) = 1.3	Vi (l) = 1.1	Vr (l) = 0.9
2. Frac - cycle	Qi (lpm) = 1.0	Vi (l) = 1.1	Vr (l) = 0.6
1. Refrac - cycle	Qi (lpm) = 1.0	Vi (l) = 0.8	Vr (l) = 0.6
2. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 1.5	Vr (l) = 0.8
3. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 1.8	Vr (l) = 1.0
4. Refrac - cycle	Qi (lpm) = 2.7	Vi (l) = 2.5	Vr (l) = 1.5
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 9.3	Vr (l) = 3.2

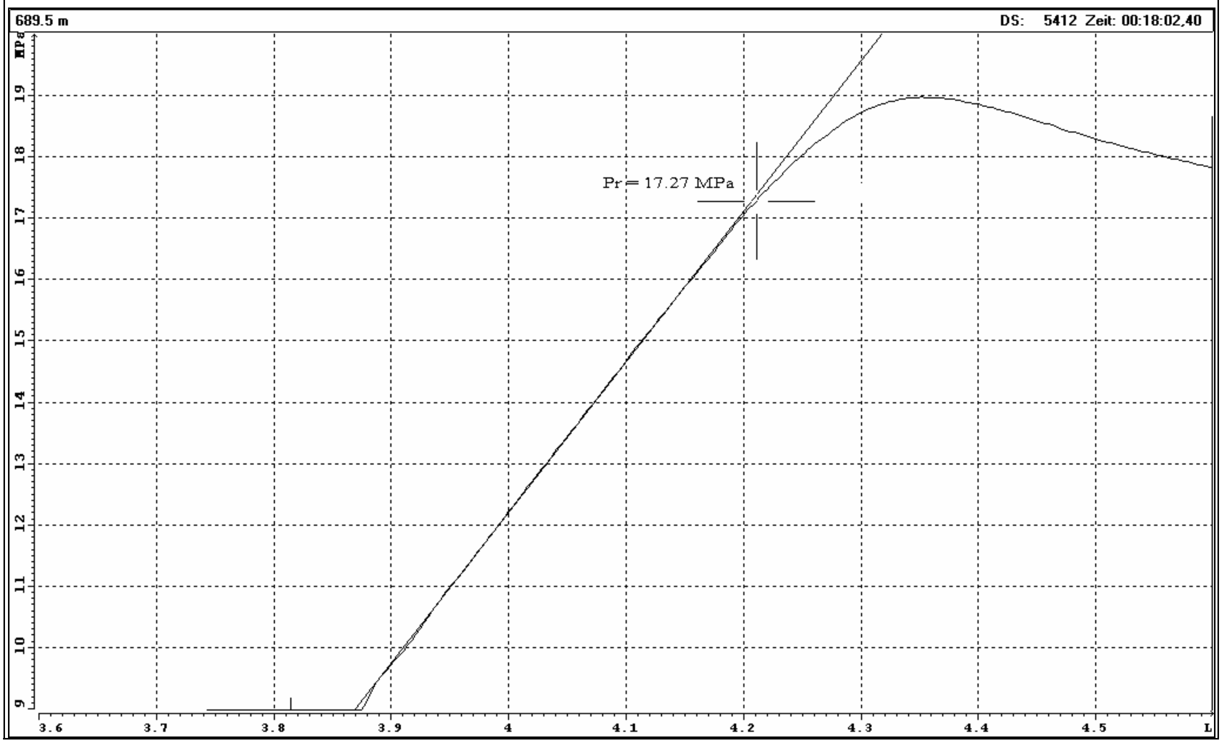
total injected volume (l): 18.1 recovered volume (l): 8.6 or 47.5 %

- Initial test type: HF
- During the 1. and 2. frac cycle, the injection was stopped at pressures of 36.3 and 36.1 MPa to prevent a damage of the packer elements. No breakdown event was observed during the frac - attempts. However, the subsequent 1. refrac - cycle demonstrates that a fracture was initiated during the 2. frac - attempt.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

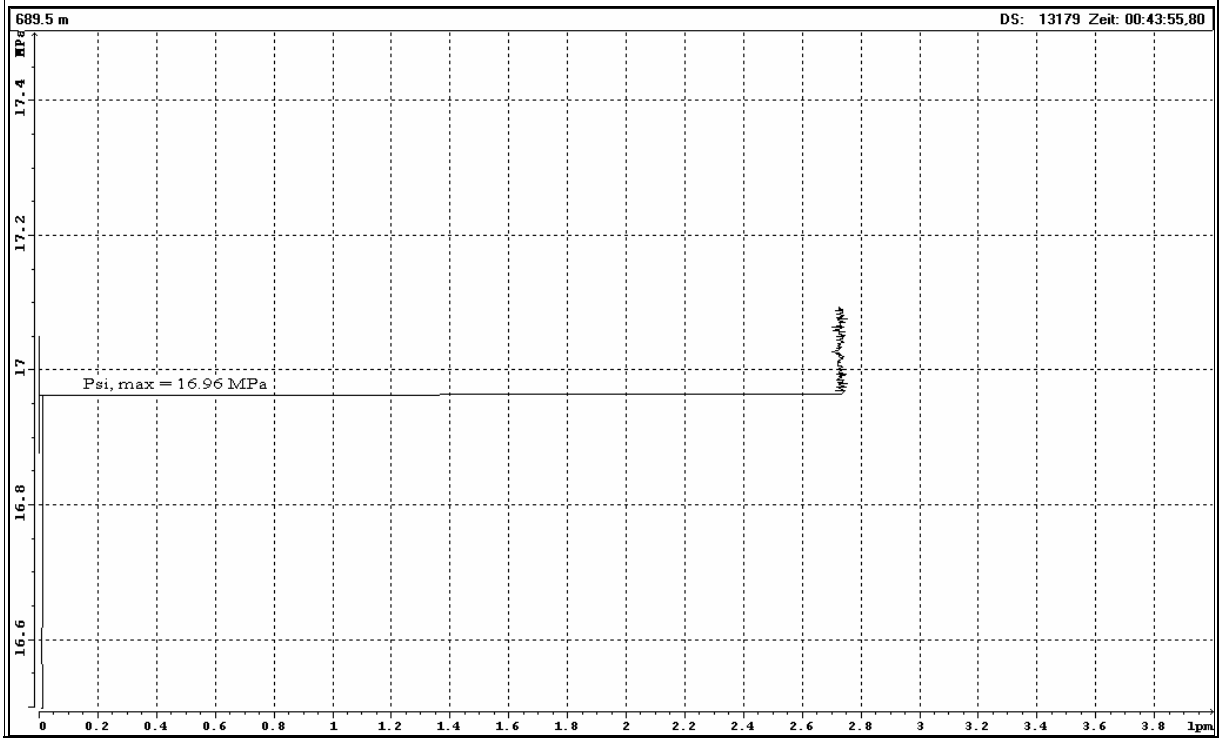
Test at 689.5 m MD: Estimation of P_{max} (1. and 2. Frac - Cycle)



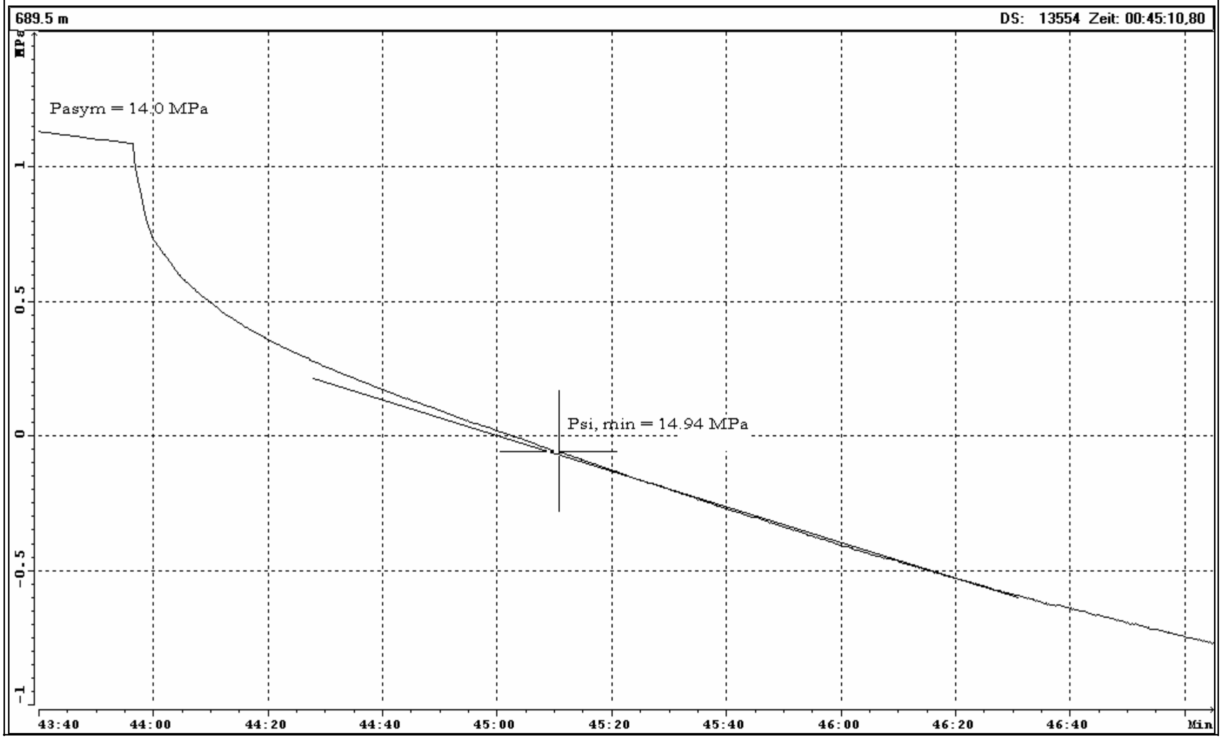
Test at 689.5 m MD: Estimation of P_r (1. Refrac - Cycle)



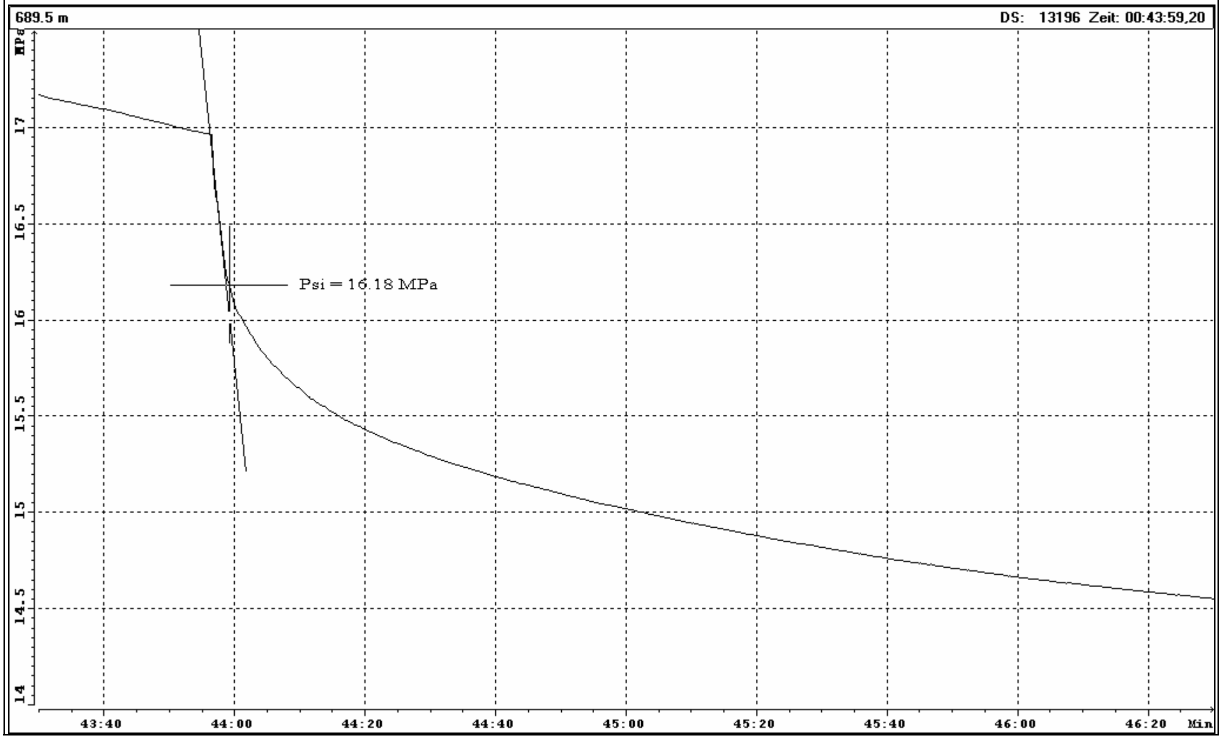
Test at 689.5 m MD: Estimation of $P_{si,\,max}$ (4. Refrac - Cycle)



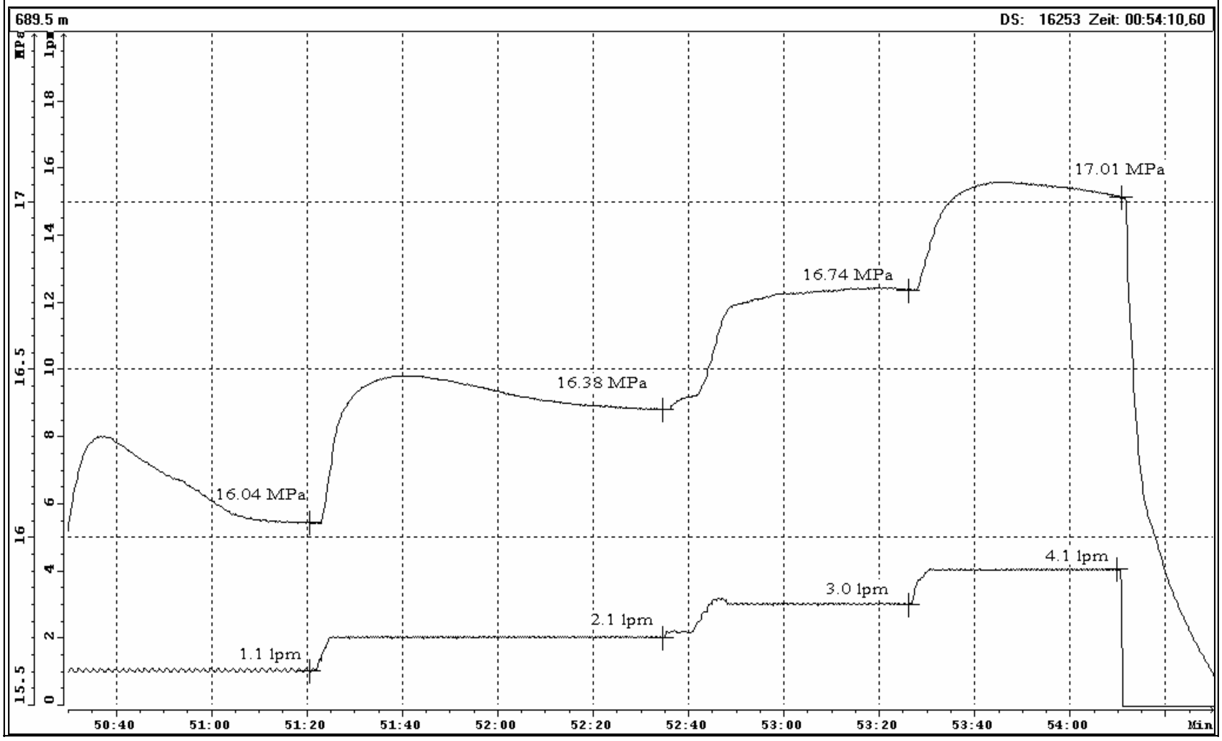
Test at 689.5 m MD: Estimation of $P_{si,\,min}$ (4. Refrac - Cycle)



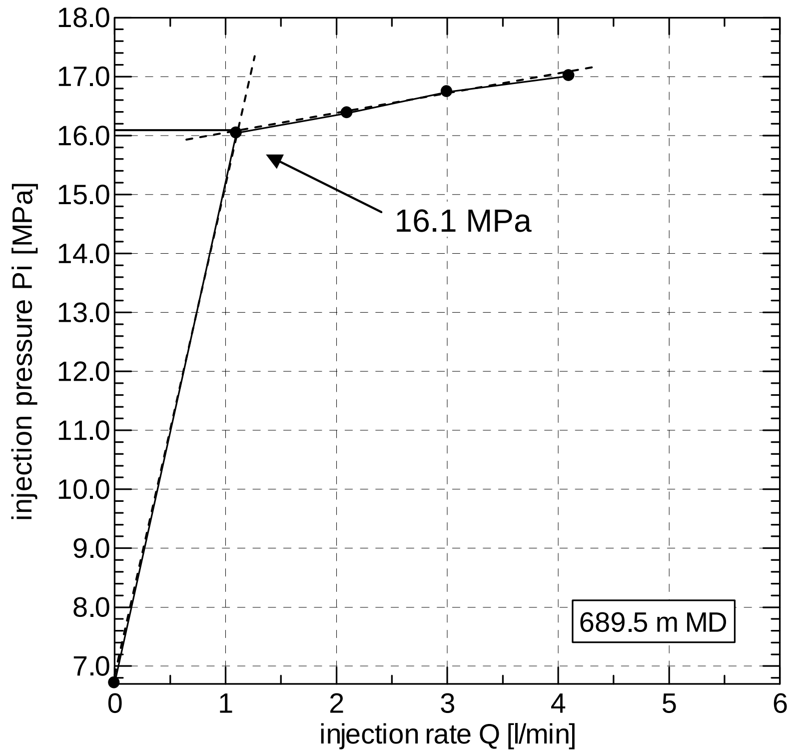
Test at 689.5 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 689.5 m MD: Analysis of Slow - Pump / Step - Rate - Test

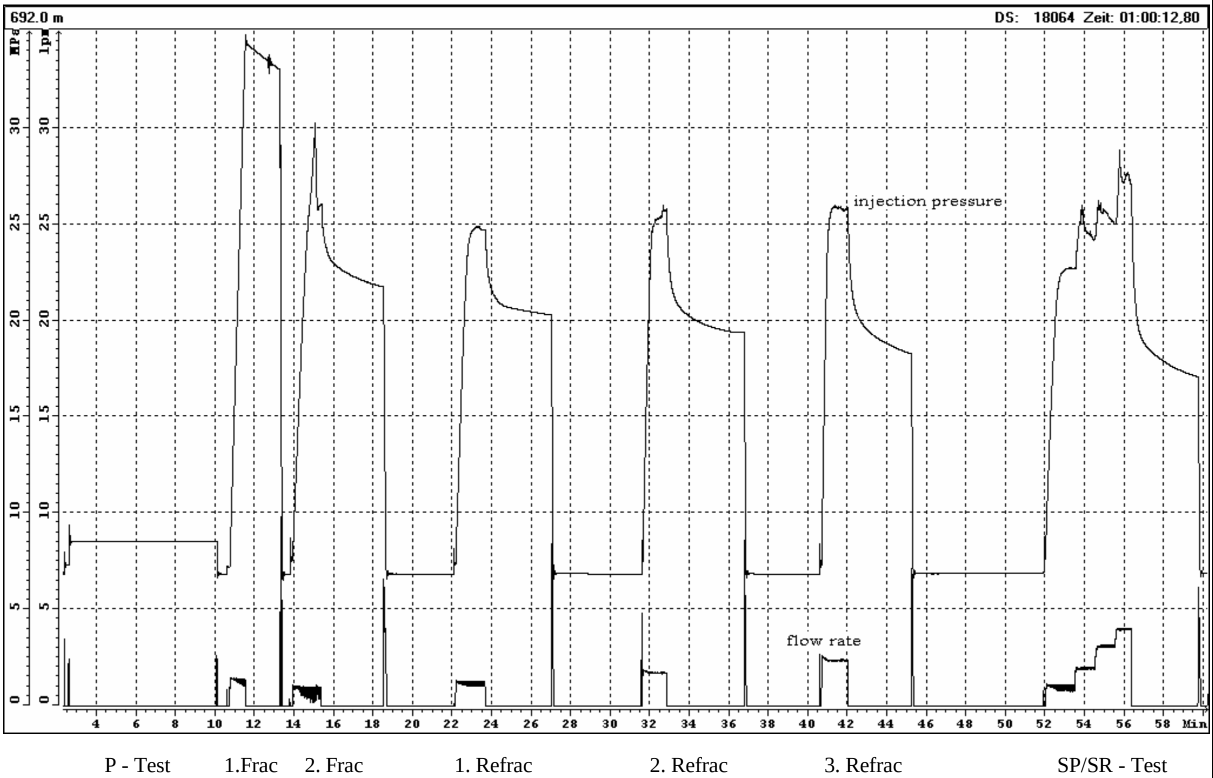


Test at 689.5 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 14 AT 692.0 m MD / 684.58 m TVD

Test at 692.0 m MD: Overview - Plot



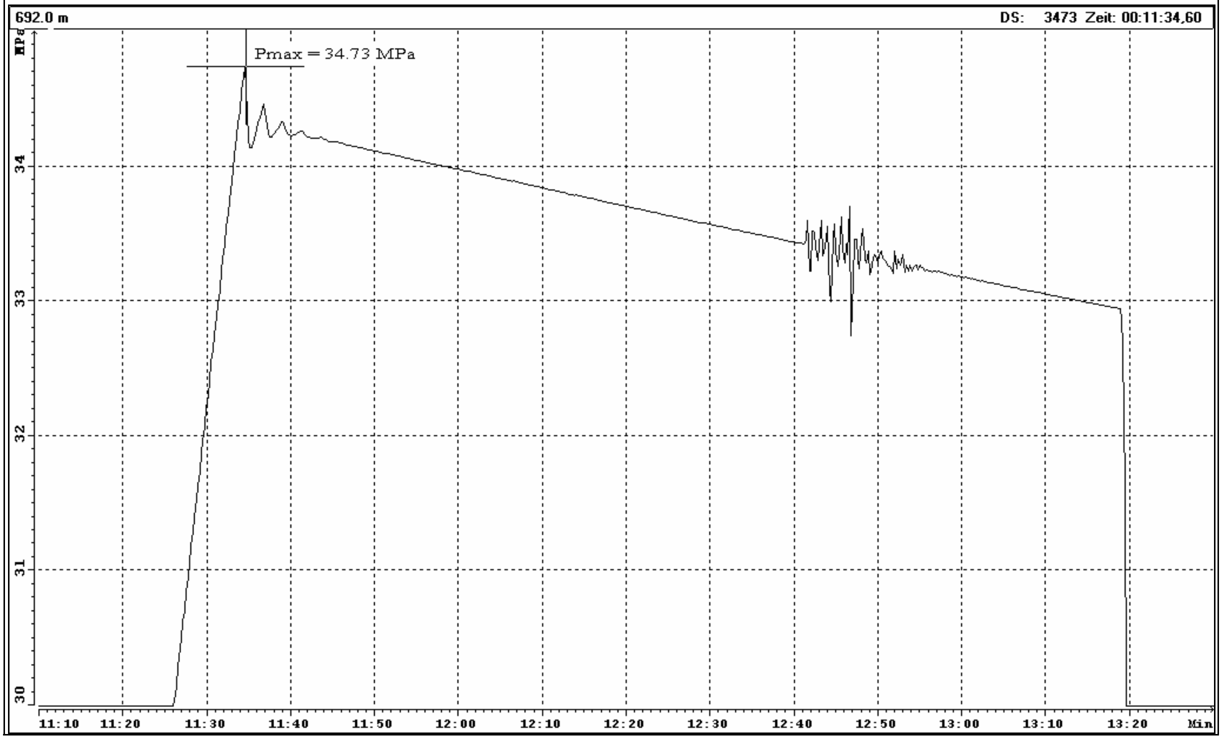
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.0 MPa in 435 sec.		
1. Frac - cycle	Qi (lpm) = 1.2	Vi (l) = 1.0	Vr (l) = 0.8
2. Frac - cycle	Qi (lpm) = 1.0	Vi (l) = 1.15	Vr (l) = 0.75
1. Refrac - cycle	Qi (lpm) = 1.1	Vi (l) = 1.8	Vr (l) = 0.8
2. Refrac - cycle	Qi (lpm) = 1.7	Vi (l) = 2.1	Vr (l) = 0.6
3. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 3.2	Vr (l) = 0.7
SP/SR - test	Qi (lpm) = 1.0-4.0	Vi (l) = 9.75	Vr (l) = 1.0

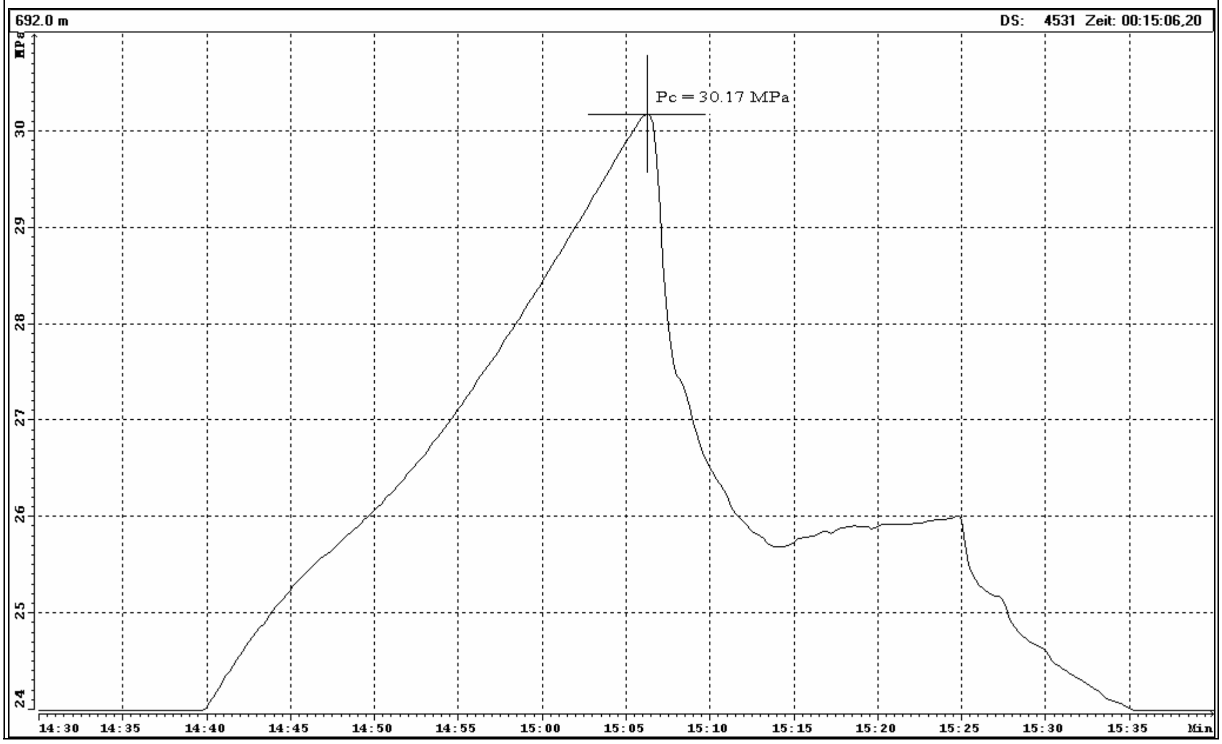
total injected volume (l): 19.0 recovered volume (l): 4.65 or 24.5 %

- Initial test type: HF
- During the 1. frac cycle, the injection was stopped at a pressure of 34.7 MPa to prevent a damage of the packer elements. No breakdown event was observed during the frac - attempt. However, the subsequent 2. frac - cycle demonstrates the initiation of a fracture with a distinct breakdown event at 30.2 MPa.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 20.6 MPa, followed by a pressure increase up to 24.8 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield slightly lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

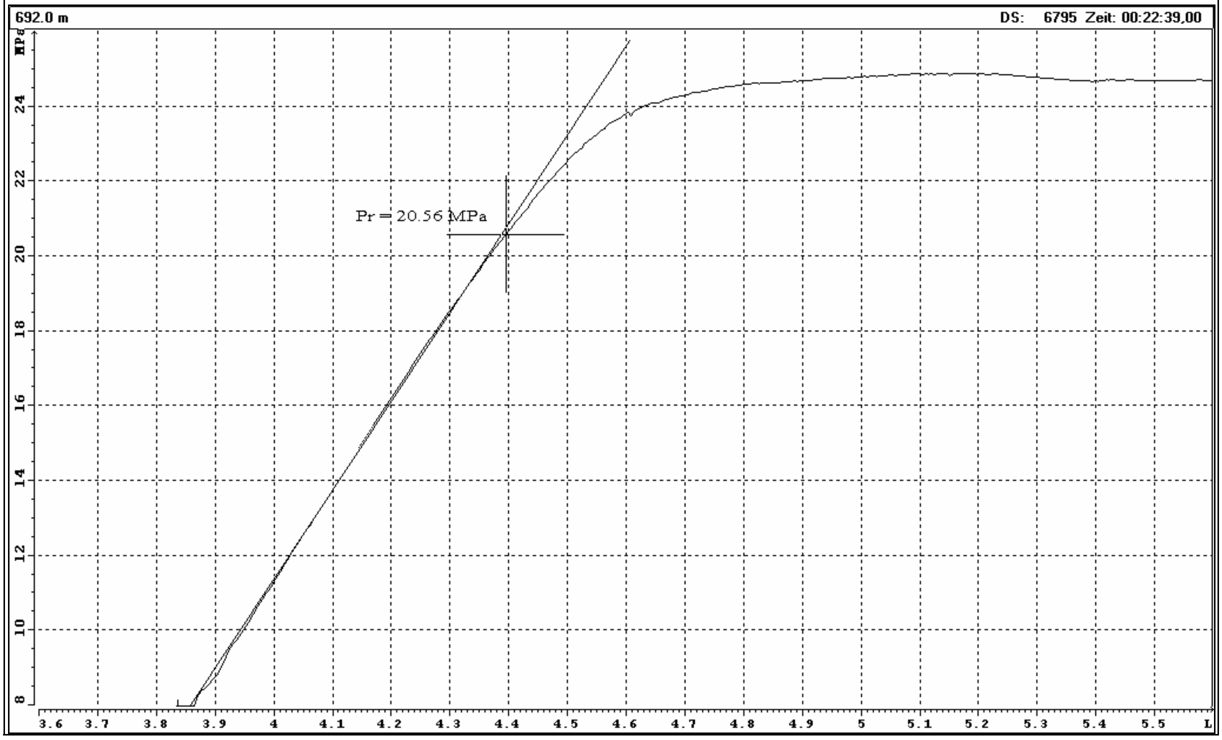
Test at 692.0 m MD: Estimation of P_{max} (1. Frac - Cycle)



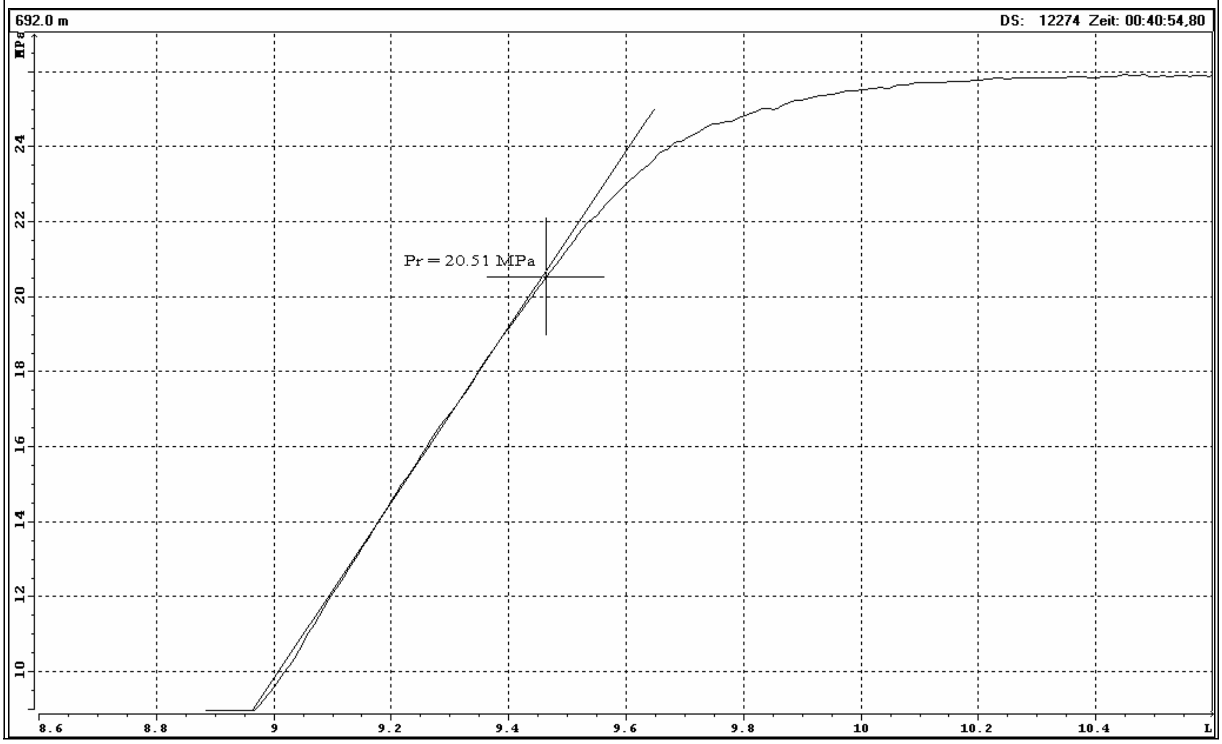
Test at 692.0 m MD: Estimation of P_c (2. Frac - Cycle)



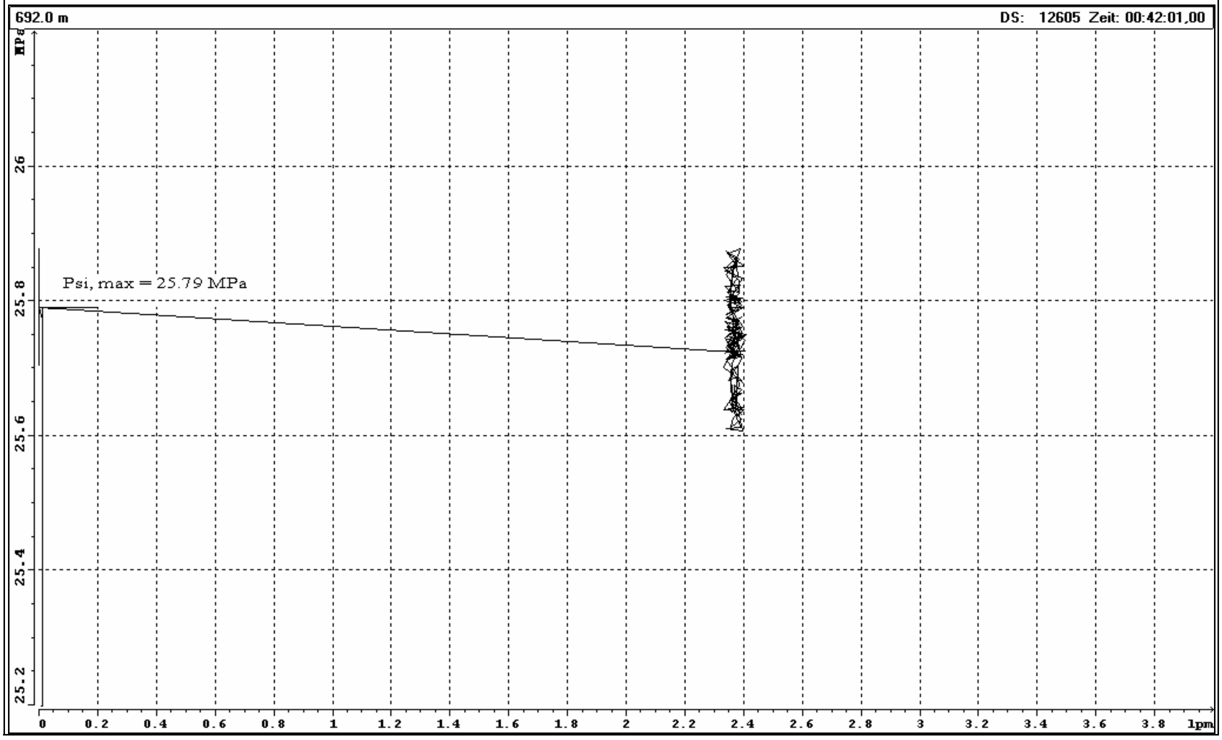
Test at 692.0 m MD: Estimation of P_r (1. Refrac - Cycle)



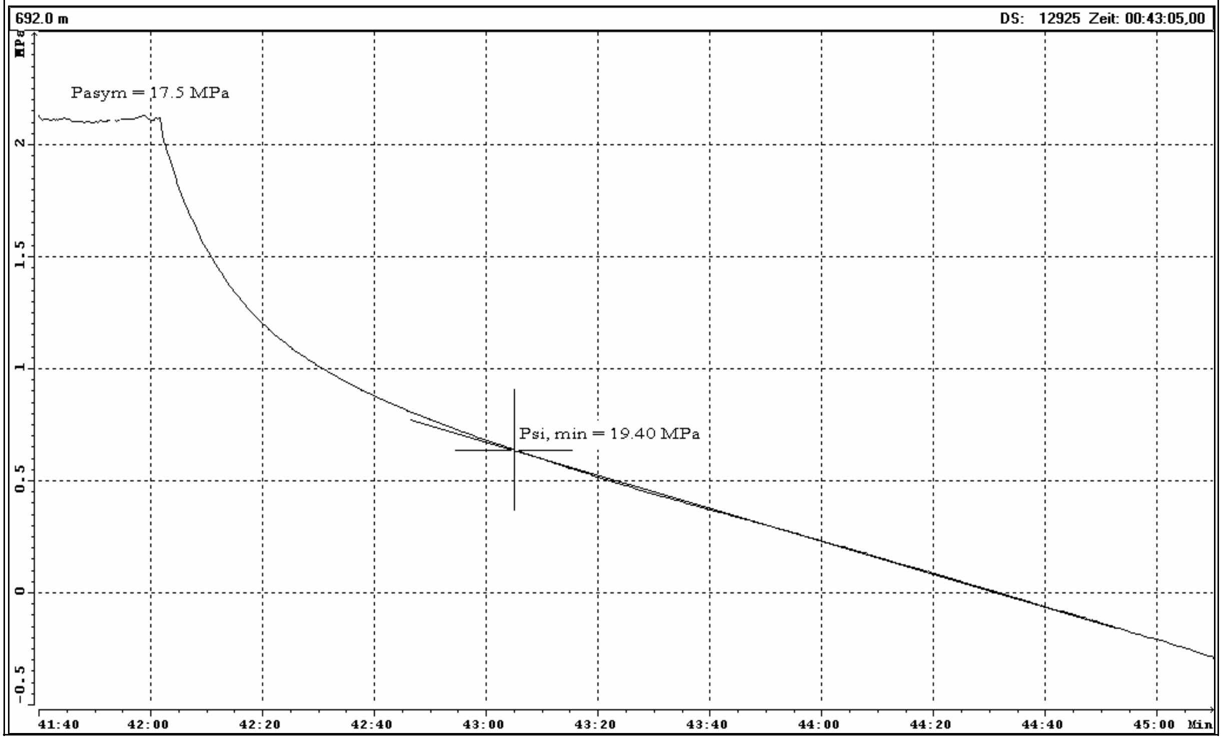
Test at 692.0 m MD: Estimation of P_r (3. Refrac - Cycle, for comparison)



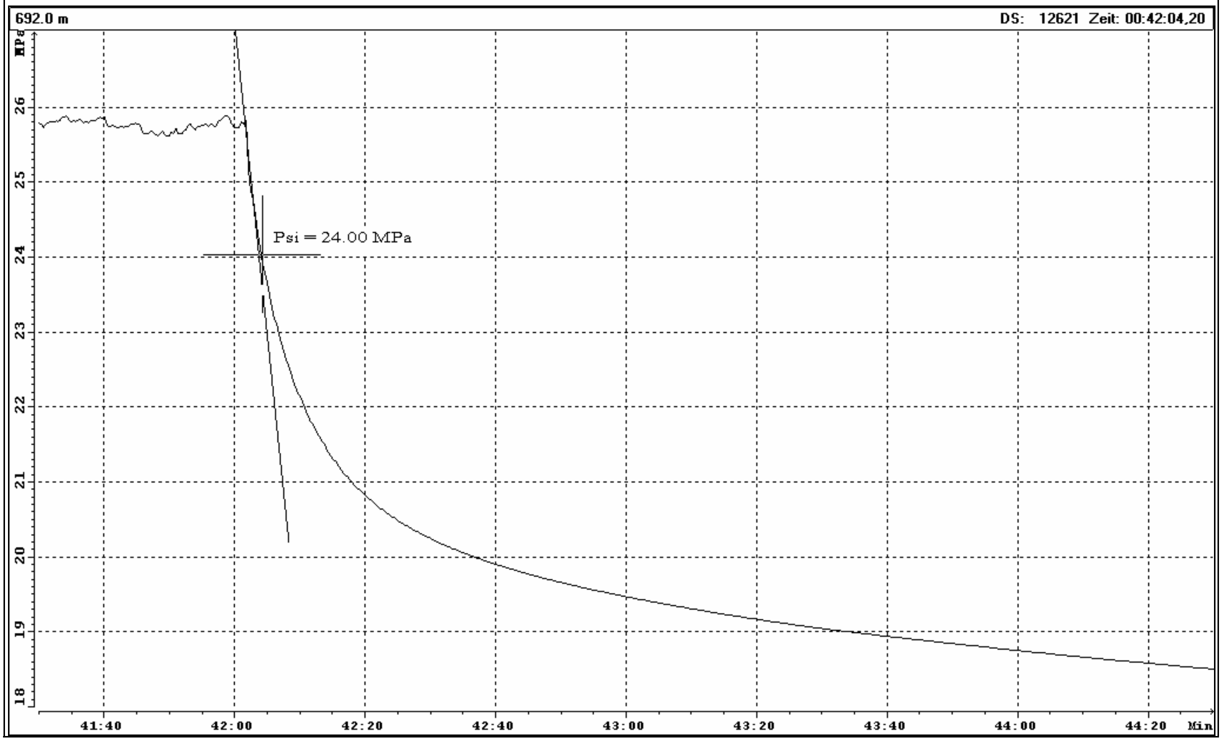
Test at 692.0 m MD: Estimation of $P_{si,\,max}$ (3. Refrac - Cycle)



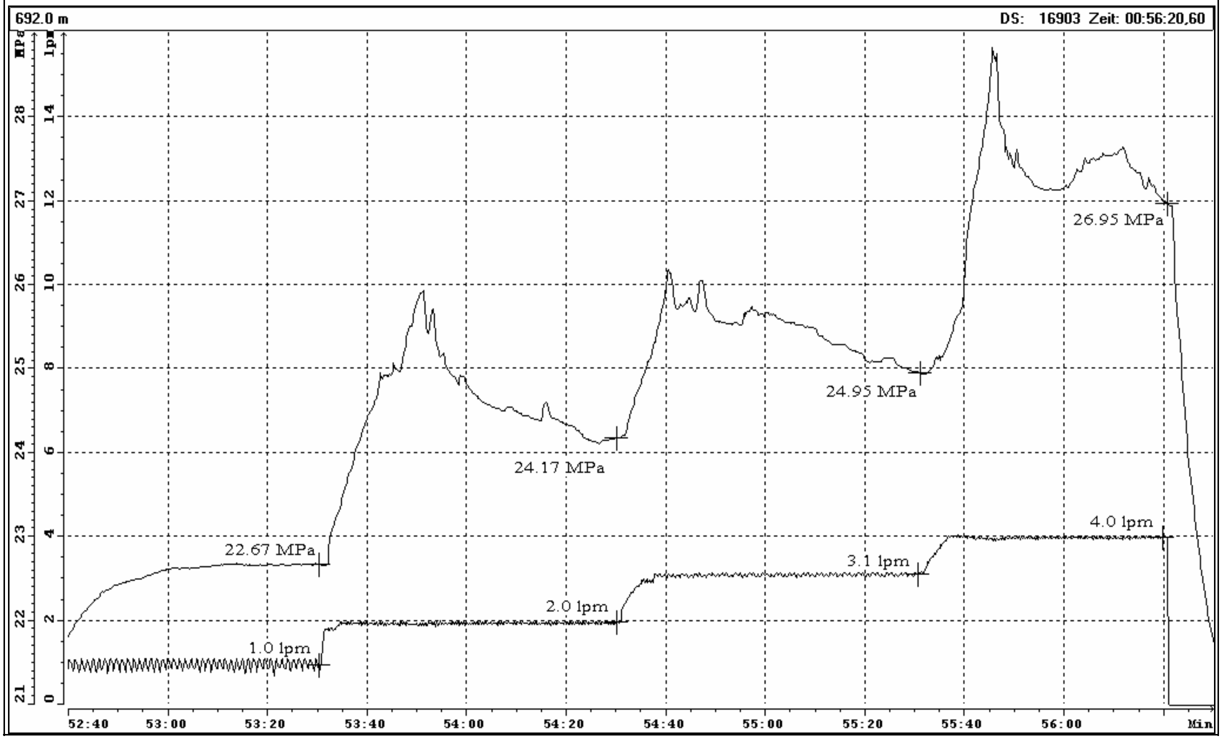
Test at 692.0 m MD: Estimation of $P_{si,\,min}$ (3. Refrac - Cycle)



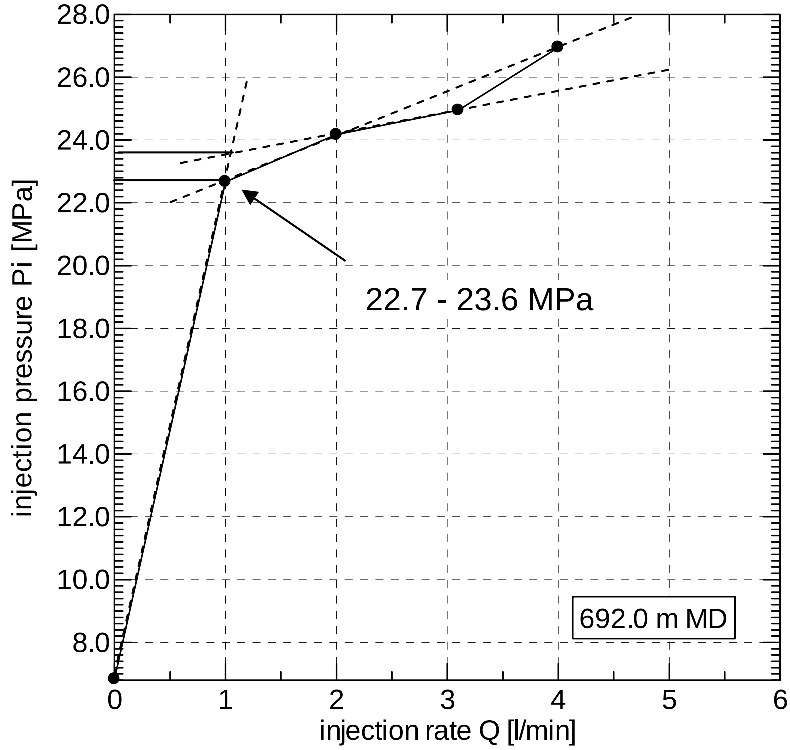
Test at 692.0 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 692.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

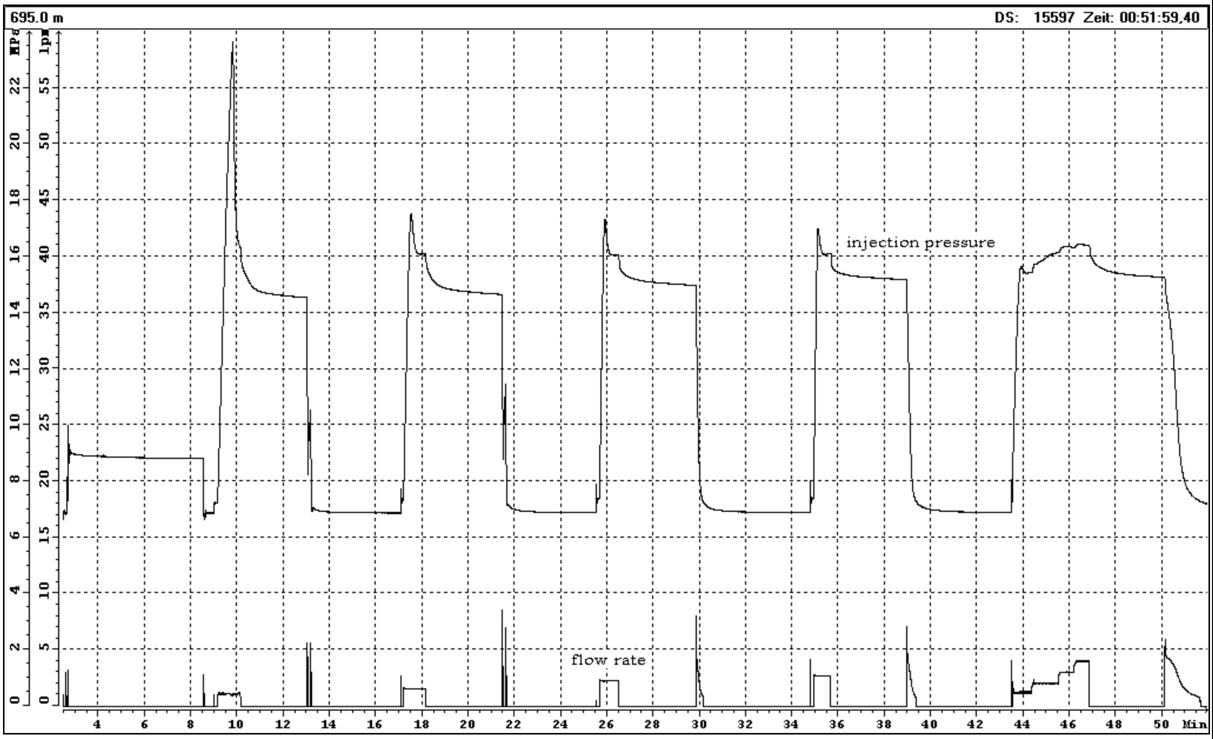


Test at 692.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 13 AT 695.0 m MD / 687.51 m TVD

Test at 695.0 m MD : Overview - Plot



P - Test Frac 1. Refrac 2. Refrac 3. Refrac SP/SR - Test

TEST SUMMARY / ANALYSIS / REMARKS

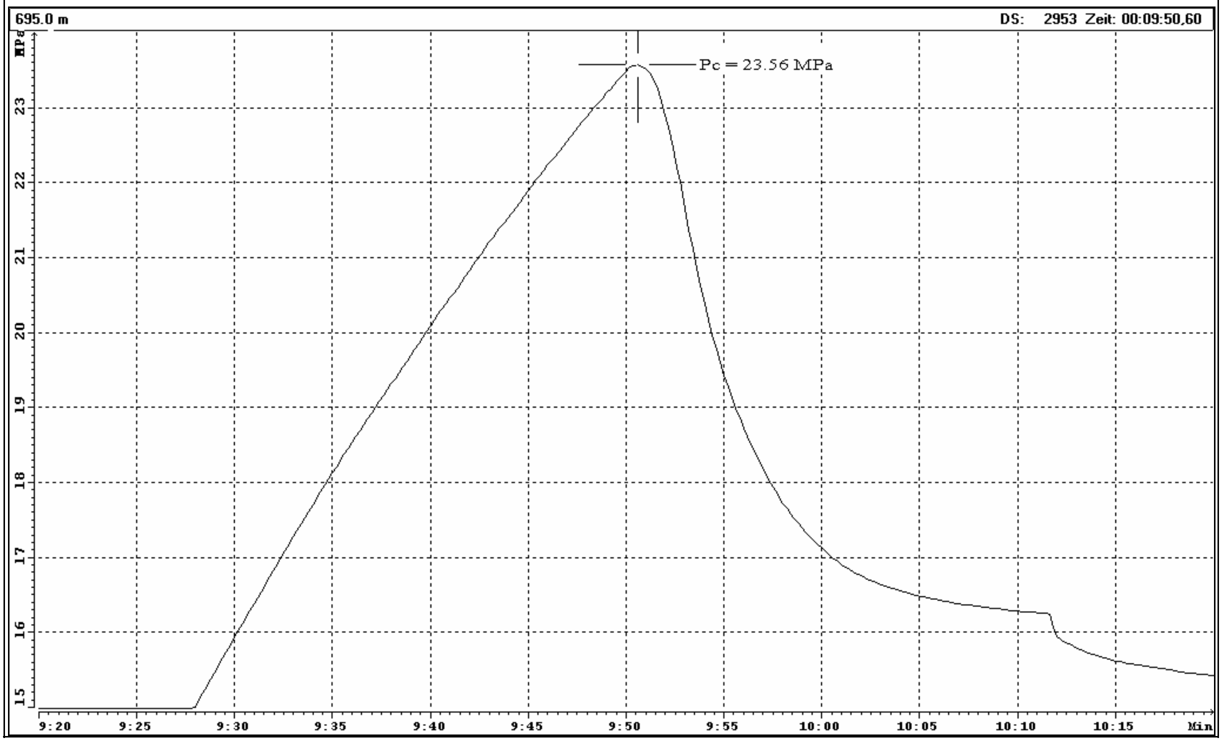
P - Test : pressure decrease: 0.15 MPa in 337 sec.

Frac - cycle	Qi (lpm) = 1.1	Vi (l) = 1.1	Vr (l) = 0.8
1. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.5	Vr (l) = 1.2
2. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 1.9	Vr (l) = 1.7
3. Refrac - cycle	Qi (lpm) = 2.7	Vi (l) = 2.05	Vr (l) = 2.0
SP/SR - test	Qi (lpm) = 1.2-4.0	Vi (l) = 8.1	Vr (l) = 6.0

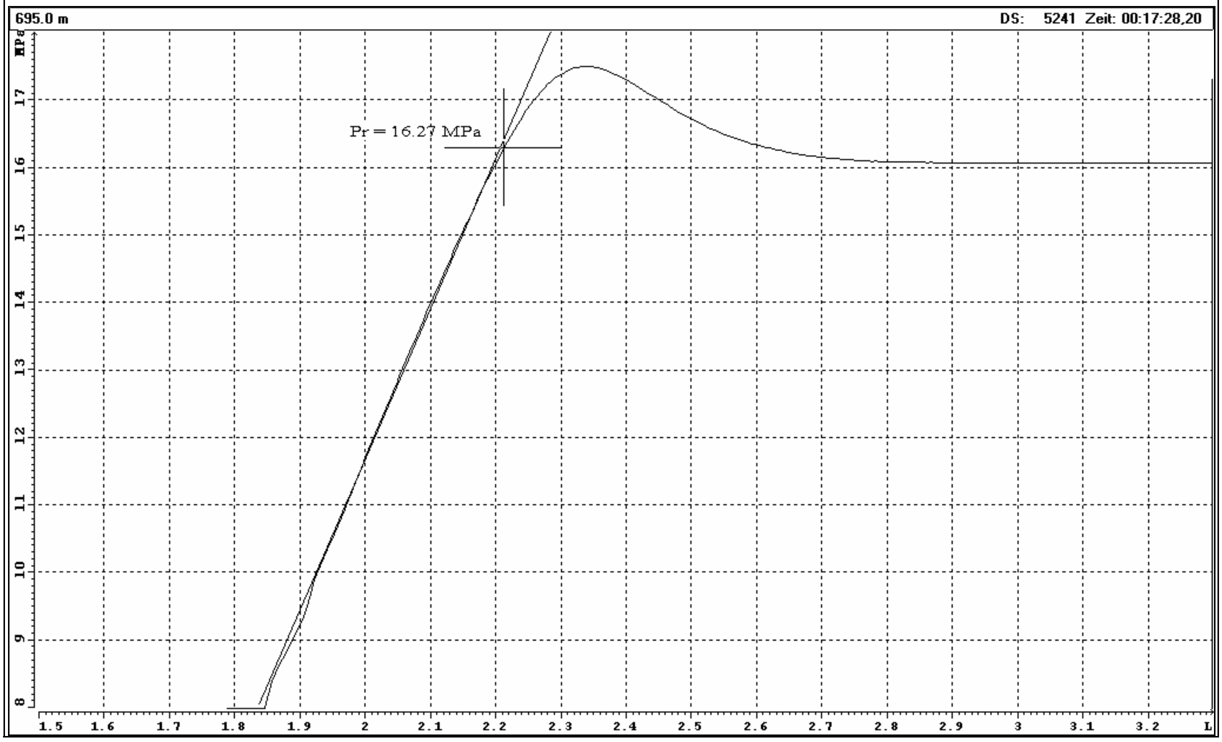
total injected volume (l): 14.65 recovered volume (l): 11.7 or 79.9 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

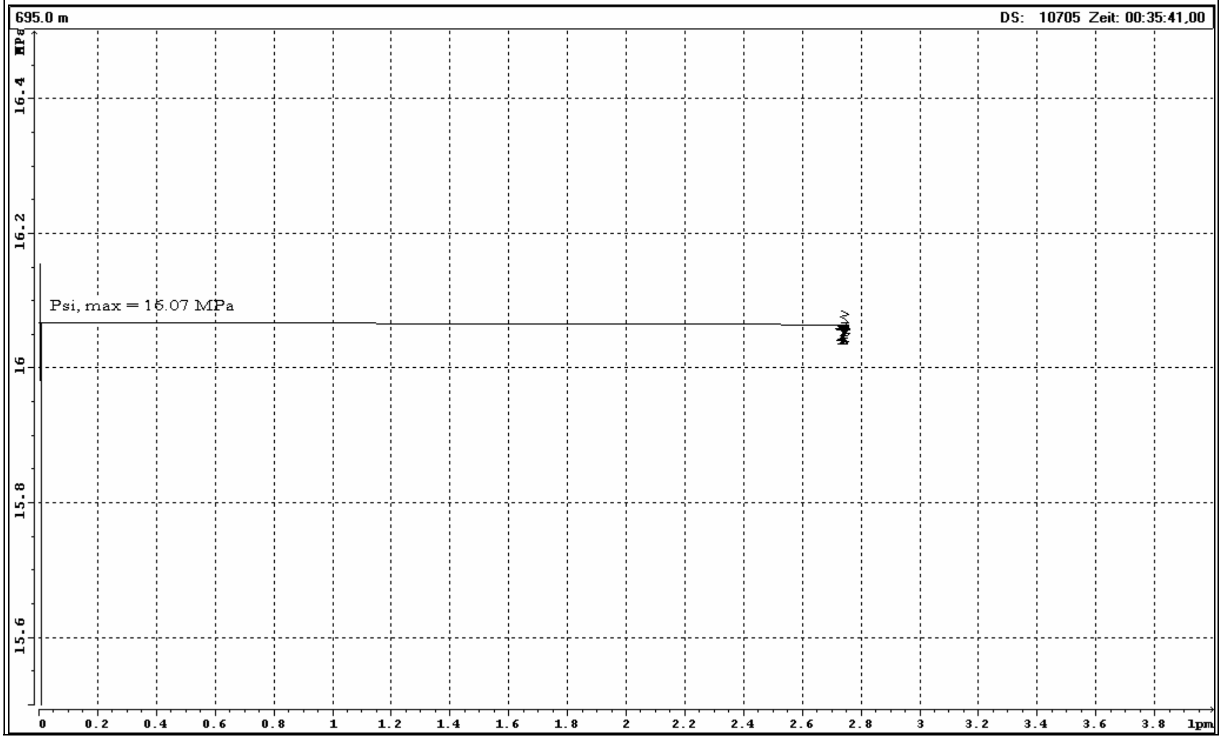
Test at 695.0 m MD: Estimation of P_c (Frac - Cycle)



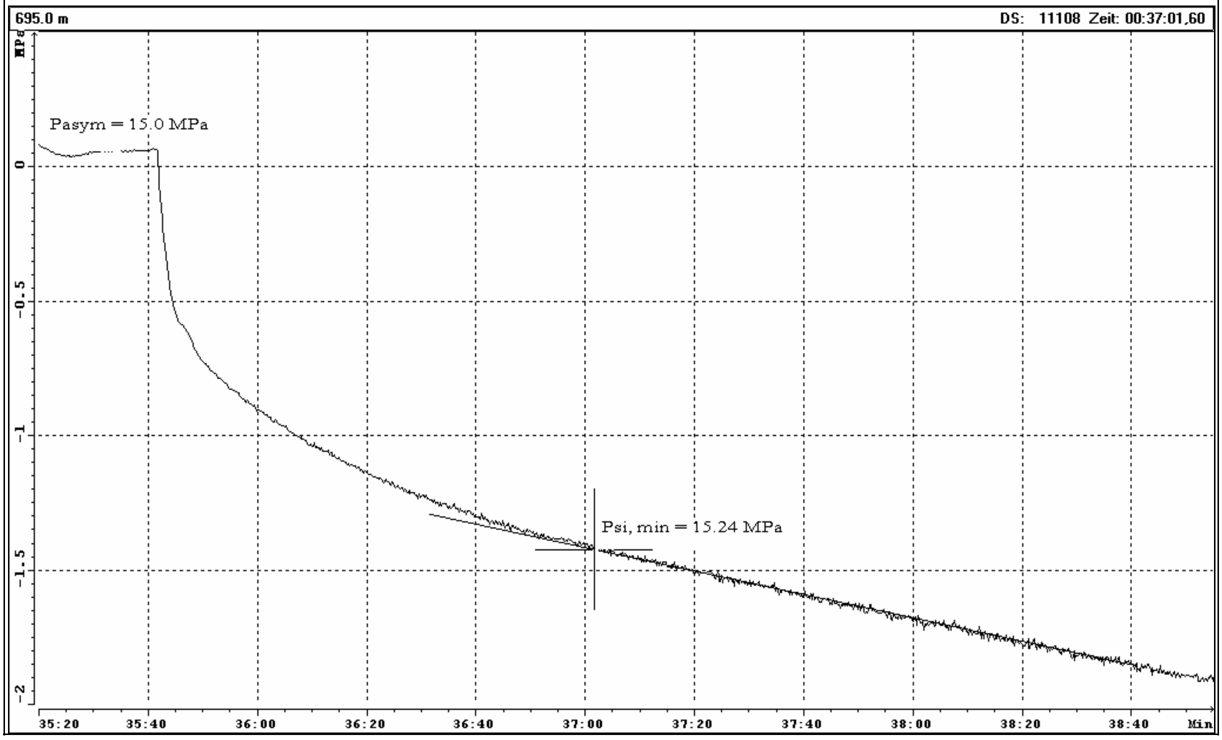
Test at 695.0 m MD: Estimation of P_r (1. Refrac - Cycle)



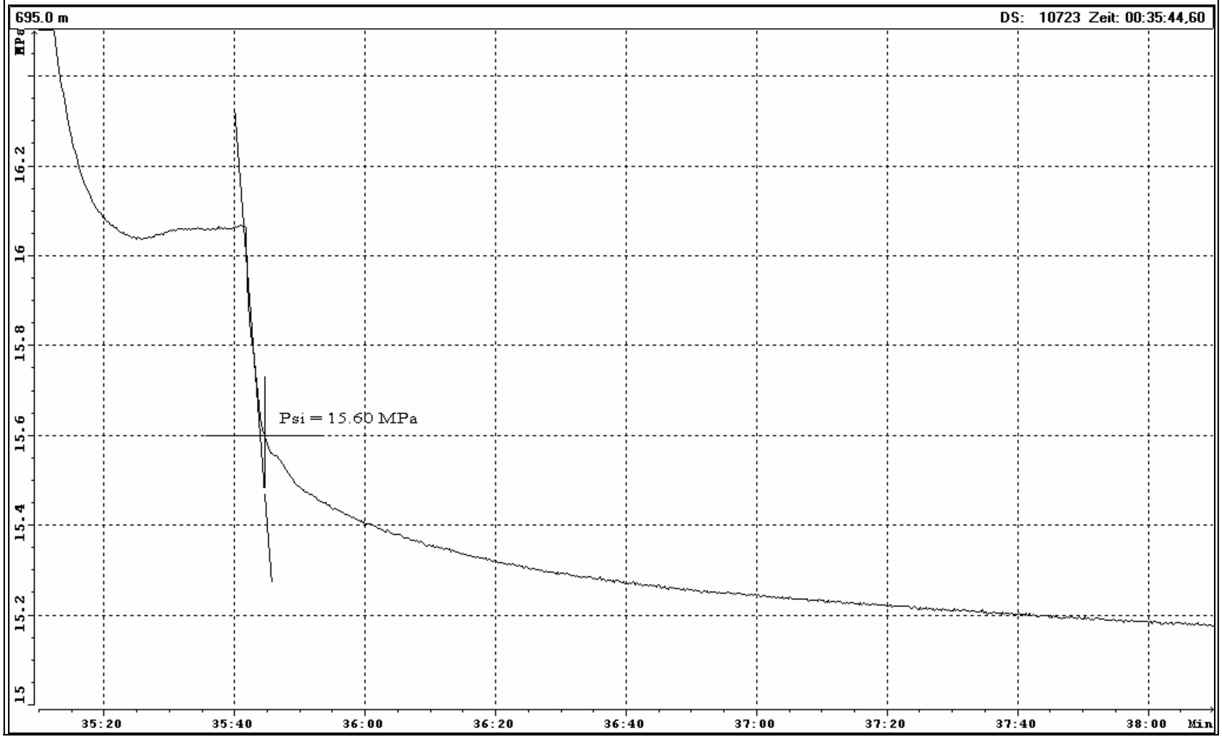
Test at 695.0 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



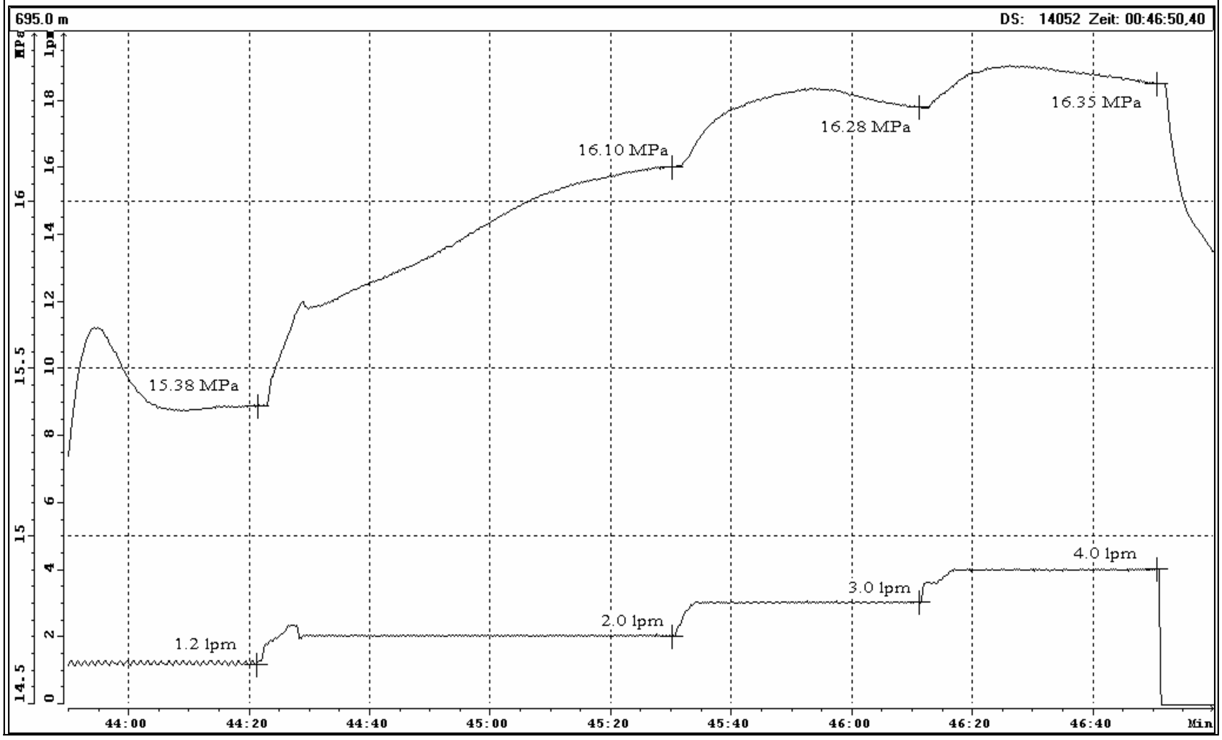
Test at 695.0 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



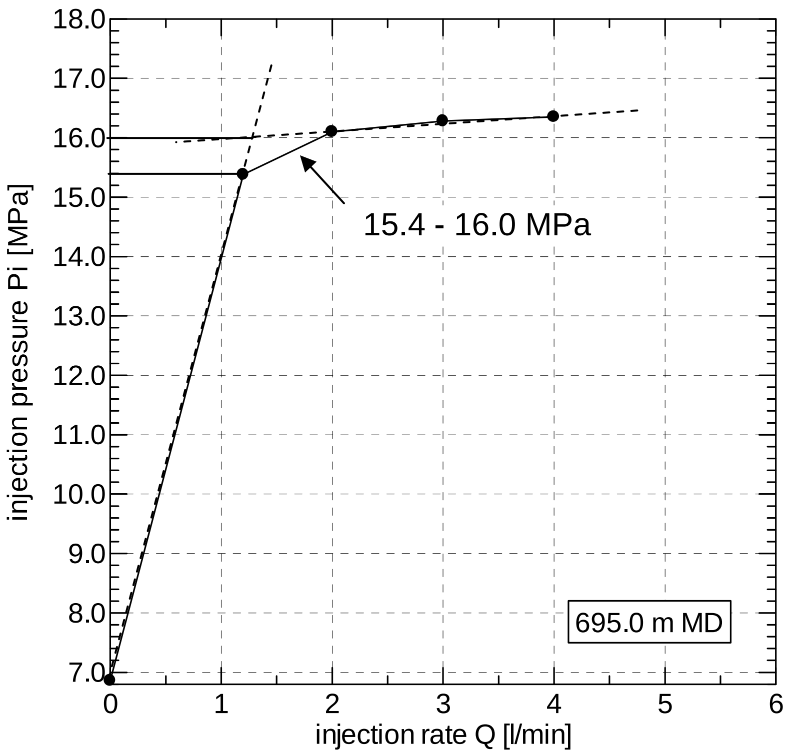
Test at 695.0 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 695.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

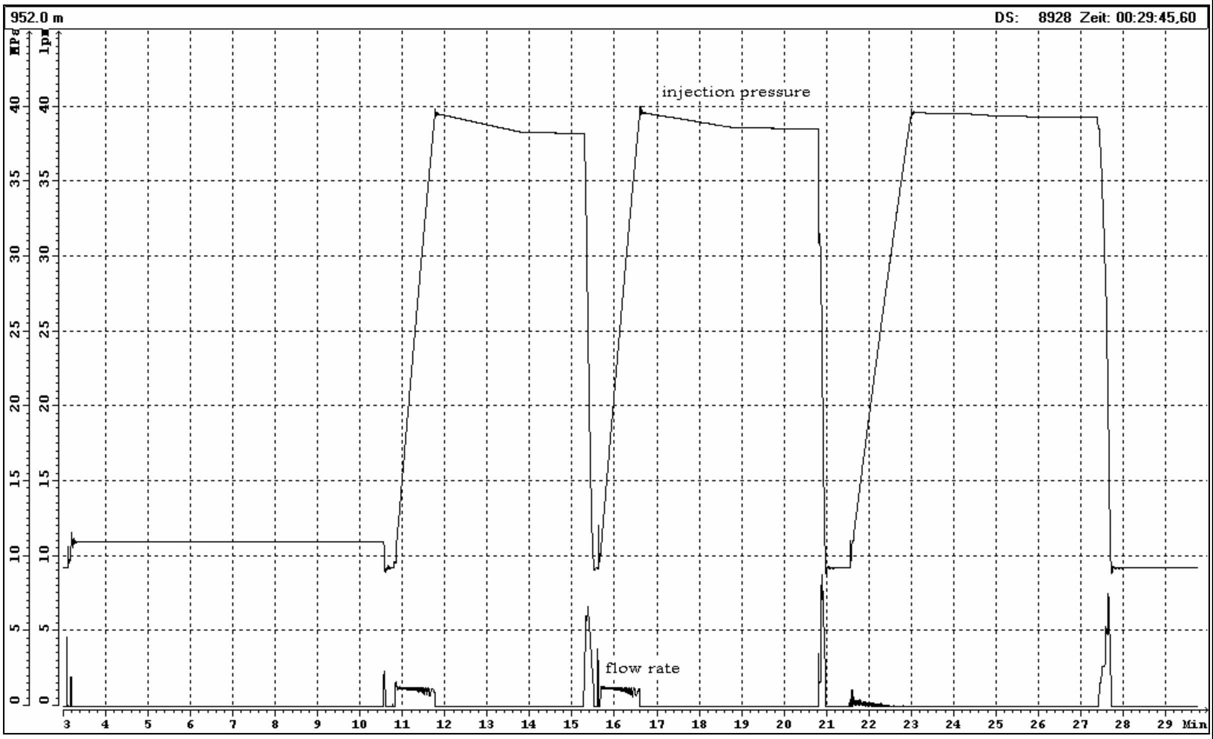


Test at 695.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 12 AT 952.0 m MD / 938.55 m TVD

Test at 952.0 m MD: Overview - Plot



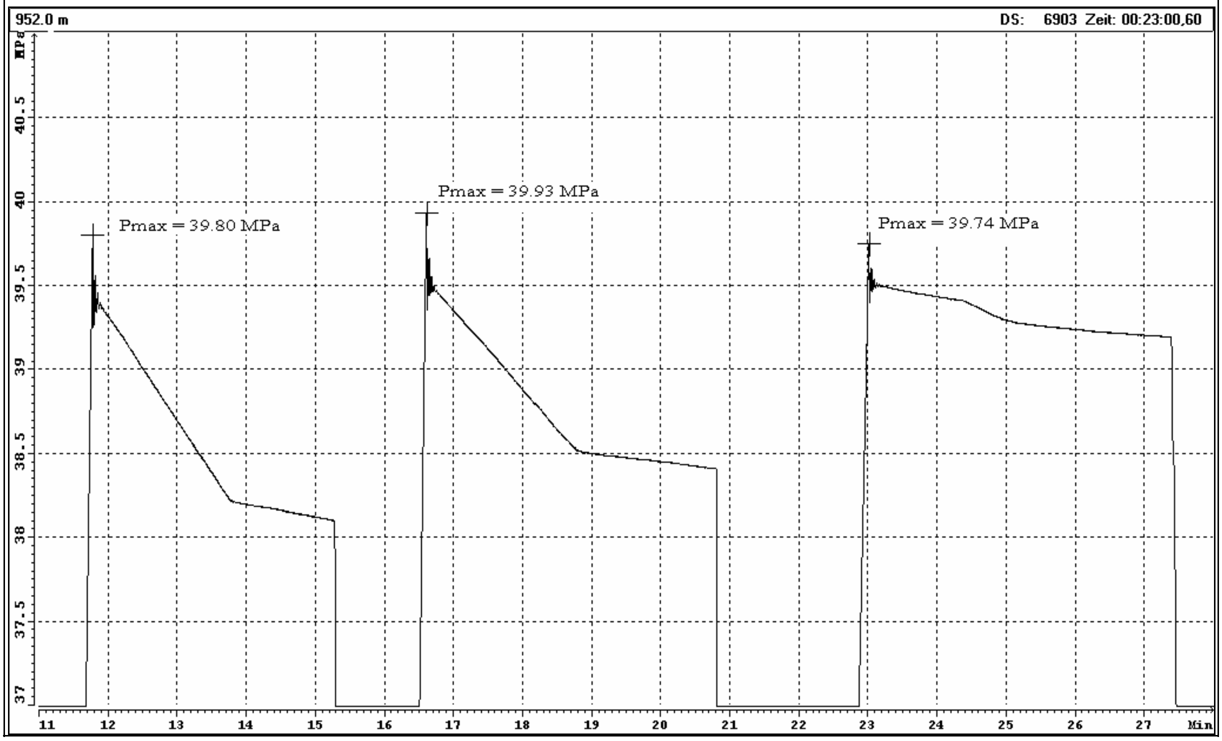
P - Test 1. Frac 2. Frac 3. Frac

TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	minor pressure increase of 0.02 MPa in 426 sec.					
1. Frac - cycle	Qi (lpm) = 1.0	Vi (l) =	1.1	Vr (l) =	1.0
2. Frac - cycle	Qi (lpm) = 1.0	Vi (l) =	1.1	Vr (l) =	0.8
3. Frac - cycle	Qi (lpm) < 1.0	Vi (l) =		Vr (l) =	1.0

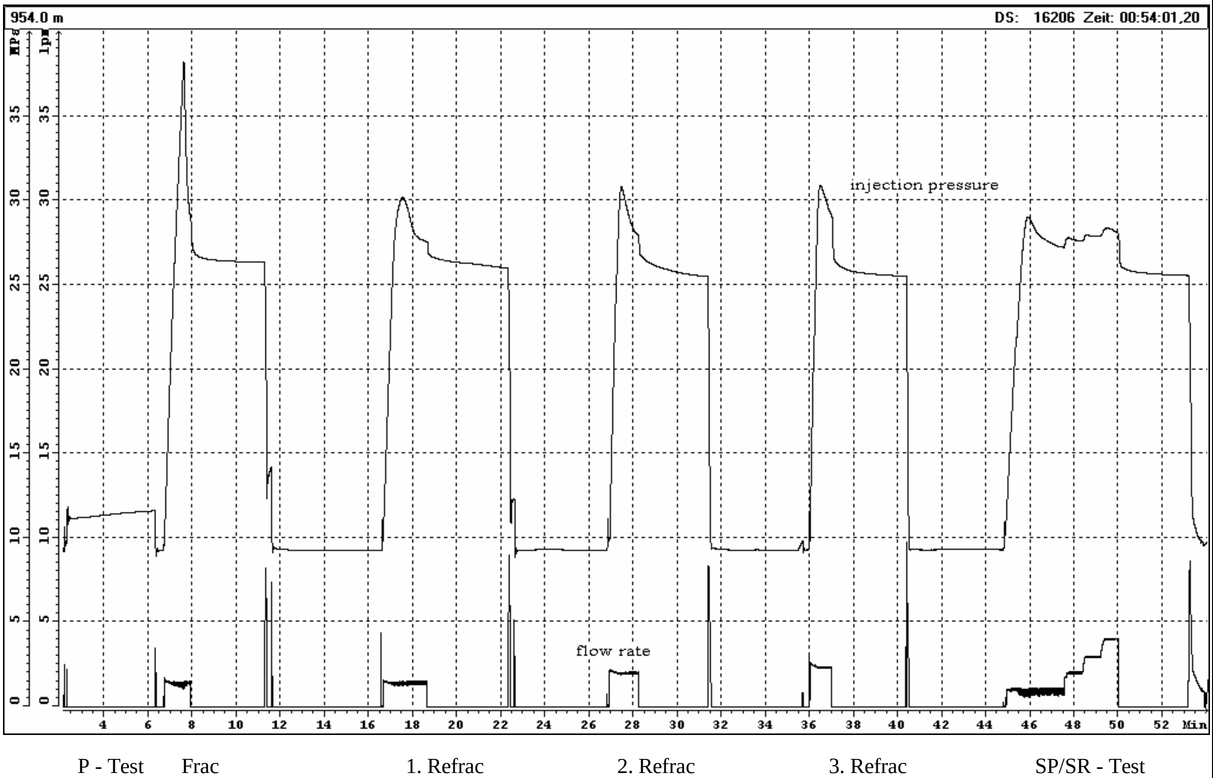
- Initial test type: HF
- During the 1., 2. and 3. frac cycle, the injection was stopped at pressures of 39.8, 39.9 and 39.7 MPa, respectively. No breakdown event was observed during the frac -attempts. Therefore, the test was abandoned to prevent a damage of the packer elements.

Test at 952.0 m MD: Estimation of P_{max} (1. , 2., and 3. Frac - Cycle)



TEST NO. 11 AT 954.0 m MD / 939.52 m TVD

Test at 954.0 m MD : Overview - Plot



TEST SUMMARY / ANALYSIS / REMARKS

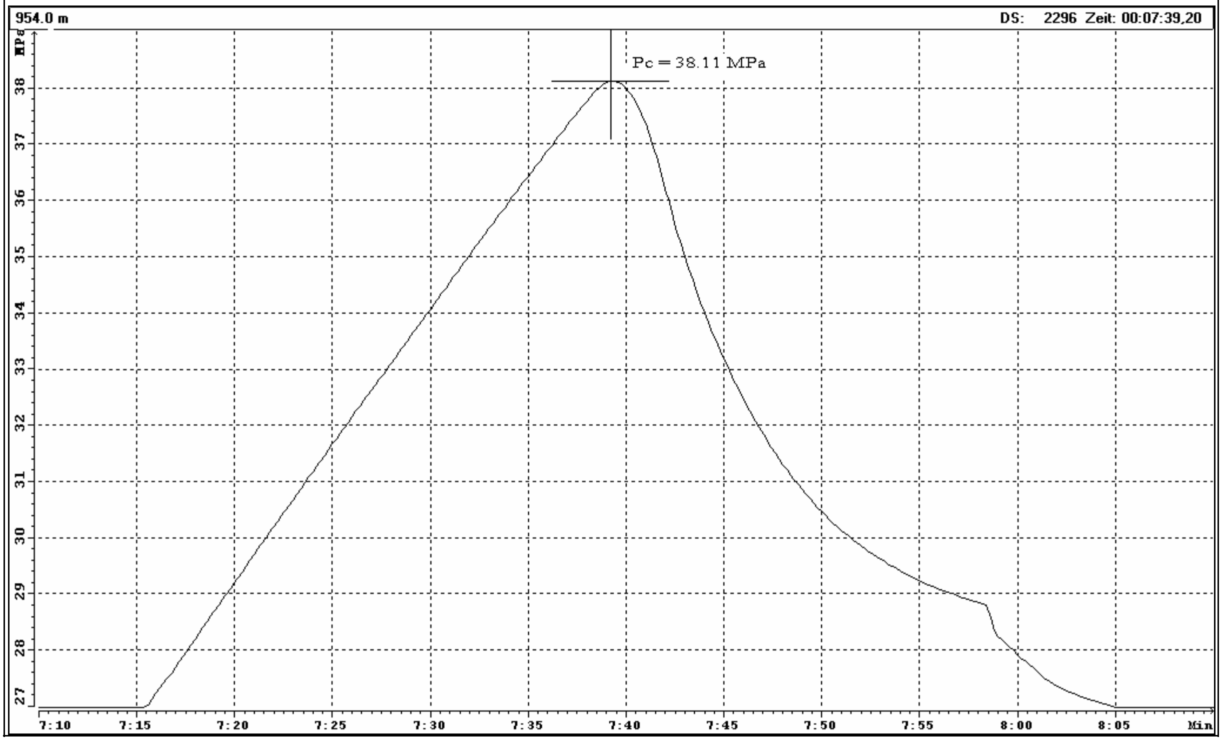
P - Test : significant pressure increase of 0.44 MPa in 226 sec.

Frac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.7	Vr (l) = 1.4
1. Refrac - cycle	Qi (lpm) = 1.5	Vi (l) = 2.8	Vr (l) = 1.5
2. Refrac - cycle	Qi (lpm) = 1.9	Vi (l) = 2.7	Vr (l) = 1.6
3. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 2.4	Vr (l) = 1.75
SP/SR - test	Qi (lpm) = 1.0-4.1	Vi (l) = 9.7	Vr (l) = 5.5

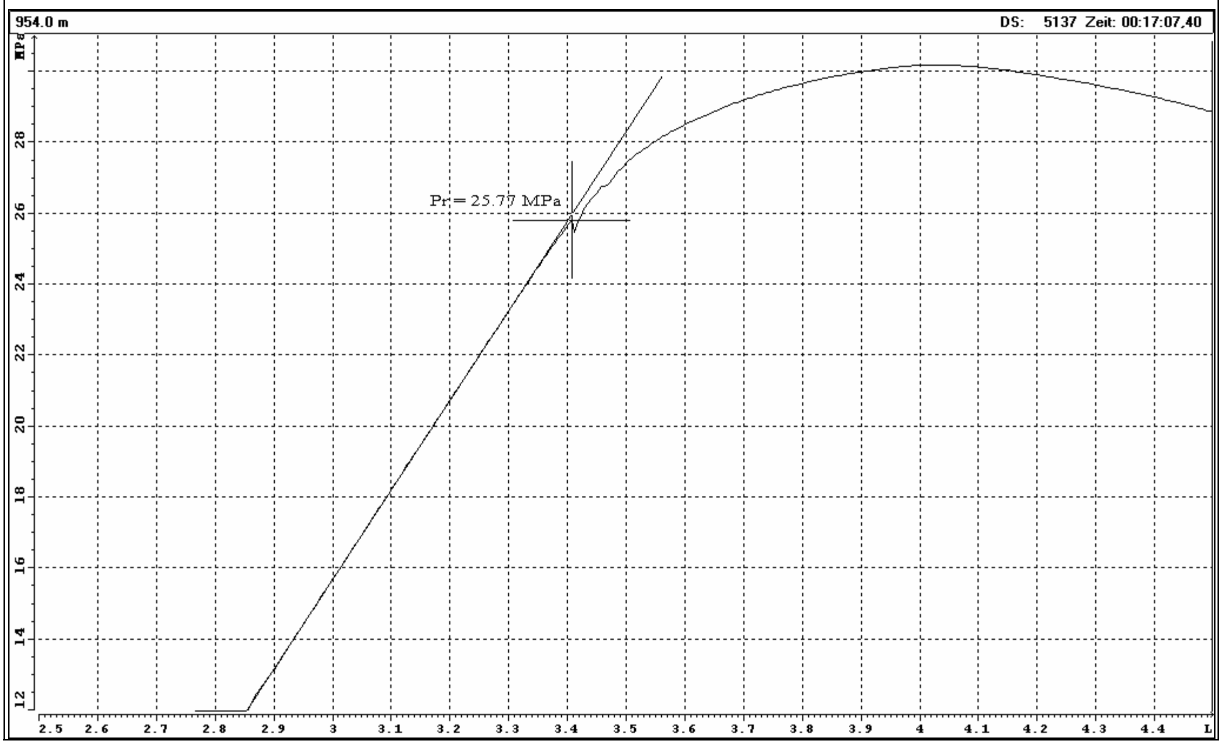
total injected volume (l): 19.3 recovered volume (l): 11.75 or 60.9 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV at 25.8 MPa, followed by a pressure increase up to 30.1 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield slightly lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

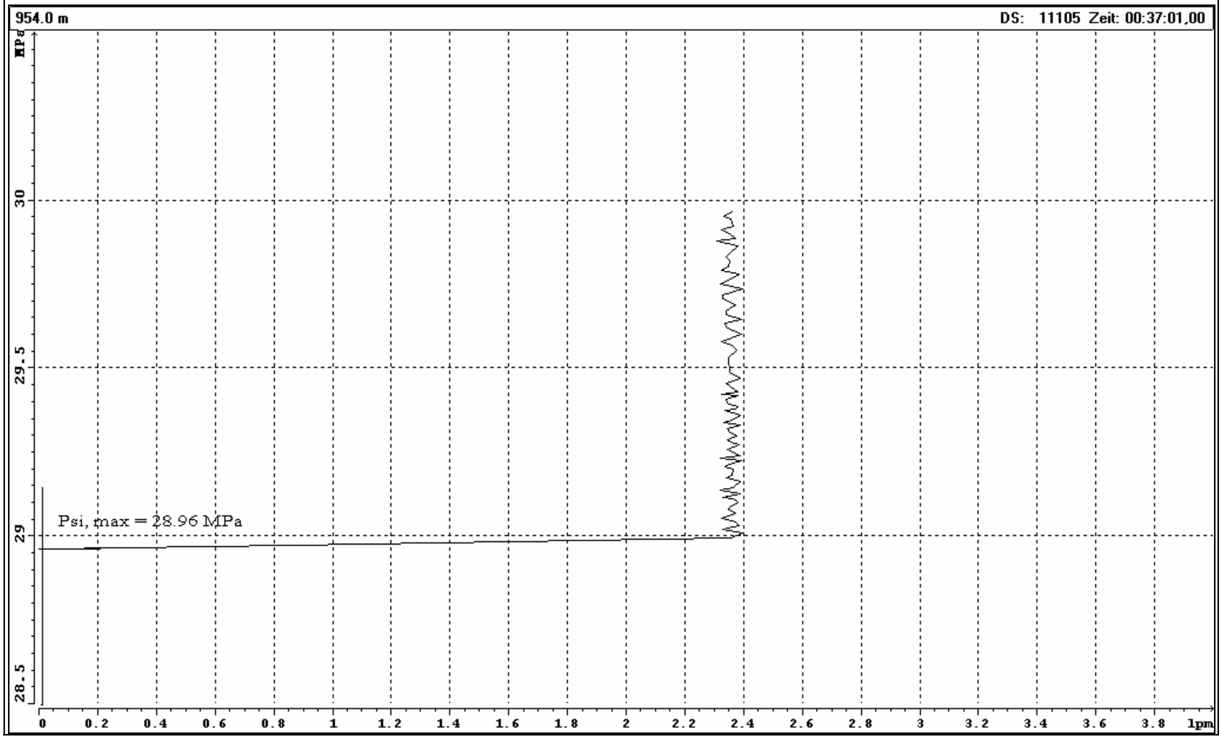
Test at 954.0 m MD: Estimation of P_c (Frac - Cycle)



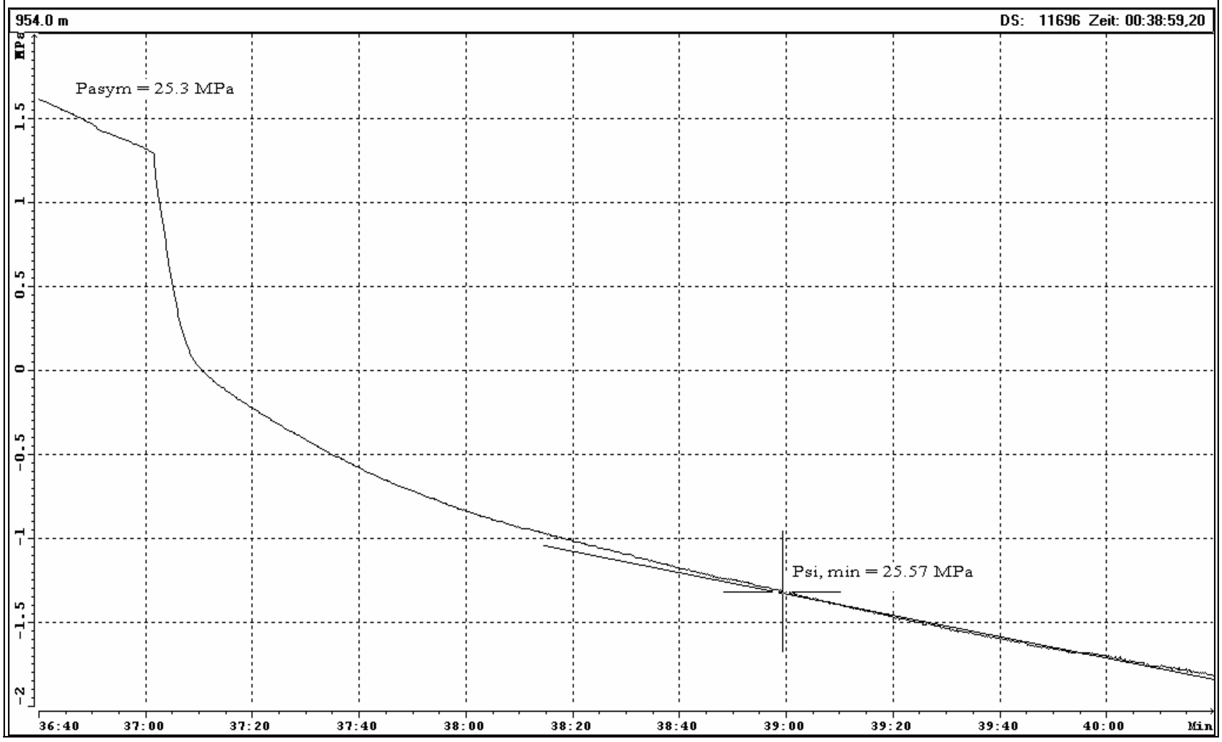
Test at 954.0 m MD: Estimation of P_r (1. Refrac - Cycle)



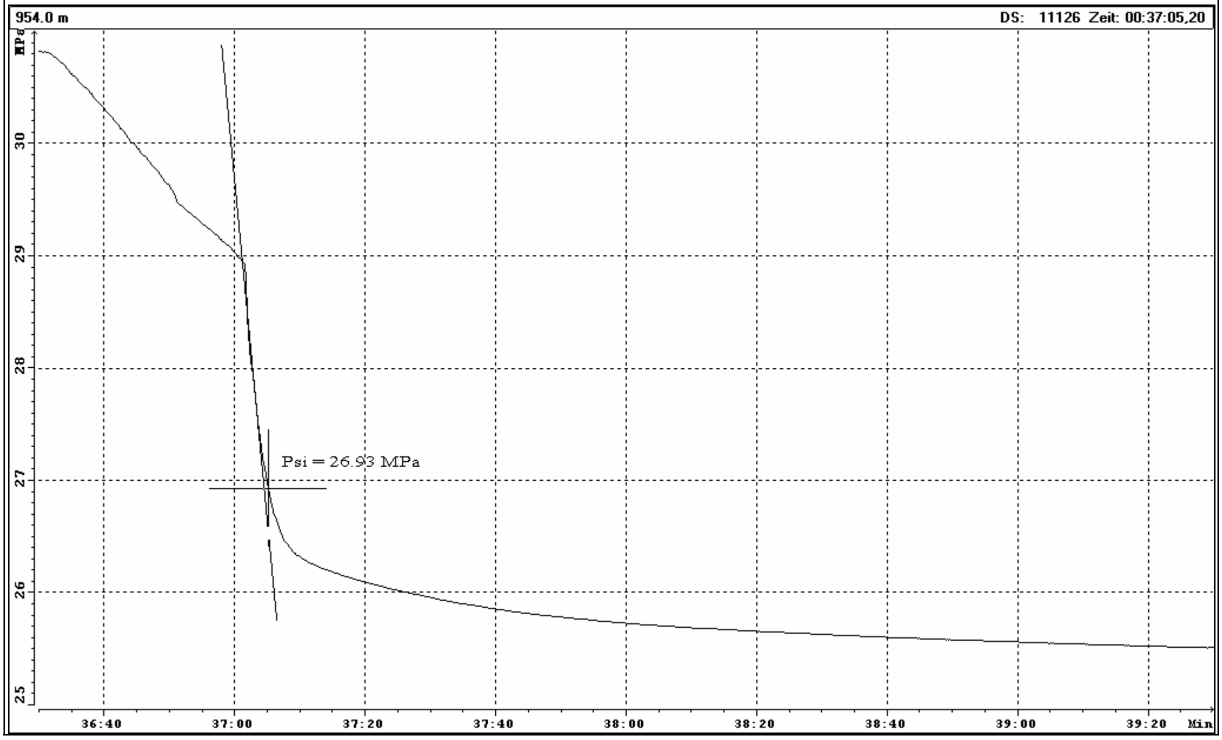
Test at 954.0 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



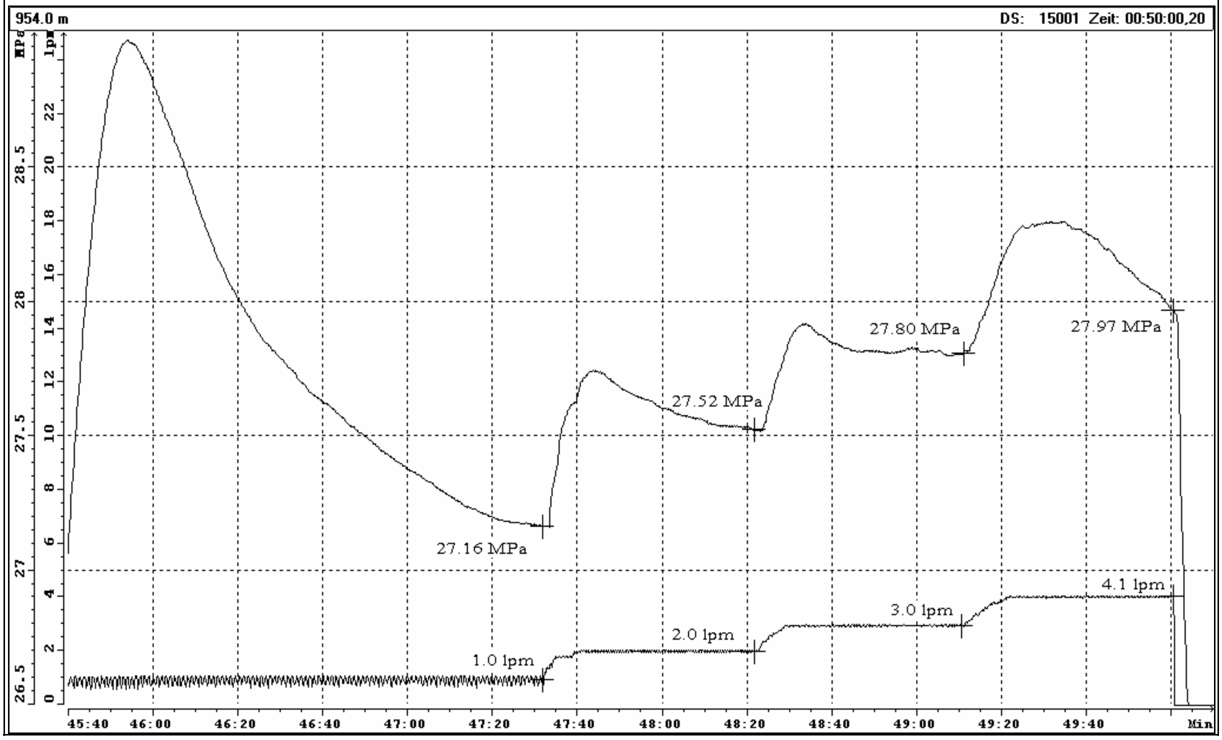
Test at 954.0 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



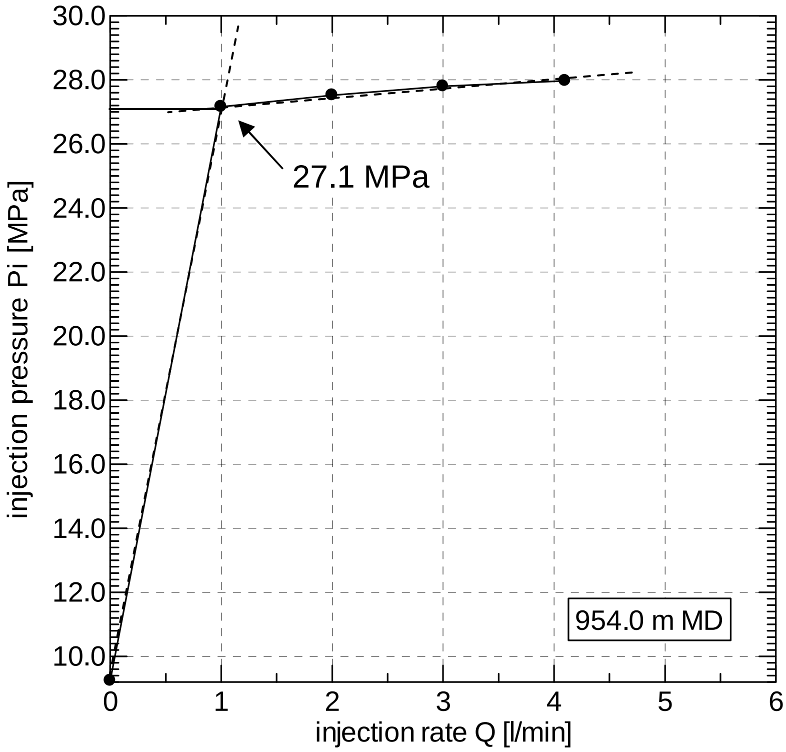
Test at 954.0 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 954.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

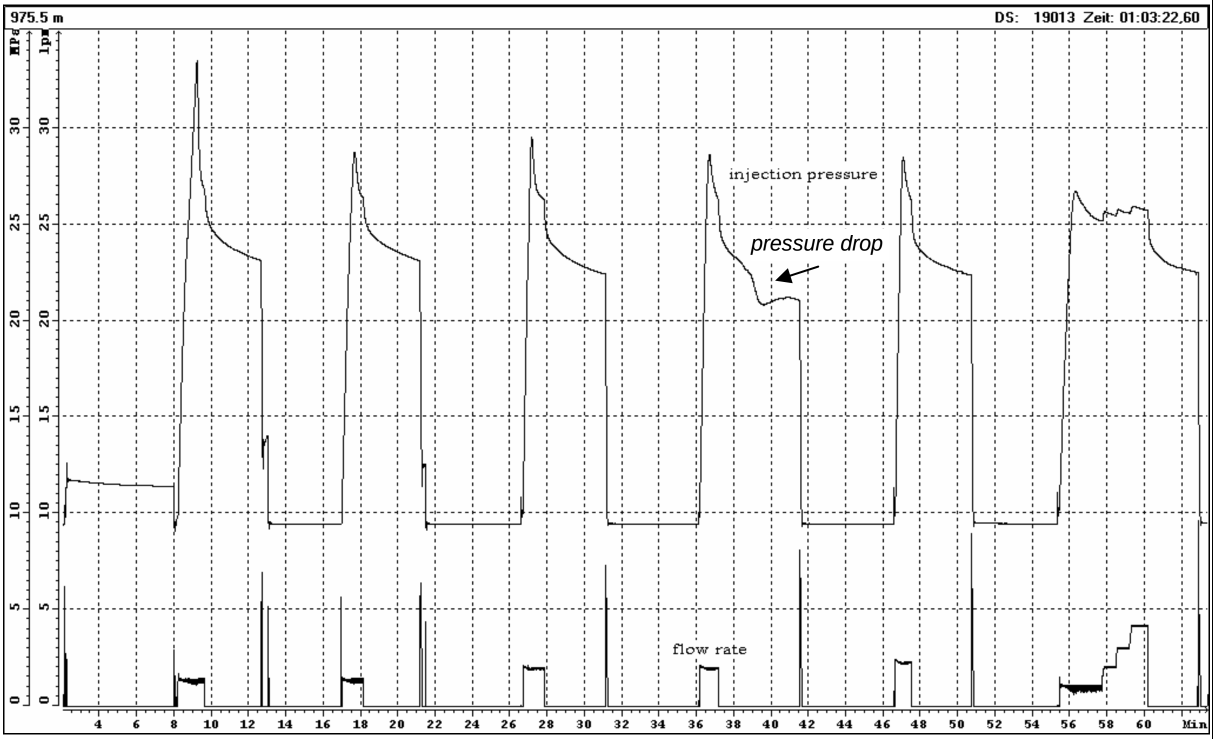


Test at 954.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 10 AT 975.5 m MD / 960.32 m TVD

Test at 975.5 m MD : Overview - Plot



P - Test Frac 1. Refrac 2. Refrac 3. Refrac 4. Refrac SP/SR - Test

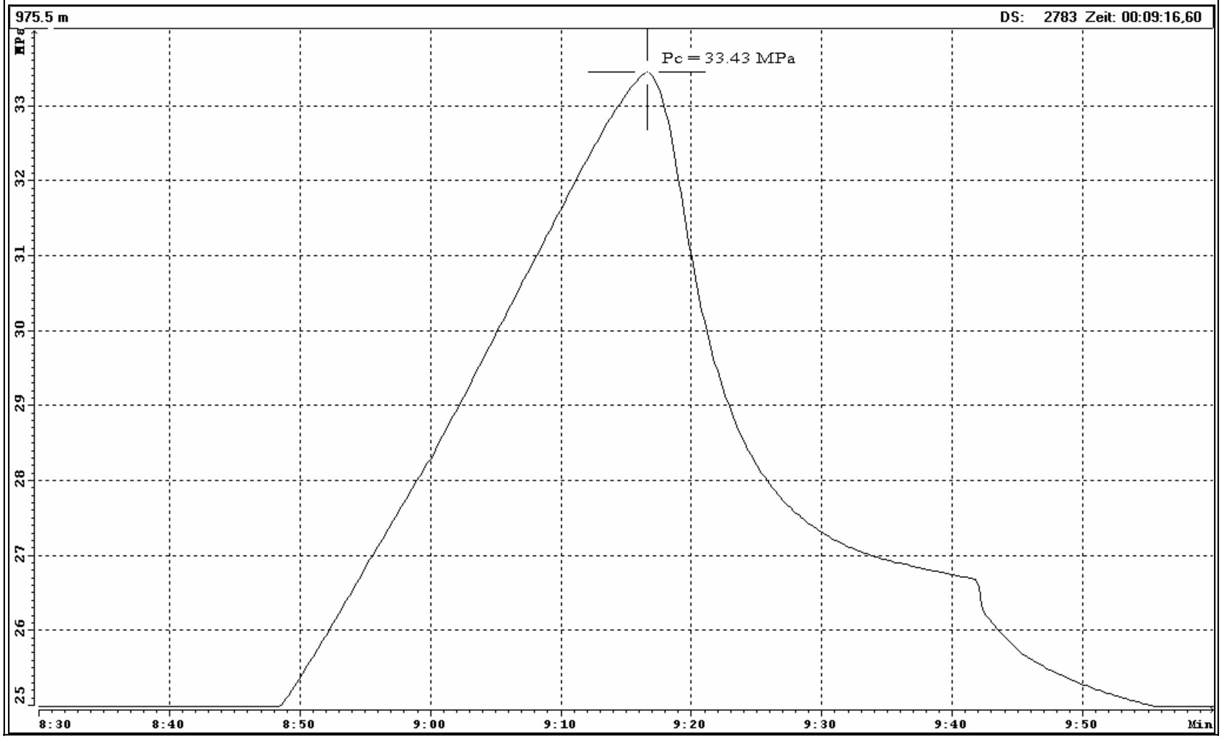
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.33 MPa in 332 sec.		
Frac - cycle	Qi (lpm) = 1.3	Vi (l) = 1.9	Vr (l) = 0.75
1. Refrac - cycle	Qi (lpm) = 1.3	Vi (l) = 1.6	Vr (l) = 0.8
2. Refrac - cycle	Qi (lpm) = 2.0	Vi (l) = 2.2	Vr (l) = 1.0
3. Refrac - cycle	Qi (lpm) = 2.0	Vi (l) = 2.0	Vr (l) = 1.0
4. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 2.0	Vr (l) = 1.2
SP/SR - test	Qi (lpm) = 1.0-4.1	Vi (l) = 10.0	Vr (l) = 1.5

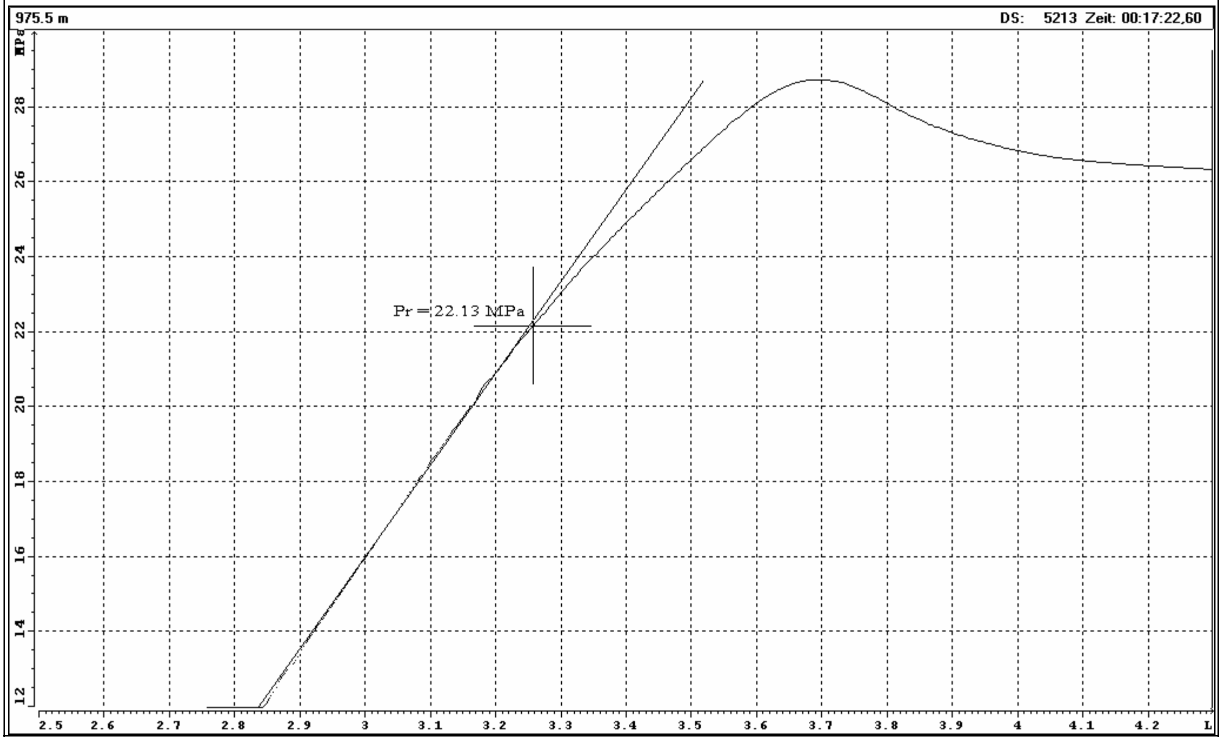
total injected volume (l): 19.7 recovered volume (l): 6.25 or 31.7 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. and 4. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 22.1 and 24.9 MPa, followed by a pressure increase up to more than 28 MPa.
- During the shut-in phase of the 3. refrac - cycle, a significant pressure drop was observed.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

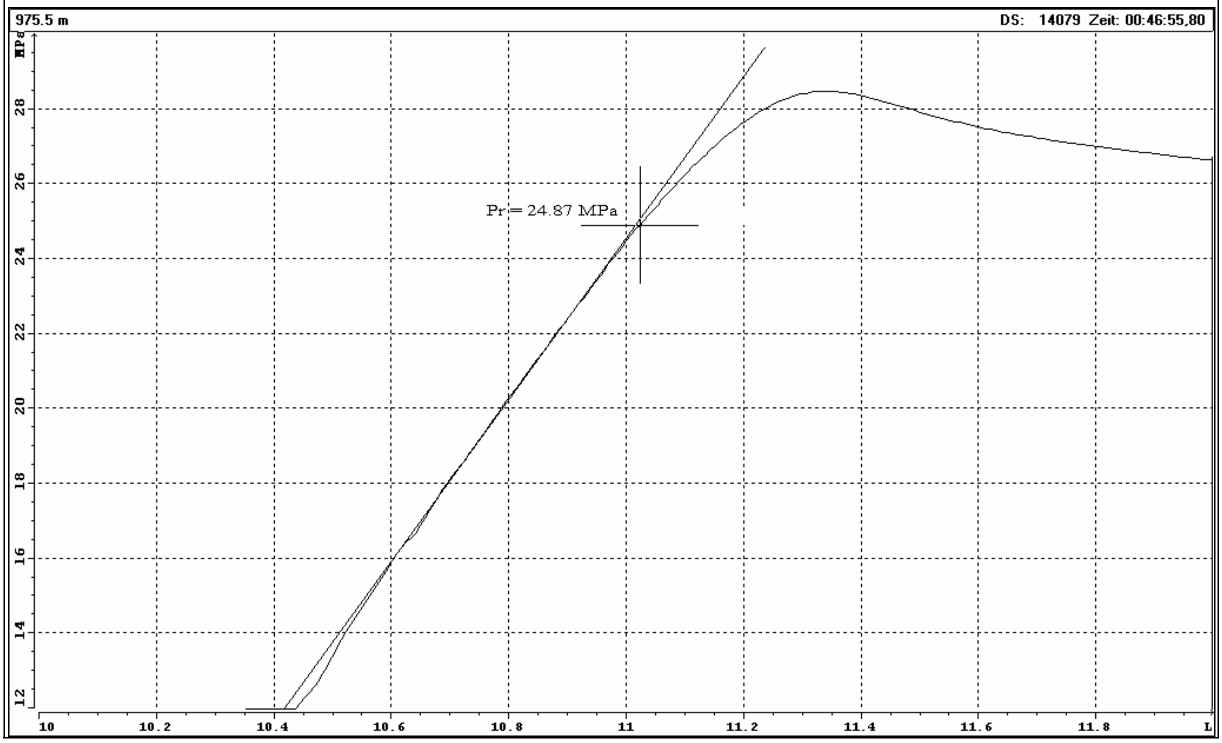
Test at 975.5 m MD: Estimation of P_c (Frac - Cycle)



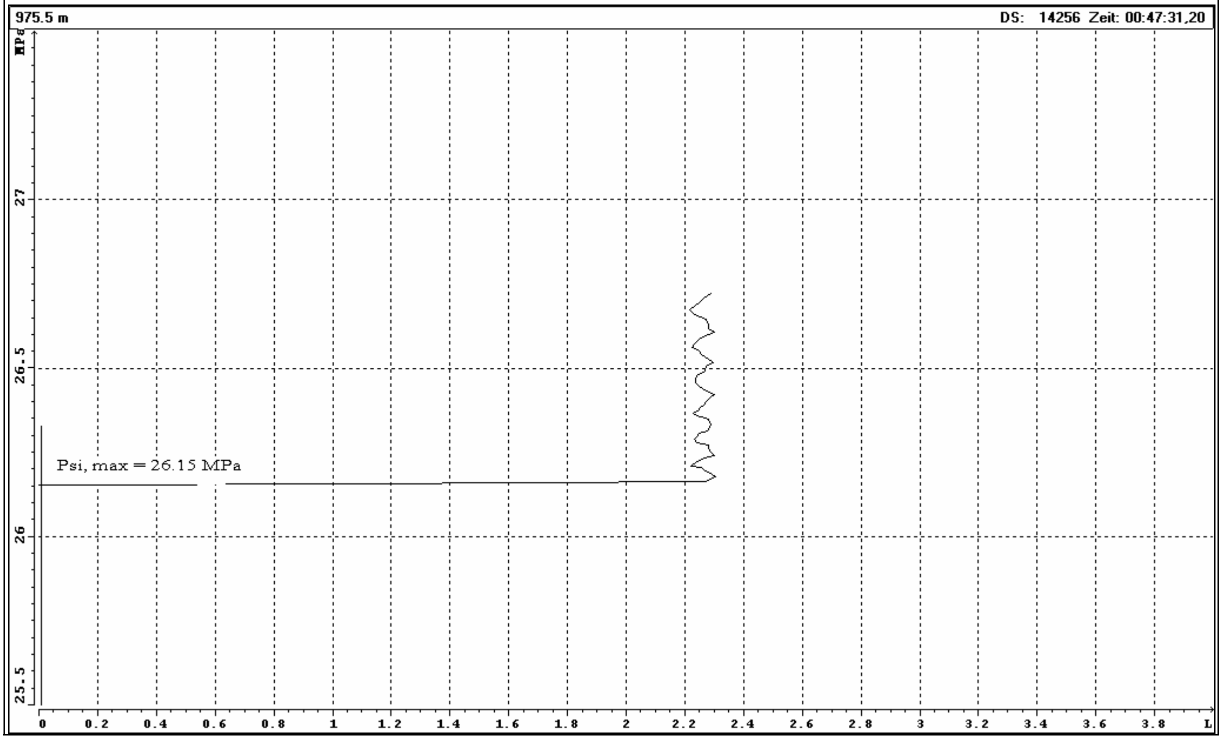
Test at 975.5 m MD: Estimation of P_r (1. Refrac - Cycle)



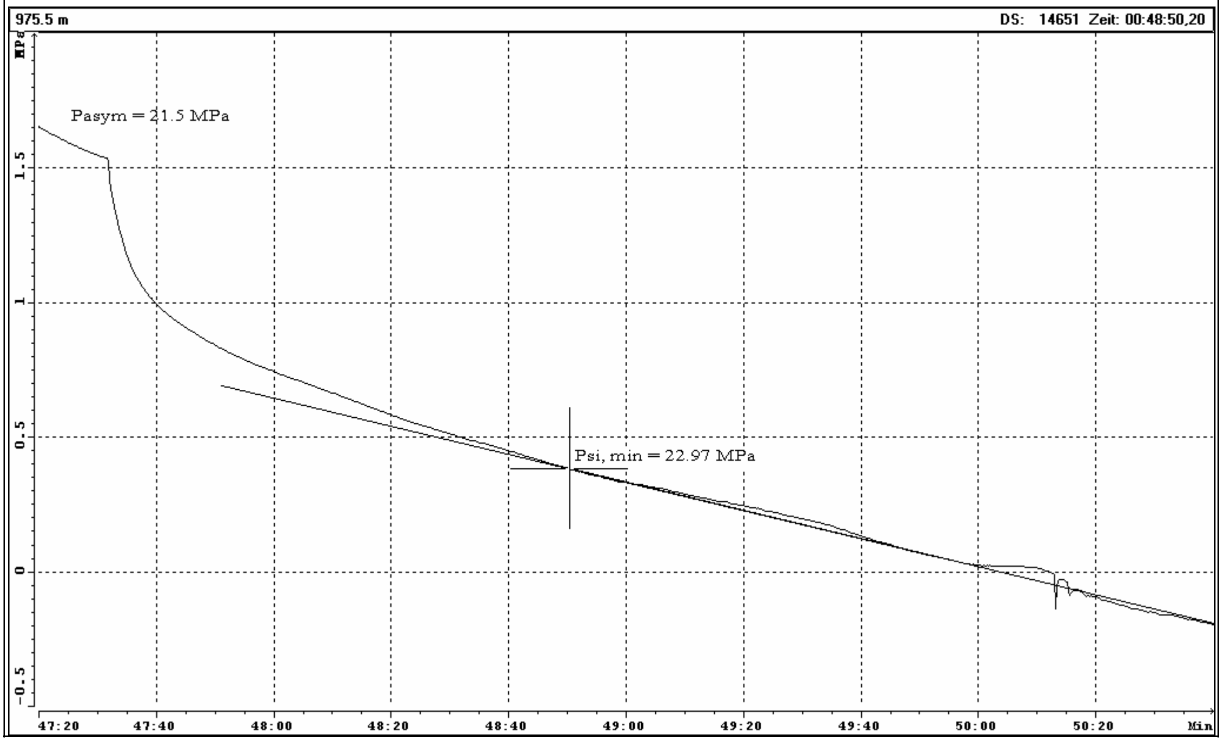
Test at 975.5 m MD: Estimation of P_r (4. Refrac - Cycle)



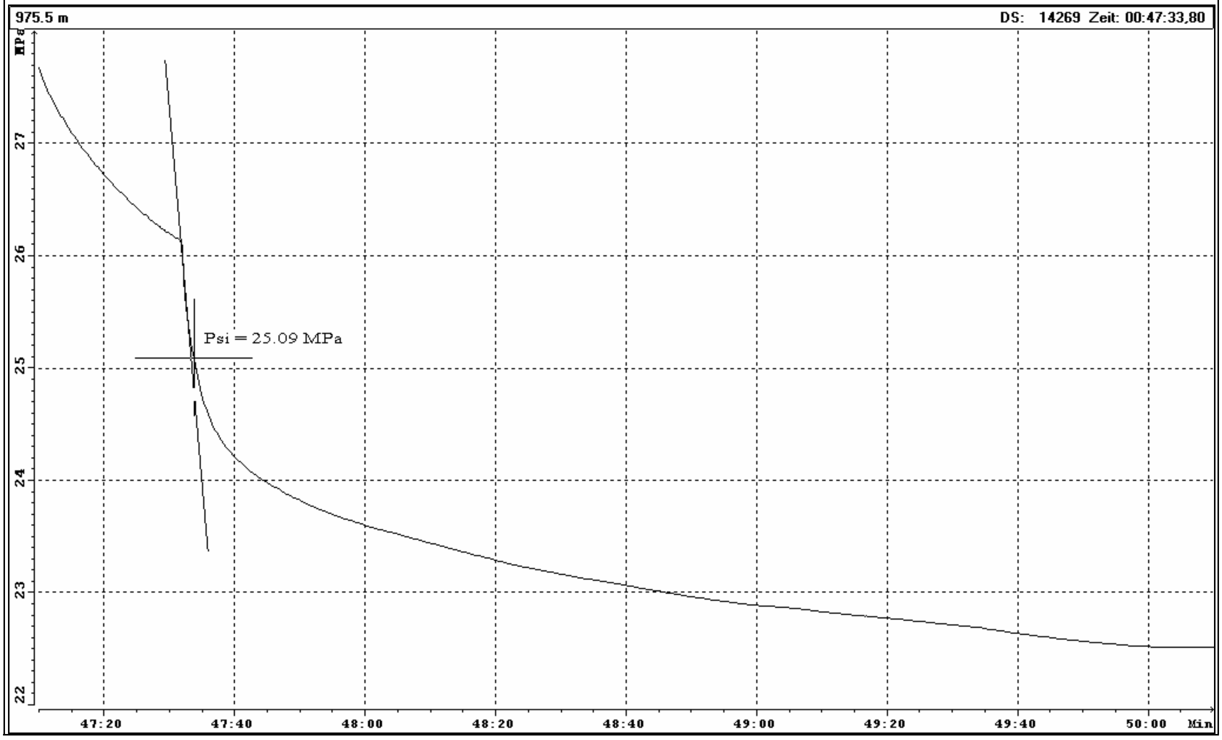
Test at 975.5 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



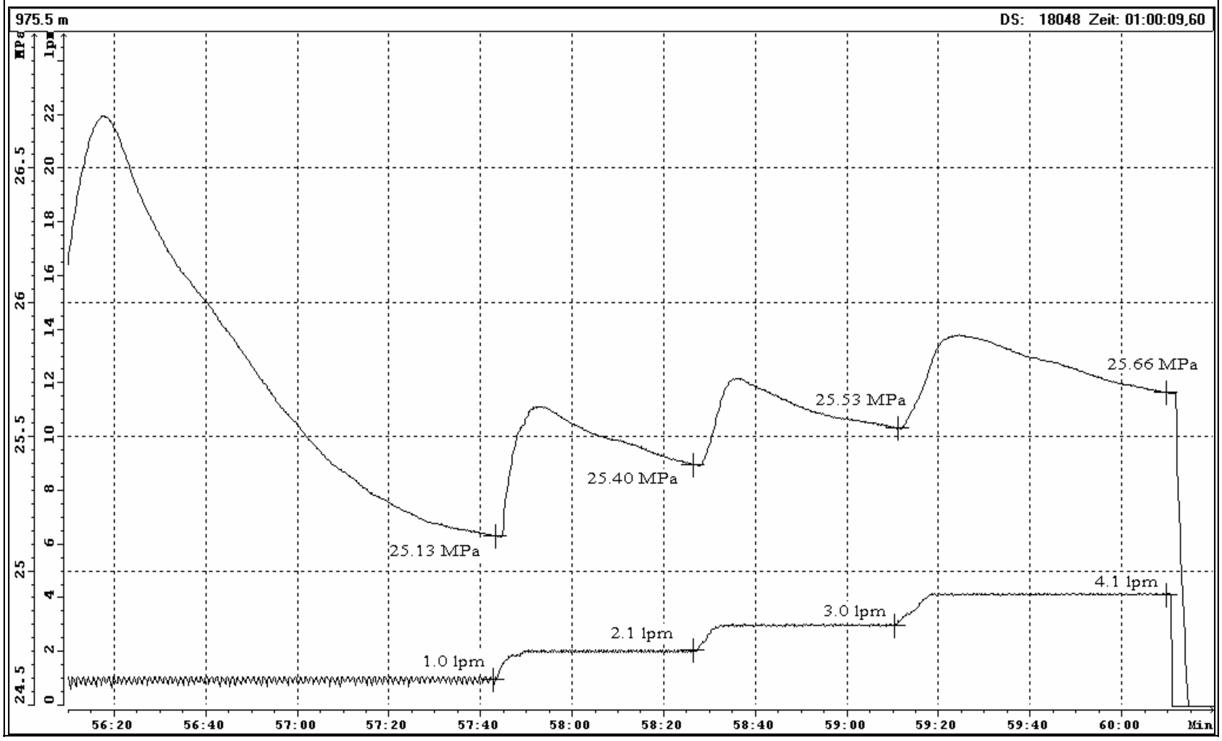
Test at 975.5 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



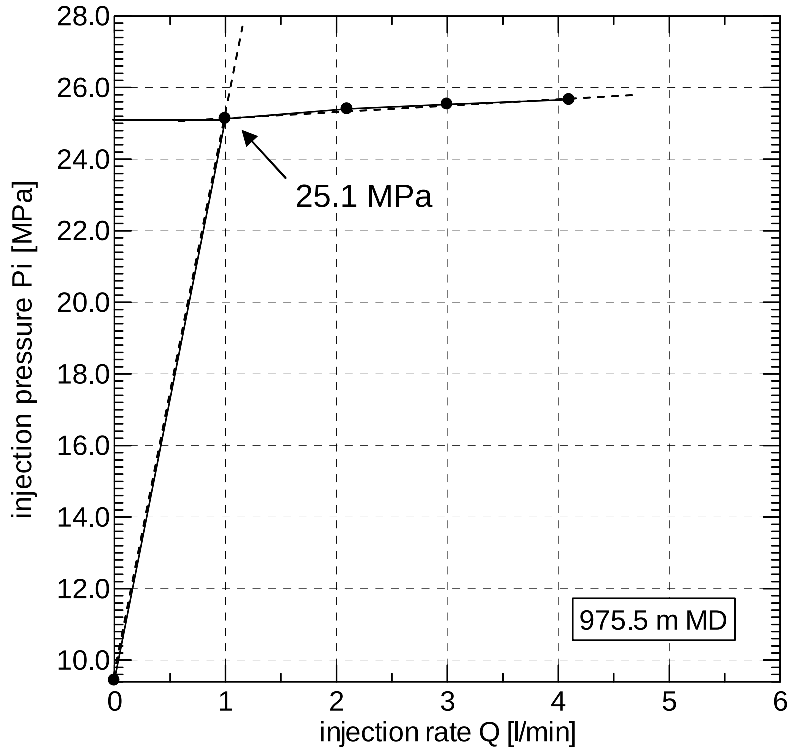
Test at 975.5 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 975.5 m MD: Analysis of Slow - Pump / Step - Rate - Test



Test at 975.5 m MD: Examination of P_{si} (Step - Rate - Test)



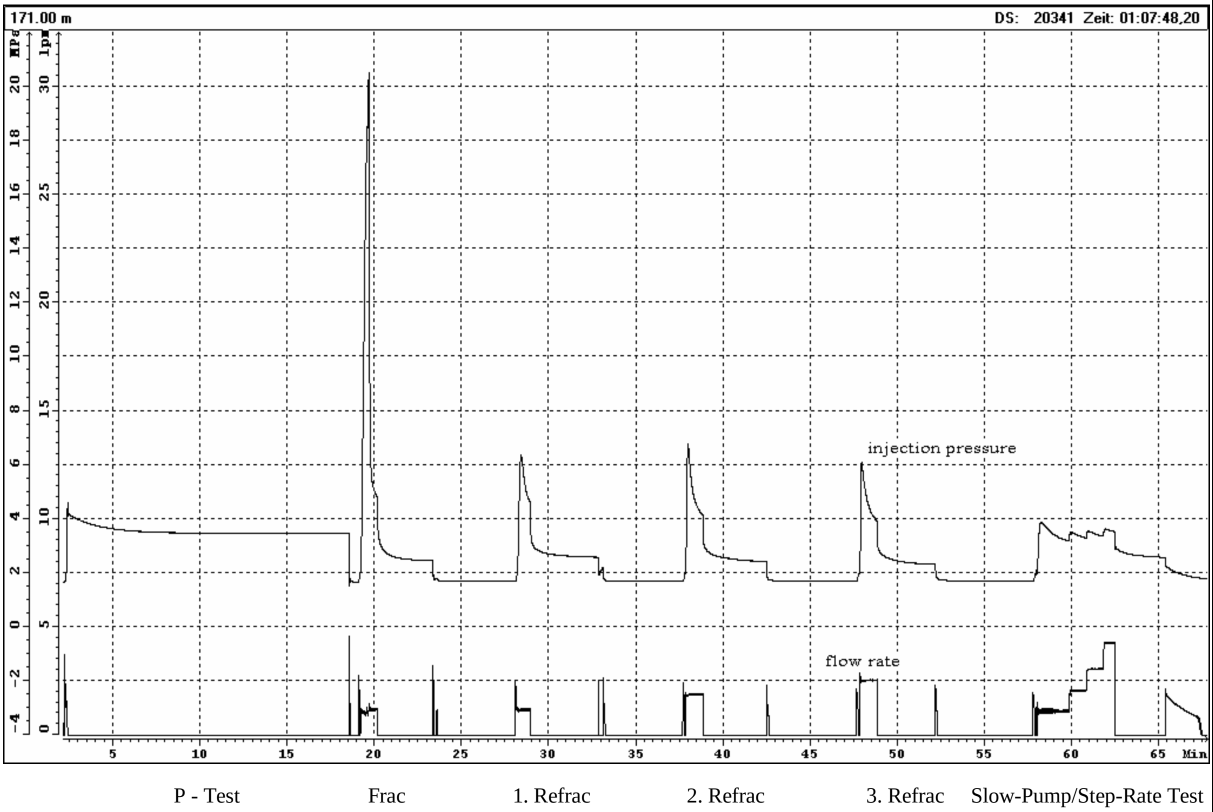
Appendix B2

Records from in-situ Hydrofrac / Hydraulic Injection Tests together with Evaluation of Characteristic Pressure Data

Borehole No. KFM01B

TEST NO. 1 AT 171.00 m MD / 167.07 m TVD

Test at 171.00 m MD : Overview - Plot



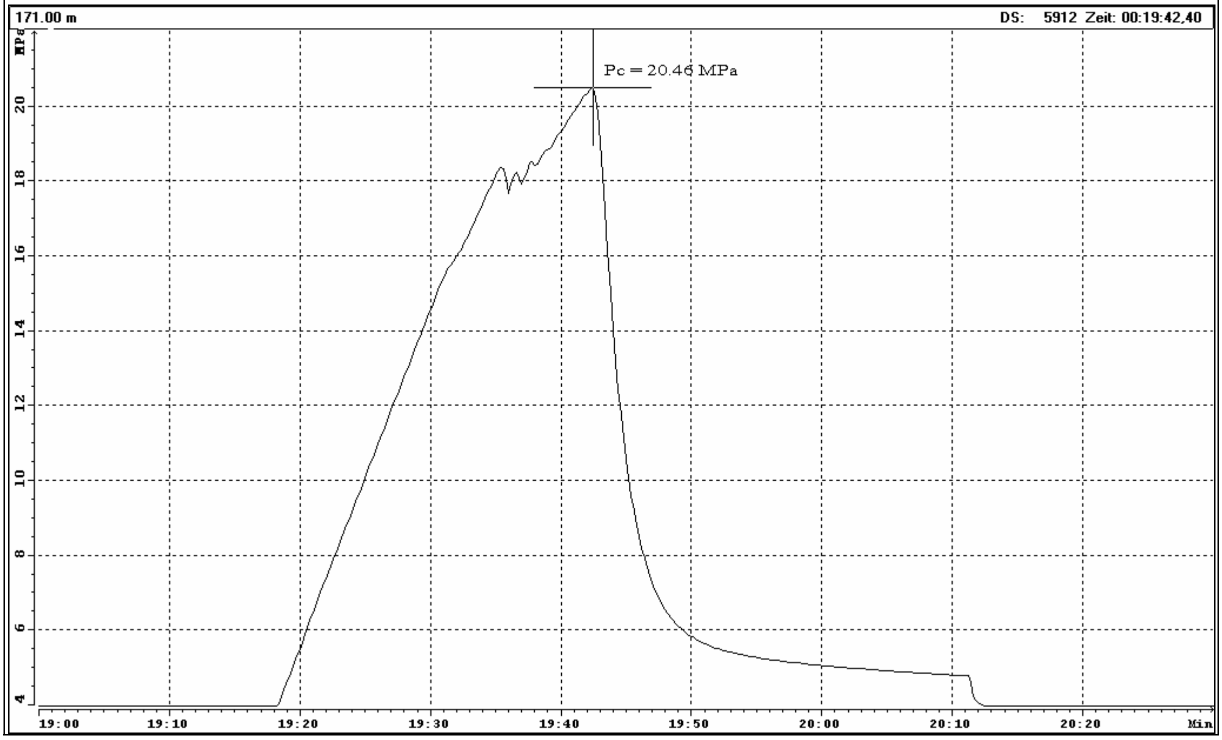
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.69 MPa in 961 sec.		
Frac - cycle	Qi (lpm) = 1.1	Vi (l) = 1.3	Vr (l) = 0.4
1. Refrac - cycle	Qi (lpm) = 1.2	Vi (l) = 1.1	Vr (l) = 0.6
2. Refrac - cycle	Qi (lpm) = 1.9	Vi (l) = 2.1	Vr (l) = 0.9
3. Refrac - cycle	Qi (lpm) = 2.5	Vi (l) = 2.7	Vr (l) = 1.3
SP/SR - test	Qi (lpm) = 1.1-4.3	Vi (l) = 10.2	Vr (l) = 5.0

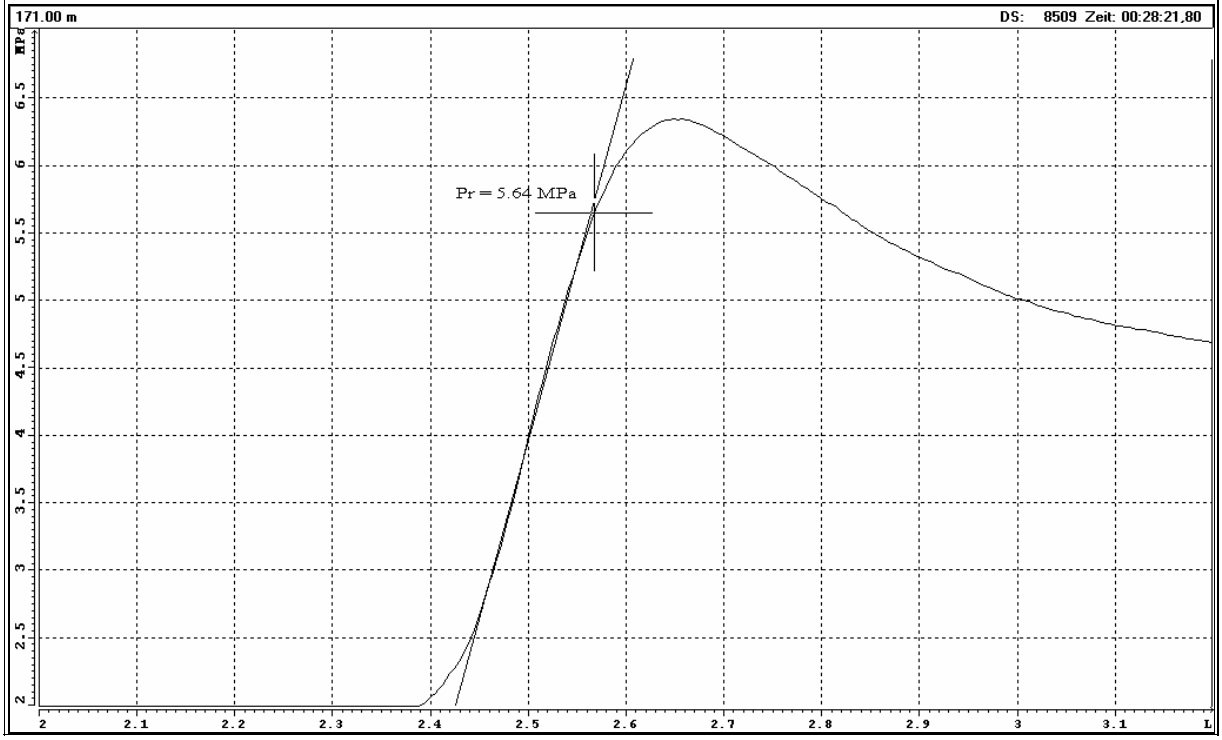
total injected volume (l): 17.4 recovered volume (l): 8.2 or 47.1 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. and 2. refrac - cycle, since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

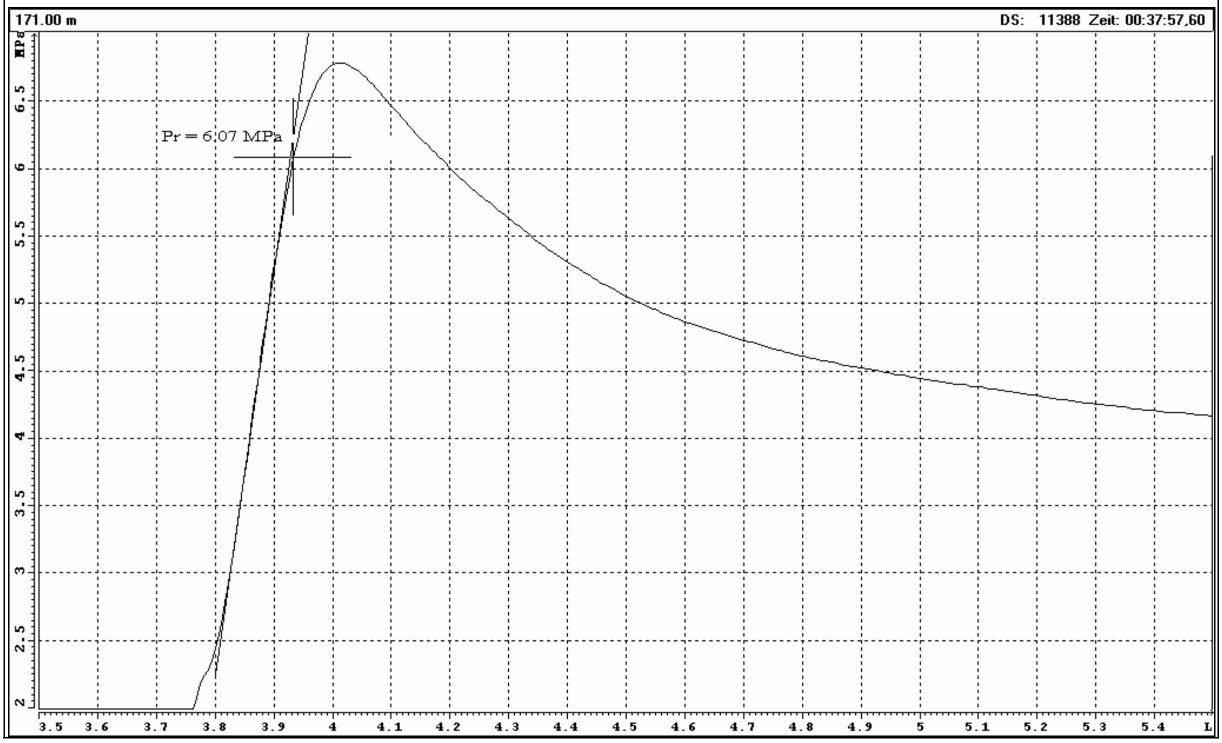
Test at 171.00 m MD: Estimation of P_c (Frac - Cycle)



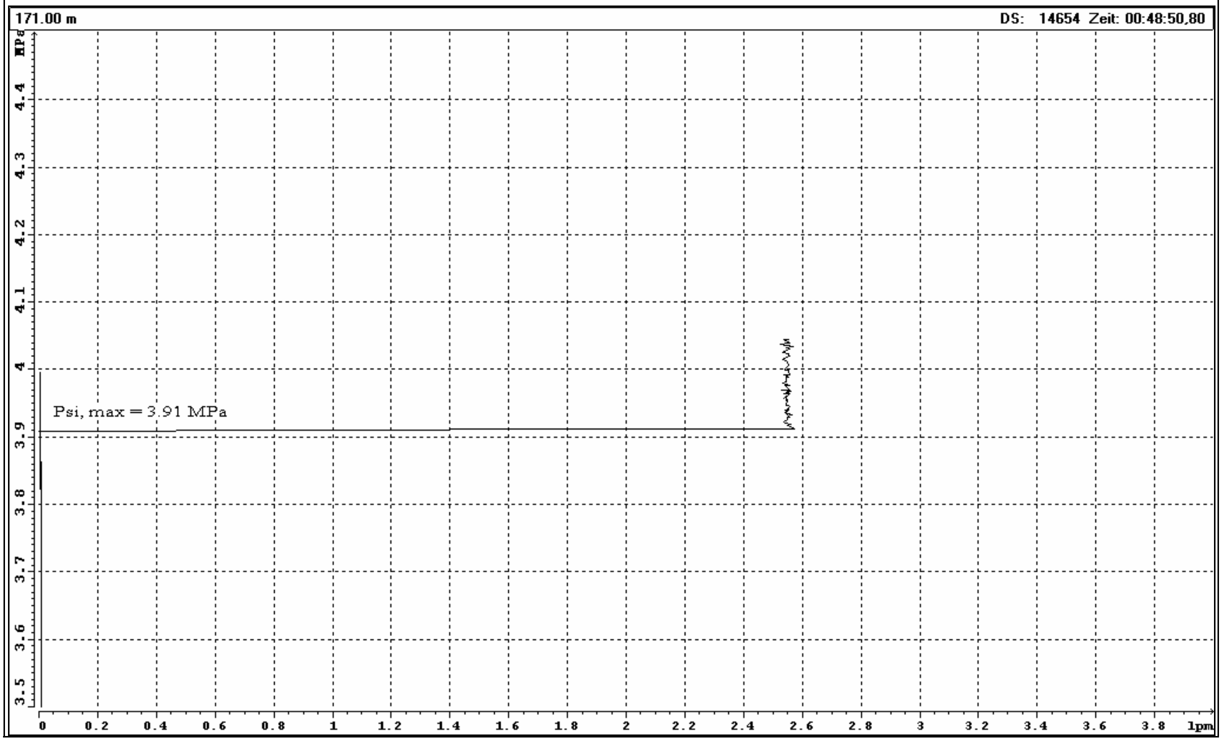
Test at 171.00 m MD: Estimation of P_r (1. Refrac - Cycle)



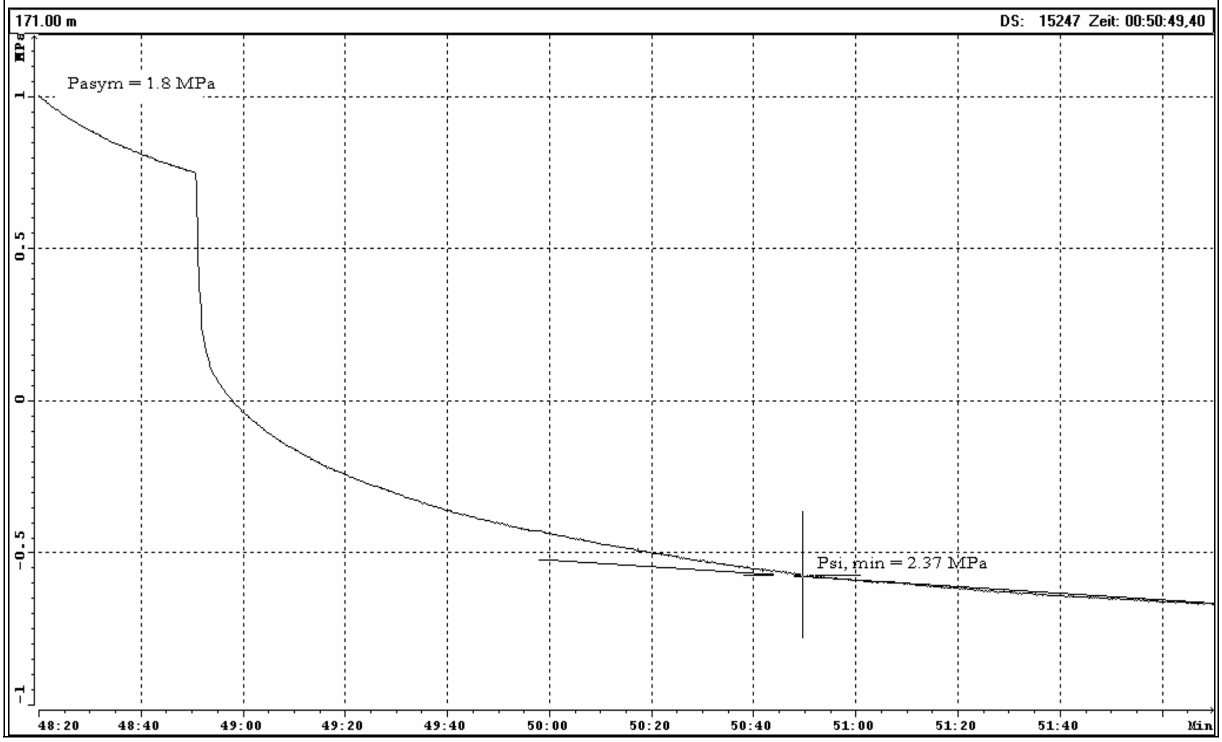
Test at 171.00 m MD: Estimation of P_r (2. Refrac - Cycle)



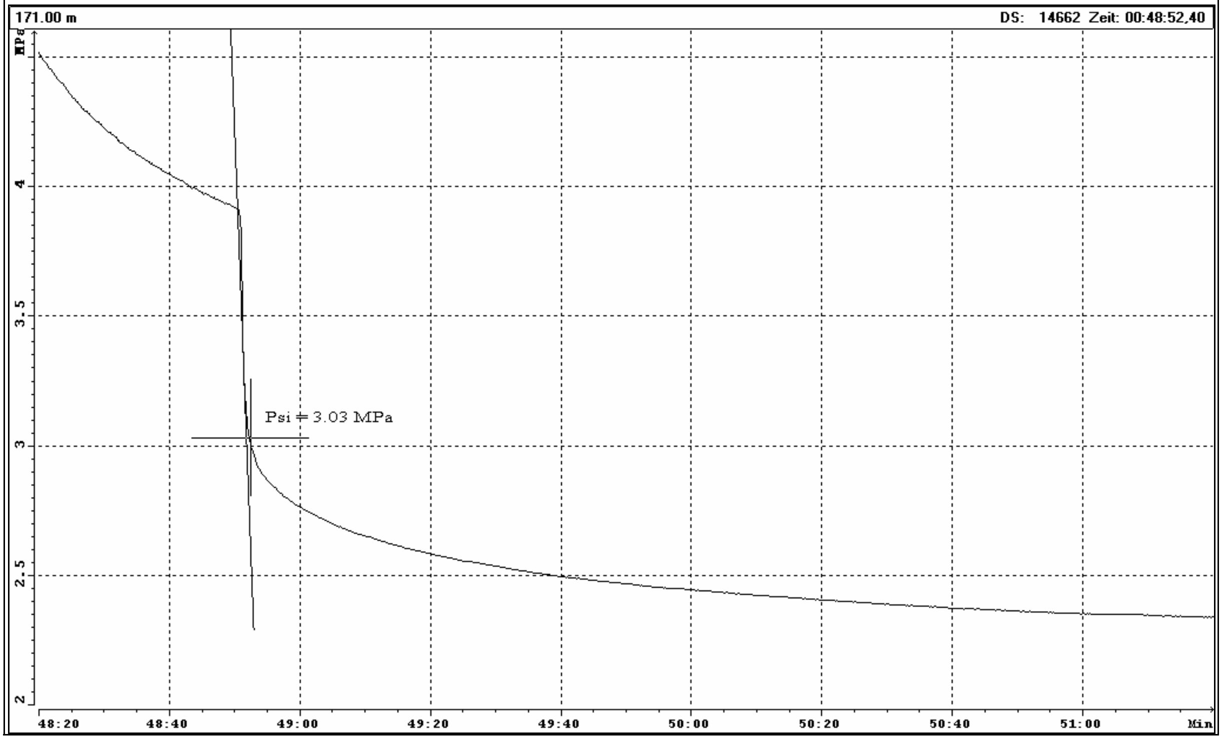
Test at 171.00 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



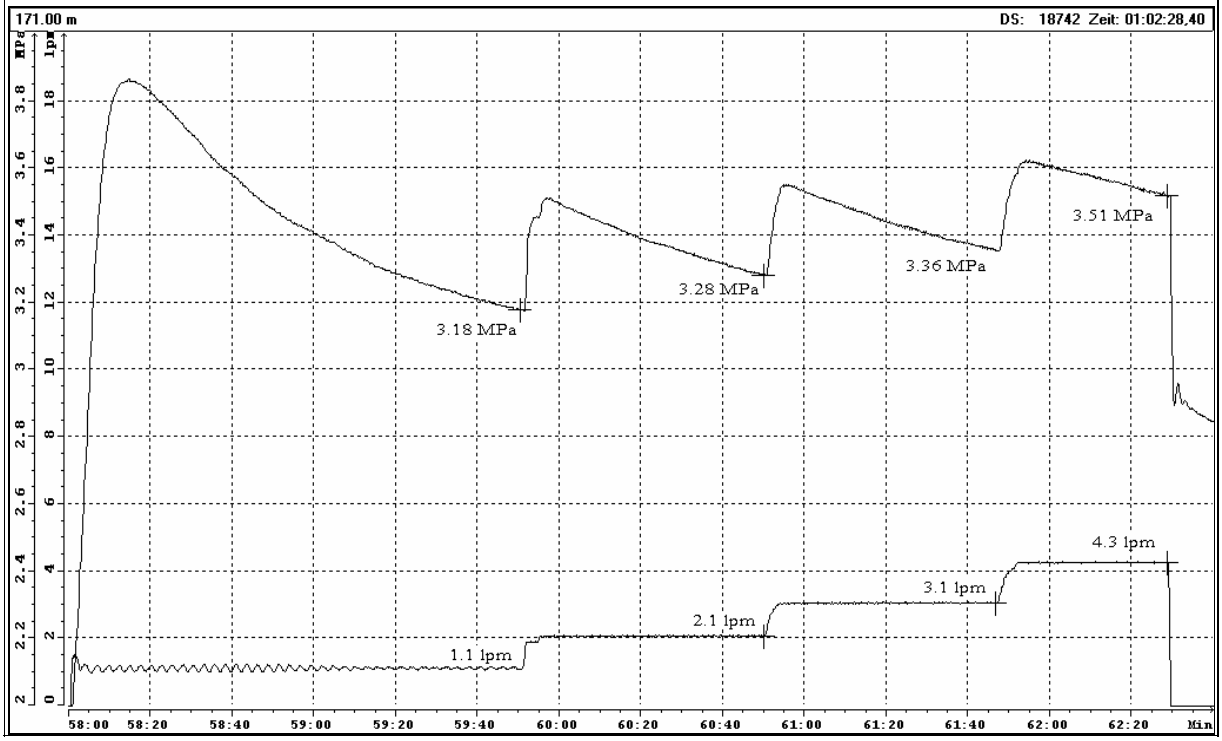
Test at 171.00 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



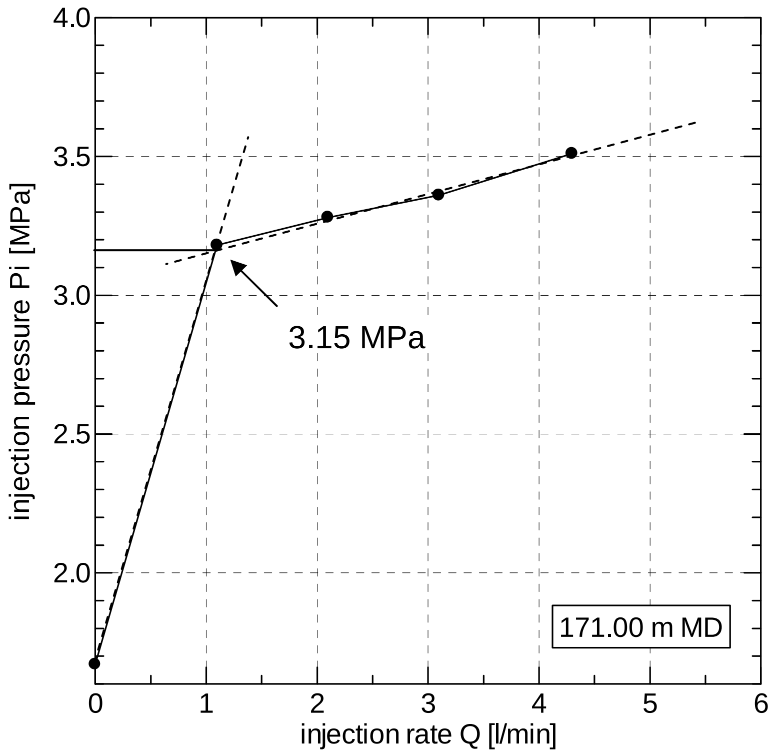
Test at 171.00 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 171.00 m MD: Analysis of Slow - Pump / Step - Rate - Test

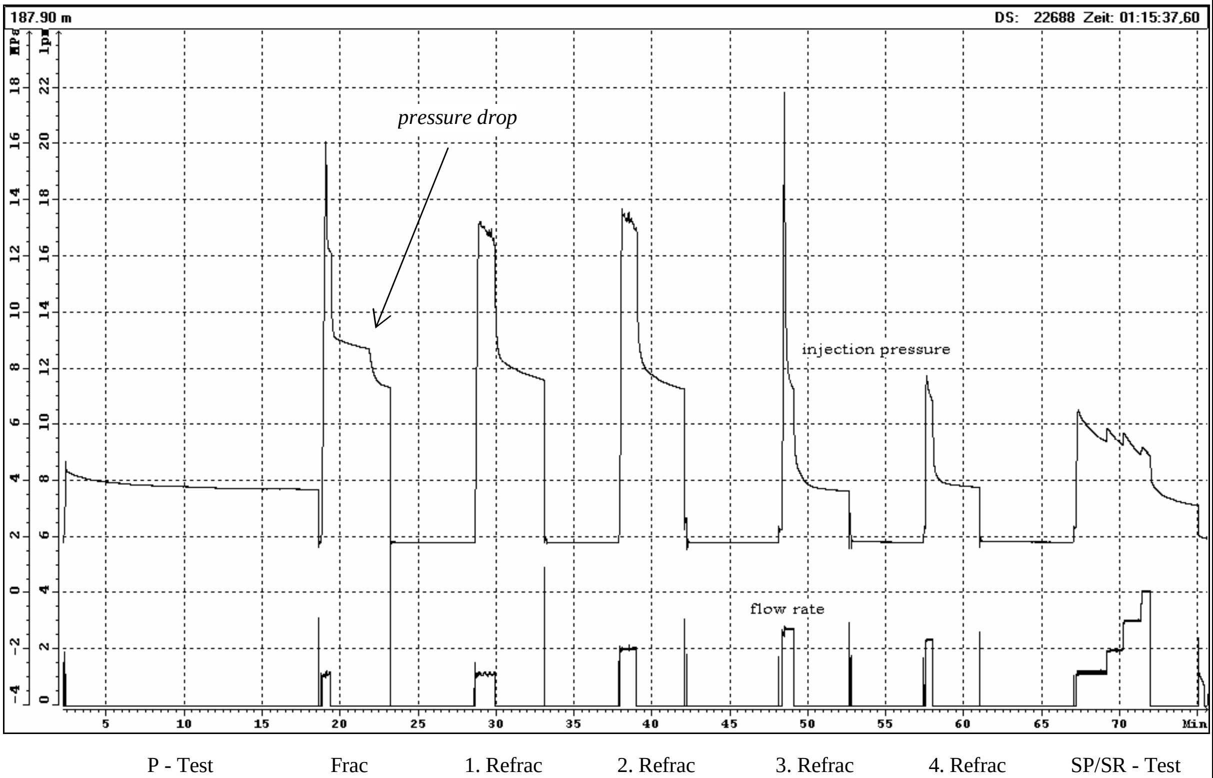


Test at 171.00 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 2 AT 187.90 m MD / 183.46 m TVD

Test at 187.90 m MD: Overview - Plot



<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

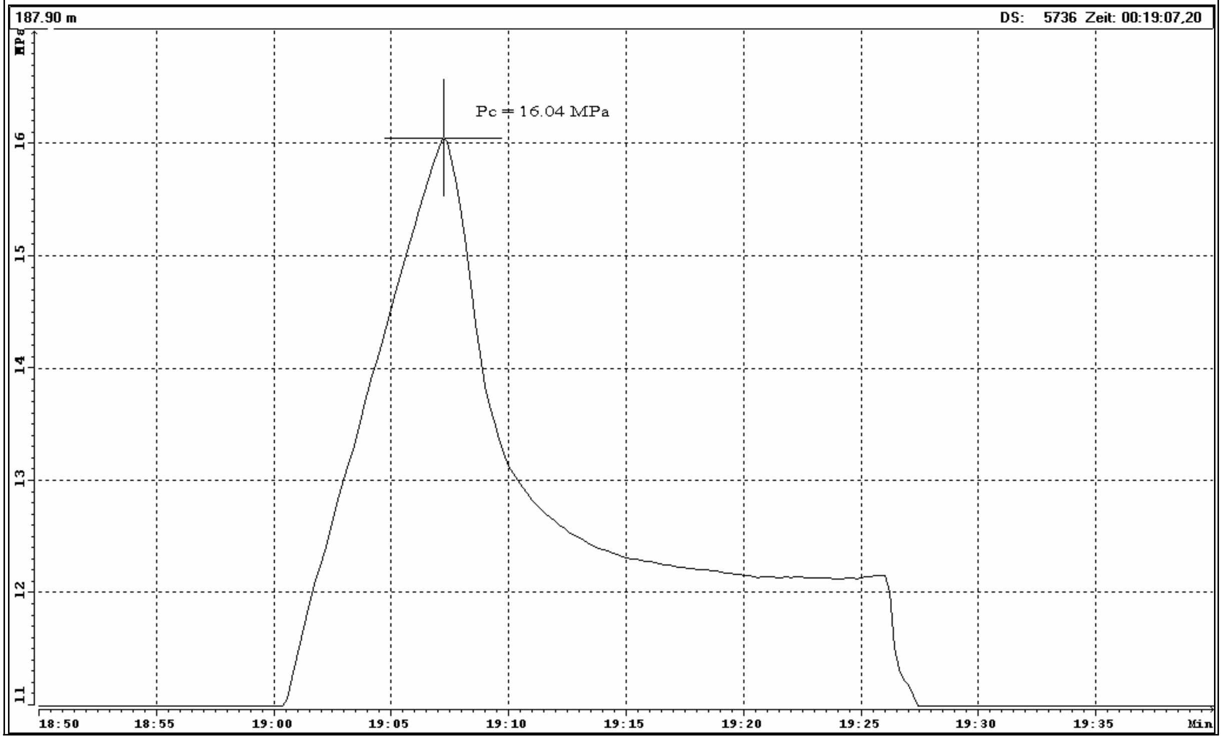
P - Test : pressure decrease: 0.65 MPa in 967 sec.

Frac - cycle	Qi (lpm) = 1.1	Vi (l) = 0.7	Vr (l) = 0.15
1. Refrac - cycle	Qi (lpm) = 1.1	Vi (l) = 1.5	Vr (l) = 0.15
2. Refrac - cycle	Qi (lpm) = 2.1	Vi (l) = 2.2	Vr (l) = 0.15
3. Refrac - cycle	Qi (lpm) = 2.7	Vi (l) = 2.0	Vr (l) = 0.6
4. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 1.2	Vr (l) = 1.0
SP/SR - test	Qi (lpm) = 1.2-4.1	Vi (l) = 10.4	Vr (l) = 2.0

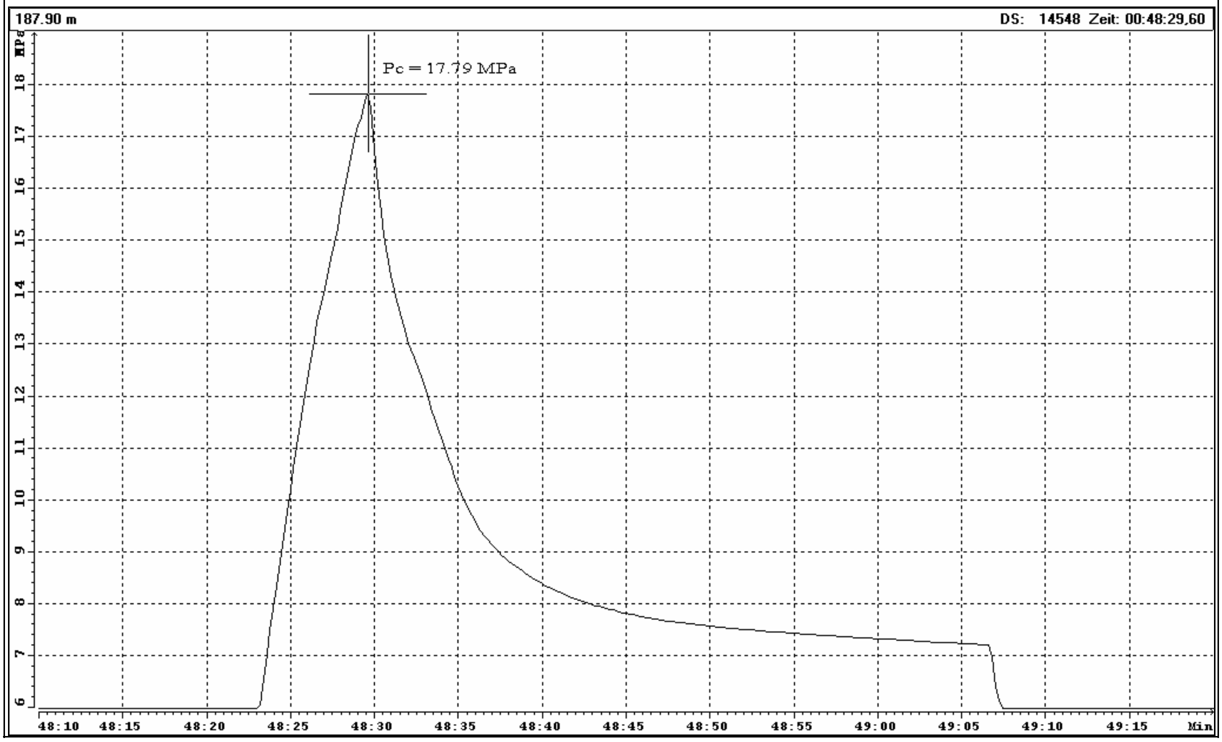
total injected volume (l): 18.0 recovered volume (l): 4.05 or 22.5 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event. At the end of the shut-in phase, a pressure drop was observed. A second distinct breakdown event was observed during the 3. refrac cycle.
- The refrac - pressure was determined from the 1. refrac - cycle. After the 2. breakdown event during the 3. refrac - cycle, the 4. refrac - cycle shows a significant lower fracture re-opening pressure.
- The shut-in phases yield distinct shut-in pressure values, which decreases from about 10.1 MPa during the 1. and 2. refrac - cycle to about 5 MPa after the 2. breakdown event. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

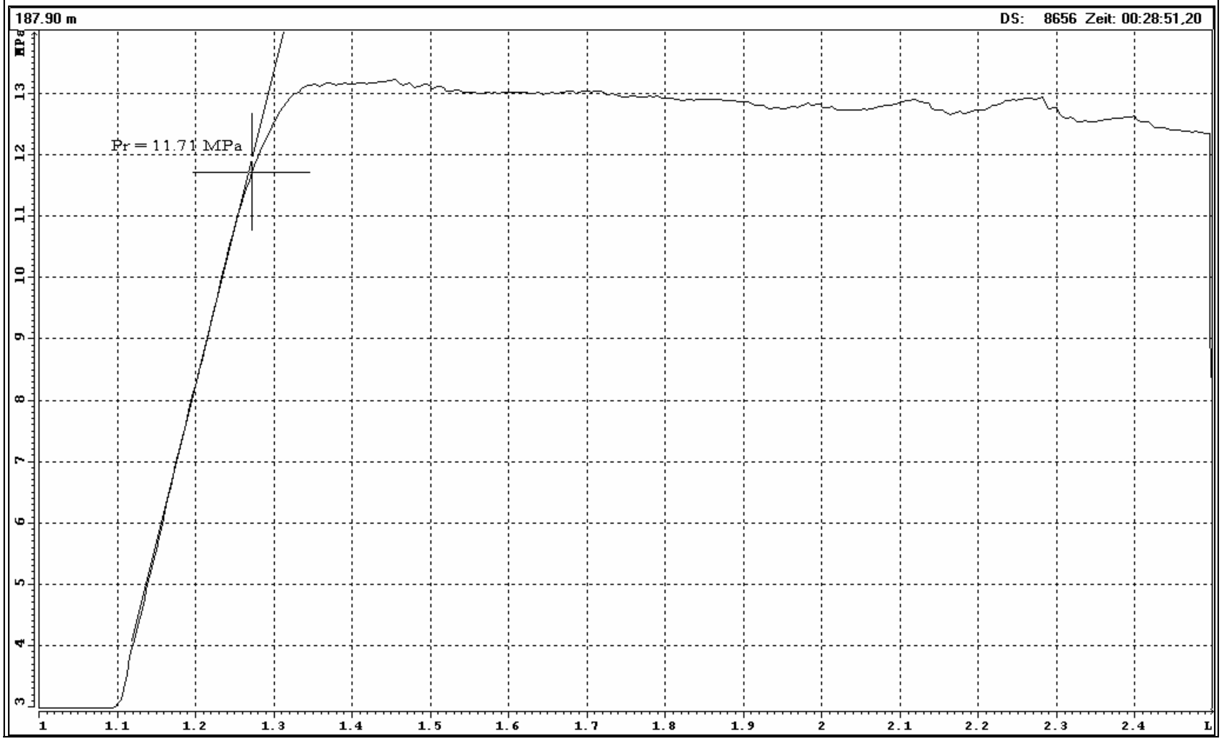
Test at 187.90 m MD: Estimation of first P_c (Frac - Cycle)



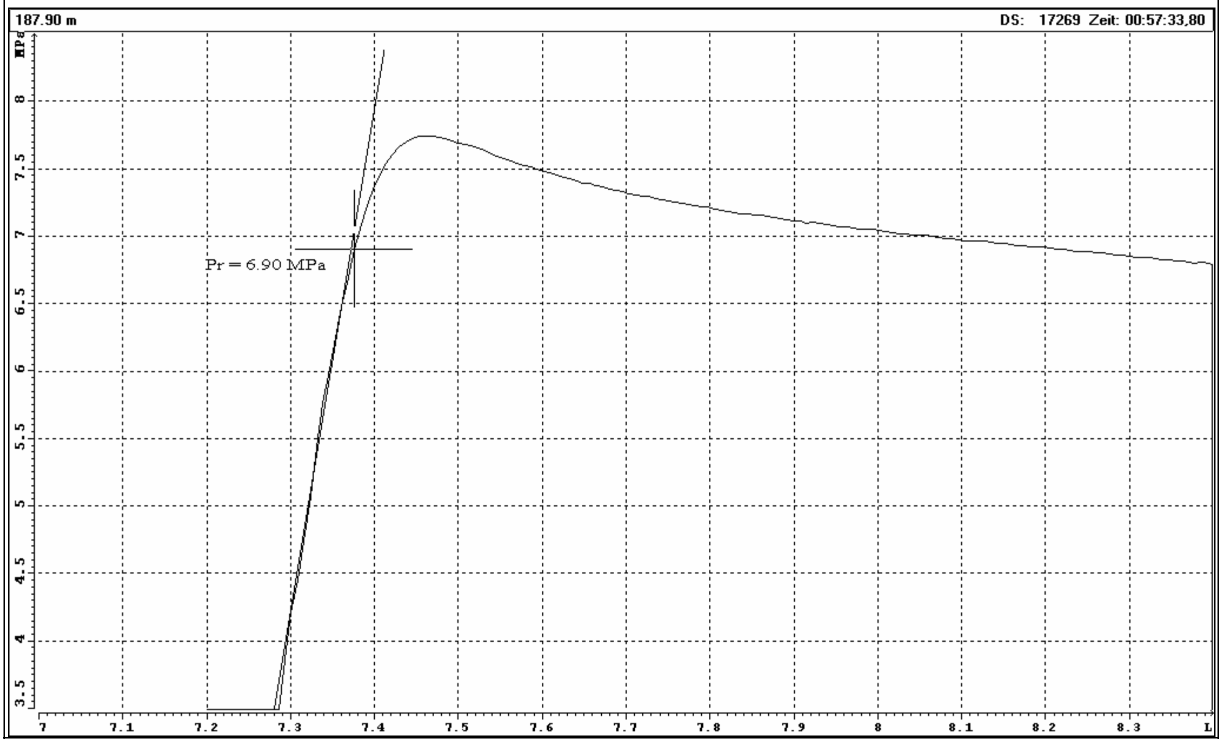
Test at 187.90 m MD: Estimation of second P_c (3. Refrac - Cycle)



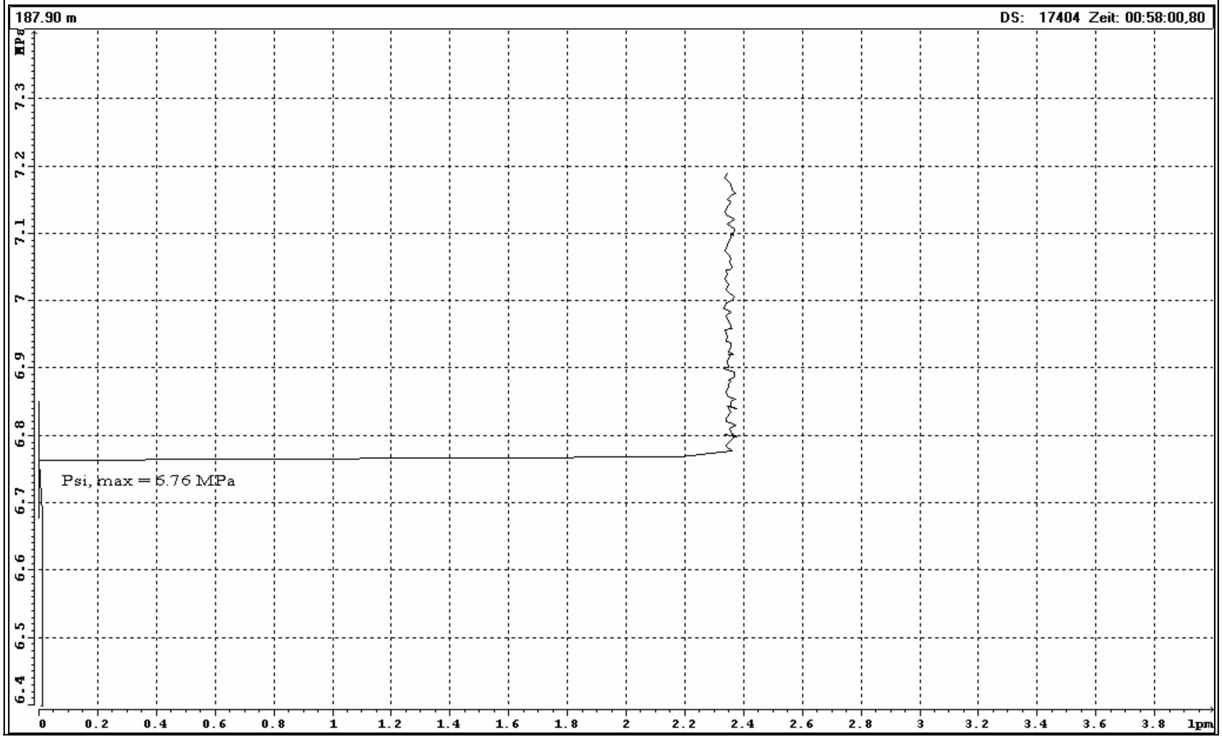
Test at 187.90 m MD: Estimation of P_r (1. Refrac - Cycle)



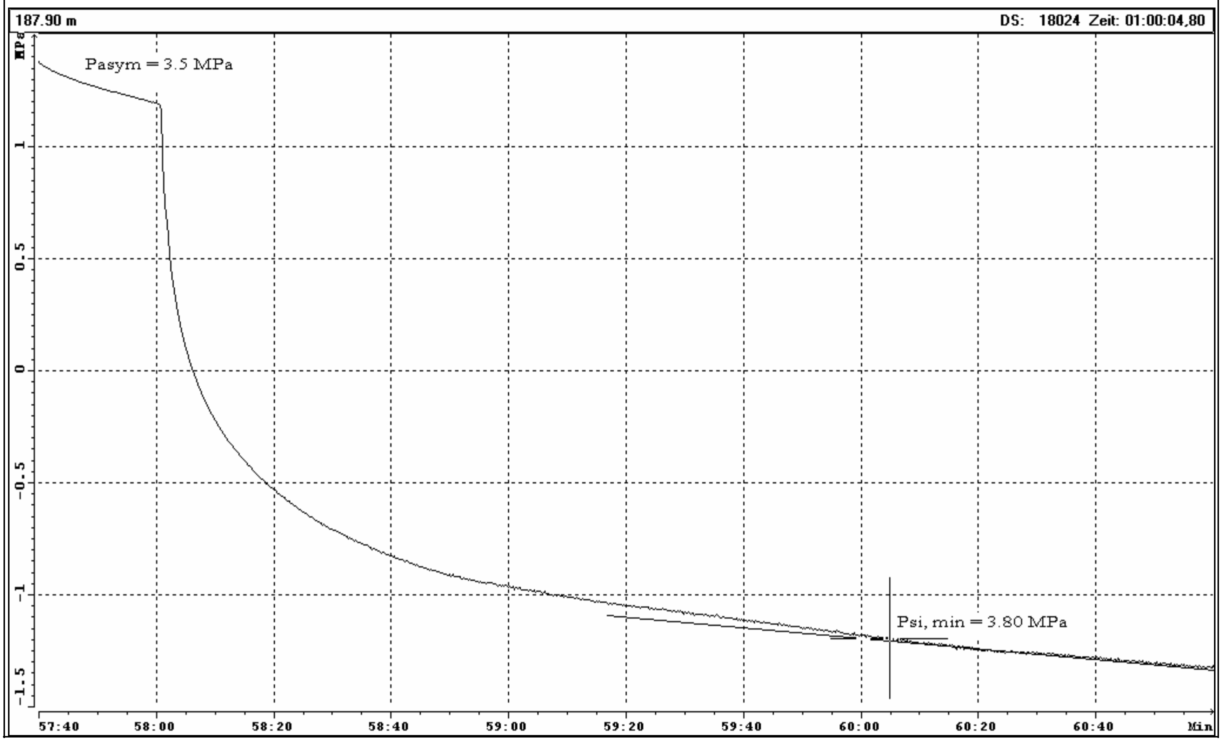
Test at 187.90 m MD: Estimation of P_r (4. Refrac - Cycle)



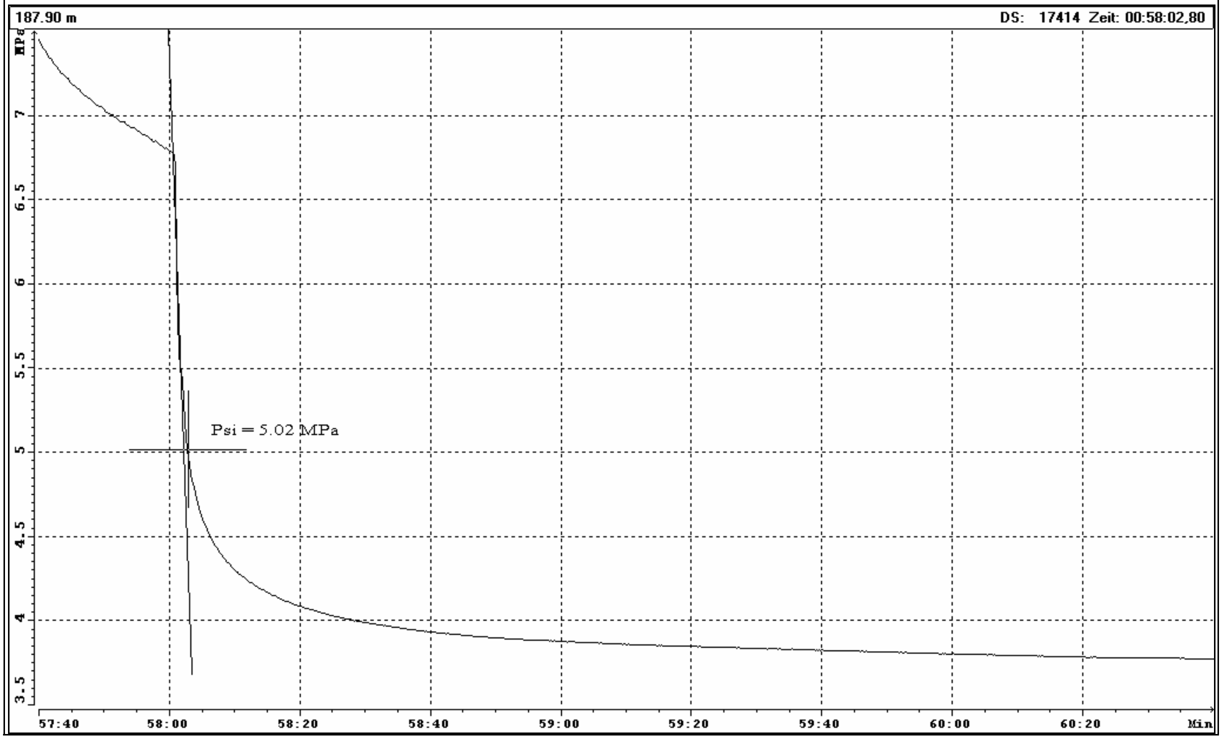
Test at 187.90 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



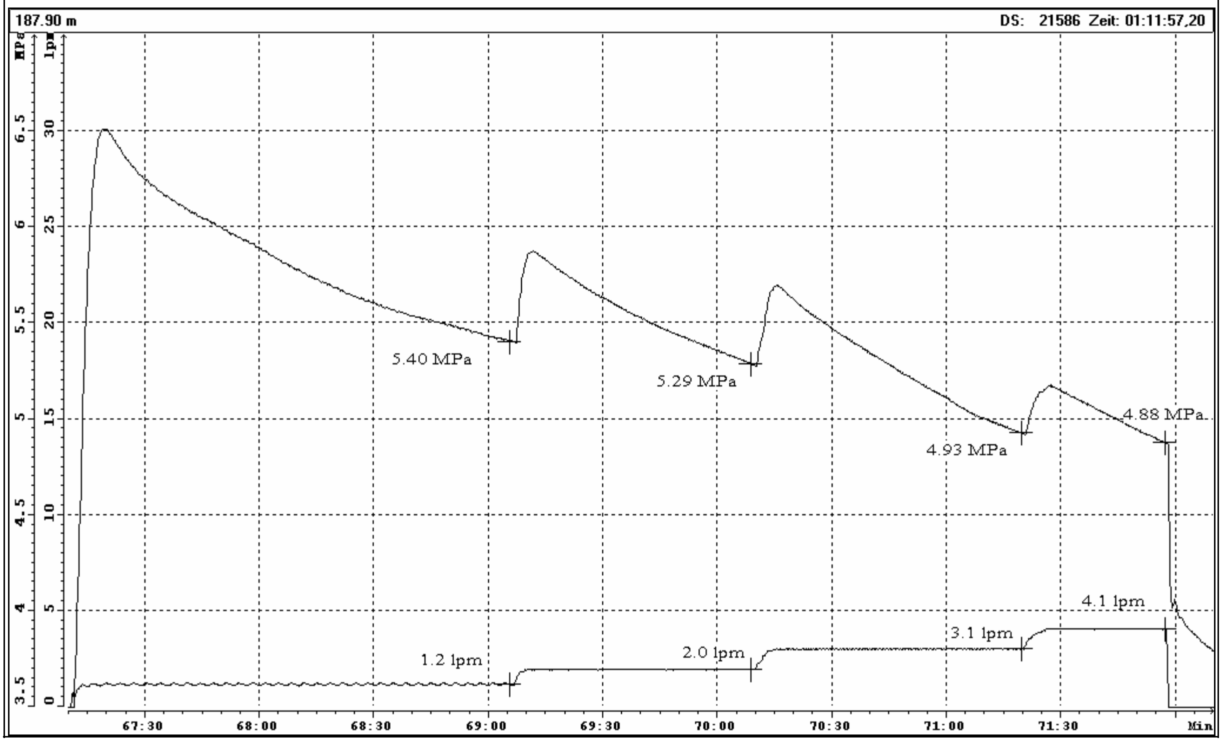
Test at 187.90 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



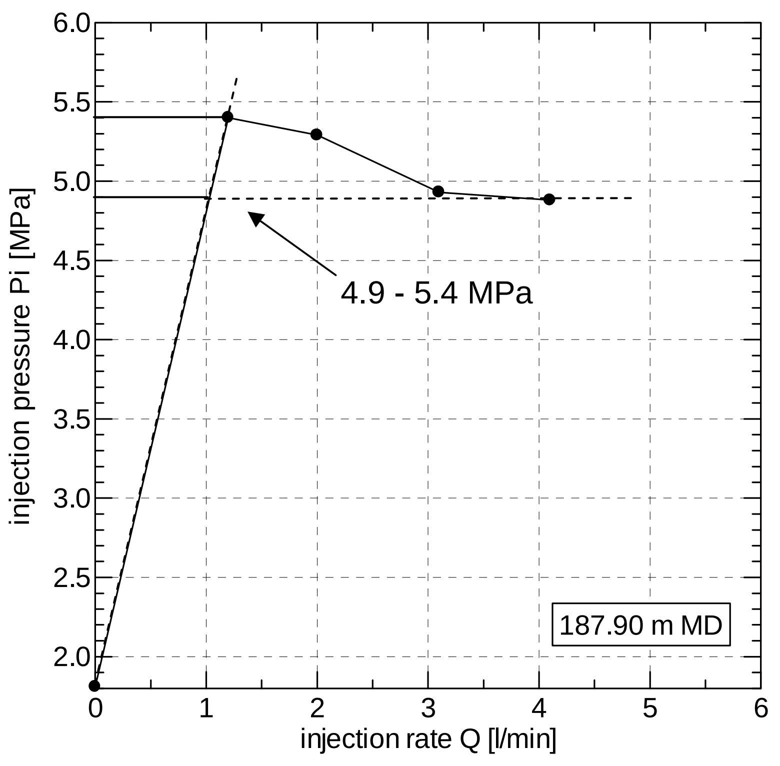
Test at 187.90 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 187.90 m MD: Analysis of Slow - Pump / Step - Rate - Test

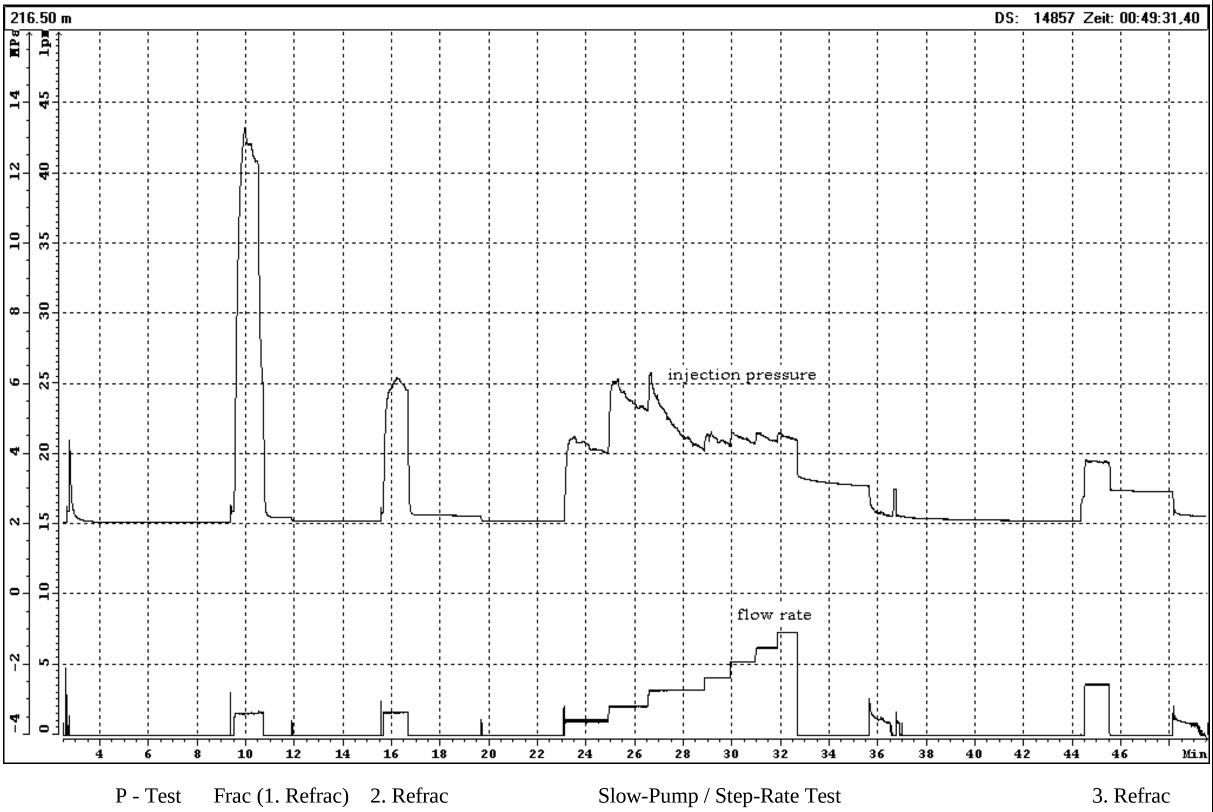


Test at 187.90 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 3 AT 216.50 m MD / 211.13 m TVD

Test at 216.50 m MD: Overview - Plot



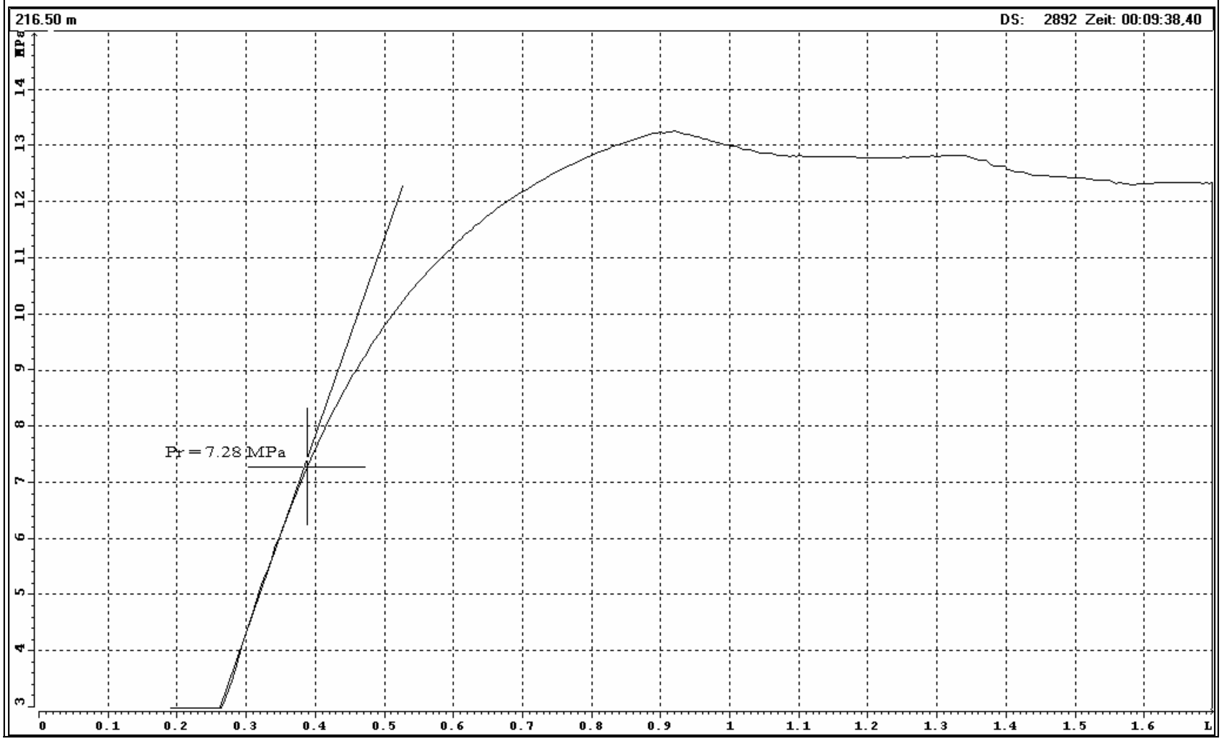
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.70 MPa in 130 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.5	Vi (l) = 2.0	Vr (l) = 0.4
2. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.7	Vr (l) = 0.6
SP/SR - test	Qi (lpm) = 1.0-7.3	Vi (l) = 34.0	Vr (l) = 5.0
3. Refrac - cycle	Qi (lpm) = 3.6	Vi (l) = 3.8	Vr (l) = 4.0

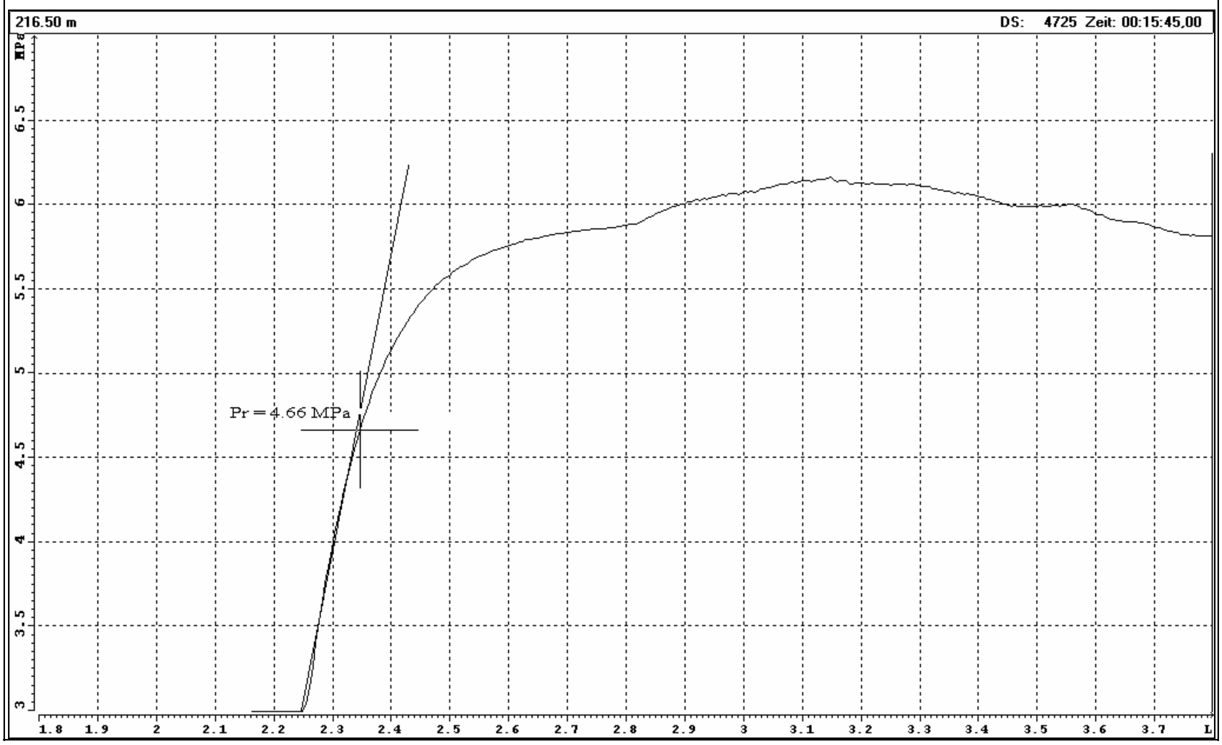
total injected volume (l): 41.5 recovered volume (l): 10.0 or 24.1 %

- Initial test type: HTPF-h
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- Due to the high conductivity of the stimulated fracture, the 1. and 2. refrac - cycle do not show distinct shut-in pressure values. In addition, a significant decrease of the injection pressure was observed between the two cycles. Therefore, the shut-in pressure was only estimated from the slow-pump / step-rate test data.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 7.3 MPa, followed by a pressure increase up to 13.2 MPa. In comparison to the first cycle, the 2. refrac - cycle yield a much lower fracture re-opening pressure.

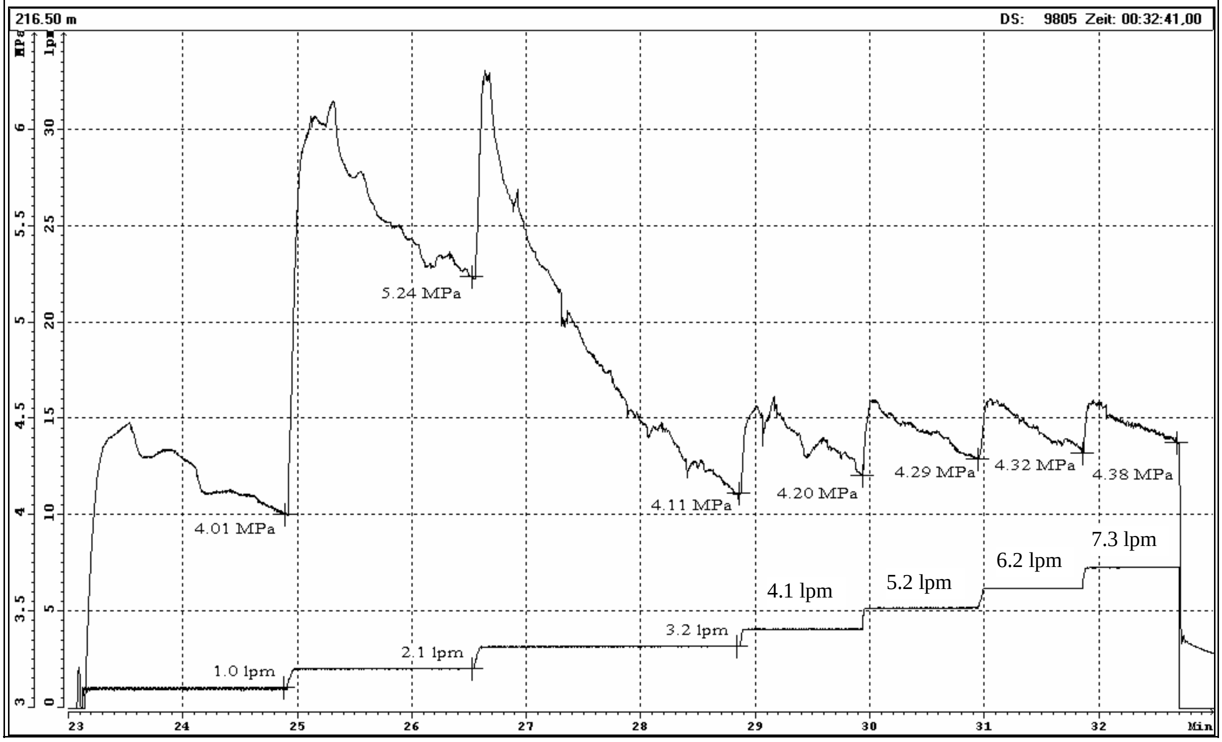
Test at 216.50 m MD: Estimation of P_r (1. Refrac - Cycle)



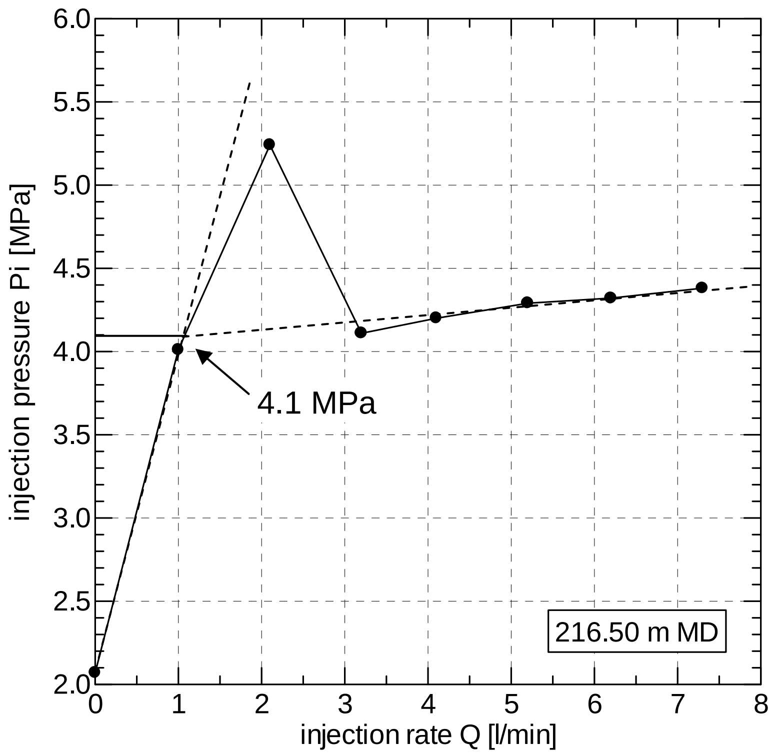
Test at 216.50 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



Test at 216.50 m MD: Analysis of Slow - Pump / Step - Rate - Test

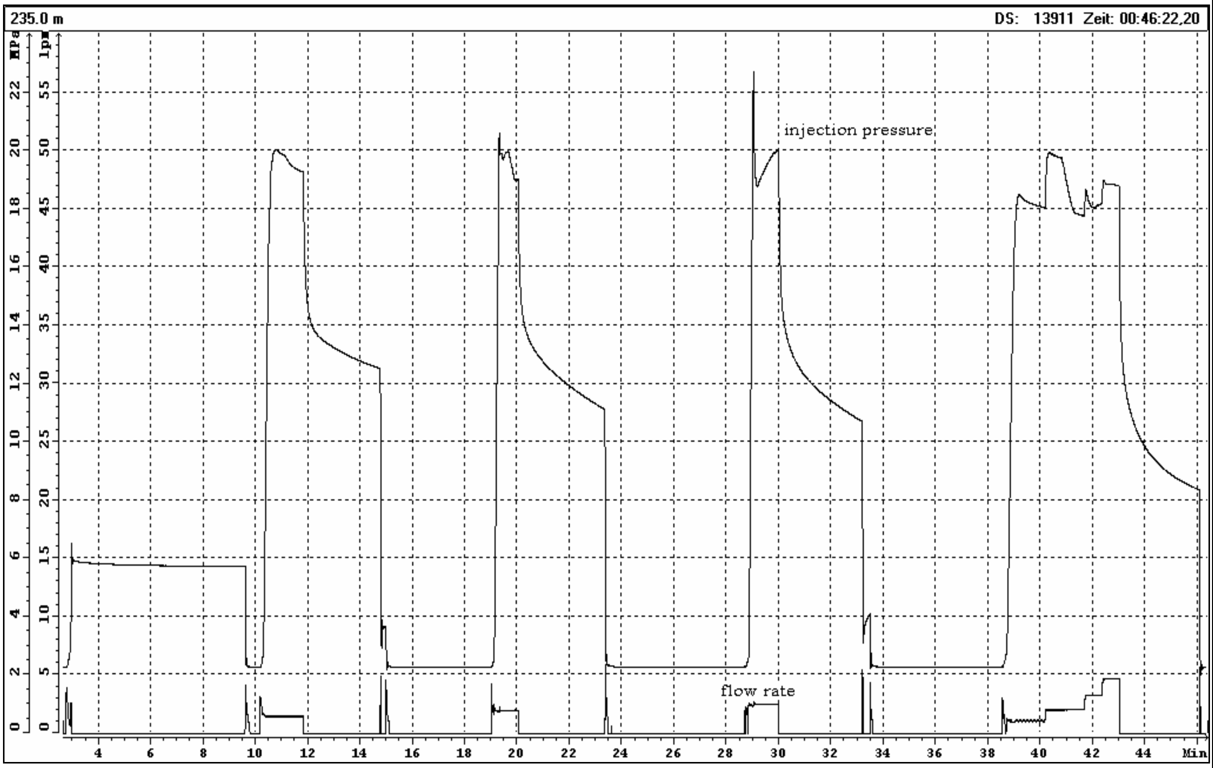


Test at 216.50 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 12 AT 235.0 m MD / 228.97 m TVD

Test at 235.0 m MD : Overview - Plot



P - Test Frac (1. Refrac) 2. Refrac 3. Refrac Slow-Pump/Step-Rate Test

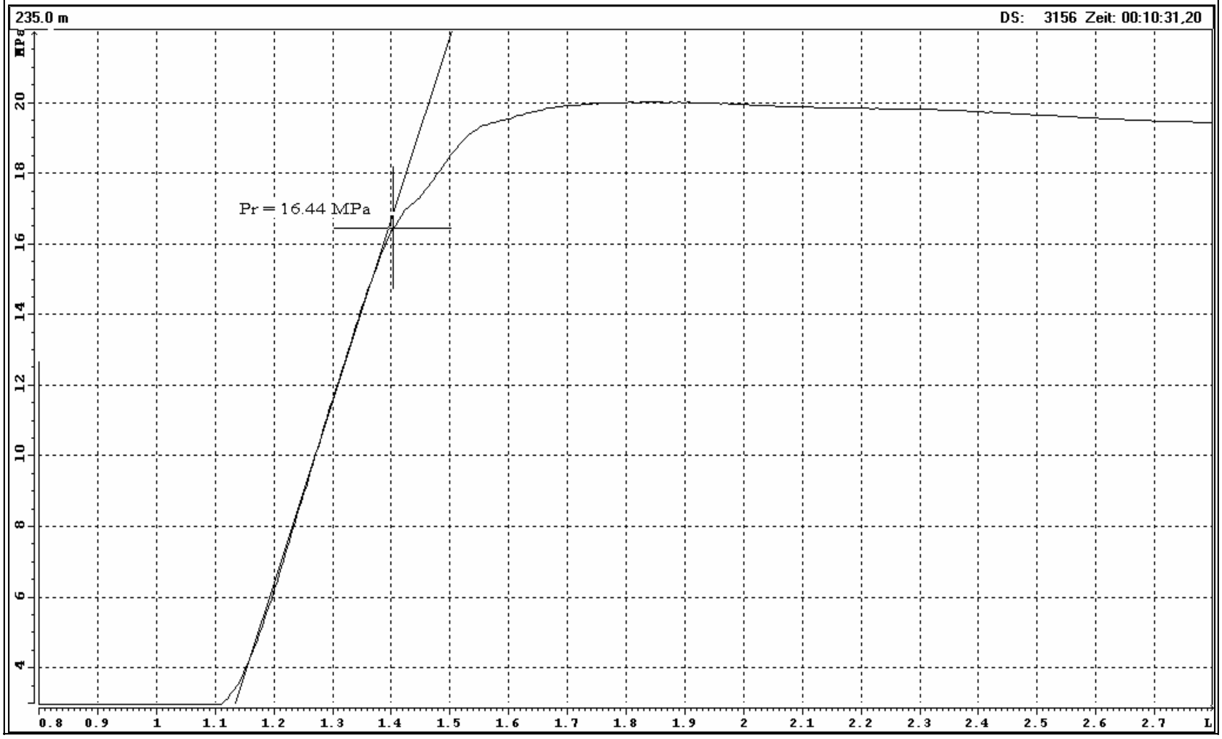
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.19 MPa in 391 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.5	Vi (l) = 2.6	Vr (l) = 0.5
2. Refrac - cycle	Qi (lpm) = 2.0	Vi (l) = 2.1	Vr (l) = 0.5
3. Refrac - cycle	Qi (lpm) = 2.5	Vi (l) = 3.1	Vr (l) = 0.5
SP/SR - test	Qi (lpm) = 1.1-4.7	Vi (l) = 10.2	Vr (l) = 0.25

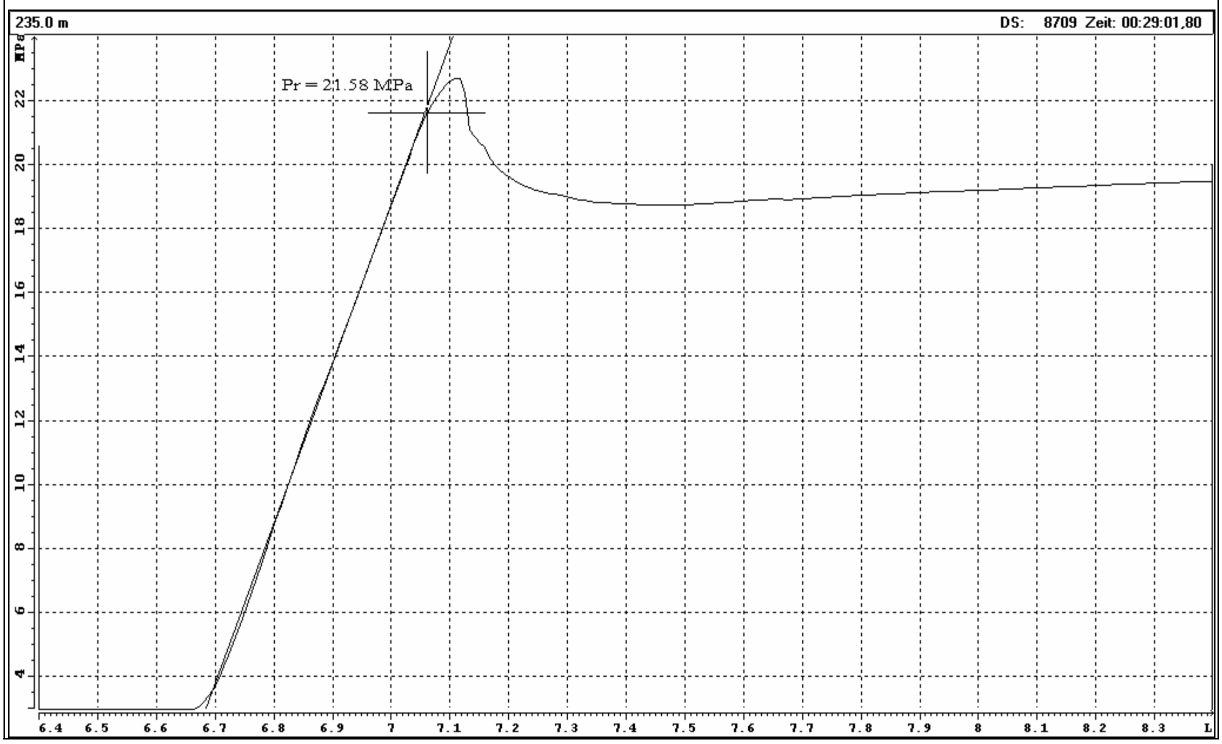
total injected volume (l): 18.0 recovered volume (l): 1.75 or 9.7 %

- Initial test type: HF
- Although the test section contains no visible fracture, the frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. and 3. refrac - cycle, since the later cycle with higher injection flow-rate yield a higher fracture re-opening pressure with a rather distinct fracture opening phase.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

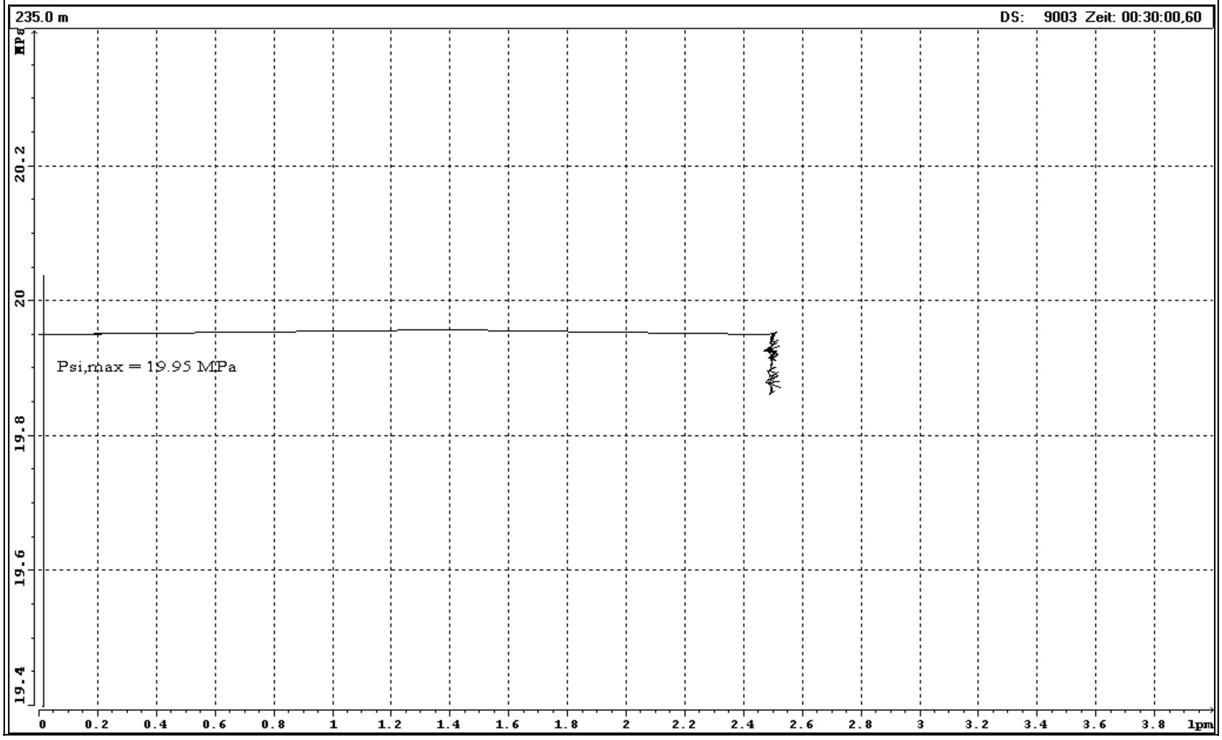
Test at 235.0 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



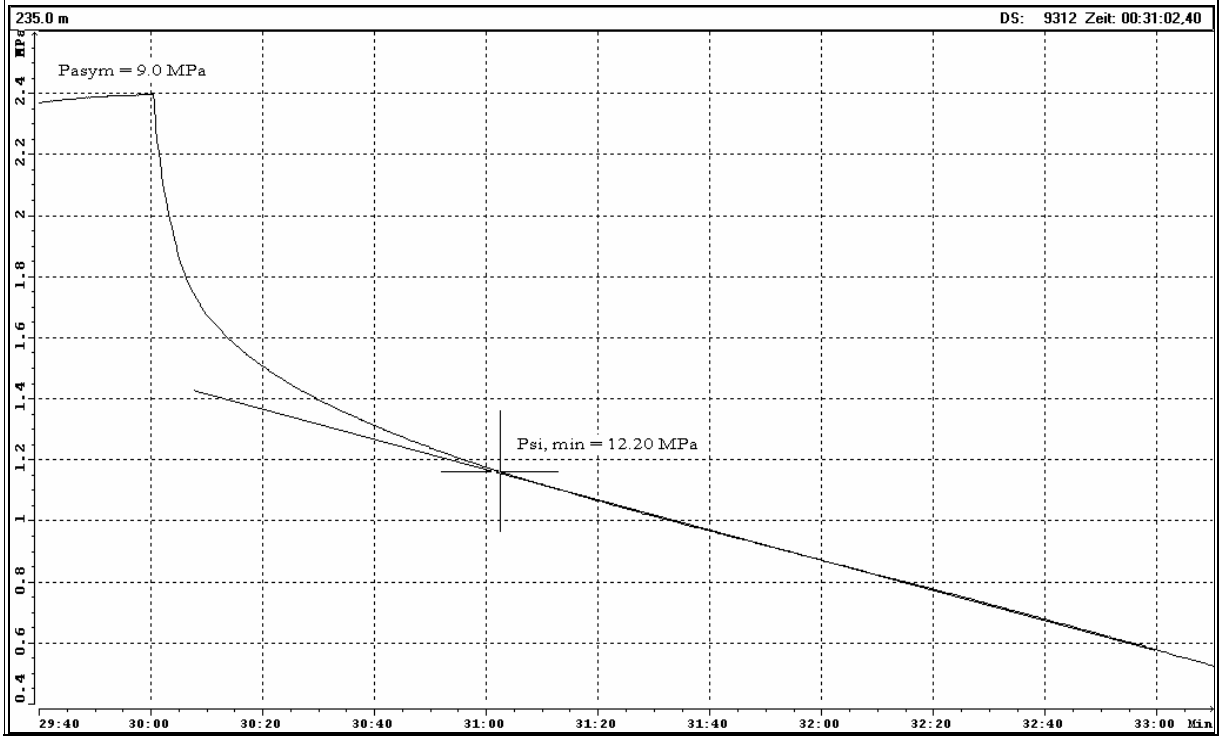
Test at 235.0 m MD: Estimation of P_r (3. Refrac - Cycle)



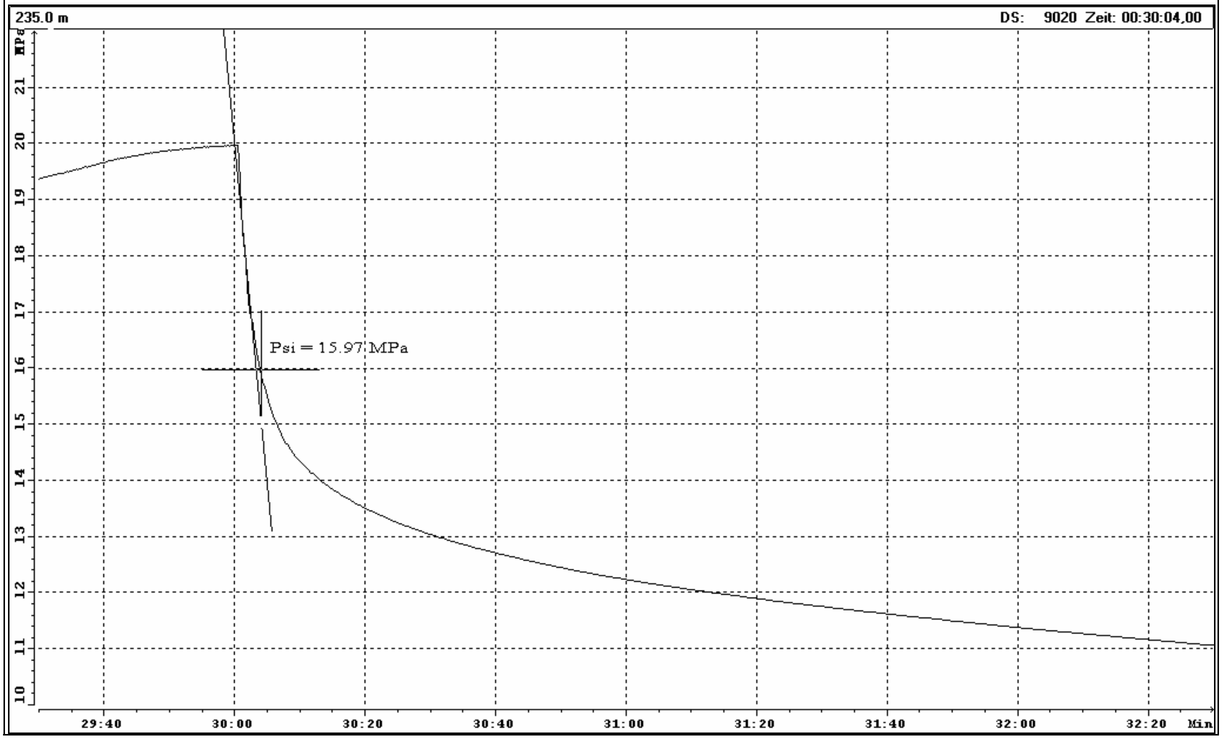
Test at 235.0 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



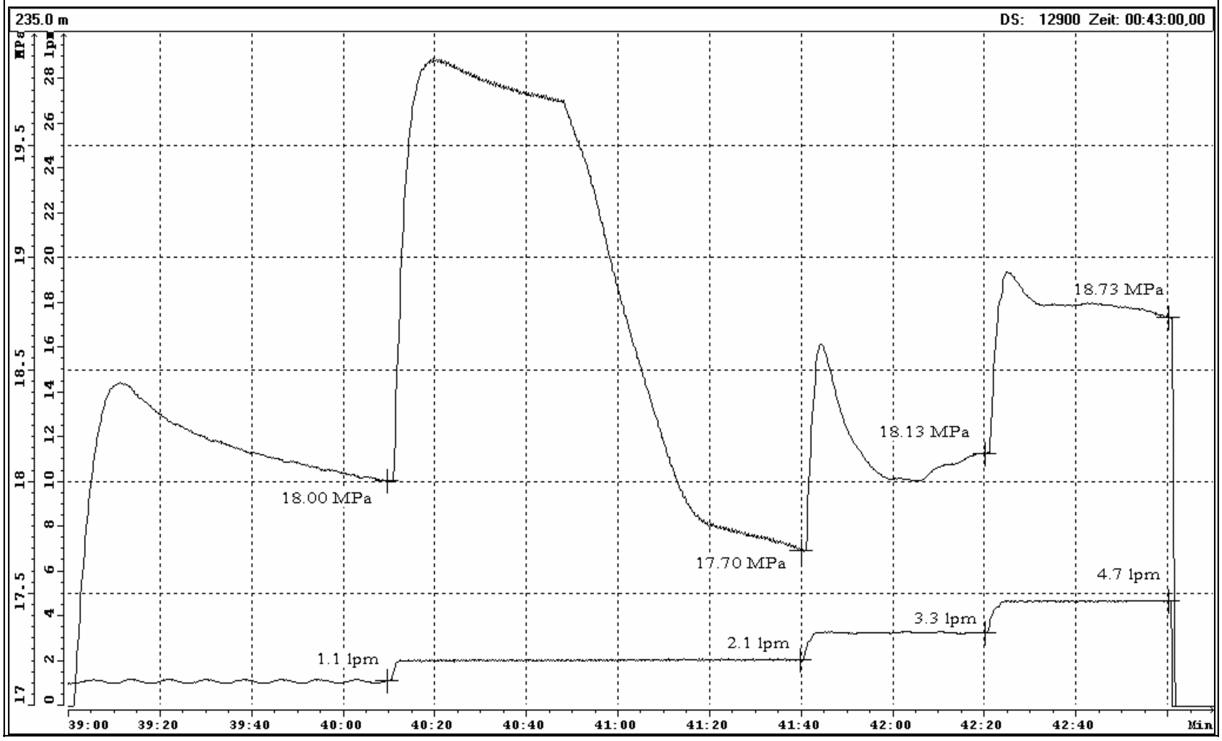
Test at 235.0 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



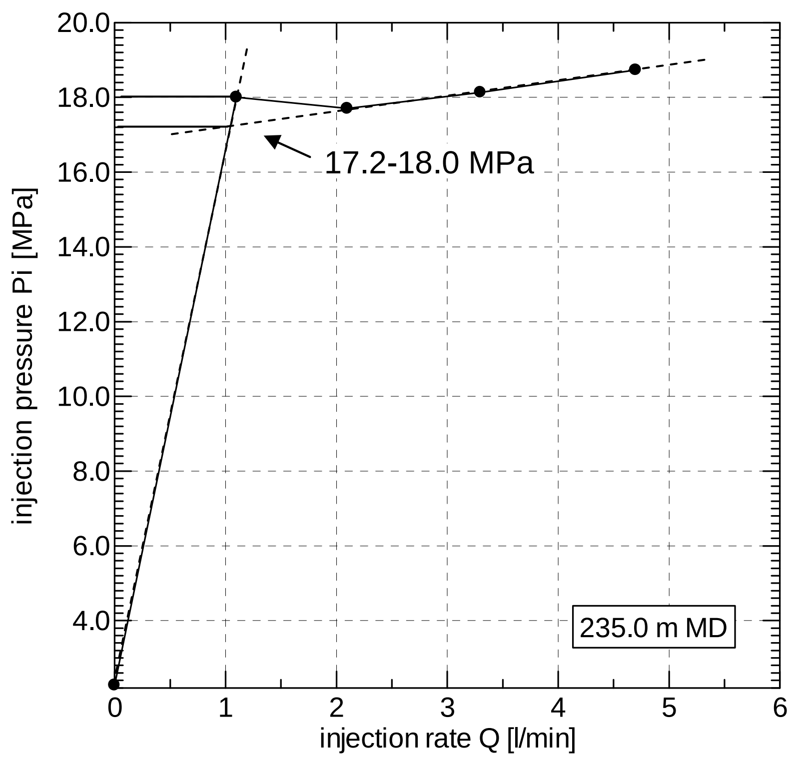
Test at 235.0 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 235.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

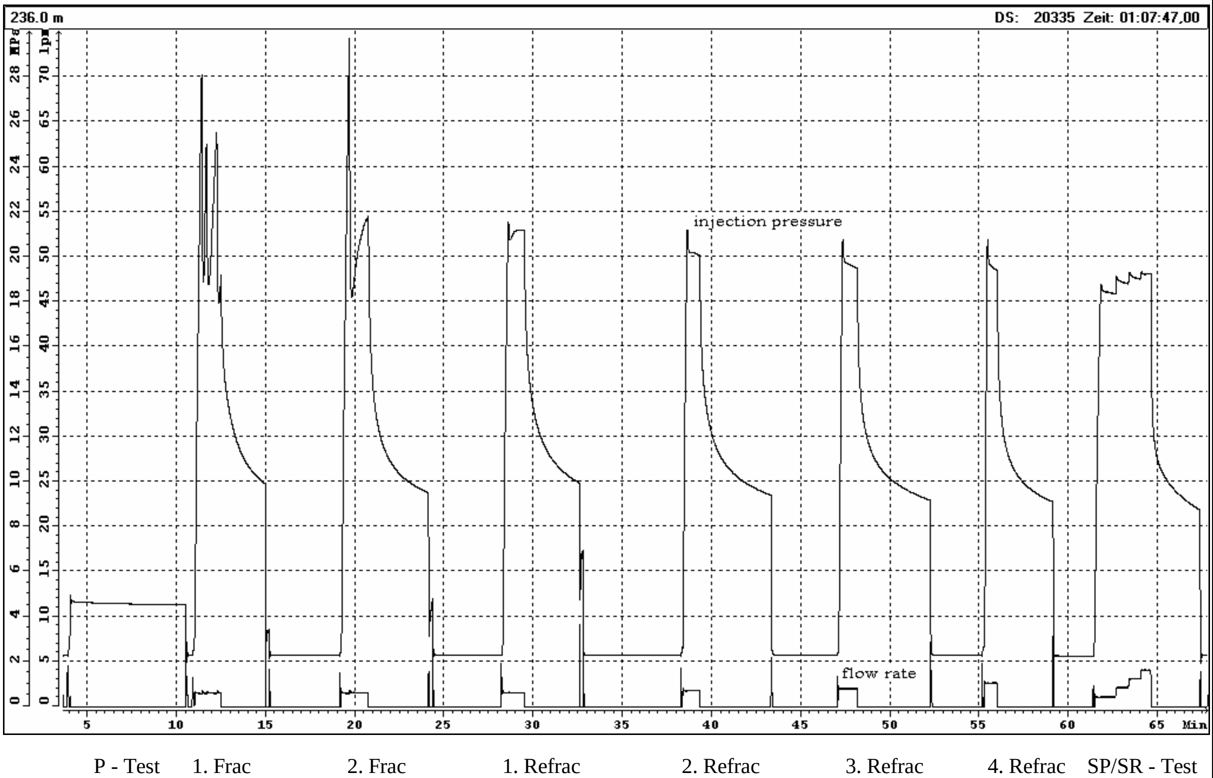


Test at 235.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 11 AT 236.0 m MD / 229.94 m TVD

Test at 236.0 m MD: Overview - Plot



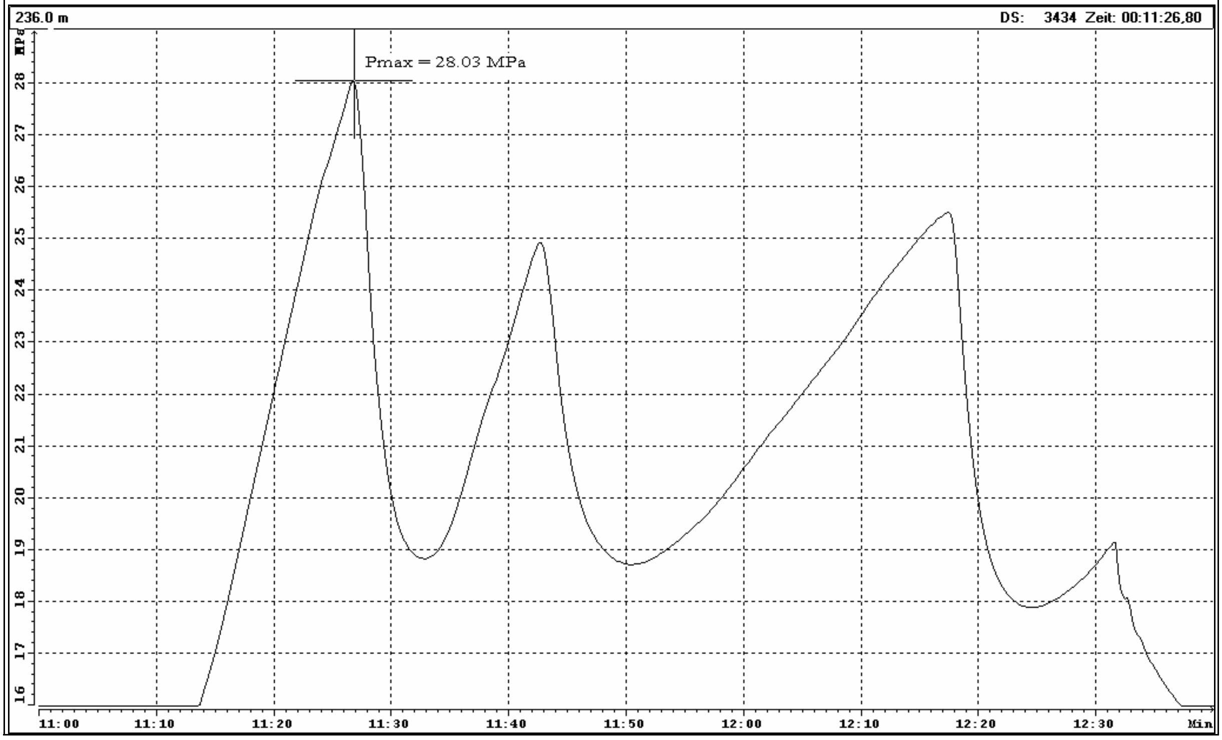
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.15 MPa in 382 sec.		
1. Frac - cycle	Qi (lpm) = 1.5	Vi (l) = 2.5	Vr (l) = 0.4
2. Frac - cycle	Qi (lpm) = 1.5	Vi (l) = 2.6	Vr (l) = 0.7
1. Refrac - cycle	Qi (lpm) = 1.5	Vi (l) = 2.1	Vr (l) = 0.5
2. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 1.9	Vr (l) = 0.5
3. Refrac - cycle	Qi (lpm) = 2.0	Vi (l) = 2.3	Vr (l) = 0.5
4. Refrac - cycle	Qi (lpm) = 2.7	Vi (l) = 2.0	Vr (l) = 0.5
SP/SR - test	Qi (lpm) = 1.1-4.1	Vi (l) = 7.3	Vr (l) = 0.6

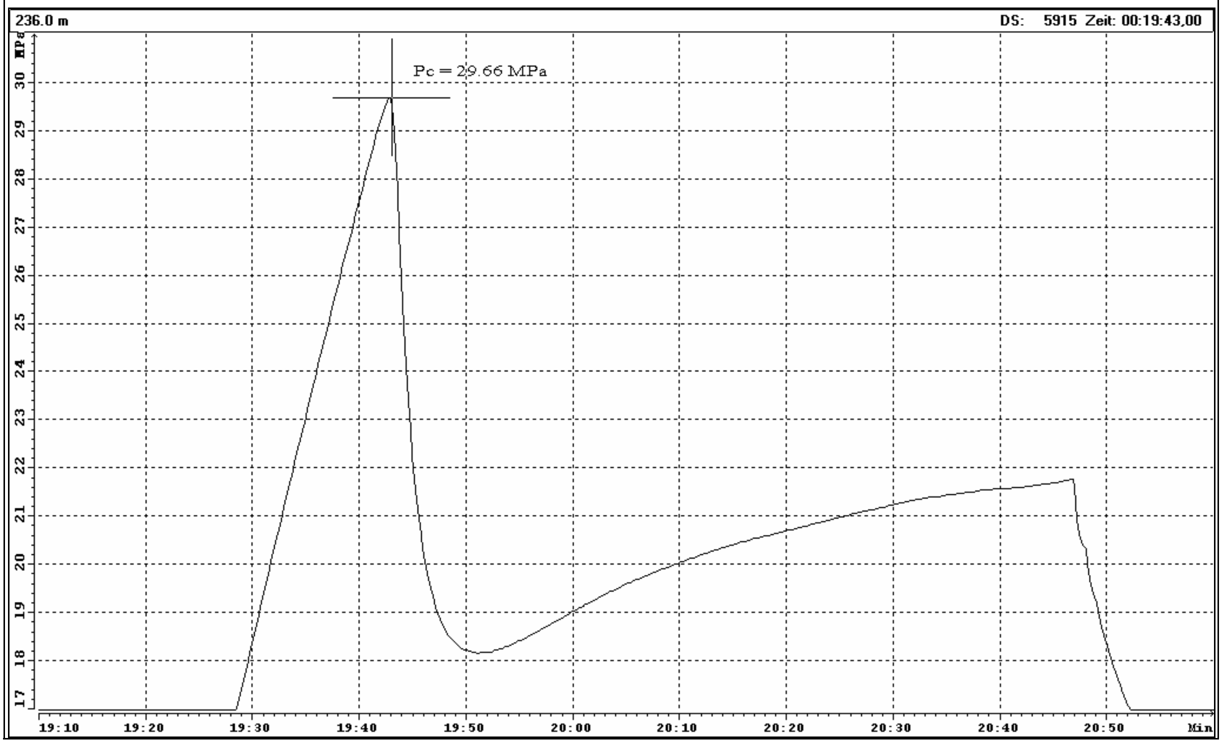
total injected volume (l): 20.7 recovered volume (l): 3.7 or 17.9 %

- Initial test type: HF
- The 1. frac - cycle is characterized by the initiation of a fracture. However, the injection pressure shows some variations (sawtooth shape). A distinct breakdown event at the maximum pressure was observed during the 2. frac - cycle.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield nearly identical fracture re-opening pressure values.
- The shut-in phases yield consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

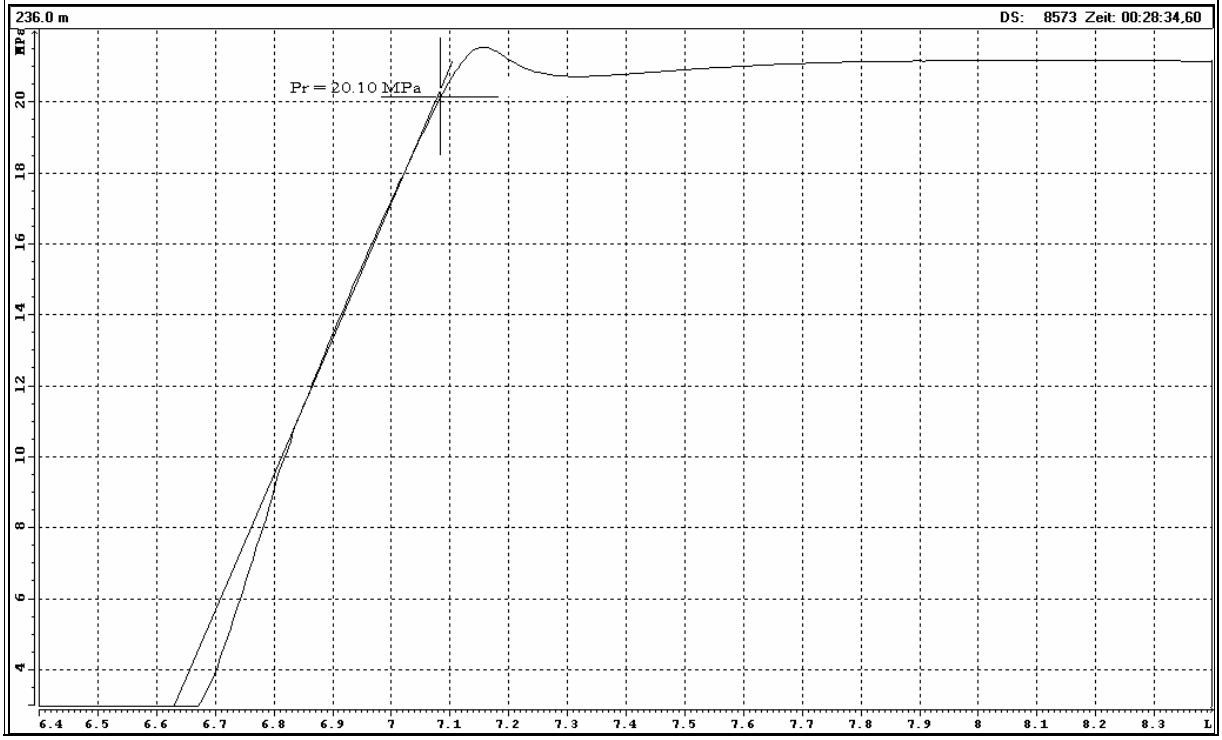
Test at 236.0 m MD: Estimation of P_c (1. Frac - Cycle)



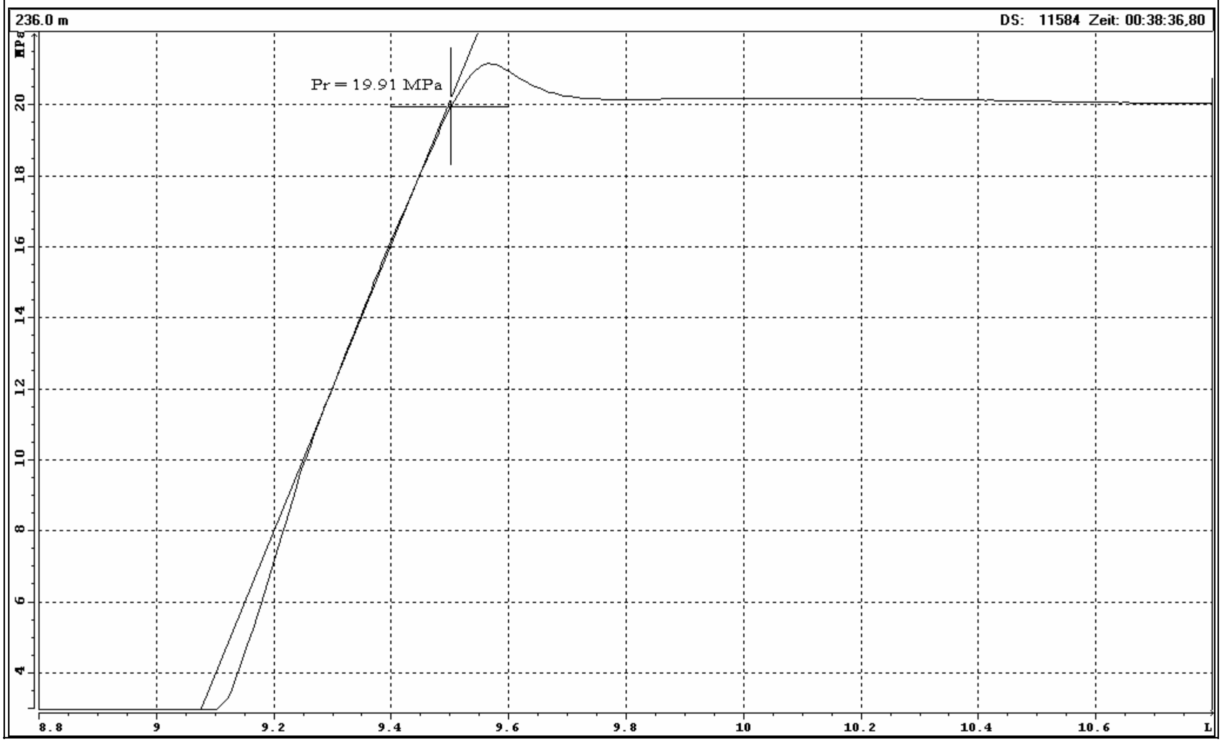
Test at 236.0 m MD: Estimation of P_c (2. Frac - Cycle)



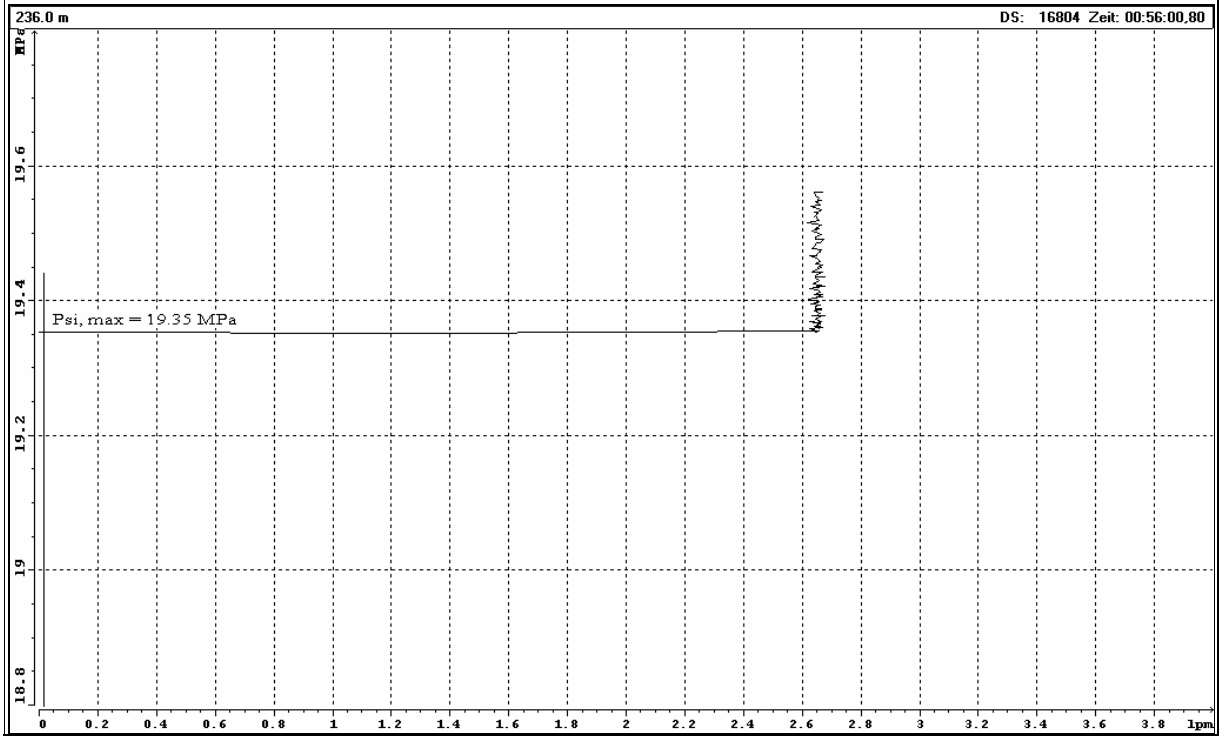
Test at 236.0 m MD: Estimation of P_r (1. Refrac - Cycle)



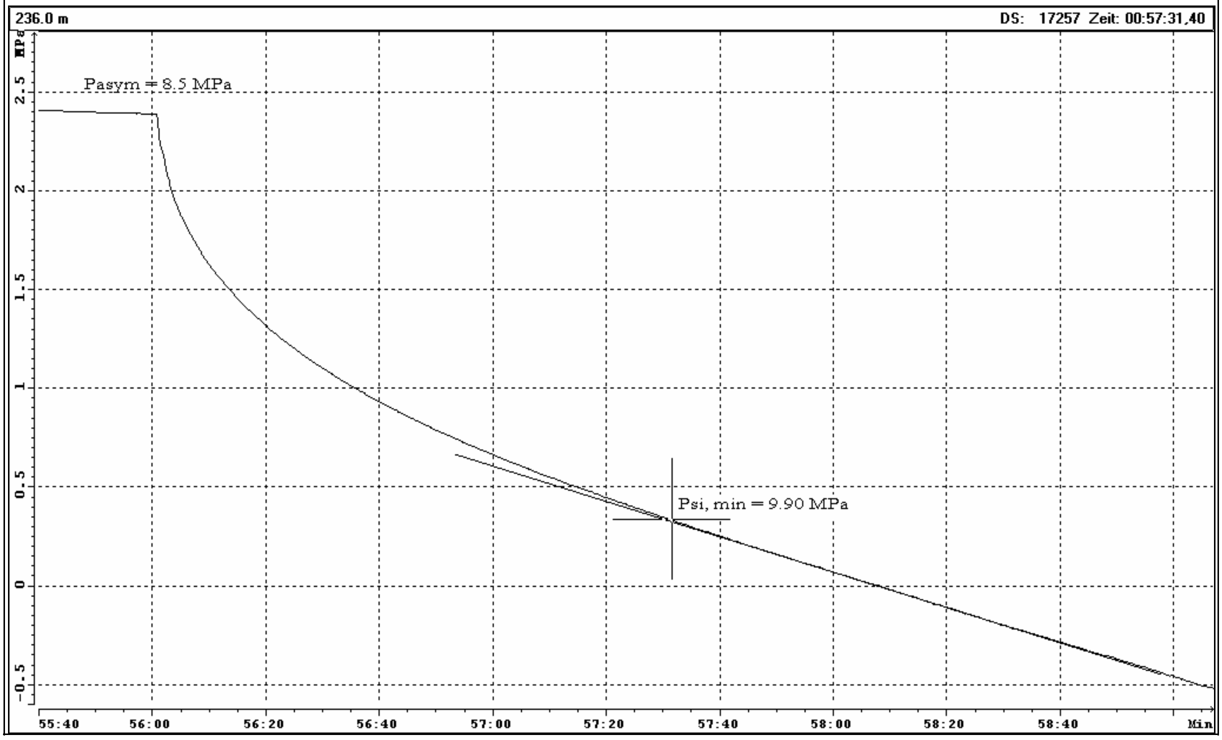
Test at 236.0 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



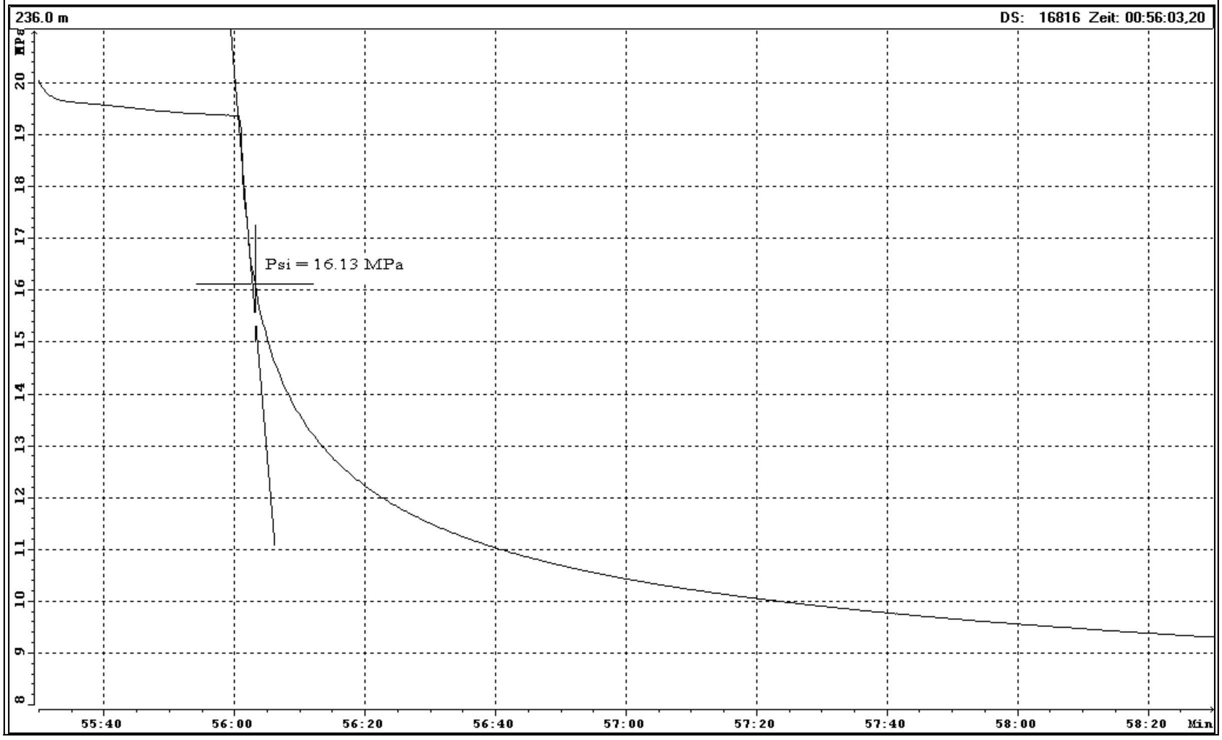
Test at 236.0 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



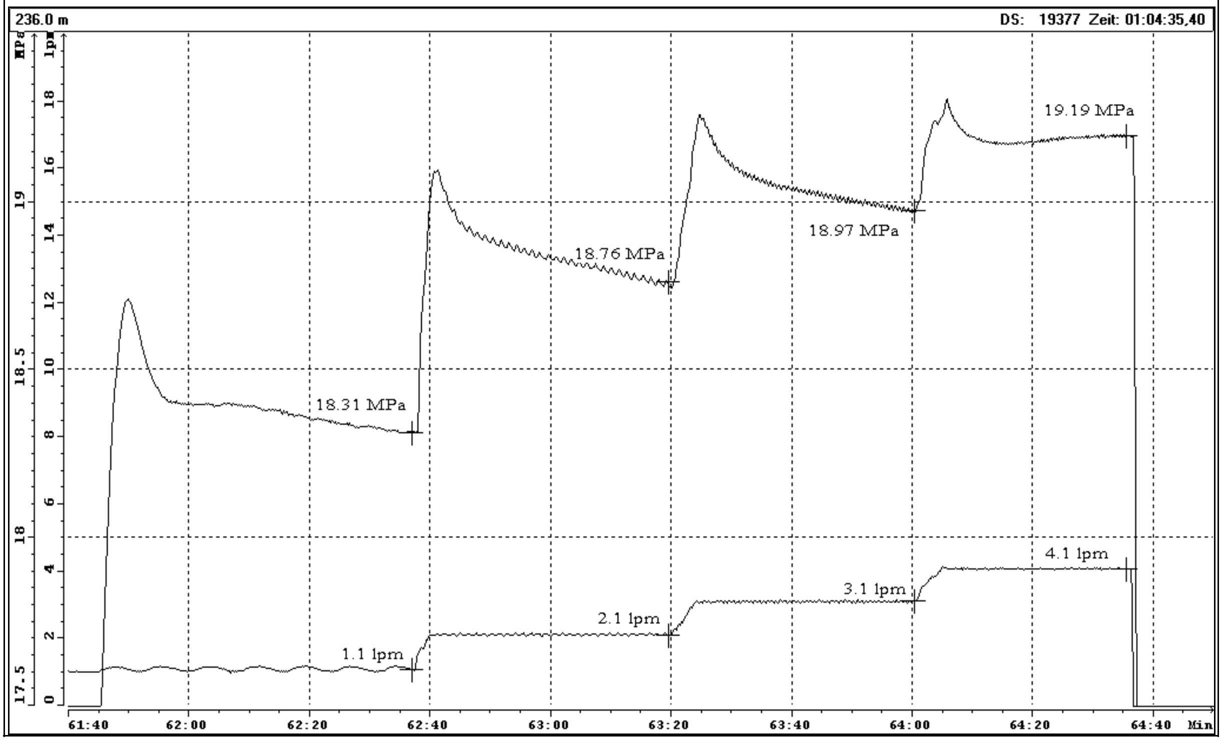
Test at 236.0 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



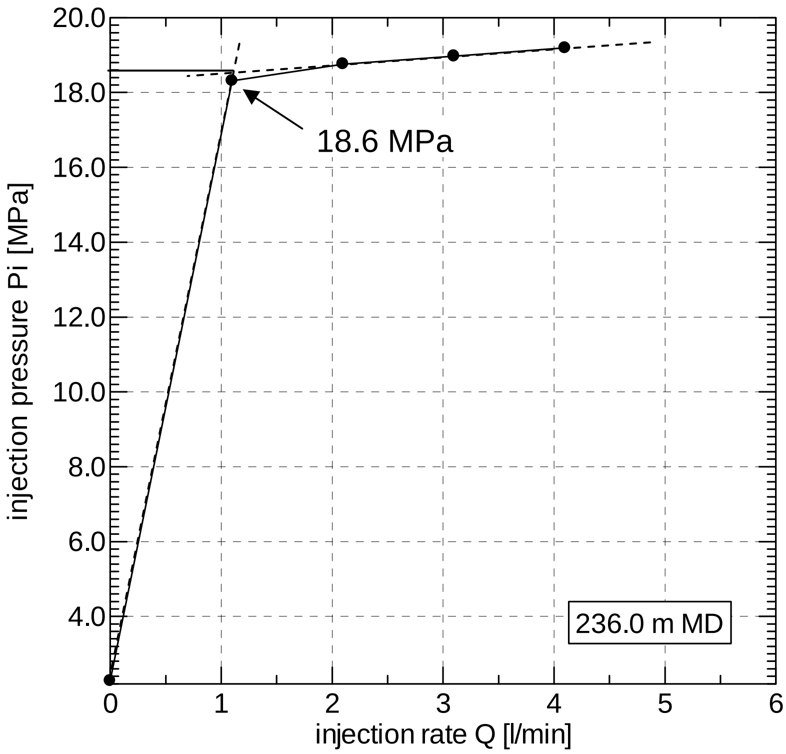
Test at 236.0 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 236.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

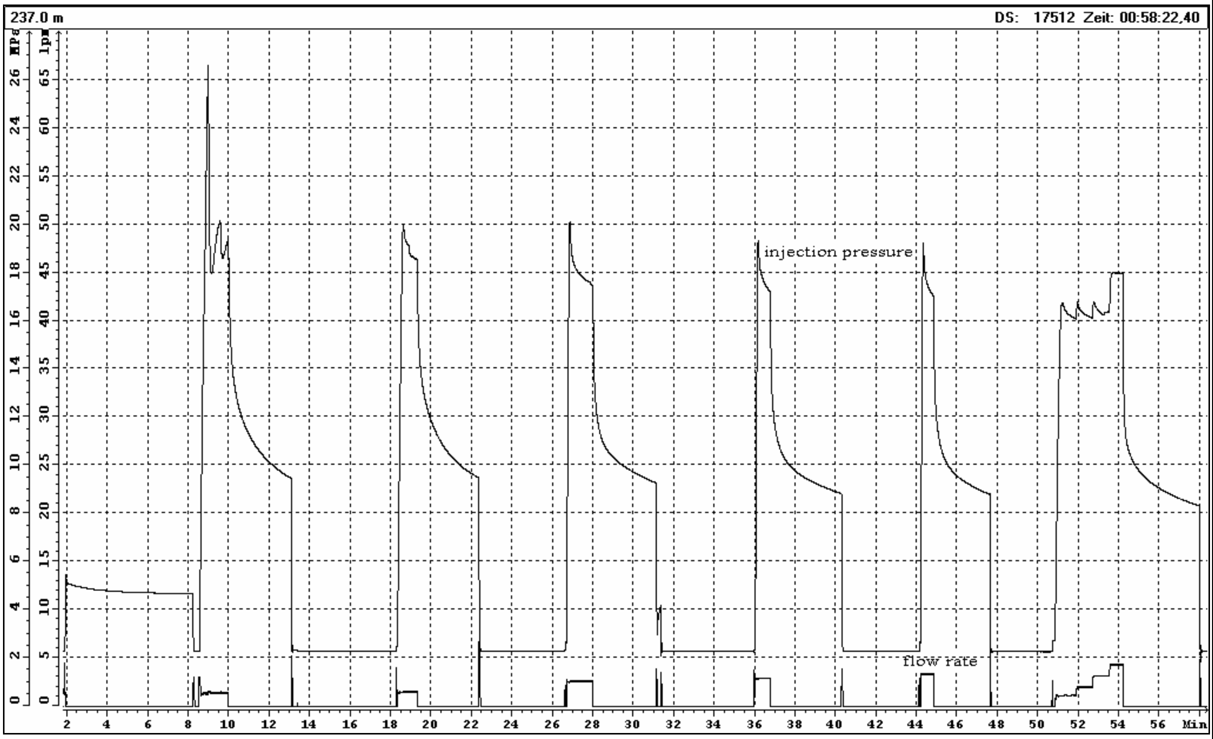


Test at 236.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 10 AT 237.0 m MD / 230.90 m TVD

Test at 237.0 m MD: Overview - Plot



P - Test Frac 1. Refrac 2. Refrac 3. Refrac 4. Refrac SP/SR - Test

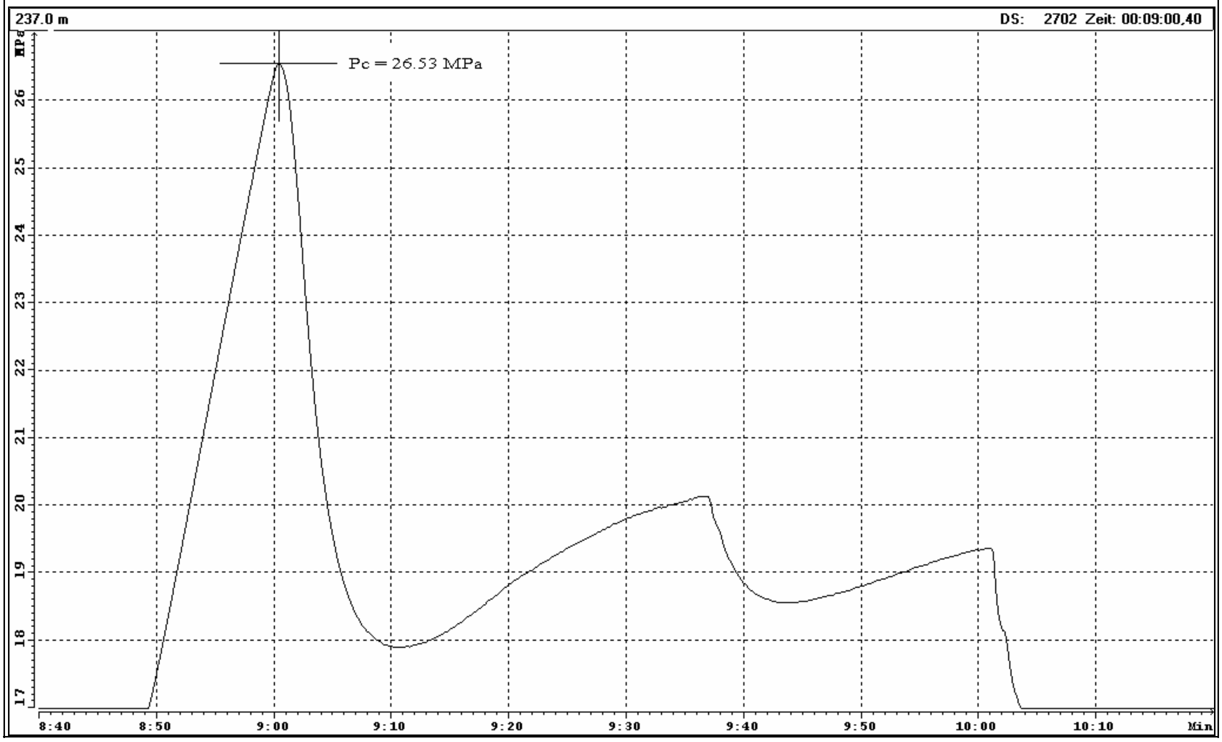
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.42 MPa in 370 sec.		
Frac - cycle	Qi (lpm) = 1.5	Vi (l) = 2.1	Vr (l) = 0.25
1. Refrac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.6	Vr (l) = 0.25
2. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 3.5	Vr (l) = 0.25
3. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 2.3	Vr (l) = 0.25
4. Refrac - cycle	Qi (lpm) = 3.4	Vi (l) = 2.2	Vr (l) = 0.20
SP/SR - test	Qi (lpm) = 1.1-4.3	Vi (l) = 8.3	Vr (l) = 0.15

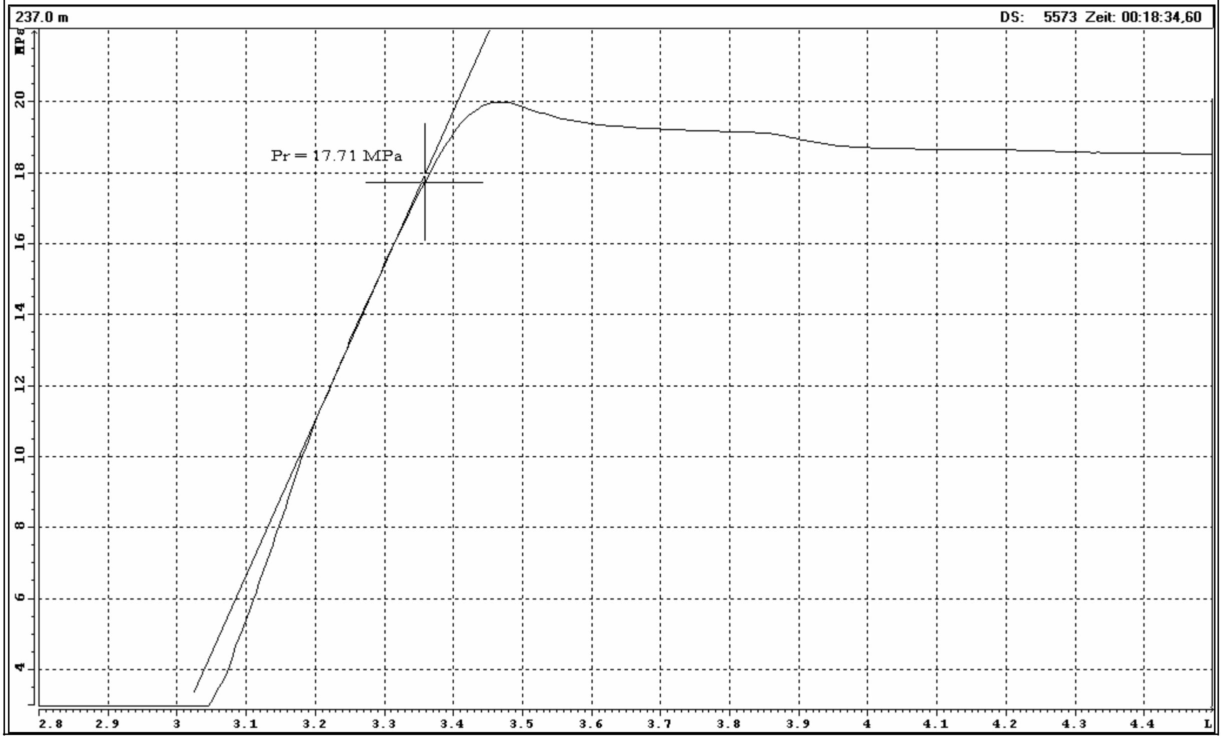
total injected volume (l): 20.0 recovered volume (l): 1.35 or 6.8 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (distinct breakdown event).
- The refrac - pressure was determined from the 1. and 2. refrac - cycle, since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

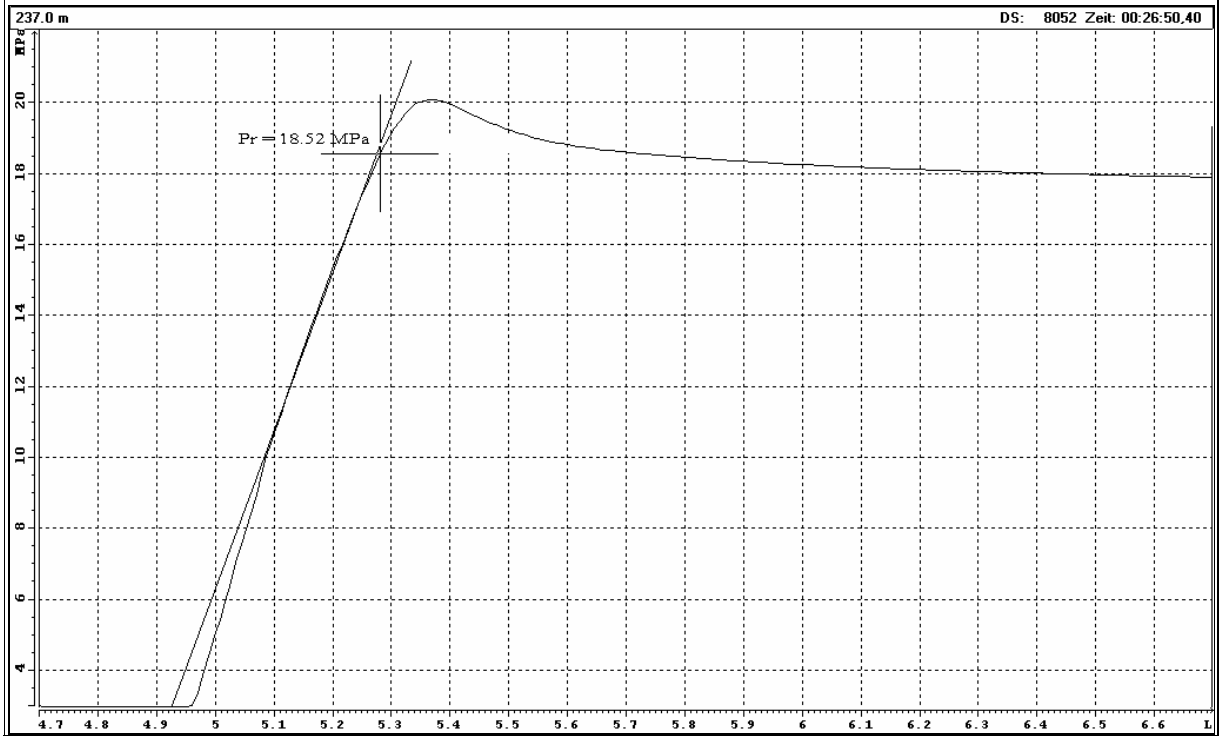
Test at 237.0 m MD: Estimation of P_c (Frac - Cycle)



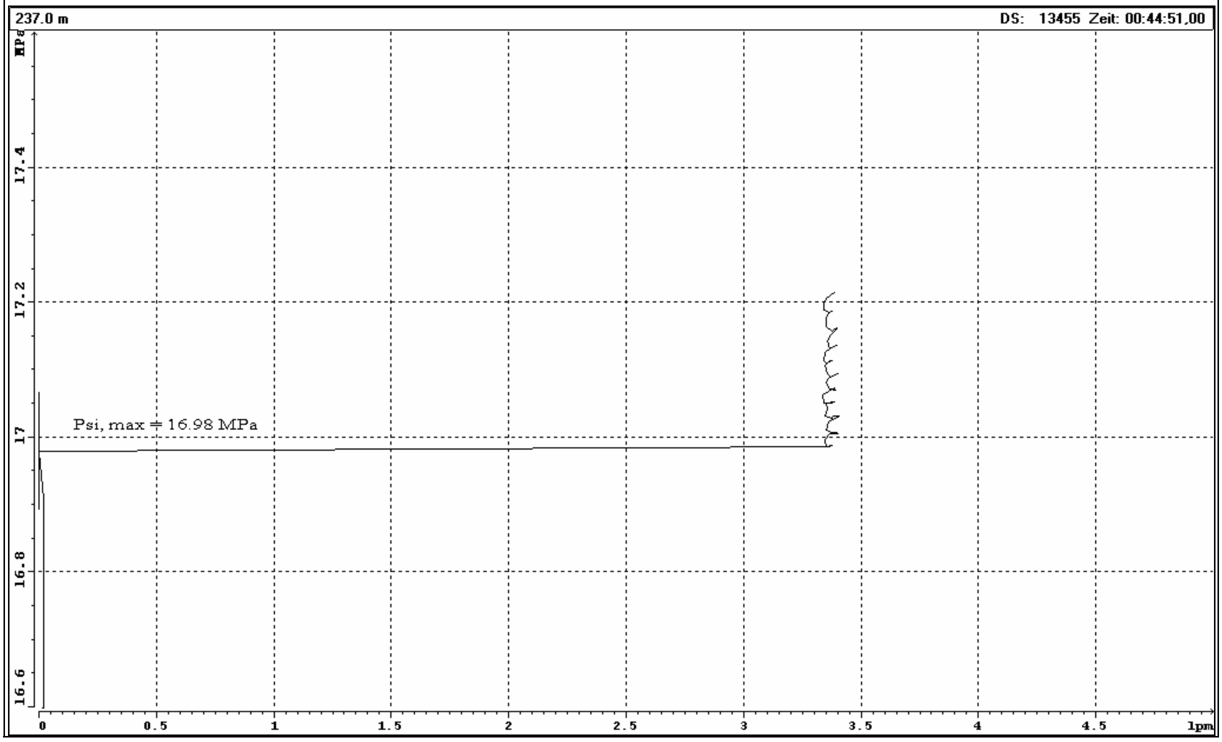
Test at 237.0 m MD: Estimation of P_r (1. Refrac - Cycle)



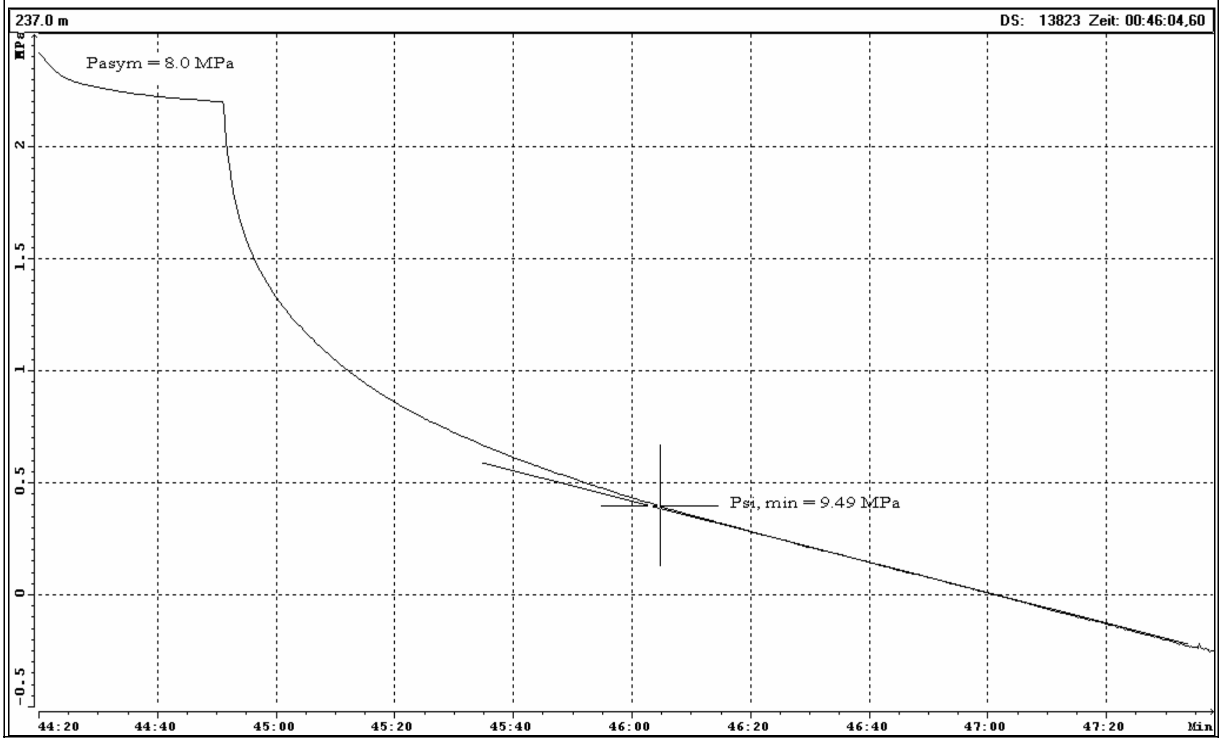
Test at 237.0 m MD: Estimation of P_r (2. Refrac - Cycle)



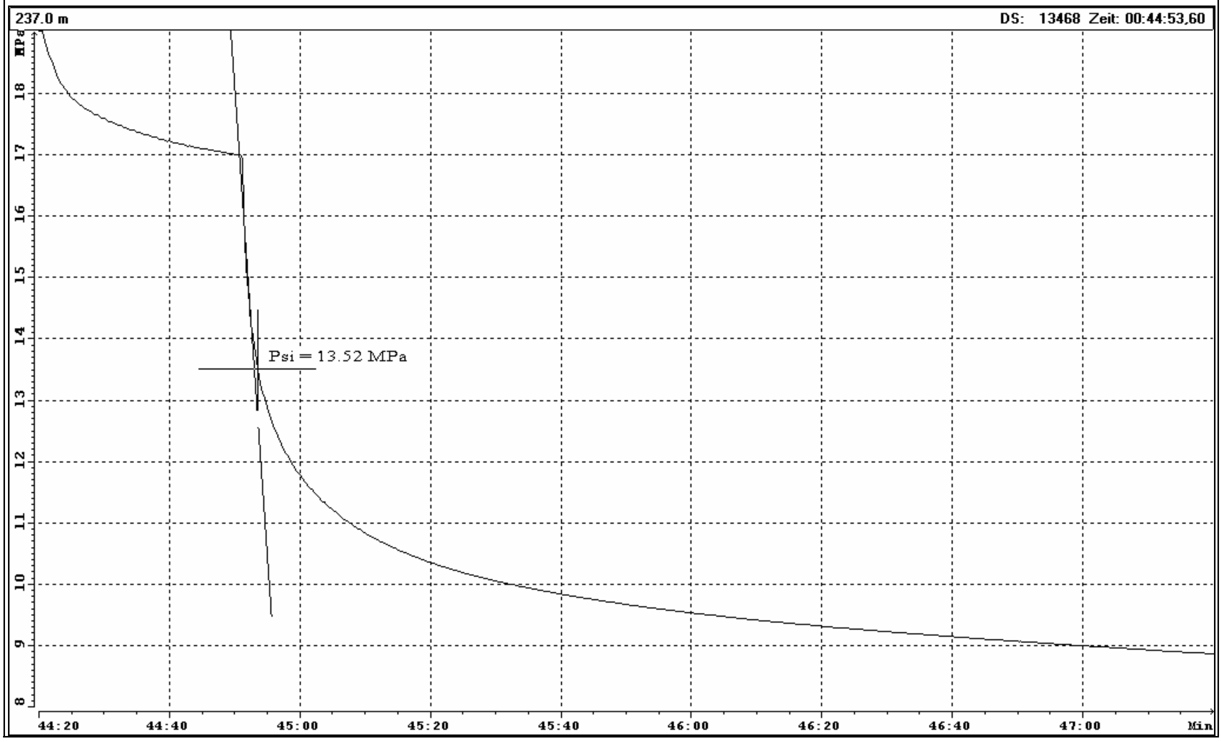
Test at 237.0 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



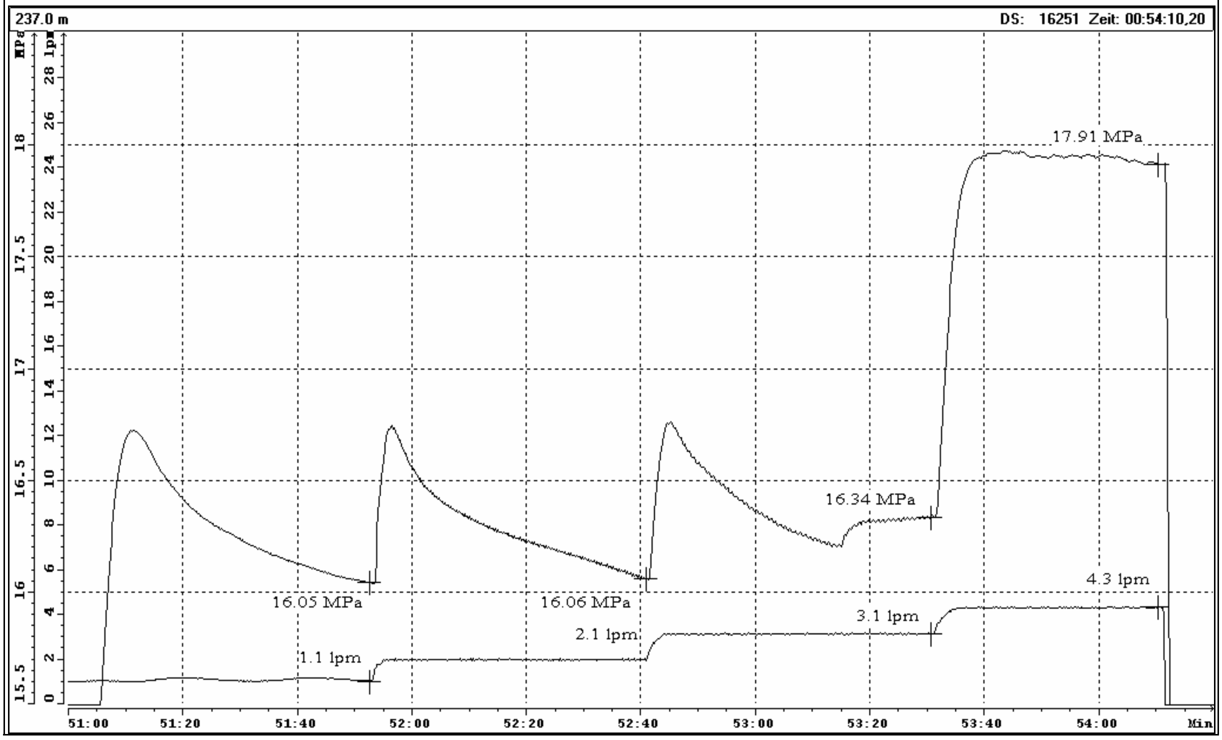
Test at 237.0 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



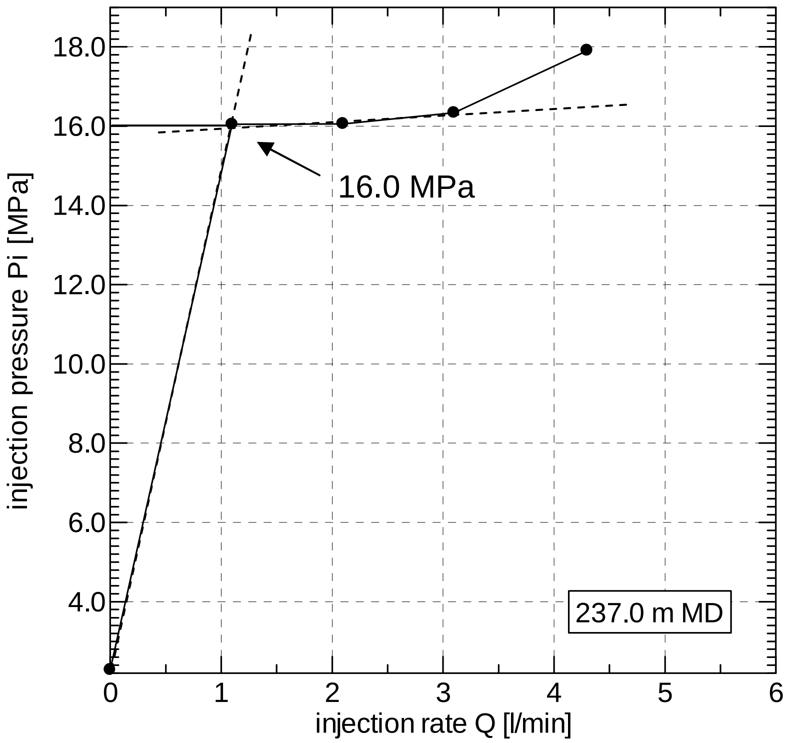
Test at 237.0 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 237.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

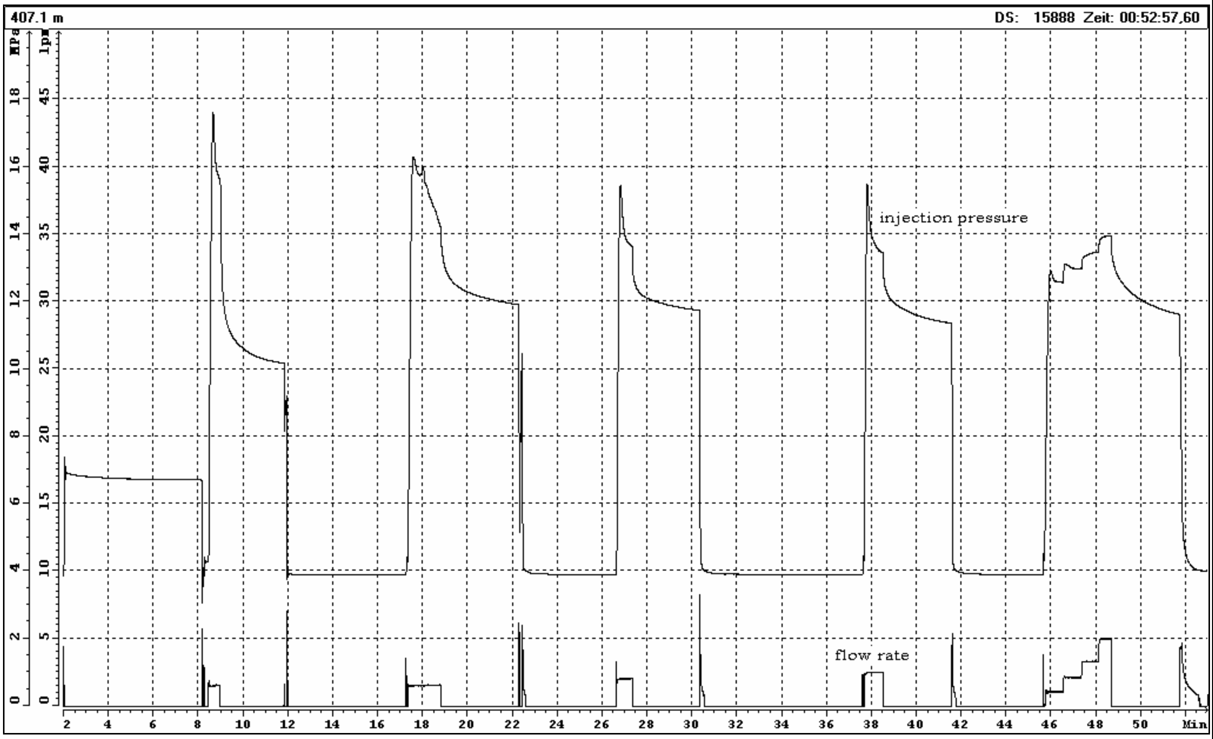


Test at 237.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 9 AT 407.1 m MD / 393.77 m TVD

Test at 407.1 m MD : Overview - Plot



P - Test Frac 1. Refrac 2. Refrac 3. Refrac SP/SR - Test

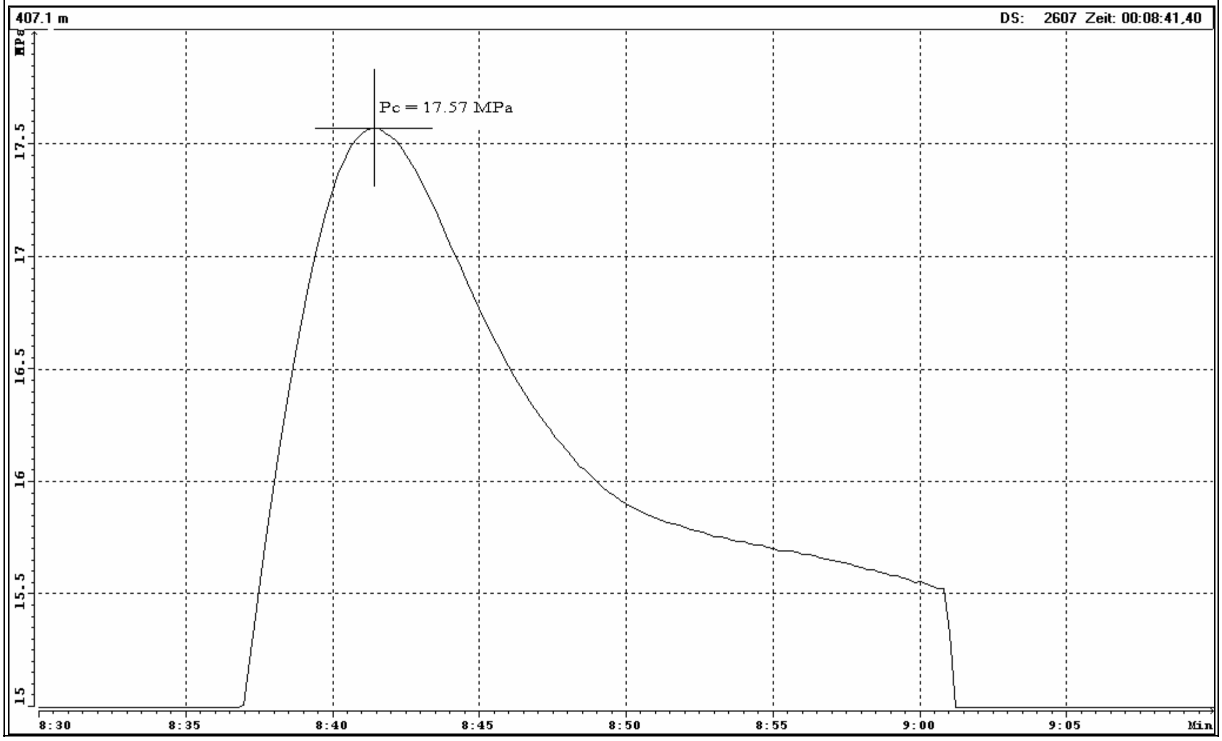
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 0.21 MPa in 356 sec.					
Frac - cycle	Qi (lpm) =	1.6	Vi (l) =	0.8	Vr (l) =	0.6
1. Refrac - cycle	Qi (lpm) =	1.6	Vi (l) =	2.4	Vr (l) =	1.3
2. Refrac - cycle	Qi (lpm) =	2.1	Vi (l) =	1.5	Vr (l) =	1.5
3. Refrac - cycle	Qi (lpm) =	2.5	Vi (l) =	2.1	Vr (l) =	1.5
SP/SR - test	Qi (lpm) =	1.1-5.0	Vi (l) =	8.0	Vr (l) =	5.0

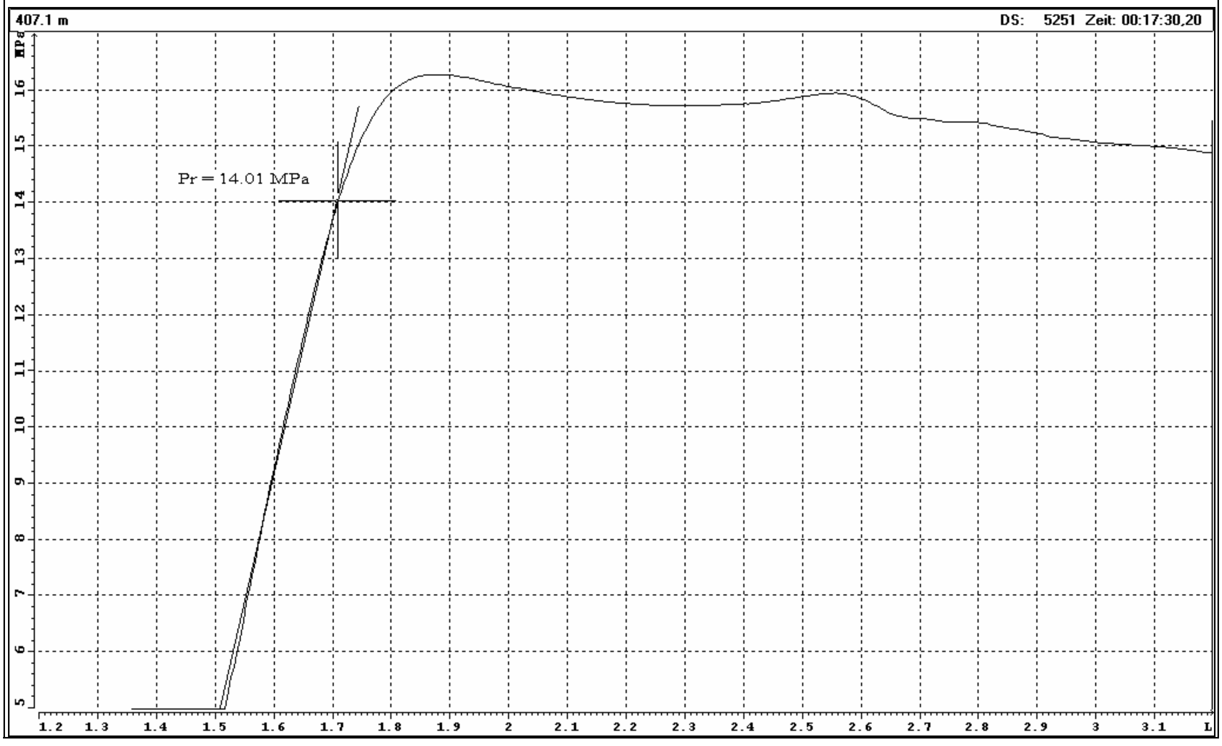
total injected volume (l): 14.8 recovered volume (l): 9.9 or 66.9 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a weak breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 14 MPa, followed by a pressure increase up to 16.25 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

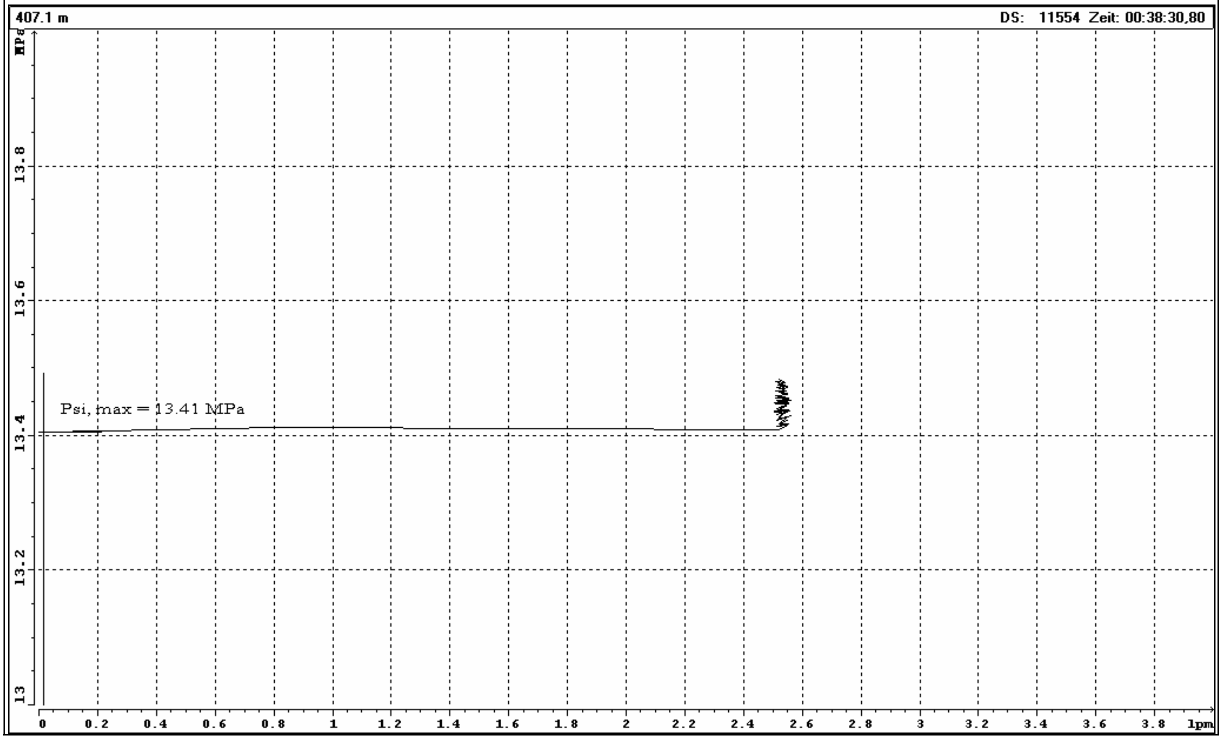
Test at 407.1 m MD: Estimation of P_c (Frac - Cycle)



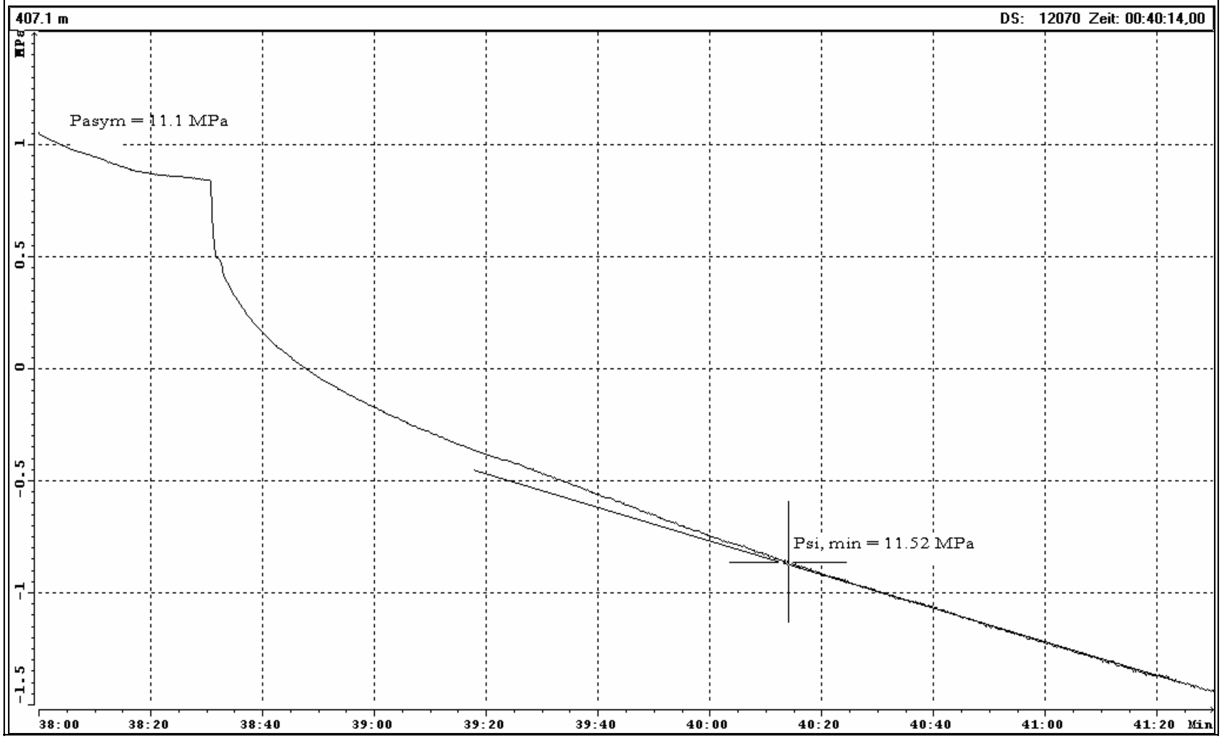
Test at 407.1 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



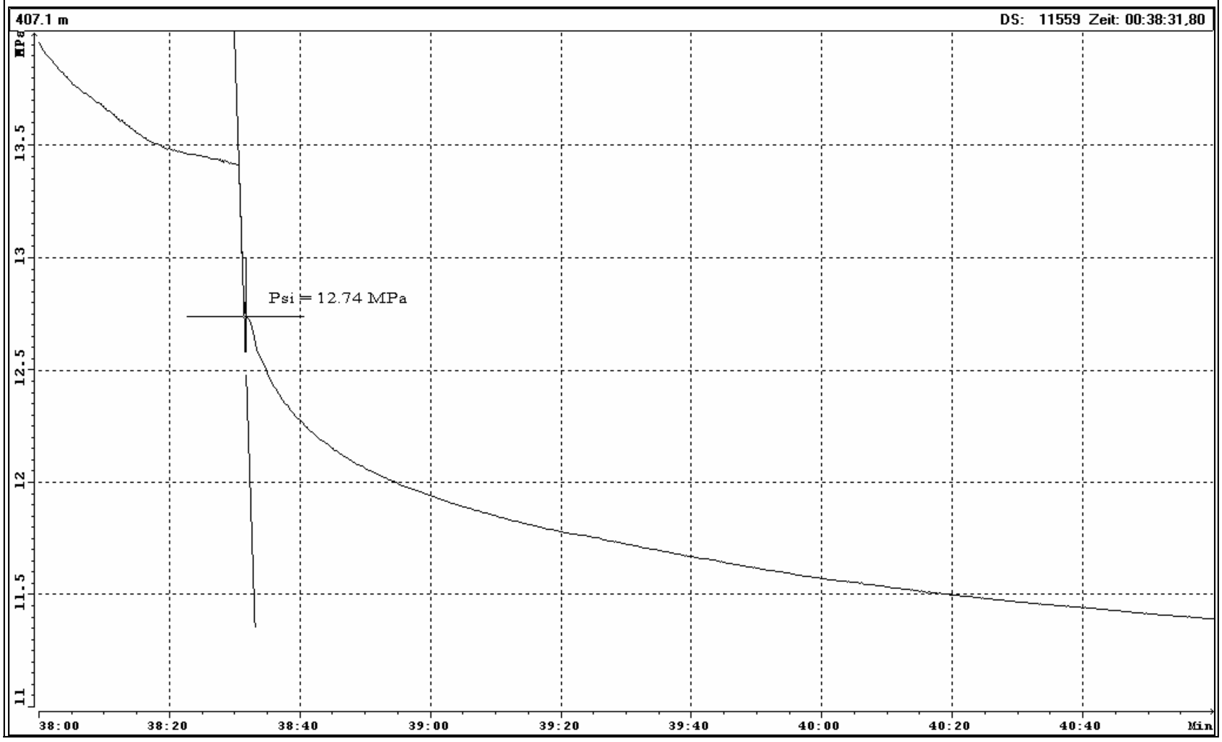
Test at 407.1 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



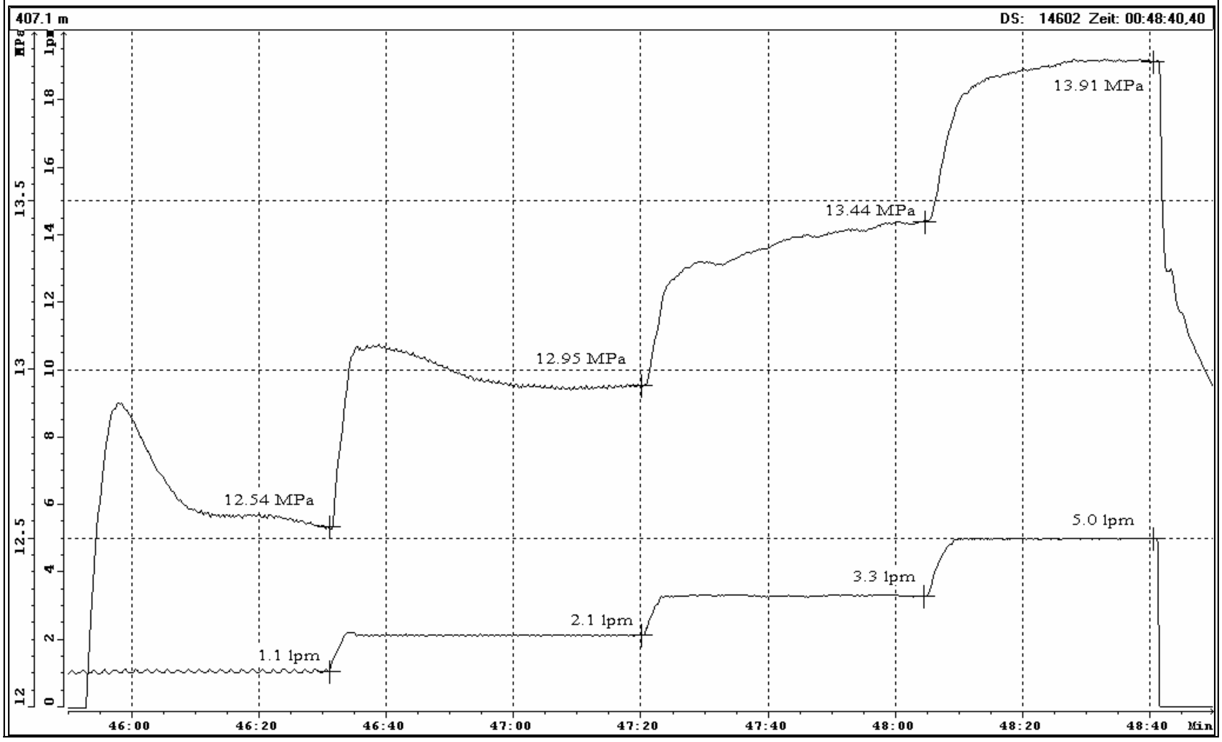
Test at 407.1 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



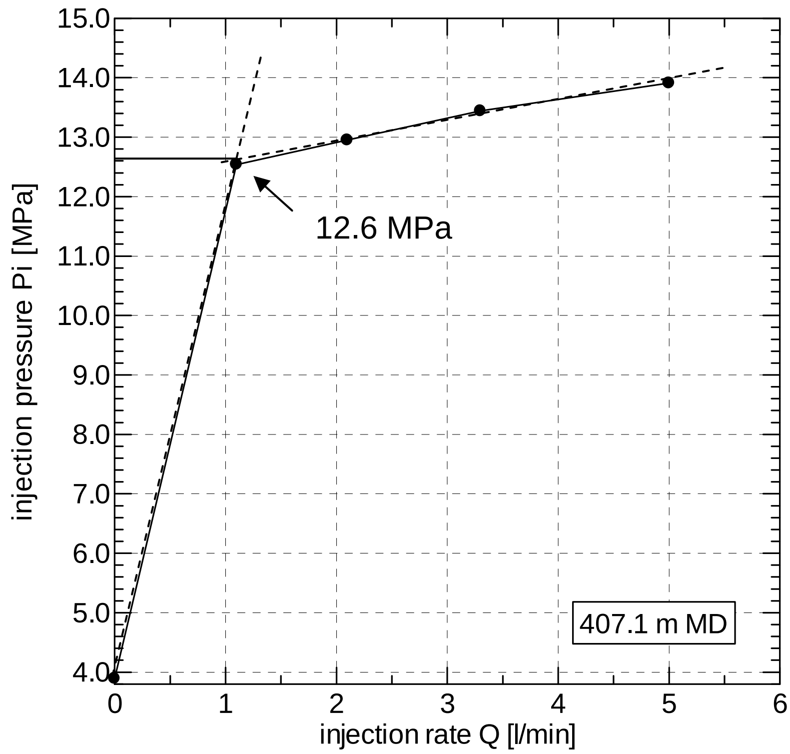
Test at 407.1 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 407.1 m MD: Analysis of Slow - Pump / Step - Rate - Test

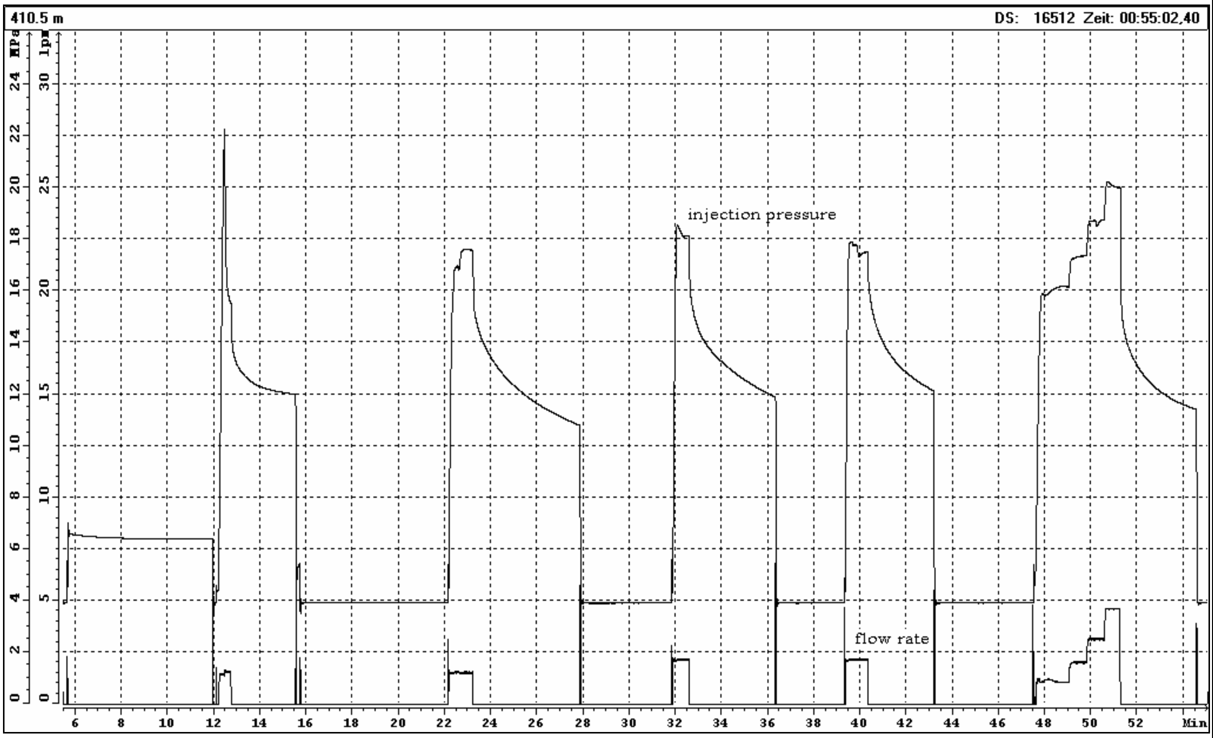


Test at 407.1 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 8 AT 410.5 m MD / 397.00 m TVD

Test at 410.5 m MD : Overview - Plot



P - Test Frac 1. Refrac 2. Refrac 3. Refrac SP/SR - Test

TEST SUMMARY / ANALYSIS / REMARKS

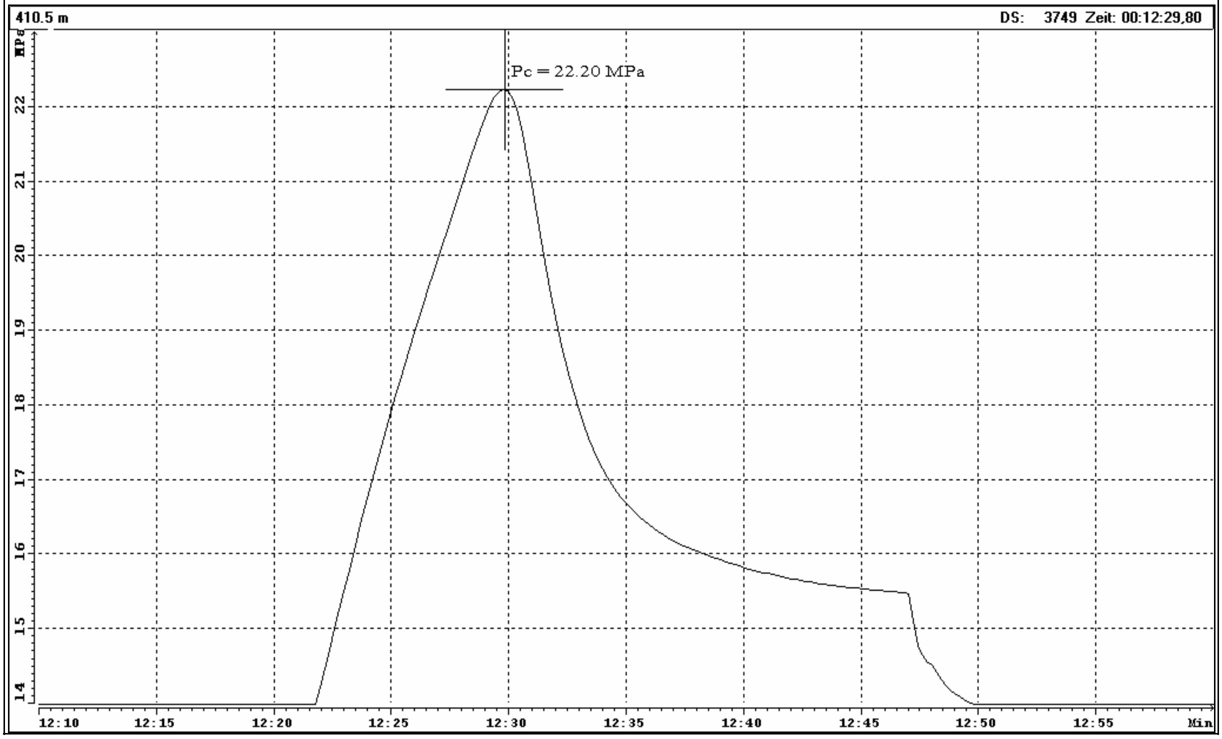
P - Test : pressure decrease: 0.34 MPa in 913 sec. (minor increase of pressure at the end of the shut-in period)

Frac - cycle	Qi (lpm) = 1.5	Vi (l) = 0.8	Vr (l) = 0.15
1. Refrac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.6	Vr (l) = 0.15
2. Refrac - cycle	Qi (lpm) = 2.1	Vi (l) = 1.5	Vr (l) = 0.15
3. Refrac - cycle	Qi (lpm) = 2.1	Vi (l) = 2.1	Vr (l) = 0.15
SP/SR - test	Qi (lpm) = 1.1-4.6	Vi (l) = 8.7	Vr (l) = 0.15

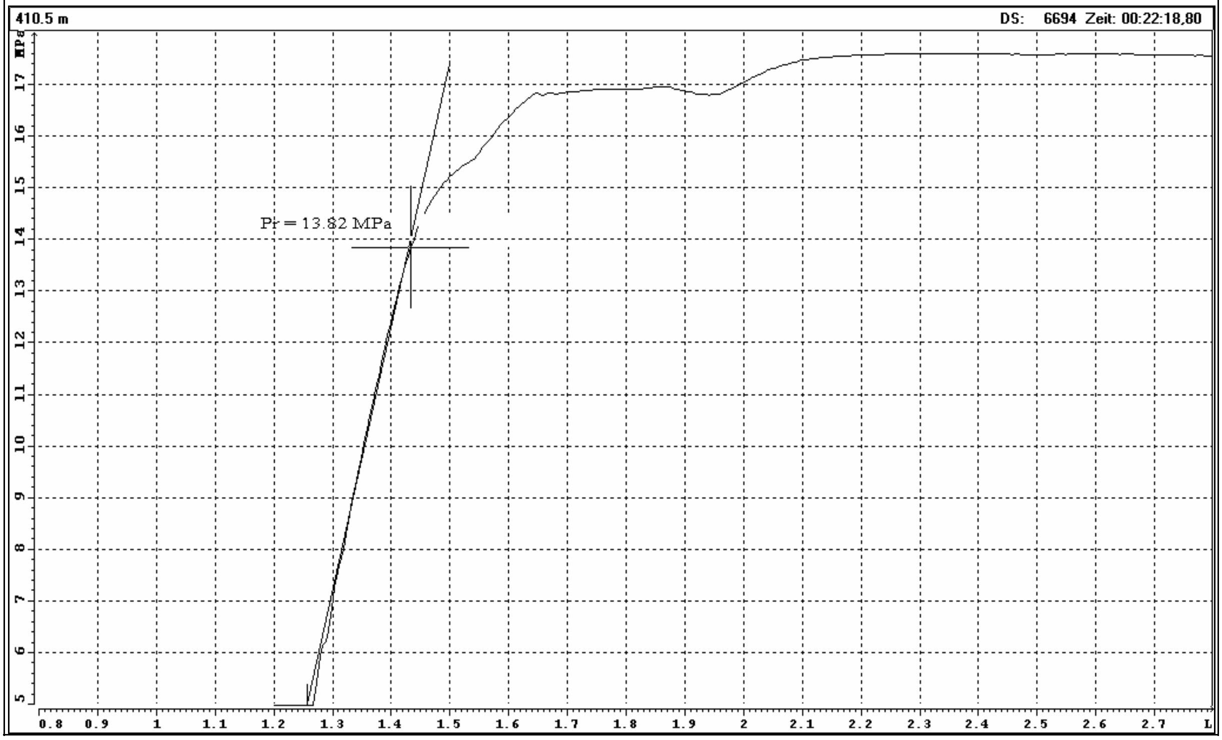
total injected volume (l): 14.7 recovered volume (l): 0.75 or 5.1 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (distinct breakdown event).
- The refrac - pressure was determined from the 1. and 3. refrac - cycle, since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- The shut-in phases yield distinct shut-in pressure values, which, however, increased from 15.3 MPa during the 1. refrac - cycle to 16.3 MPa during the 3. refrac - cycle. Therefore, the shut - in pressure of the 1. refrac - cycle was used for the stress analysis.

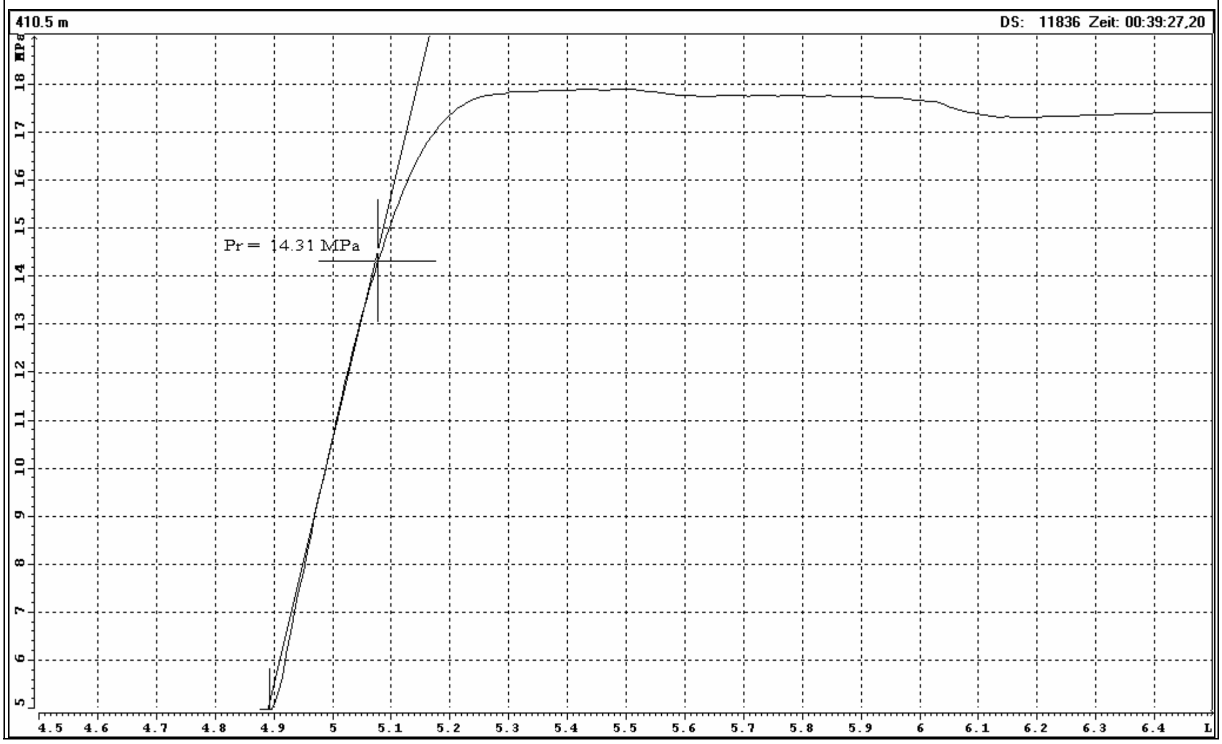
Test at 410.5 m MD: Estimation of P_c (Frac - Cycle)



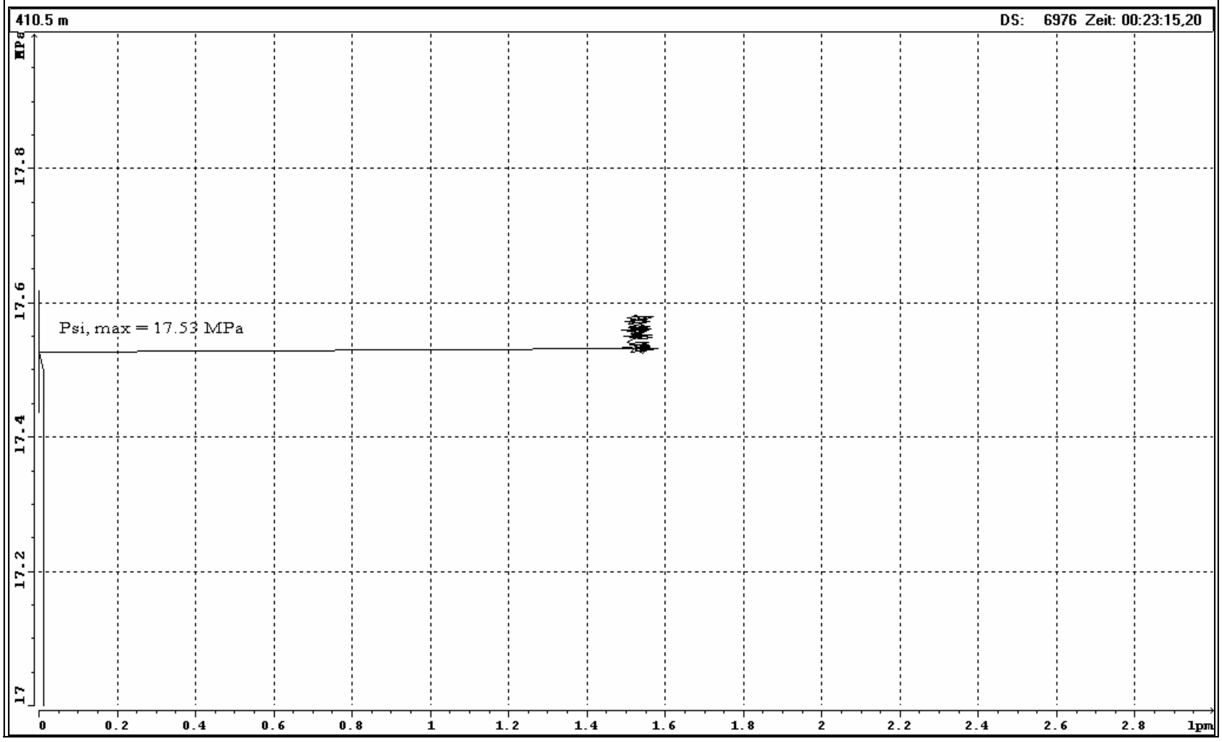
Test at 410.5 m MD: Estimation of P_r (1. Refrac - Cycle)



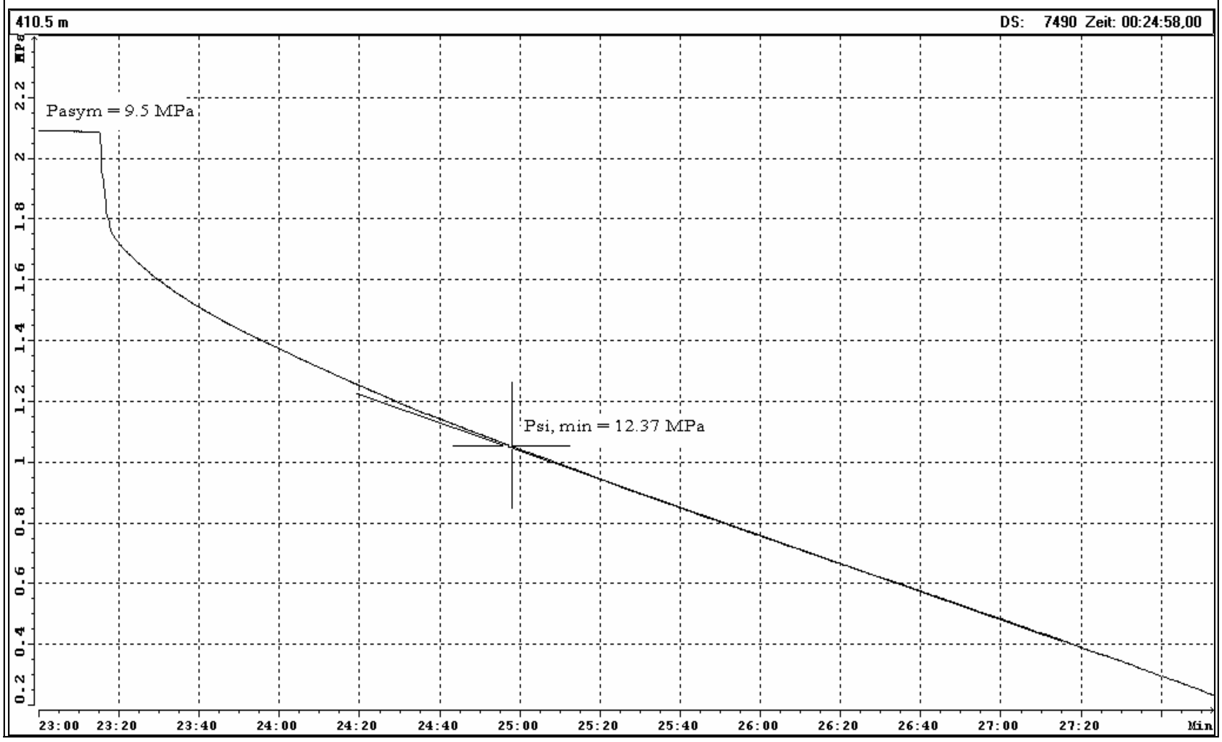
Test at 410.5 m MD: Estimation of P_r (3. Refrac - Cycle)



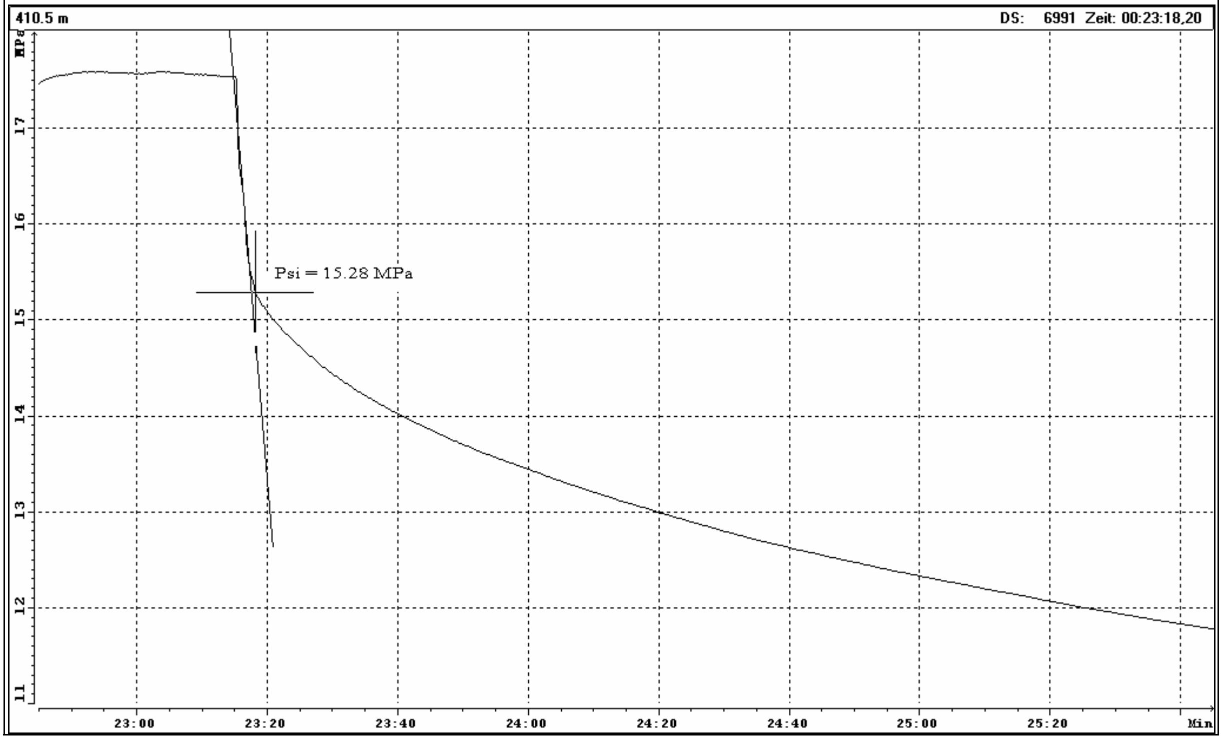
Test at 410.5 m MD: Estimation of $P_{si, max}$ (1. Refrac - Cycle)



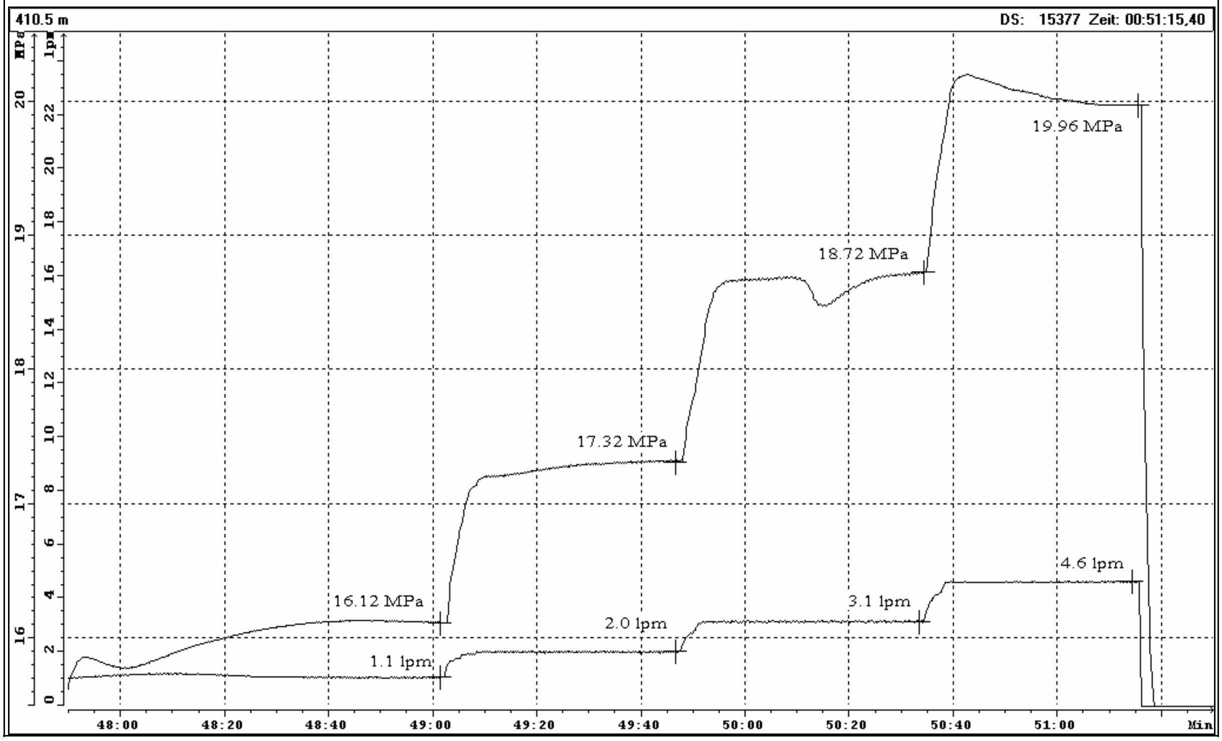
Test at 410.5 m MD: Estimation of $P_{si, min}$ (1. Refrac - Cycle)



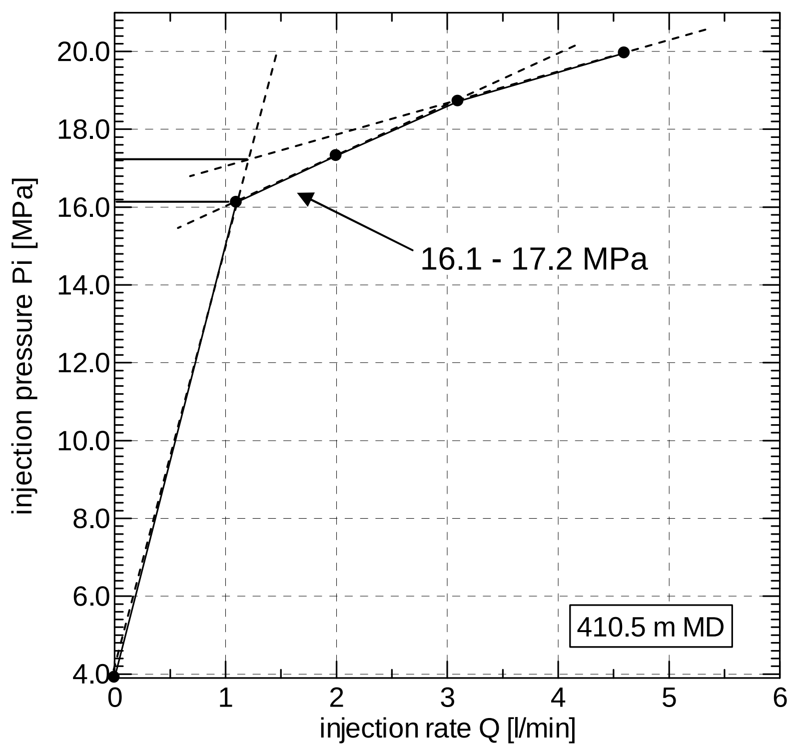
Test at 410.5 m MD: Estimation of P_{si} (1. Refrac - Cycle)



Test at 410.5 m MD: Analysis of Slow - Pump / Step - Rate - Test

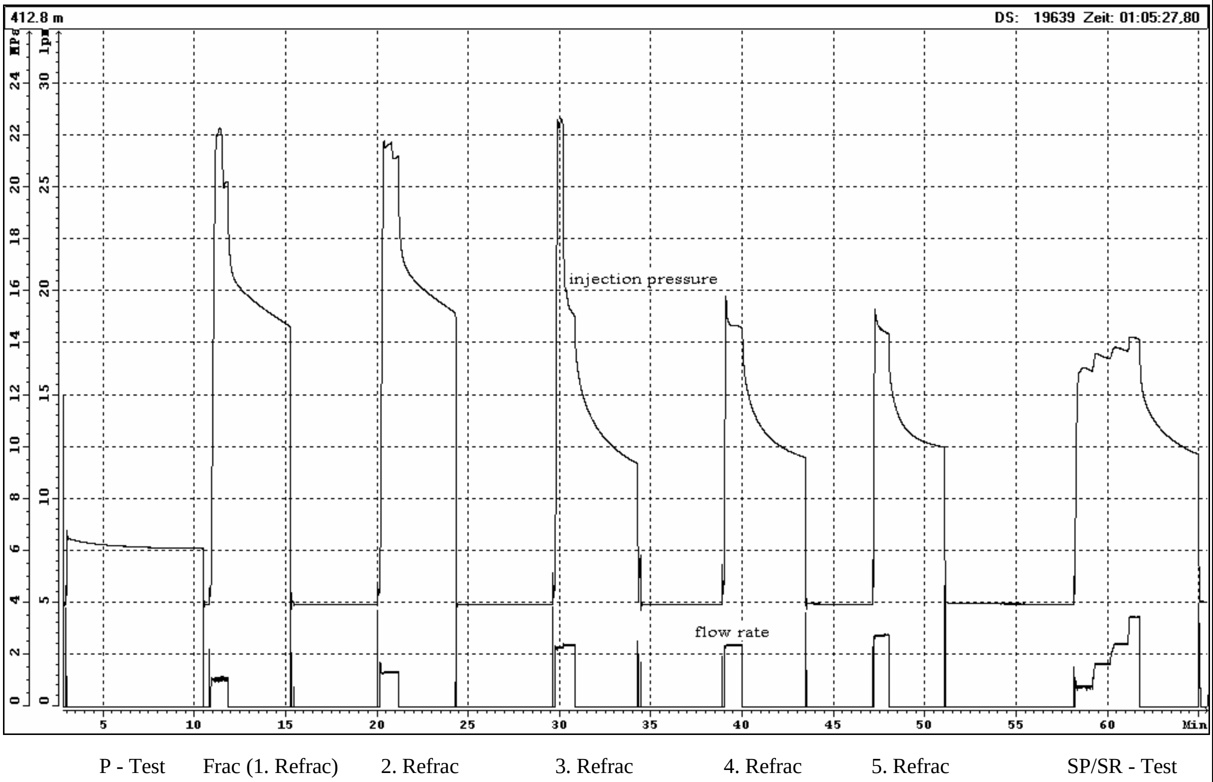


Test at 410.5 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 7 AT 412.8 m MD / 399.18 m TVD

Test at 412.8 m MD: Overview - Plot



TEST SUMMARY / ANALYSIS / REMARKS

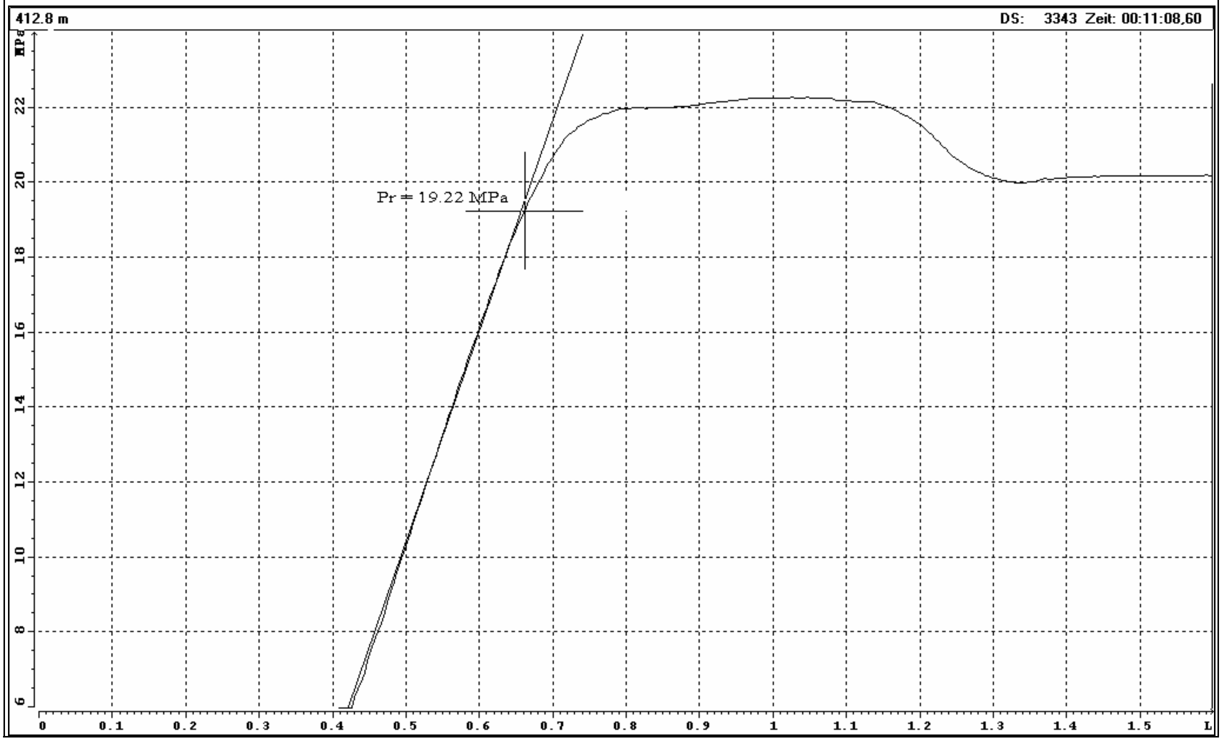
P - Test : pressure decrease: 0.39 MPa in 440 sec.

Frac (1. Refrac) - cycle	Qi (lpm) = 1.4	Vi (l) = 1.3	Vr (l) = 0.2
2. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.7	Vr (l) = 0.2
3. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 3.2	Vr (l) = 0.4
4. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 3.0	Vr (l) = 0.75
5. Refrac - cycle	Qi (lpm) = 3.4	Vi (l) = 2.8	Vr (l) = 1.6
SP/SR - test	Qi (lpm) = 1.0-4.3	Vi (l) = 8.5	Vr (l) = 3.0

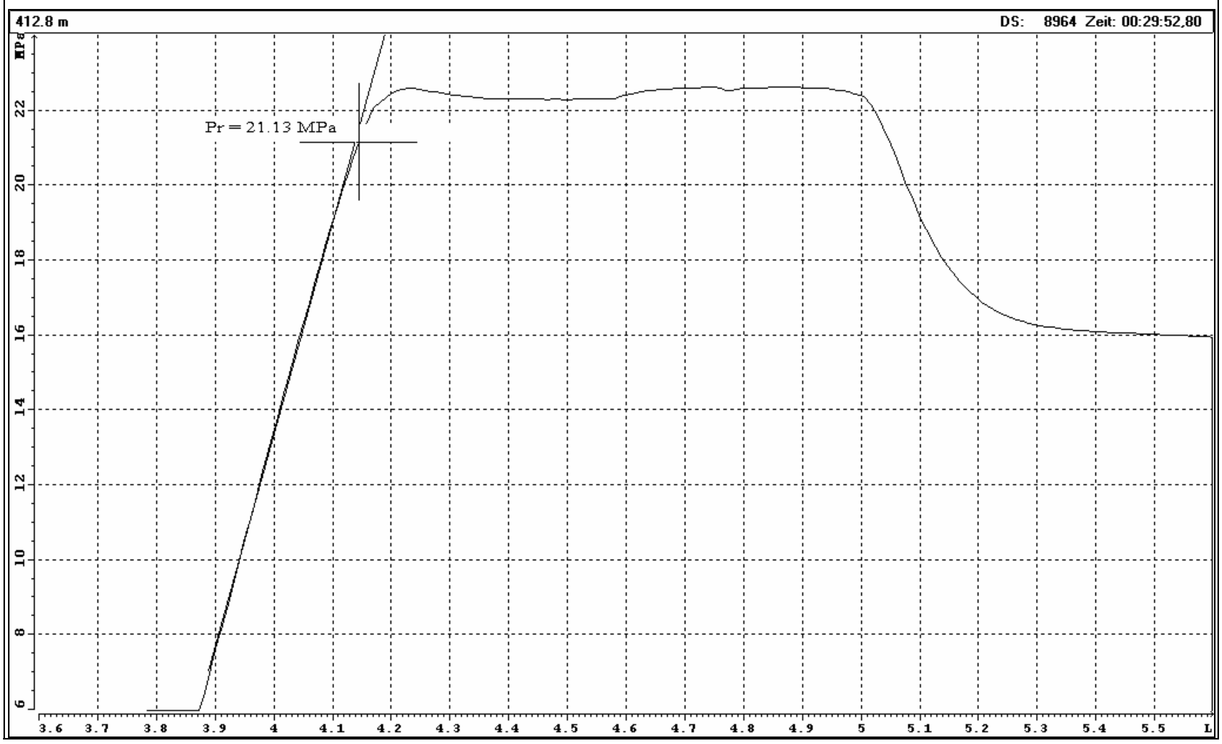
total injected volume (l): 20.5 recovered volume (l): 6.15 or 30.0 %

- Initial test type: HF
- Although the test section contains no visible fracture, the frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- A significant decrease of the injection pressure was observed during the 3. refrac - cycle.
- The refrac - pressure was determined from the 1. and 3. refrac - cycle since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- The shut-in phases yield distinct and consistent shut-in pressure values during the 3., 4. and 5. refrac - cycle. For the analysis, the shut - in pressure of the 5. refrac - cycle was used.

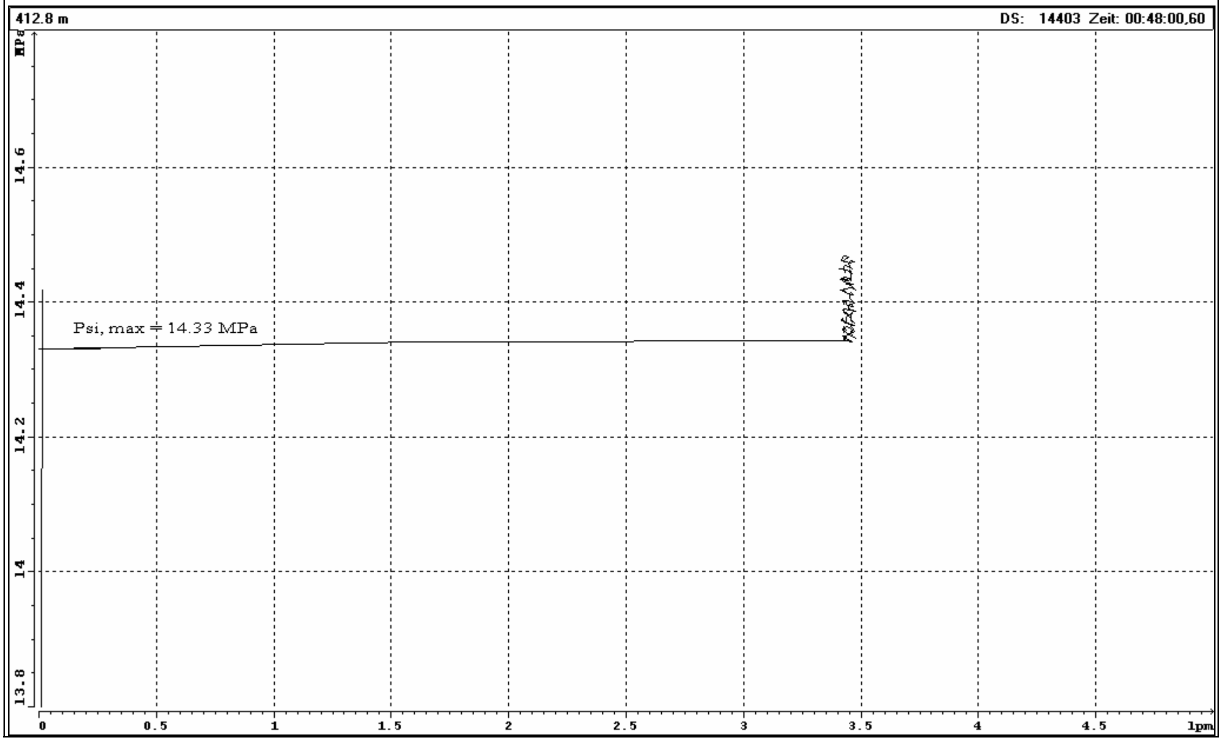
Test at 412.8 m MD: Estimation of P_r (1. Refrac - Cycle)



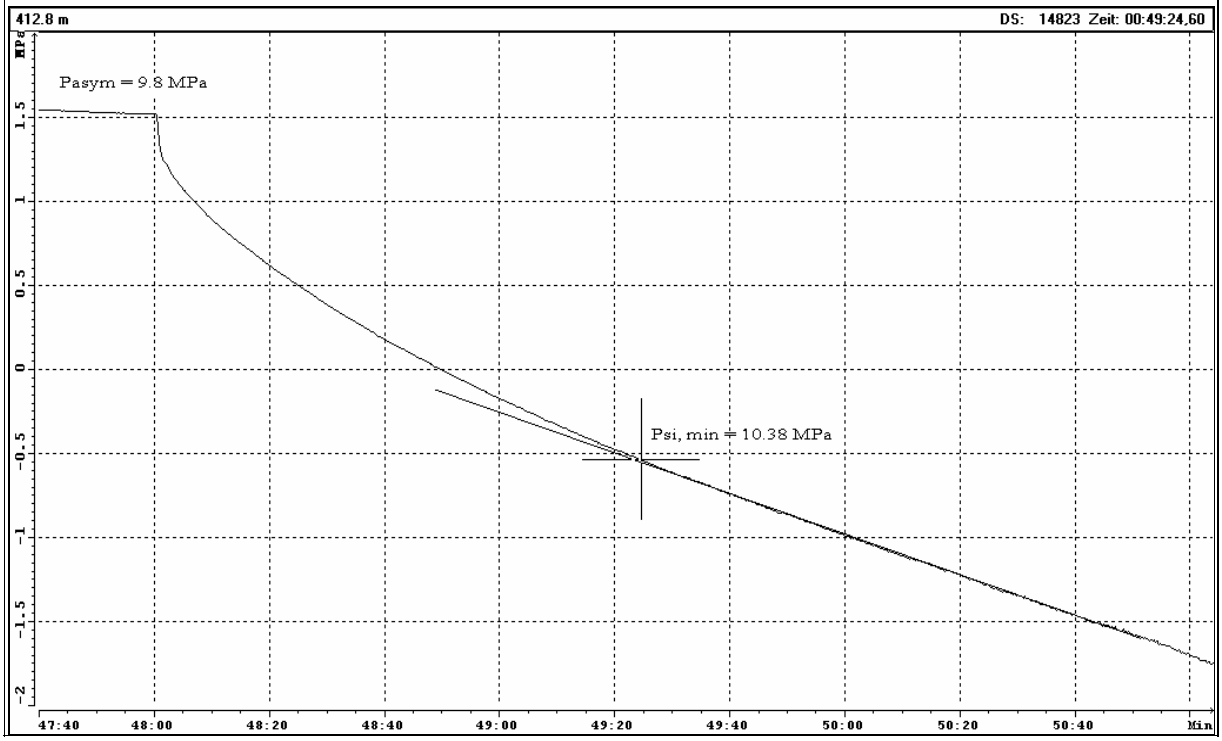
Test at 412.8 m MD: Estimation of P_r (3. Refrac - Cycle)



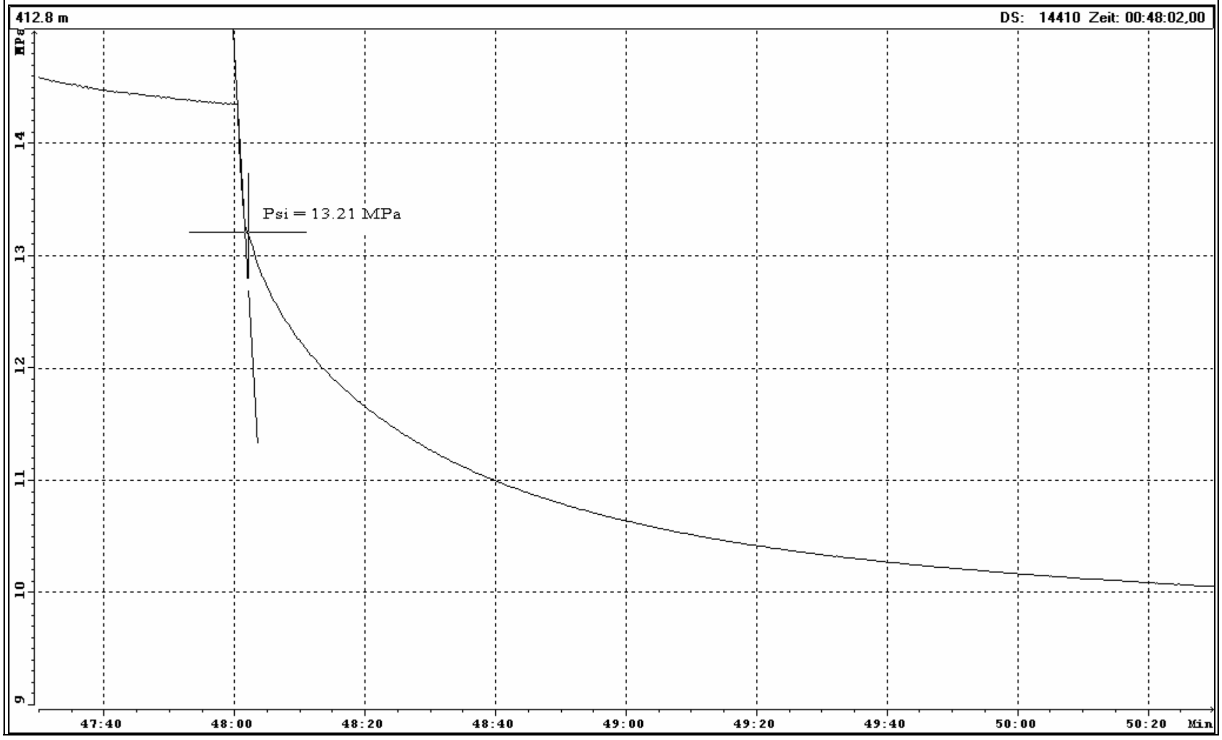
Test at 412.8 m MD: Estimation of $P_{si, max}$ (5. Refrac - Cycle)



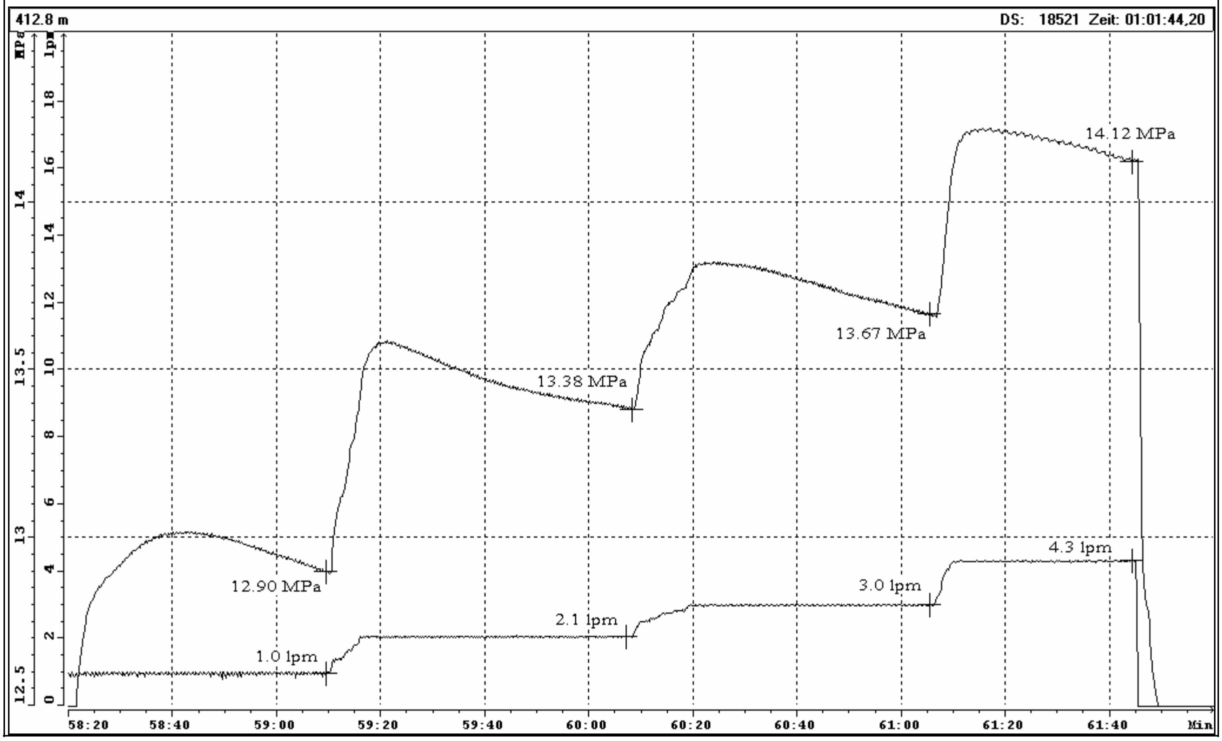
Test at 412.8 m MD: Estimation of $P_{si, min}$ (5. Refrac - Cycle)



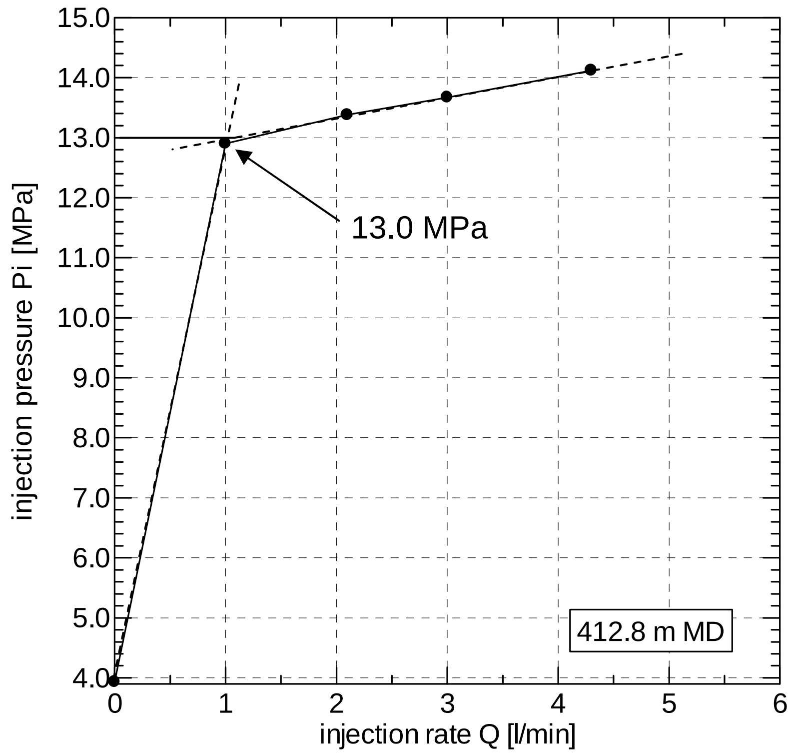
Test at 412.8 m MD: Estimation of P_{si} (5. Refrac - Cycle)



Test at 412.8 m MD: Analysis of Slow - Pump / Step - Rate - Test

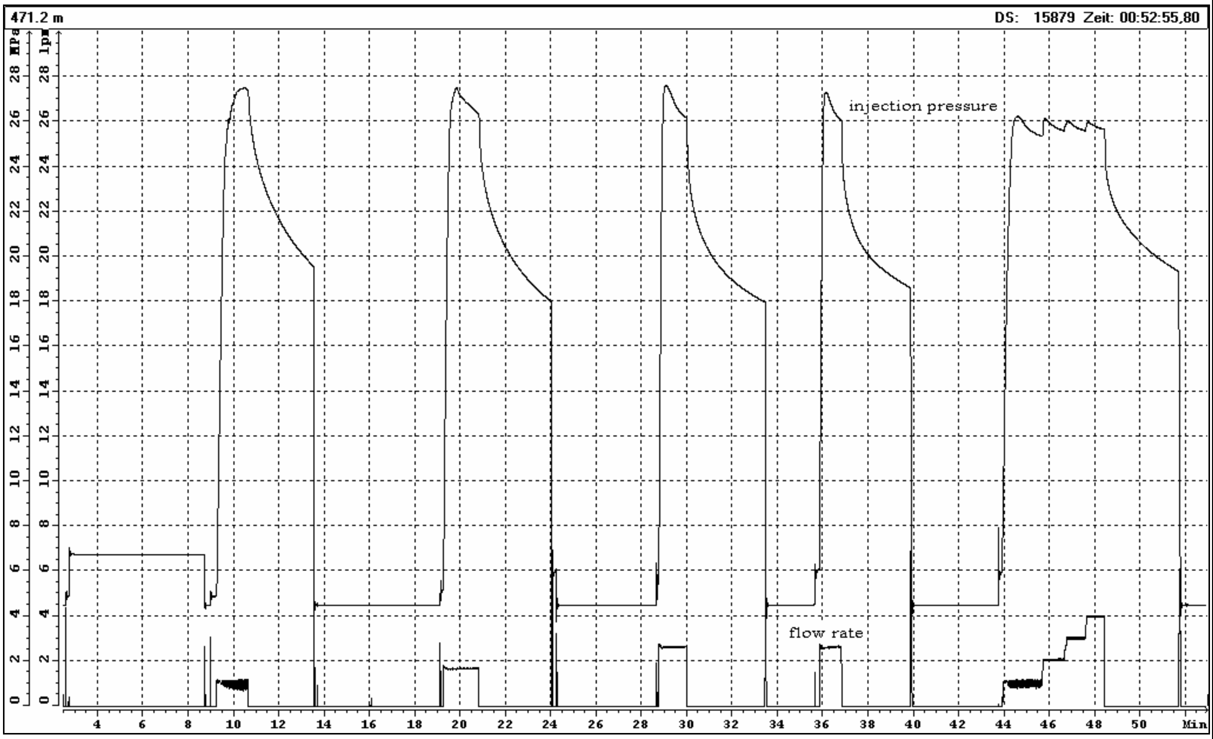


Test at 412.8 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 6 AT 471.2 m MD / 454.68 m TVD

Test at 471.2 m MD : Overview - Plot



P - Test Frac (1. Refrac) 2. Refrac 3. Refrac 4. Refrac SP/SR - Test

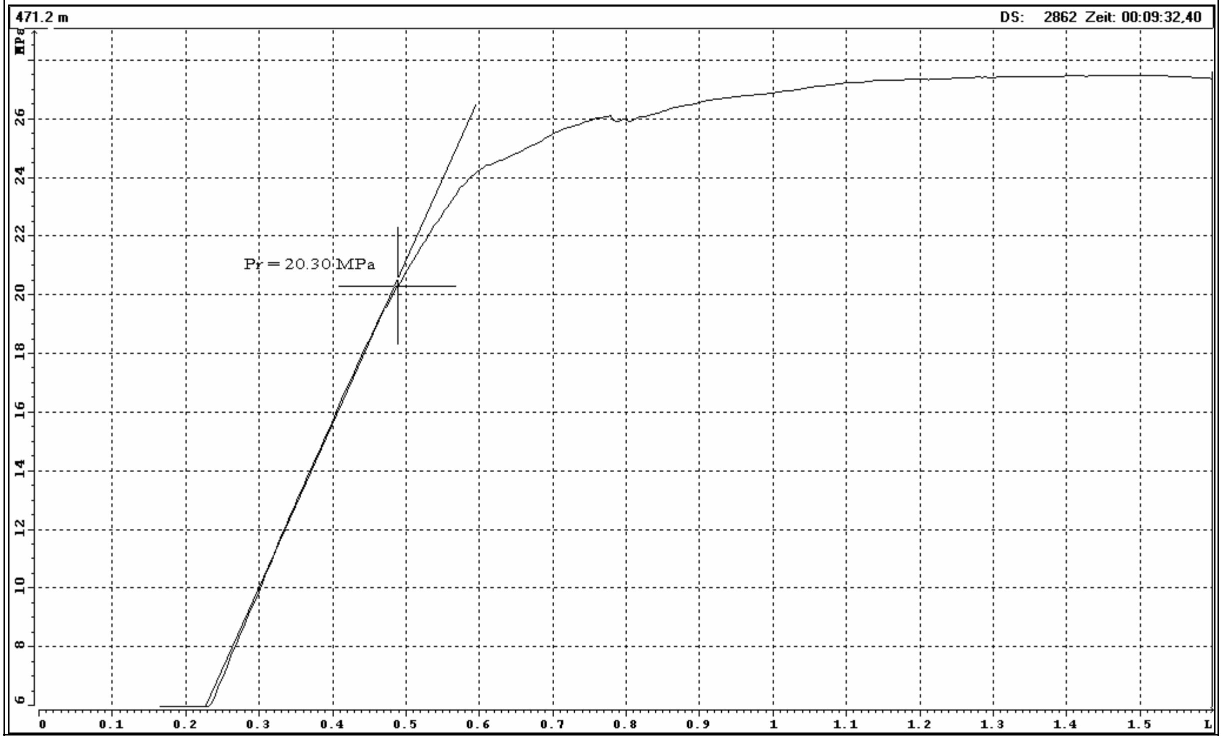
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 0.05 MPa in 190 sec., followed by a minor increase of 0.03 MPa in 159 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.1	Vi (l) = 1.5	Vr (l) = 0.3
2. Refrac - cycle	Qi (lpm) = 1.7	Vi (l) = 2.7	Vr (l) = 0.3
3. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 3.3	Vr (l) = 0.3
4. Refrac - cycle	Qi (lpm) = 2.7	Vi (l) = 2.6	Vr (l) = 0.5
SP/SR - test	Qi (lpm) = 1.0-4.0	Vi (l) = 10.0	Vr (l) = 1.0

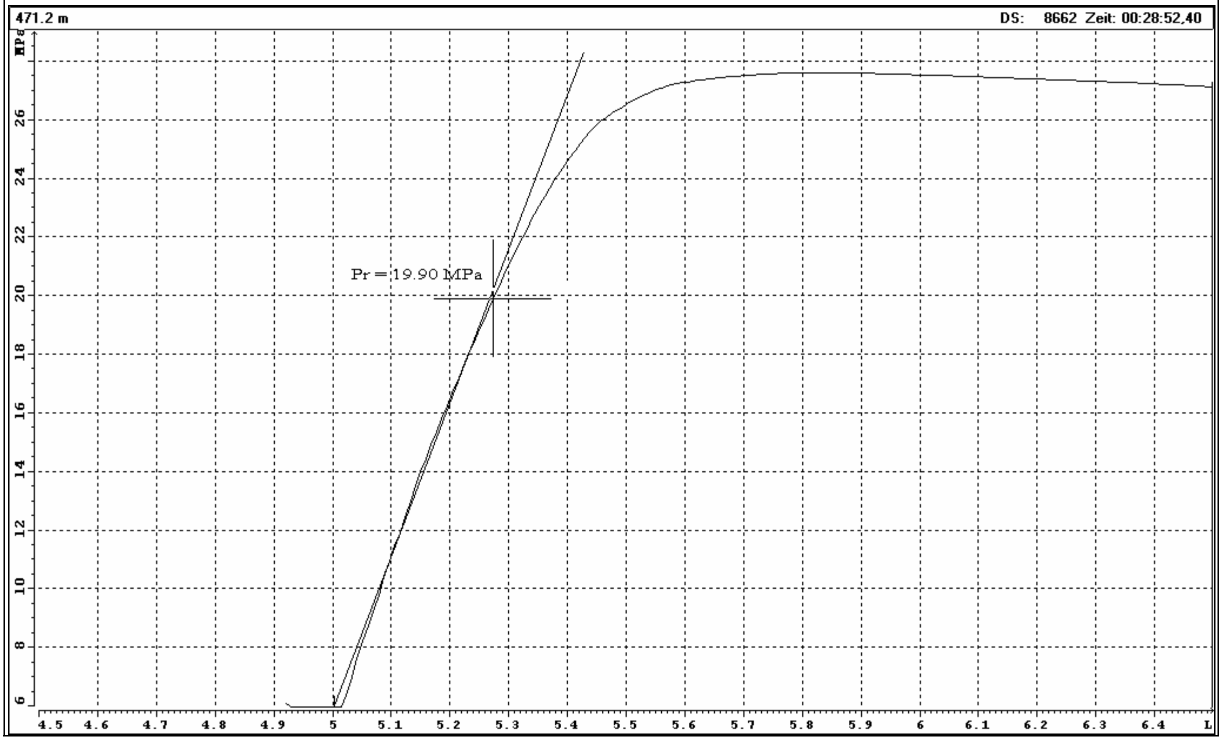
total injected volume (l): 20.1 recovered volume (l): 2.4 or 11.9 %

- Initial test type: HF
- Although the test section contains no visible fracture, the frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 20.3 MPa, followed by a pressure increase up to 27.4 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

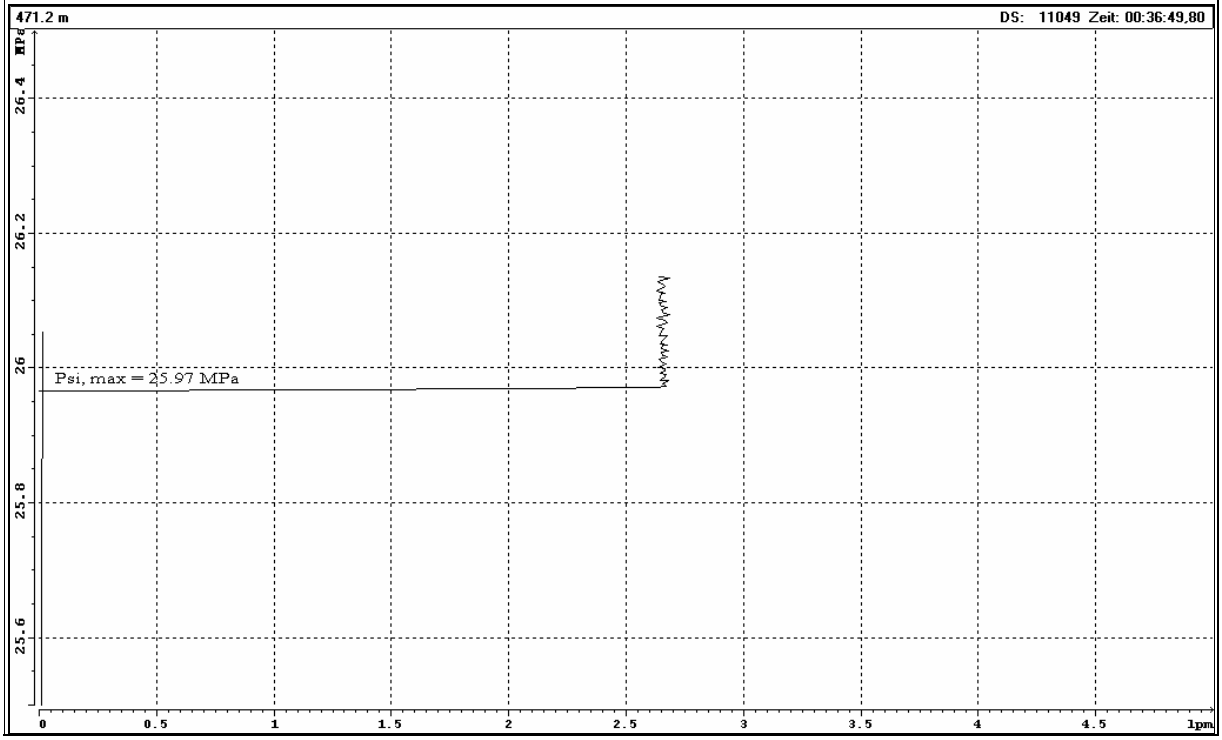
Test at 471.2 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



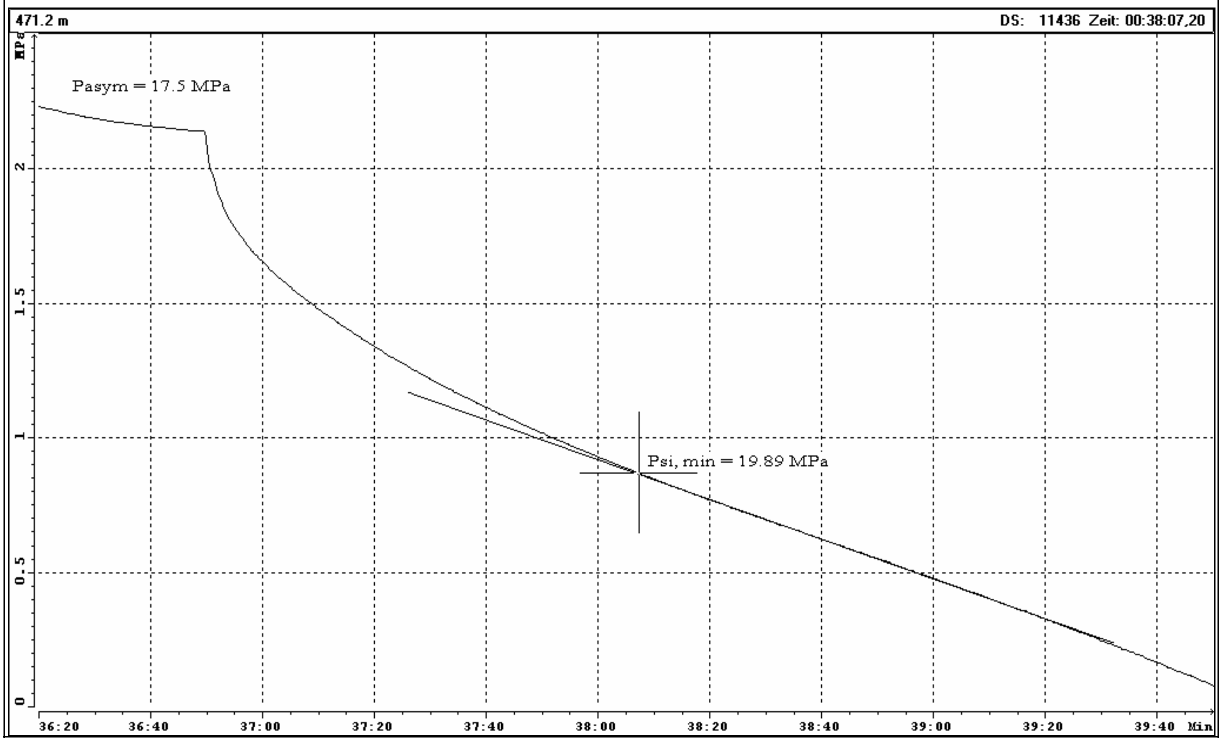
Test at 471.2 m MD: Estimation of P_r (3. Refrac - Cycle, for comparison)



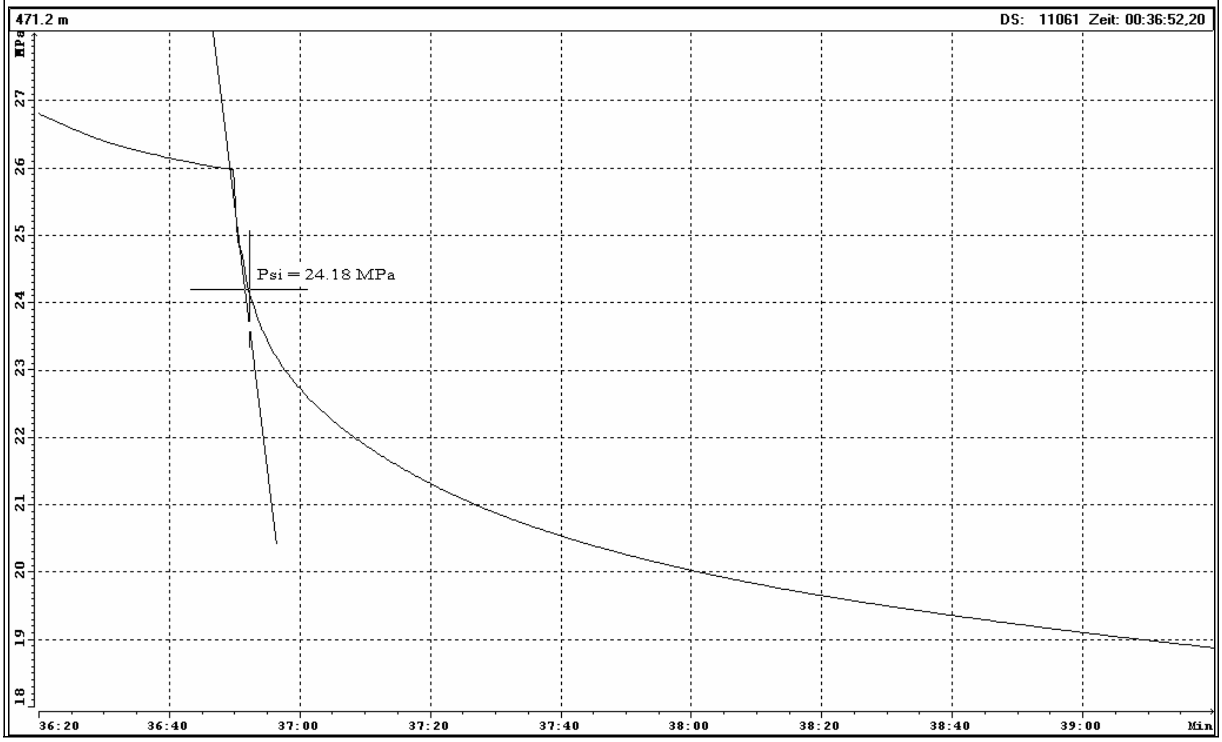
Test at 471.2 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



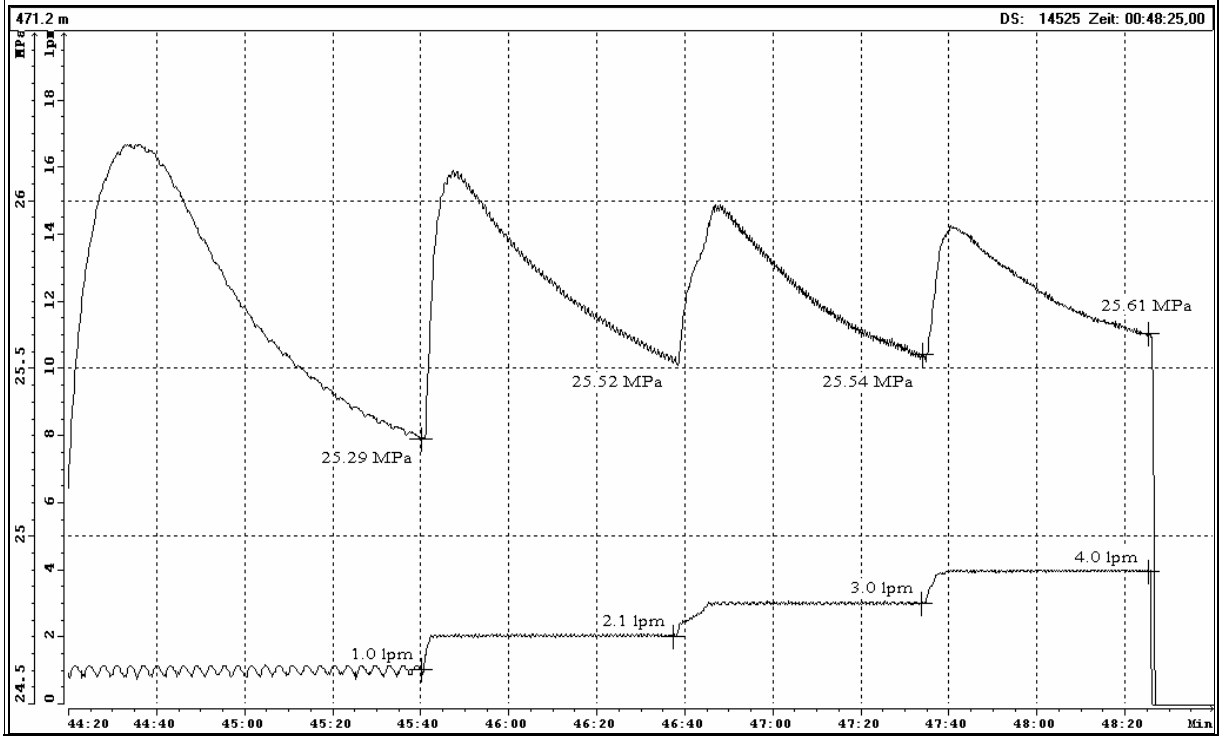
Test at 471.2 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



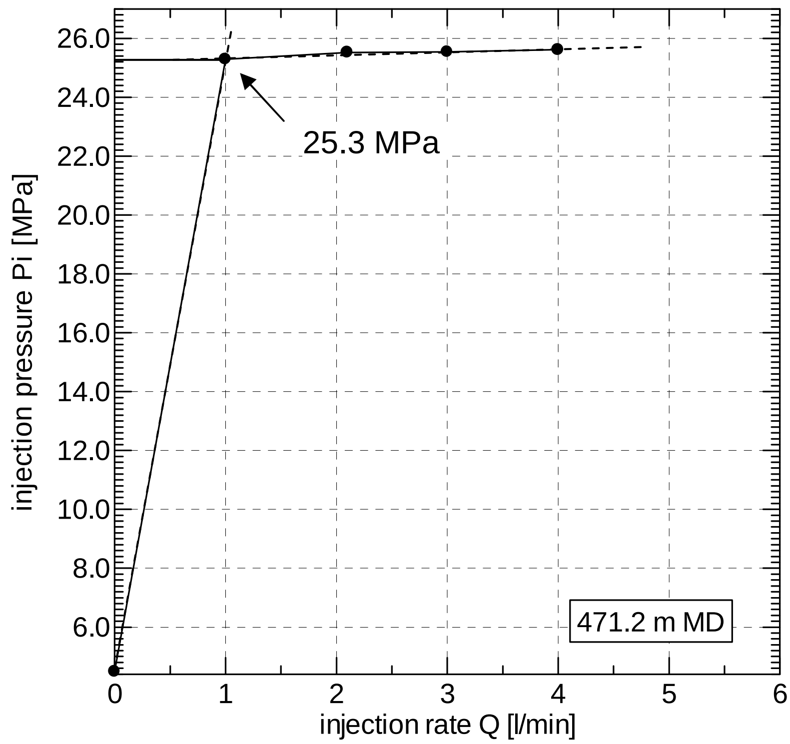
Test at 471.2 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 471.2 m MD: Analysis of Slow - Pump / Step - Rate - Test

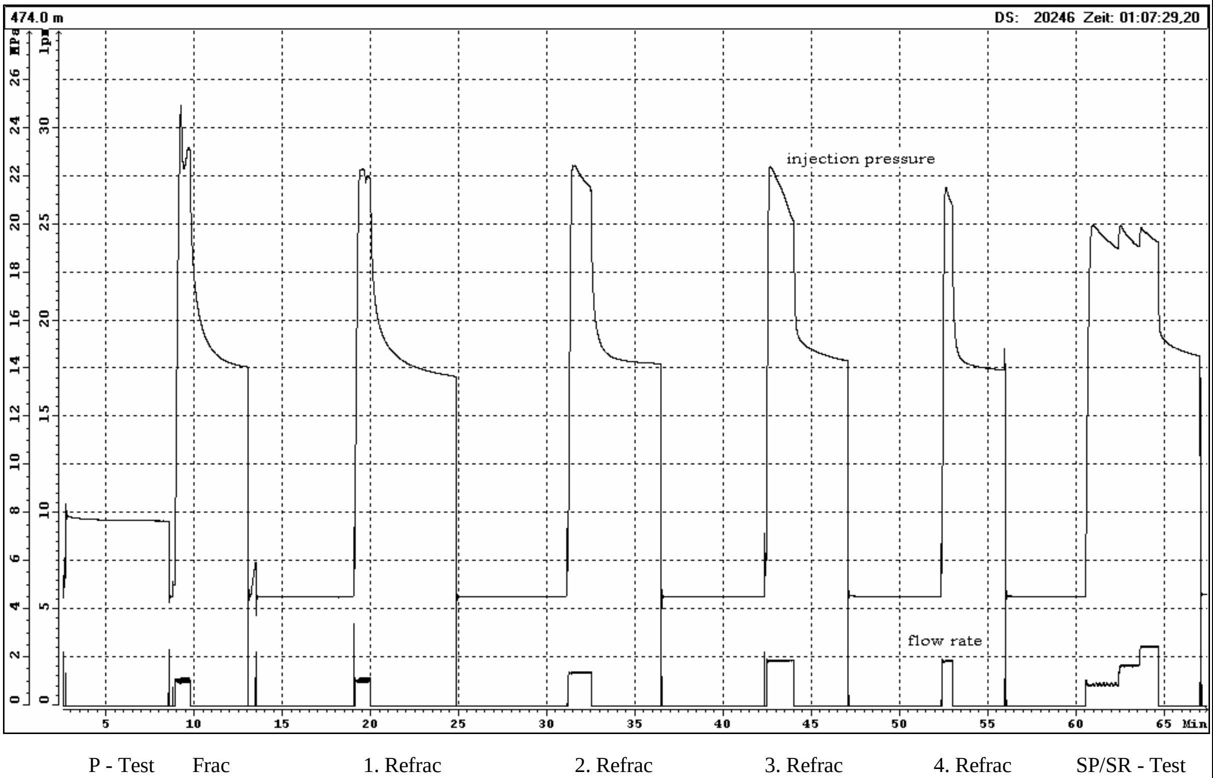


Test at 471.2 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 5 AT 474.0 m MD / 457.33 m TVD

Test at 474.0 m MD: Overview - Plot



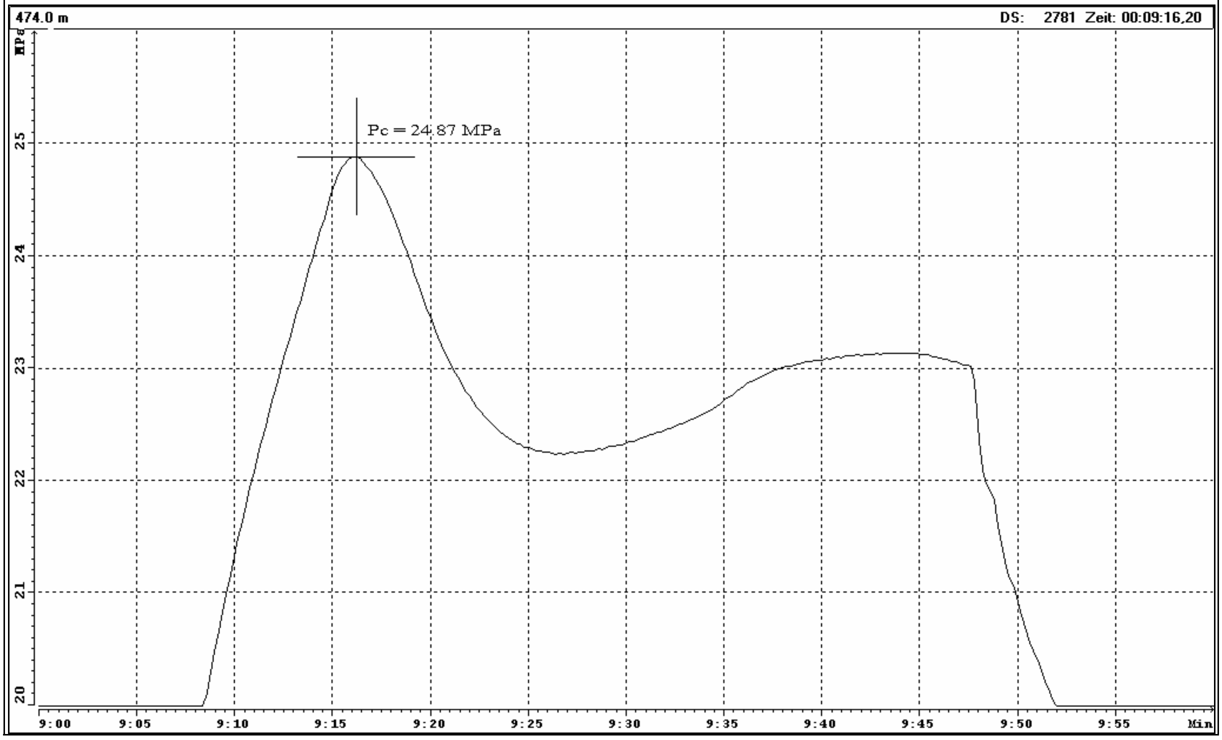
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 0.19 MPa in 342 sec.		
Frac - cycle	Qi (lpm) = 1.3	Vi (l) = 1.1	Vr (l) = 0.3
1. Refrac - cycle	Qi (lpm) = 1.3	Vi (l) = 1.2	Vr (l) = 0.4
2. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 2.2	Vr (l) = 0.8
3. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 3.7	Vr (l) = 1.7
4. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 1.3	Vr (l) = 1.3
SP/SR - test	Qi (lpm) = 1.1-3.0	Vi (l) = 7.8	Vr (l) = 2.5

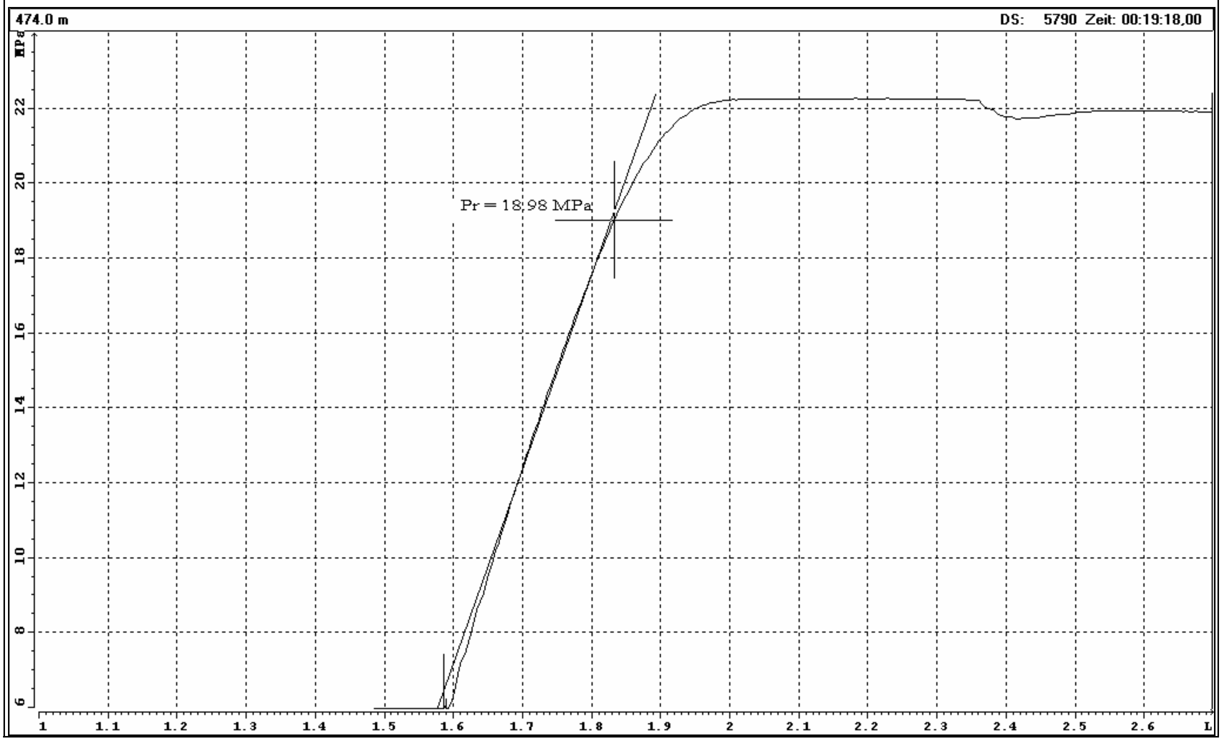
total injected volume (l): 17.3 recovered volume (l): 7.0 or 40.5 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (weak breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield slightly lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

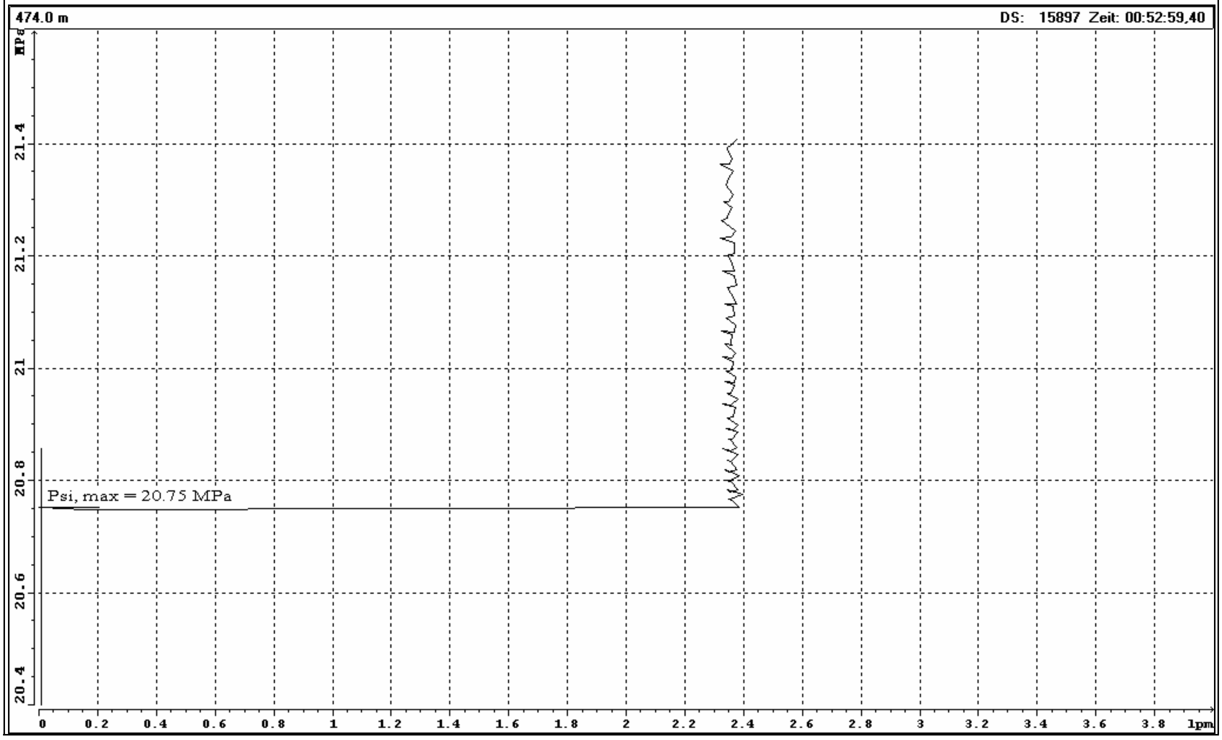
Test at 474.0 m MD: Estimation of P_c (Frac - Cycle)



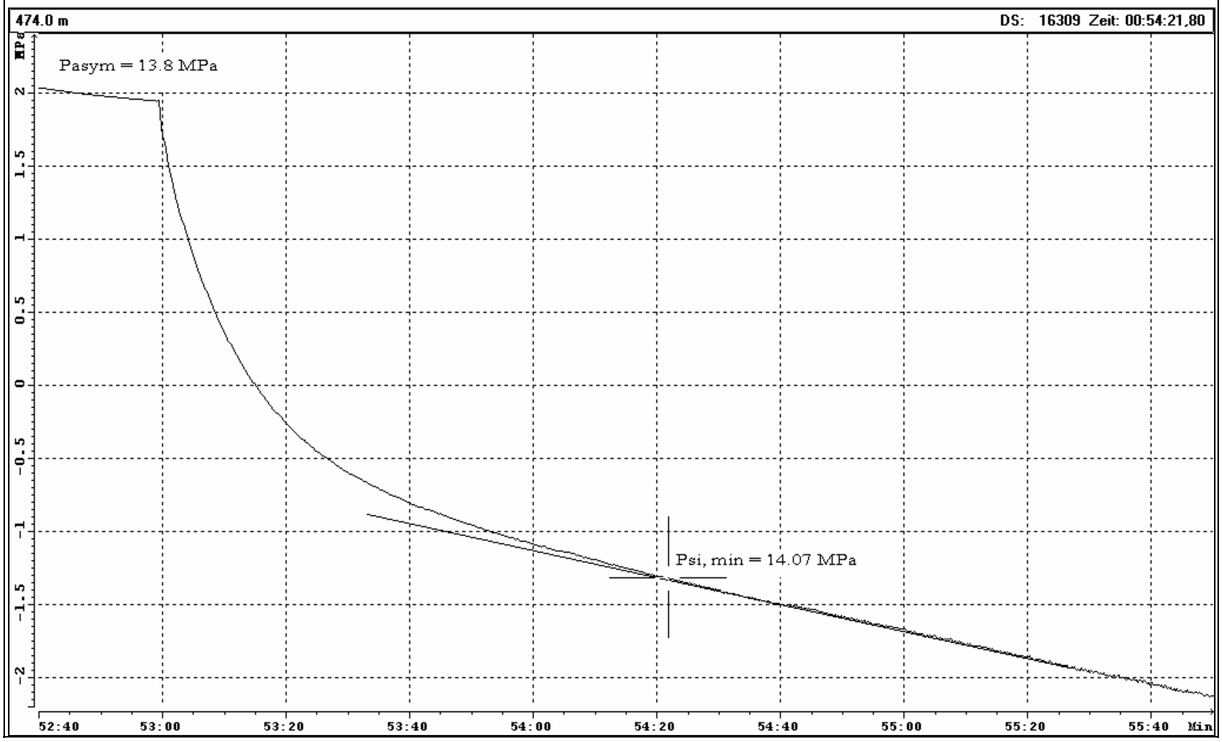
Test at 474.0 m MD: Estimation of P_r (1. Refrac - Cycle)



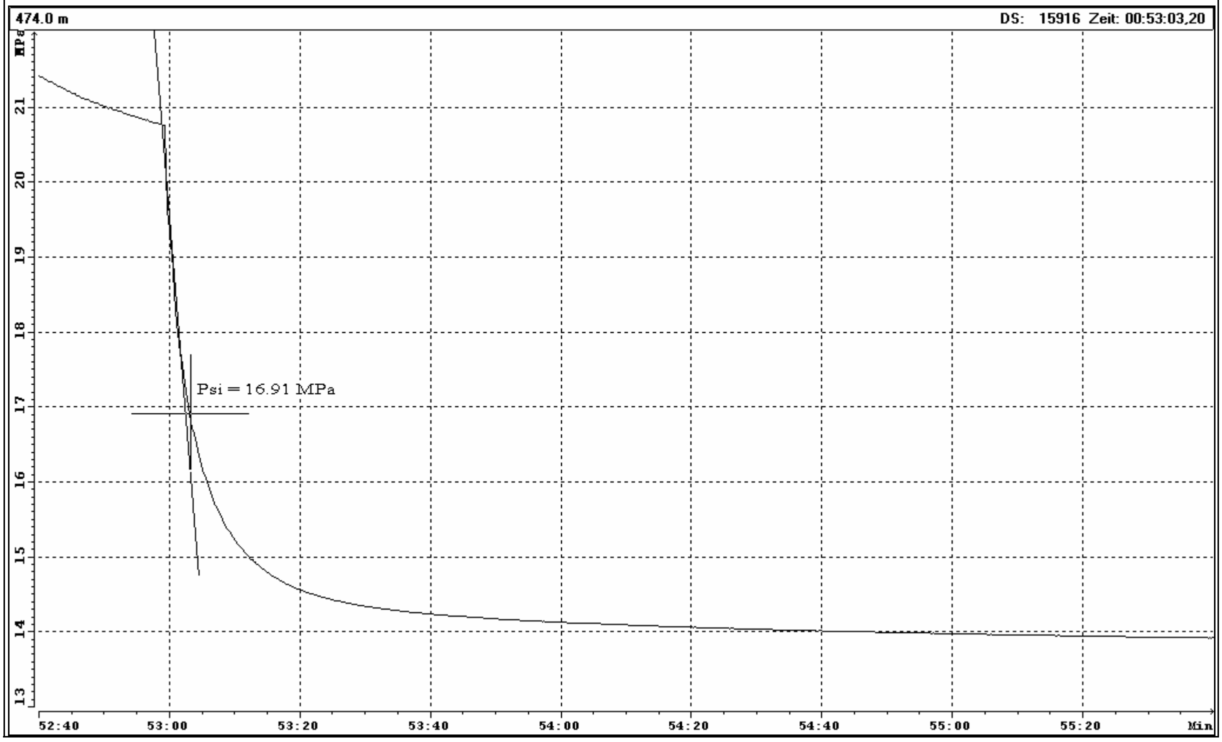
Test at 474.0 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



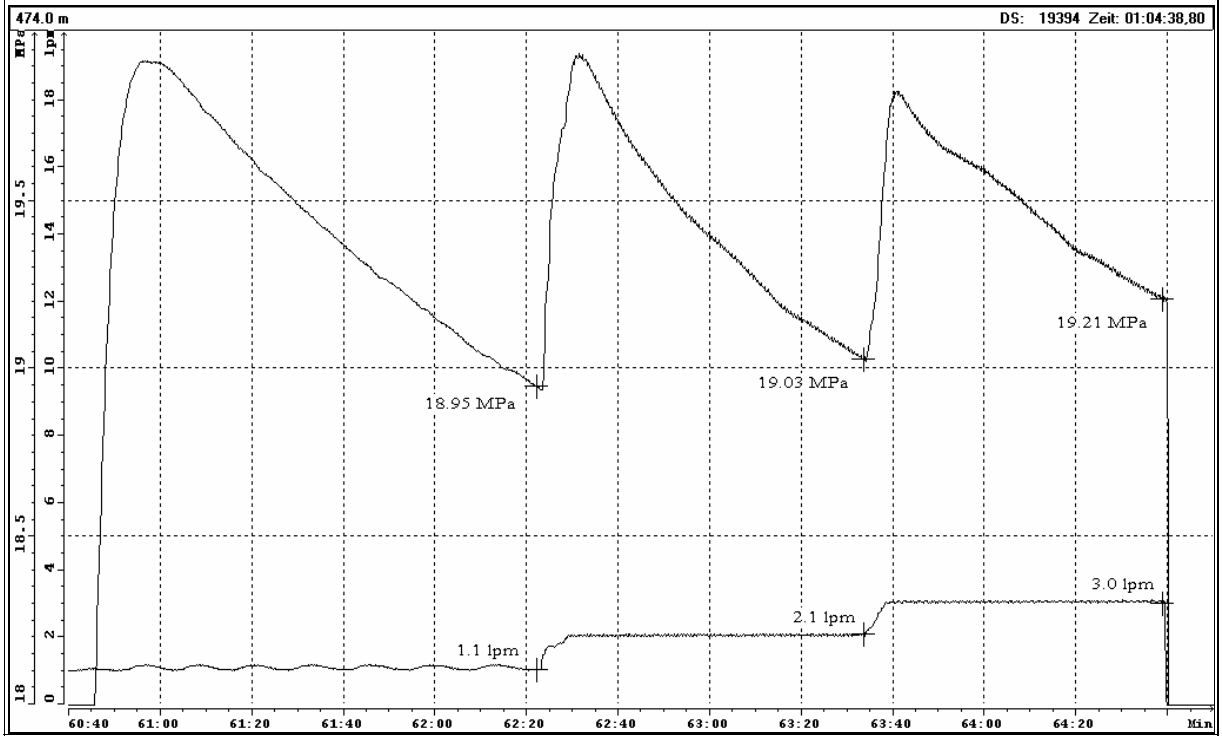
Test at 474.0 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



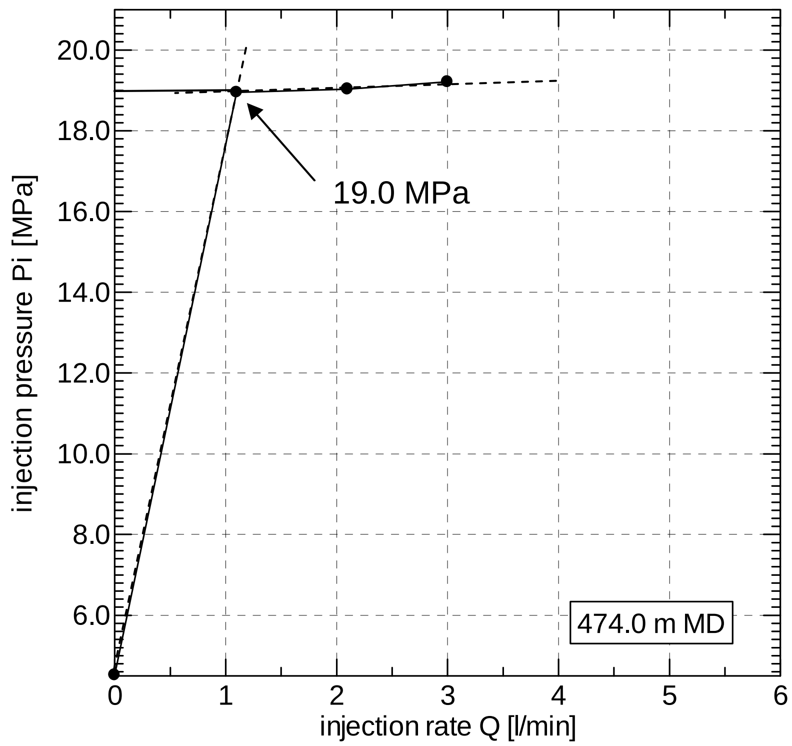
Test at 474.0 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 474.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

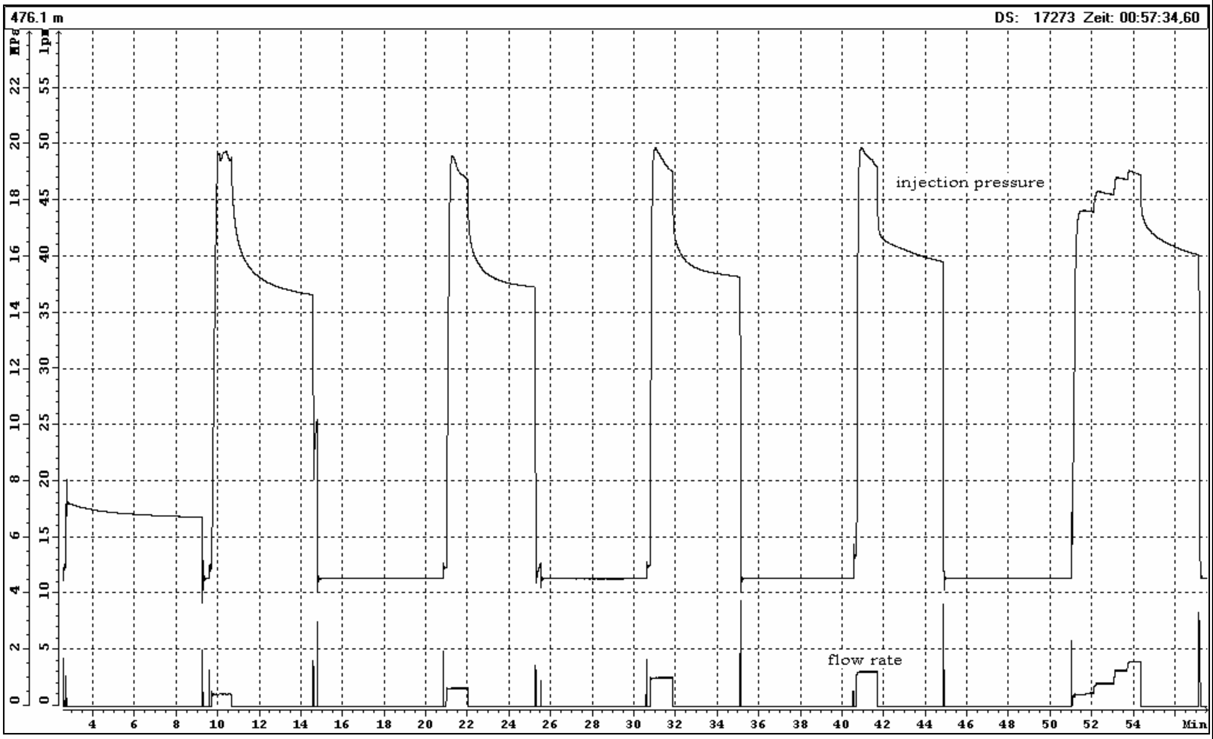


Test at 474.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 4 AT 476.1 m MD / 459.32 m TVD

Test at 476.1 m MD : Overview - Plot



P - Test Frac (1. Refrac) 2. Refrac 3. Refrac 4. Refrac SP/SR - Test

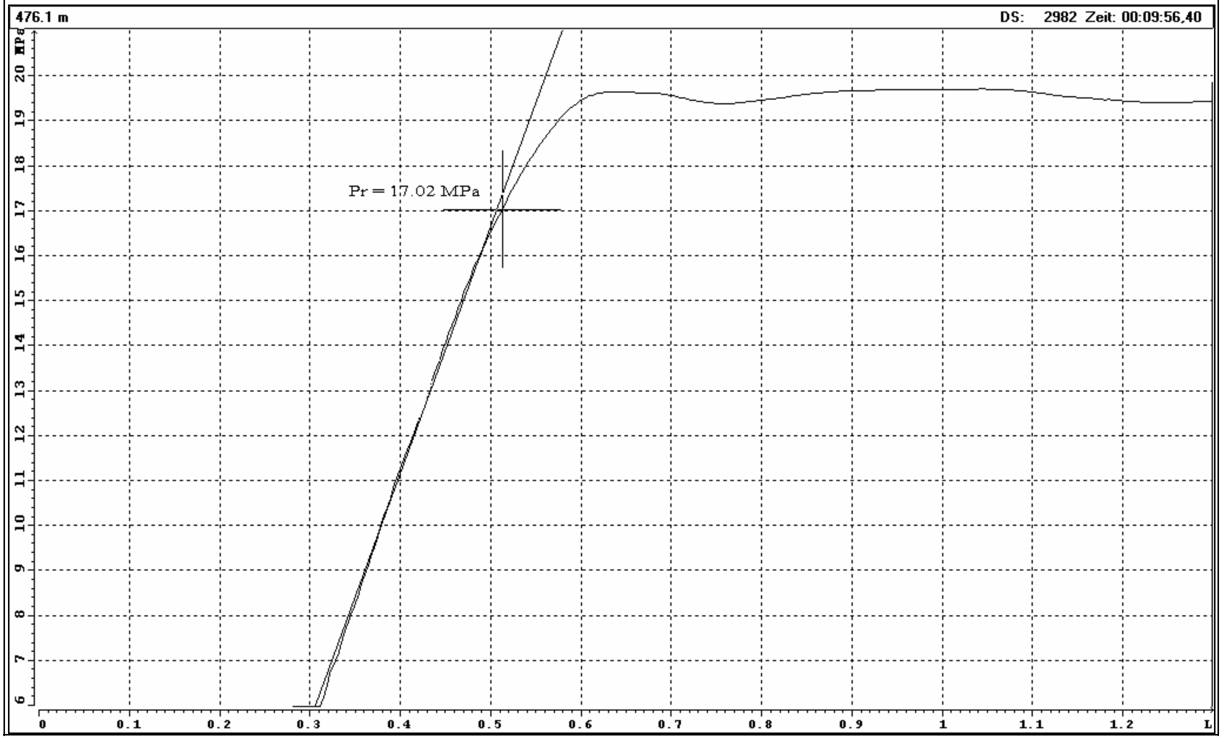
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.50 MPa in 385 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.1	Vi (l) = 1.1	Vr (l) = 0.3
2. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.7	Vr (l) = 0.3
3. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 2.8	Vr (l) = 0.5
4. Refrac - cycle	Qi (lpm) = 3.1	Vi (l) = 3.0	Vr (l) = 0.8
SP/SR - test	Qi (lpm) = 1.2-4.0	Vi (l) = 7.7	Vr (l) = 1.1

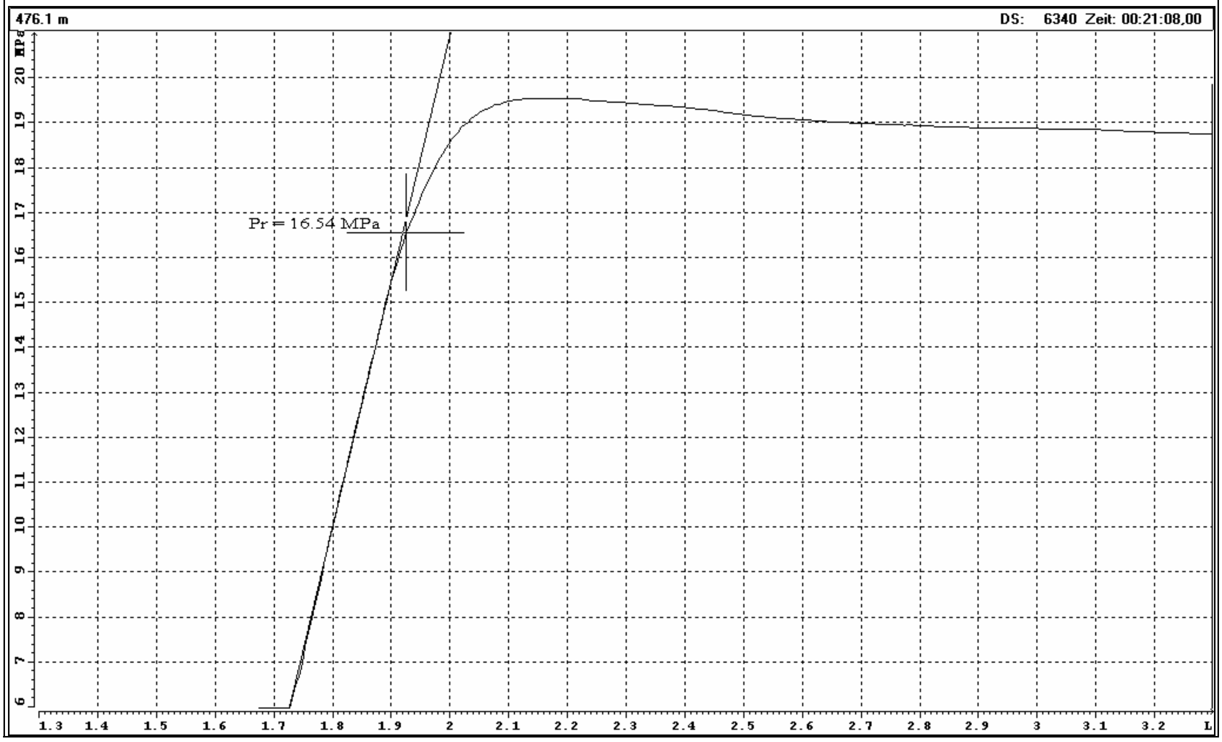
total injected volume (l): 16.3 recovered volume (l): 3.0 or 18.4 %

- Initial test type: HF
- Although the test section contains no visible fracture, the frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 20.3 MPa, followed by a pressure increase up to 27.4 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

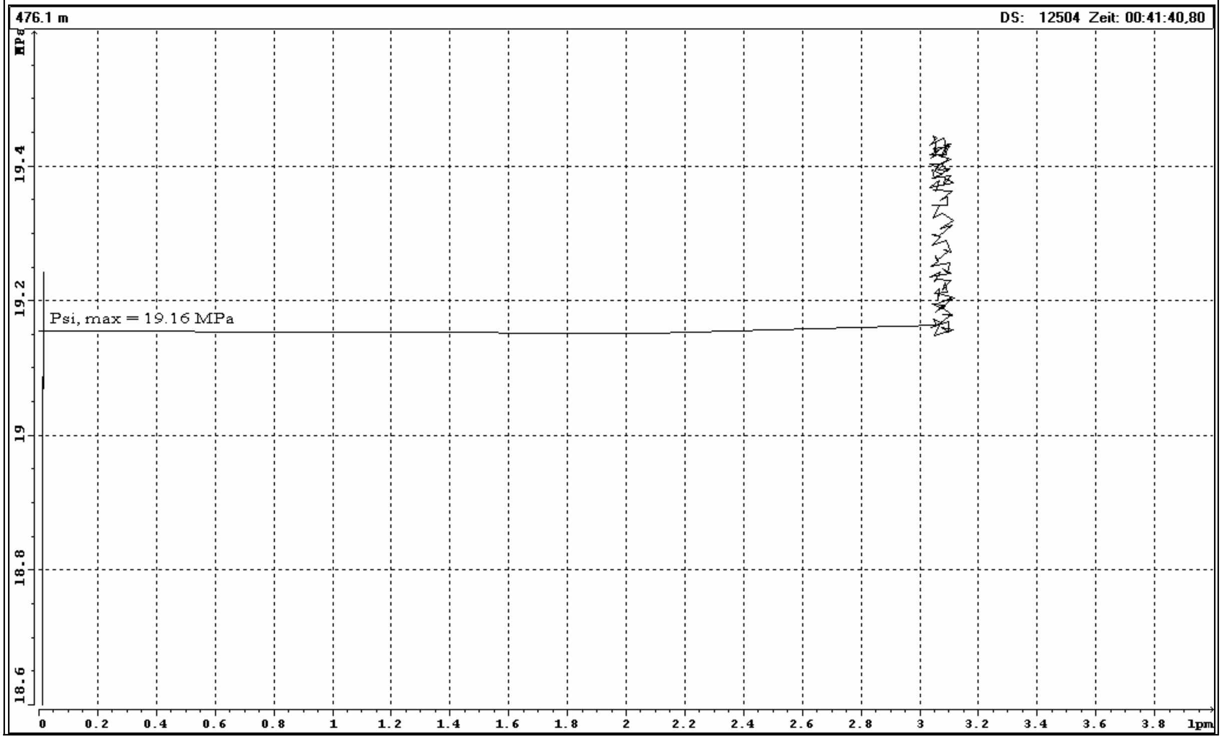
Test at 476.1 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



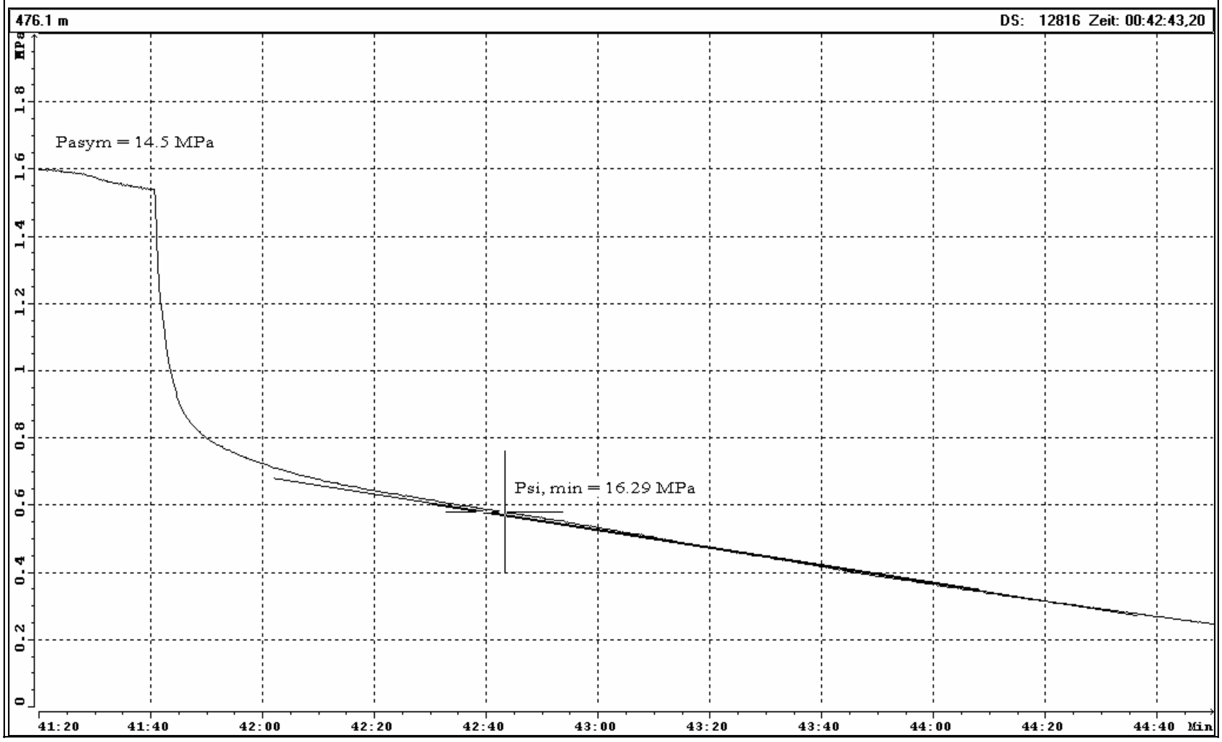
Test at 476.1 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



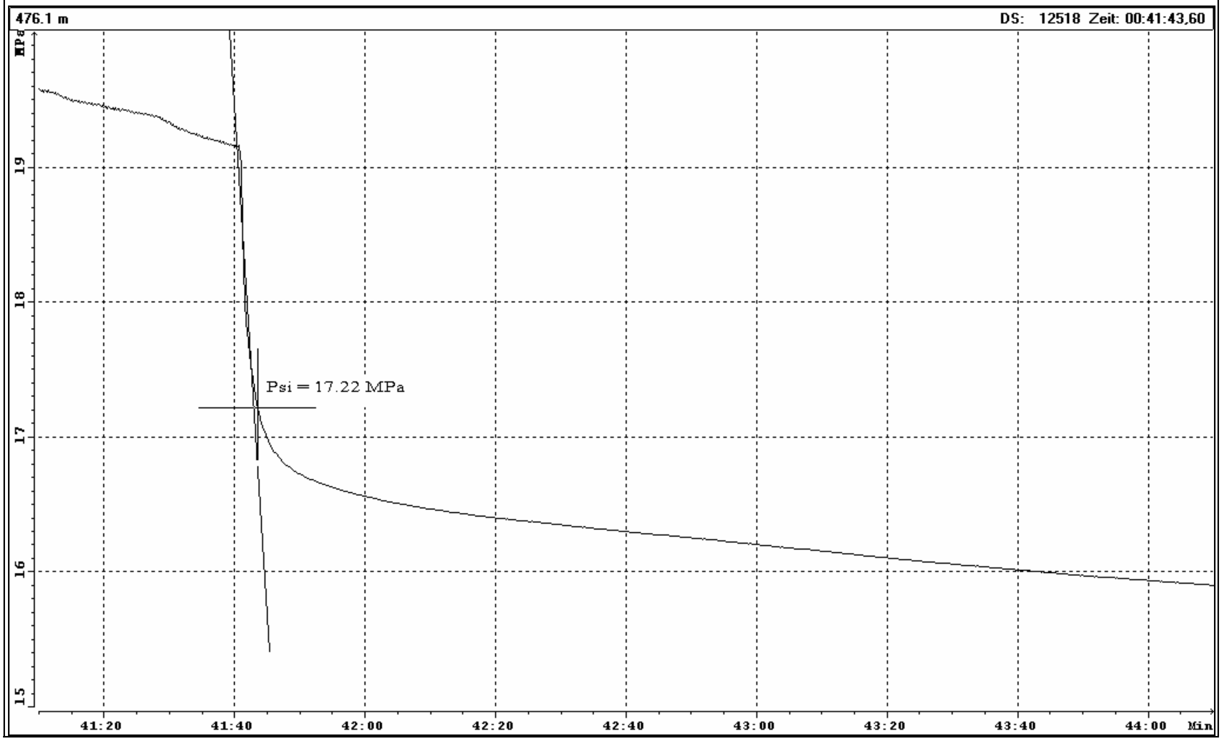
Test at 476.1 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



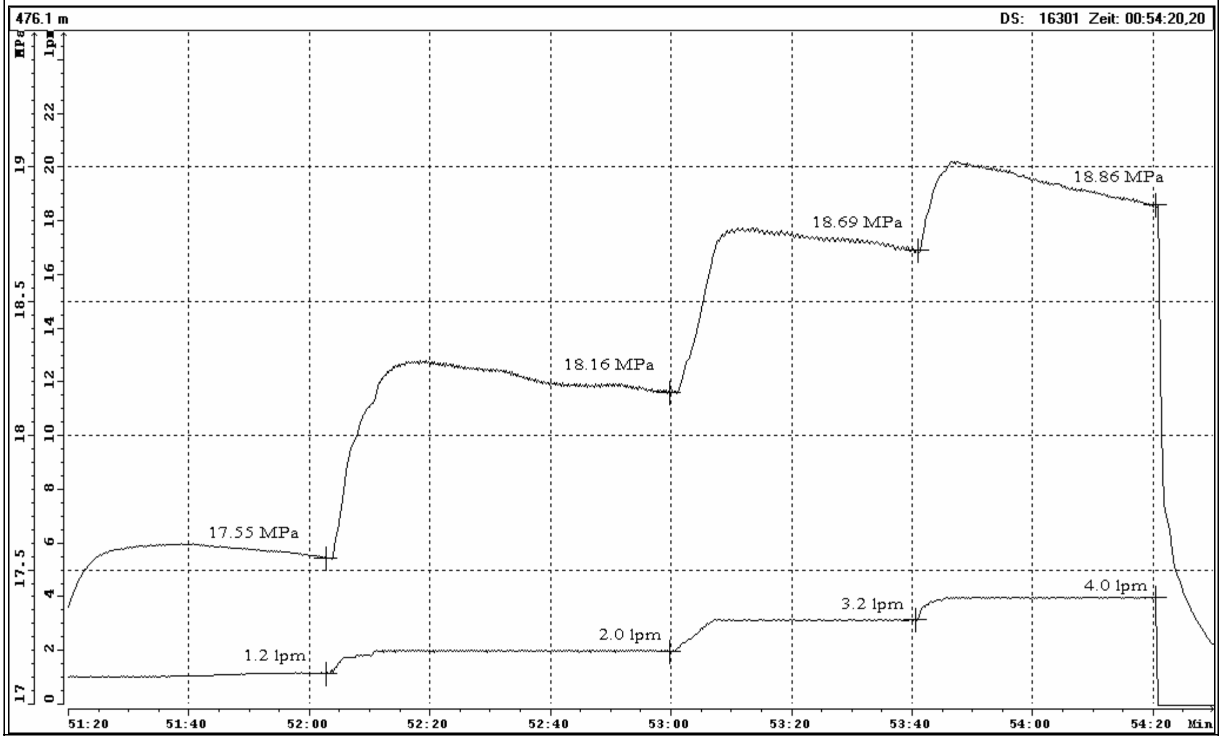
Test at 476.1 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



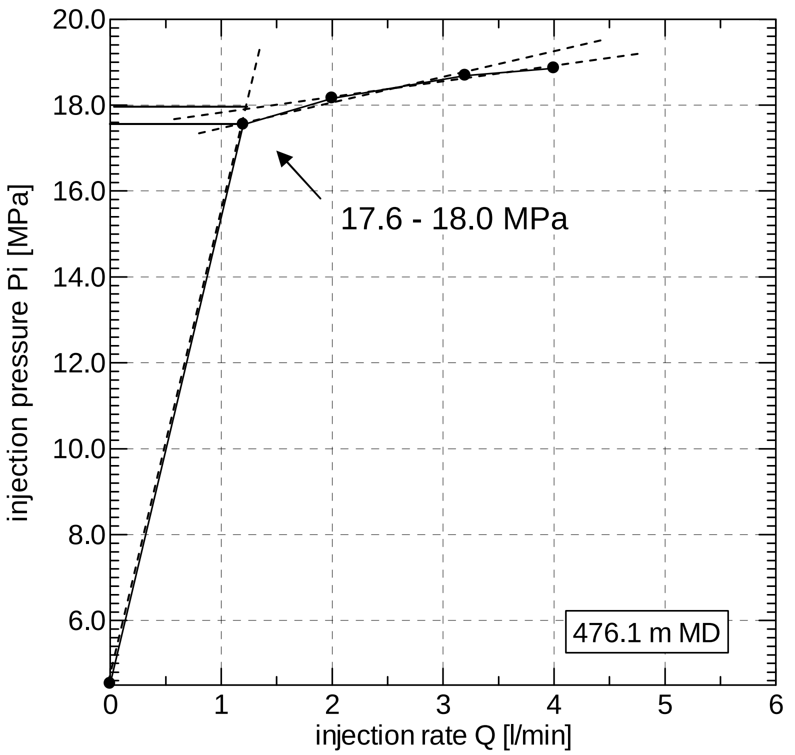
Test at 476.1 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 476.1 m MD: Analysis of Slow - Pump / Step - Rate - Test



Test at 476.1 m MD: Examination of P_{si} (Step - Rate - Test)



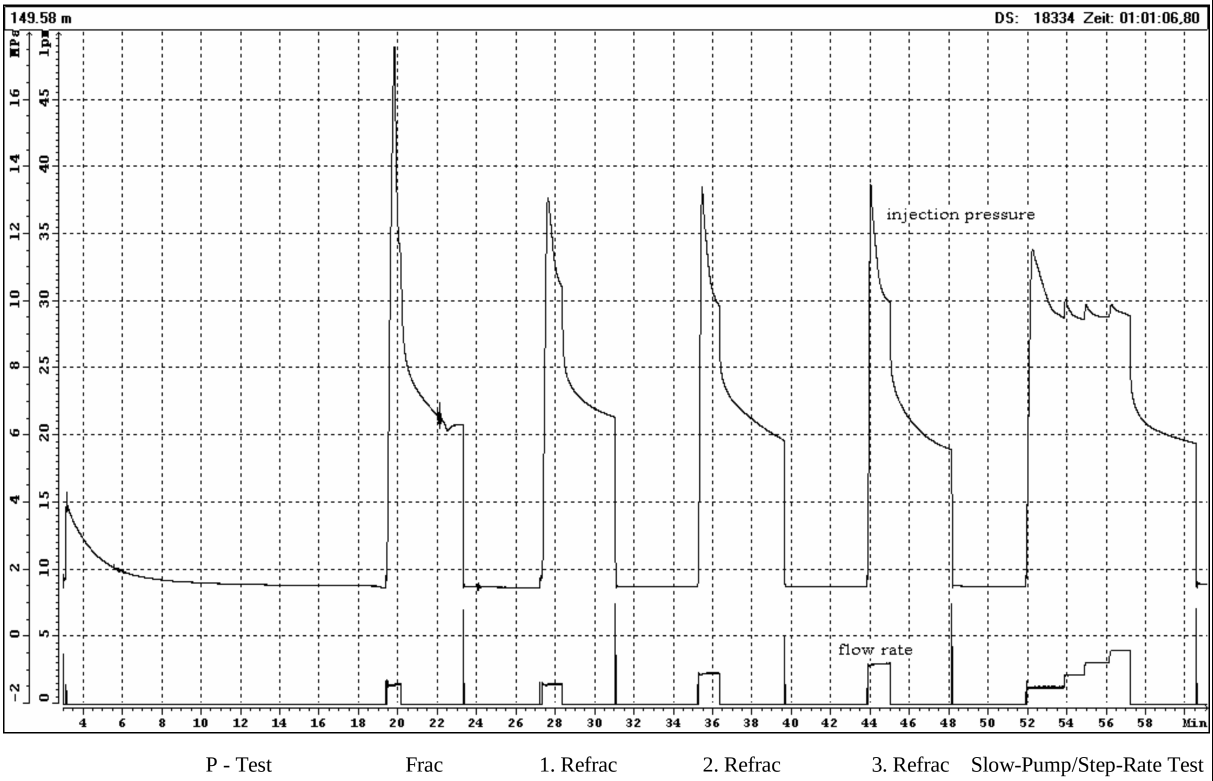
Appendix B3

Records from in-situ Hydrofrac / Hydraulic Injection Tests together with Evaluation of Characteristic Pressure Data

Borehole No. KFM02A

TEST NO. 37 AT 149.58 m MD / 149.20 m TVD

Test at 149.58 m MD : Overview - Plot



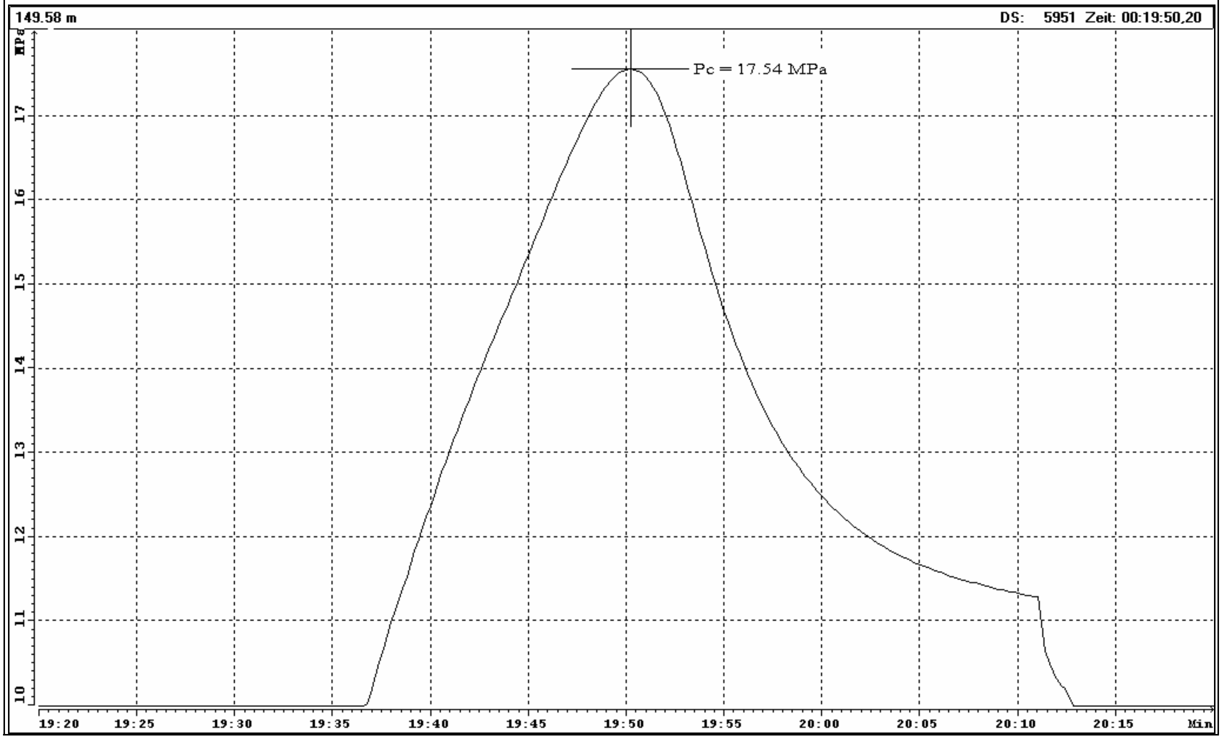
TEST SUMMARY / ANALYSIS / REMARKS

P - Test : pressure decrease: 2.31 MPa in 950 sec.

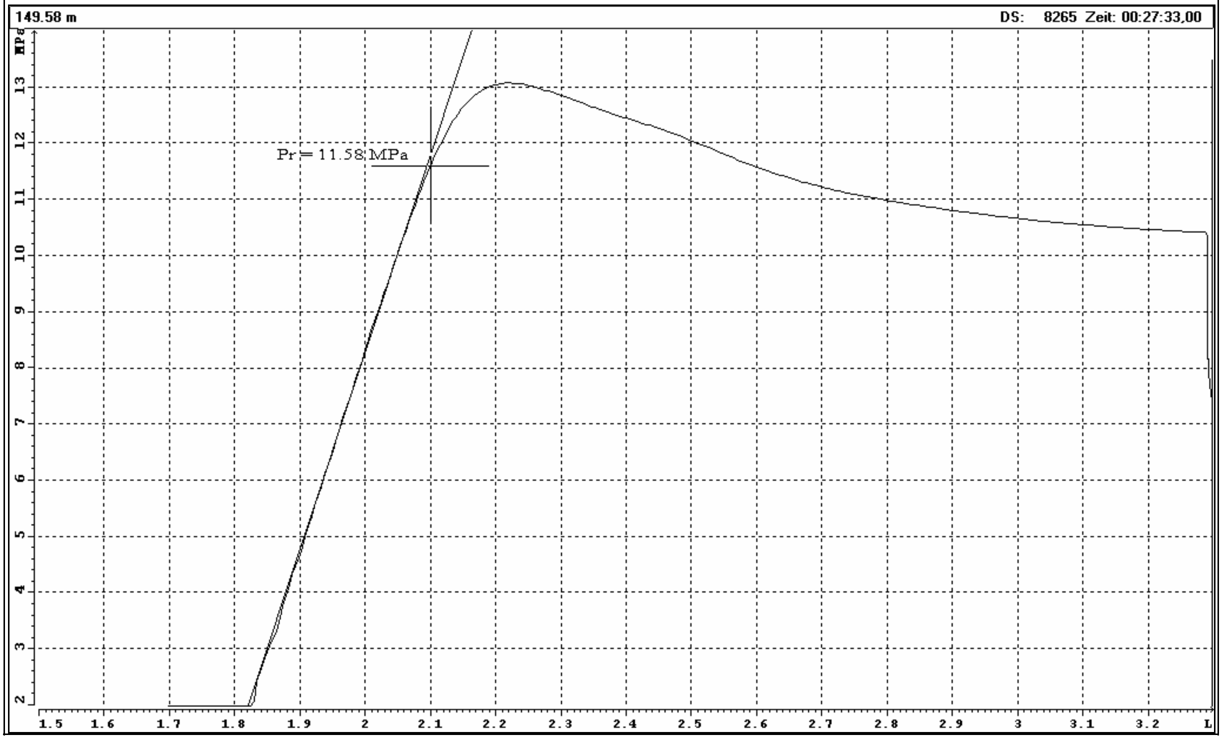
Frac - cycle	Qi (lpm) =	1.4		Vi (l) =	1.1		Vr (l) =	0.3	
1. Refrac - cycle	Qi (lpm) =	1.5		Vi (l) =	1.5		Vr (l) =	0.6	
2. Refrac - cycle	Qi (lpm) =	2.3		Vi (l) =	2.5		Vr (l) =	0.8	
3. Refrac - cycle	Qi (lpm) =	3.0		Vi (l) =	3.4		Vr (l) =	1.0	
SP/SR - test	Qi (lpm) =	1.2-4.0		Vi (l) =	12.75		Vr (l) =	1.0	
total injected volume (l):	21.25		recovered volume (l):			3.7	or	17.4	%

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. and 2. refrac - cycle, since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

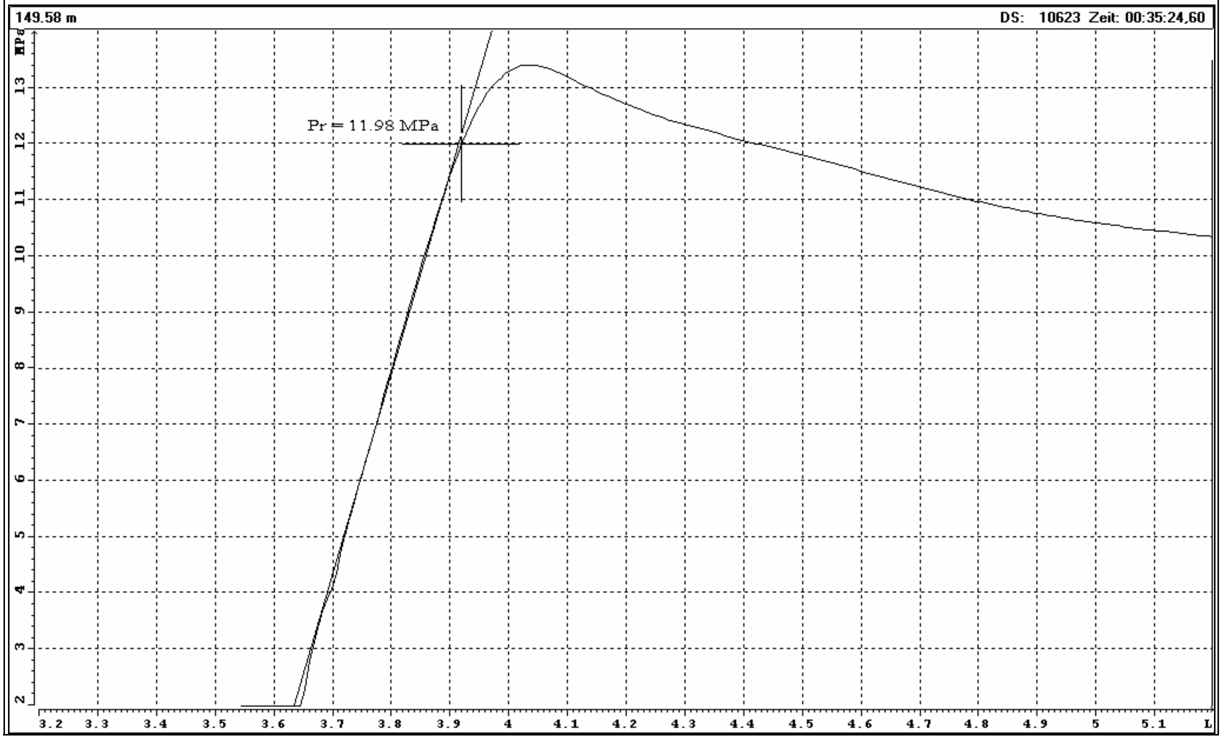
Test at 149.58 m MD: Estimation of P_c (Frac - Cycle)



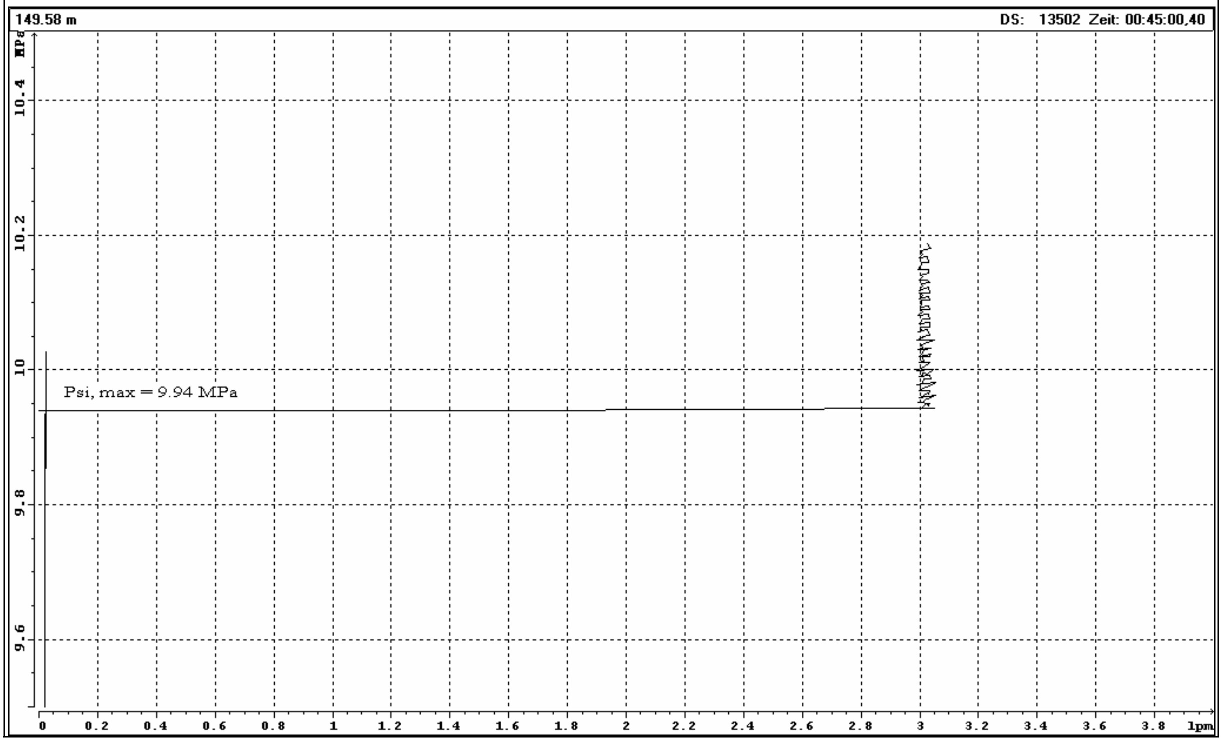
Test at 149.58 m MD: Estimation of P_r (1. Refrac - Cycle)



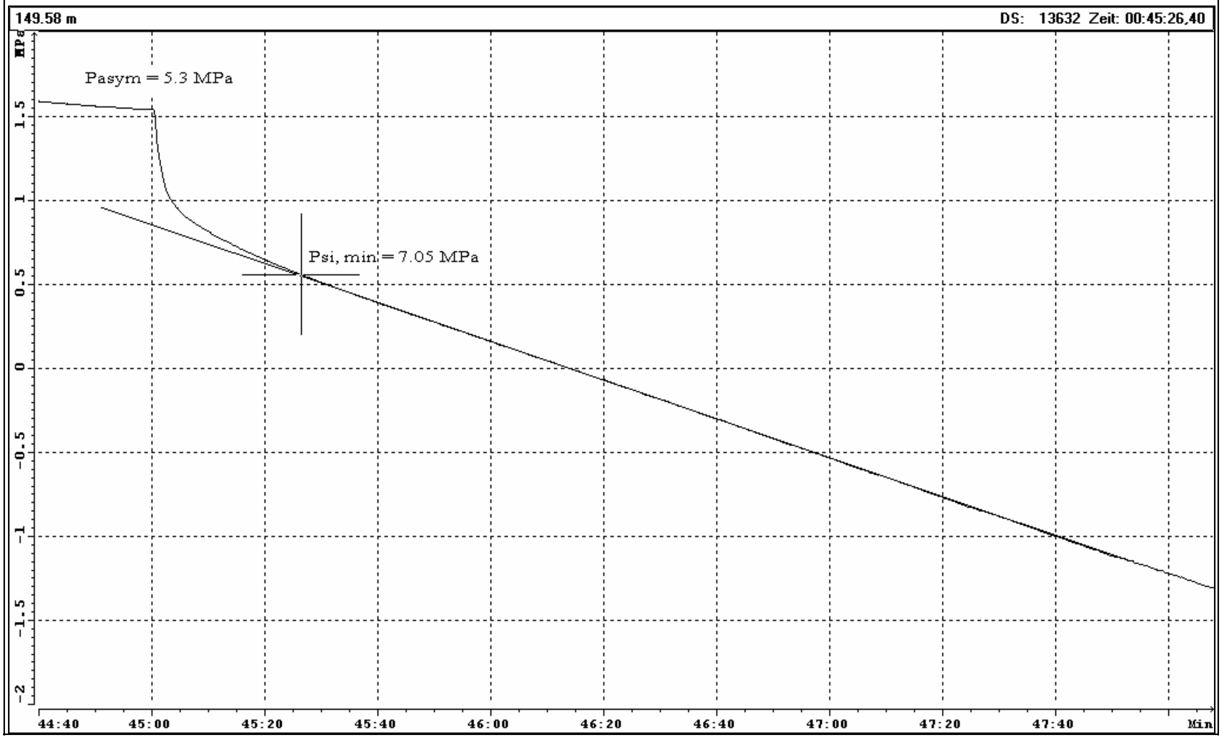
Test at 149.58 m MD: Estimation of P_r (2. Refrac - Cycle)



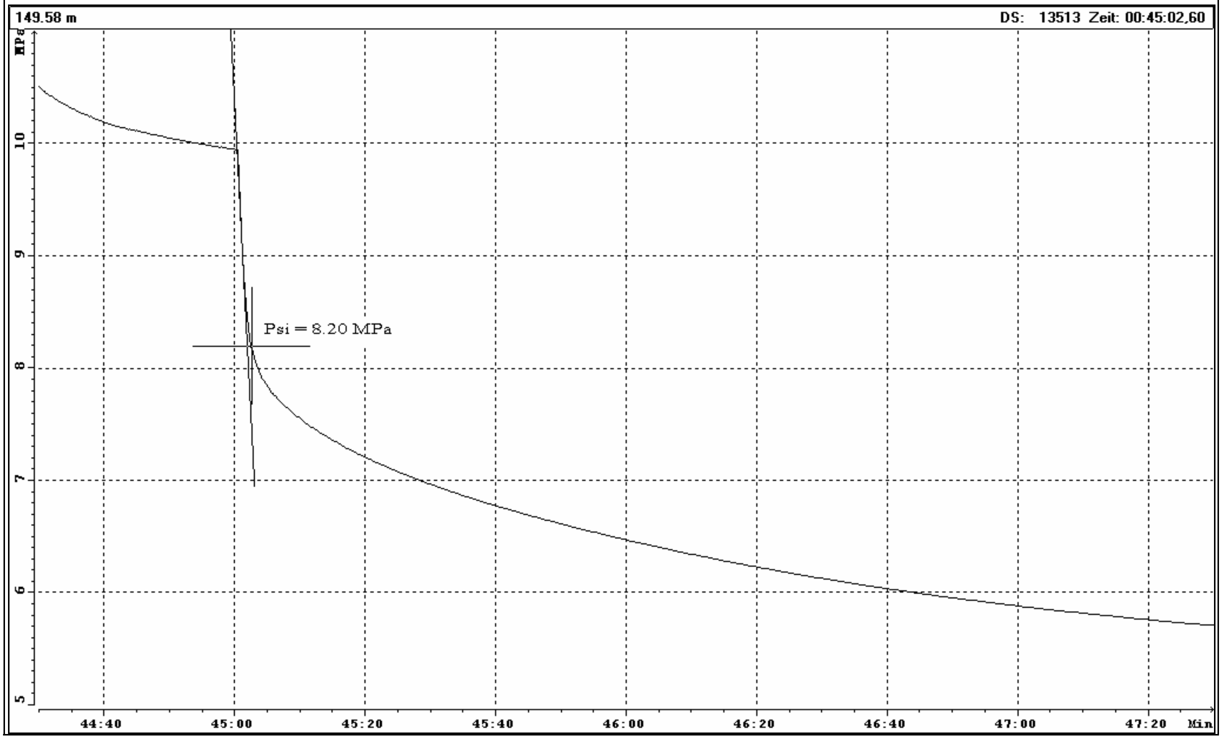
Test at 149.58 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



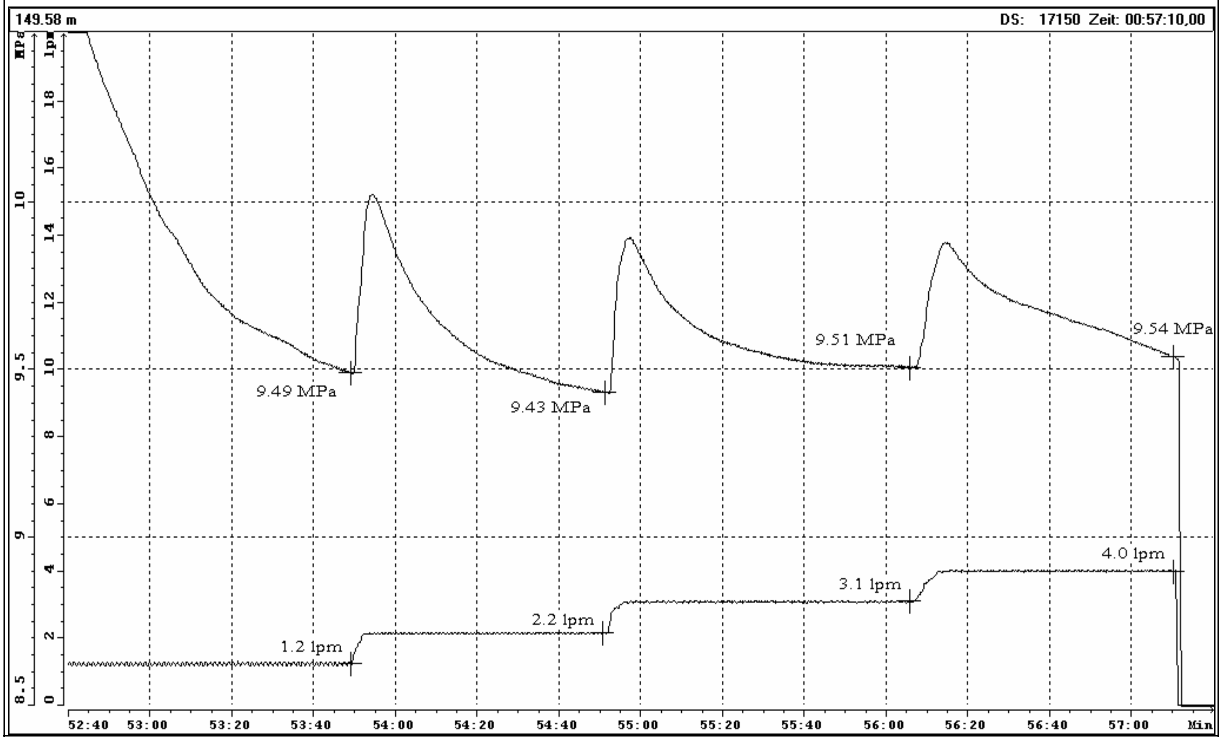
Test at 149.58 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



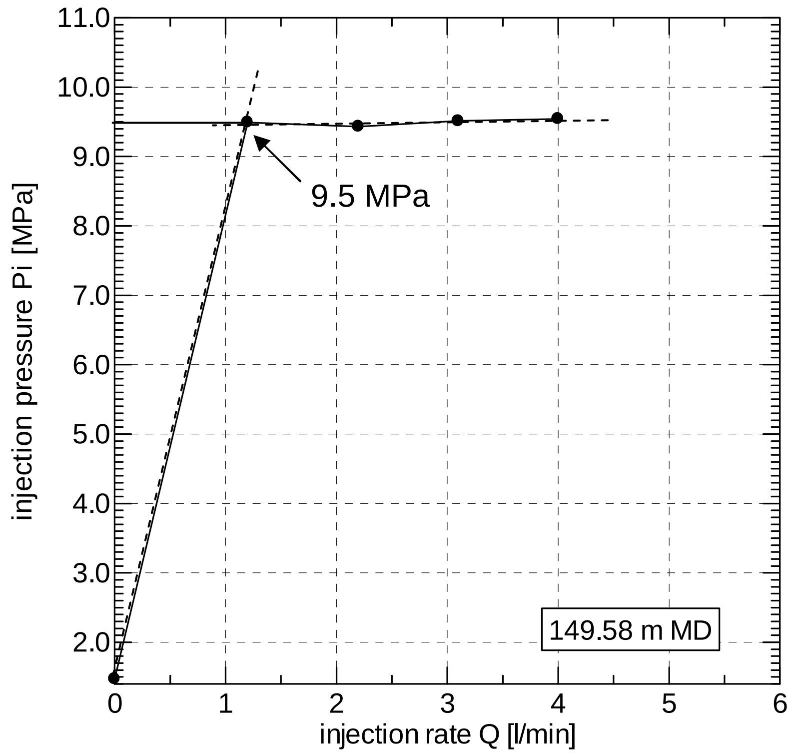
Test at 149.58 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 149.58 m MD: Analysis of Slow - Pump / Step - Rate - Test

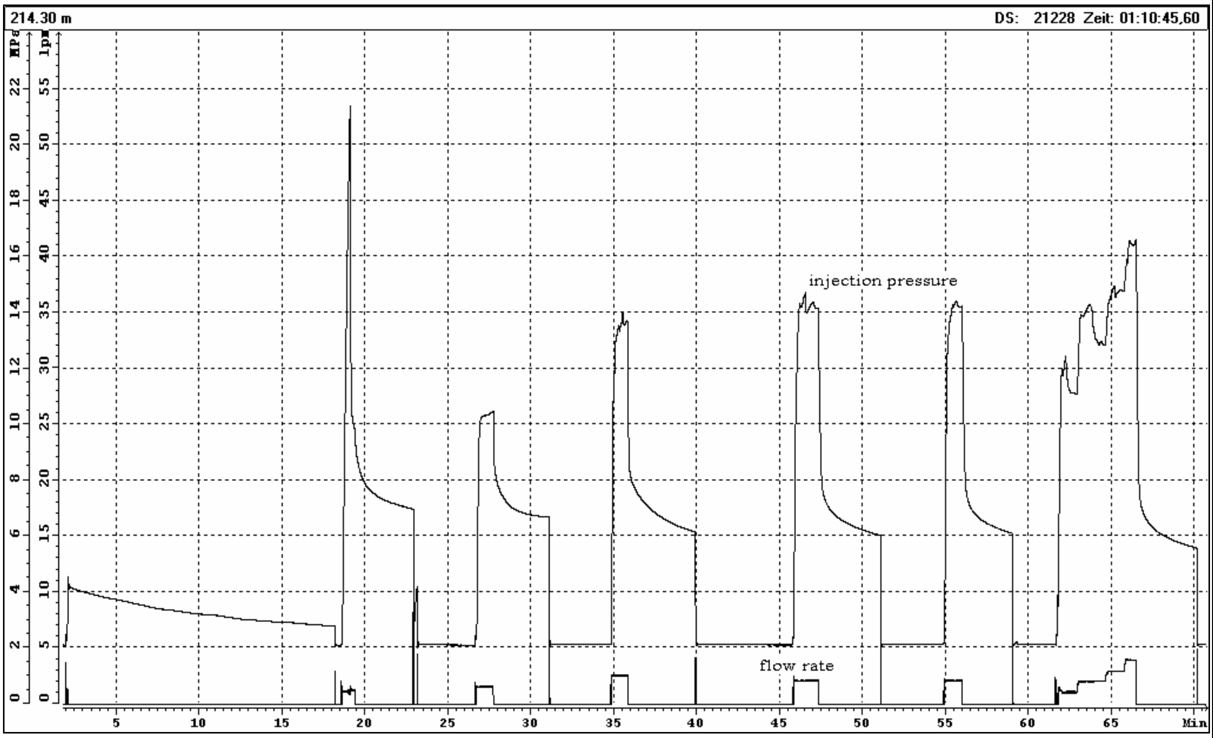


Test at 149.58 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 36 AT 214.30 m MD / 213.71 m TVD

Test at 214.30 m MD: Overview - Plot



P - Test Frac 1. Refrac 2. Refrac 3. Refrac 4. Refrac SP/SR - Test

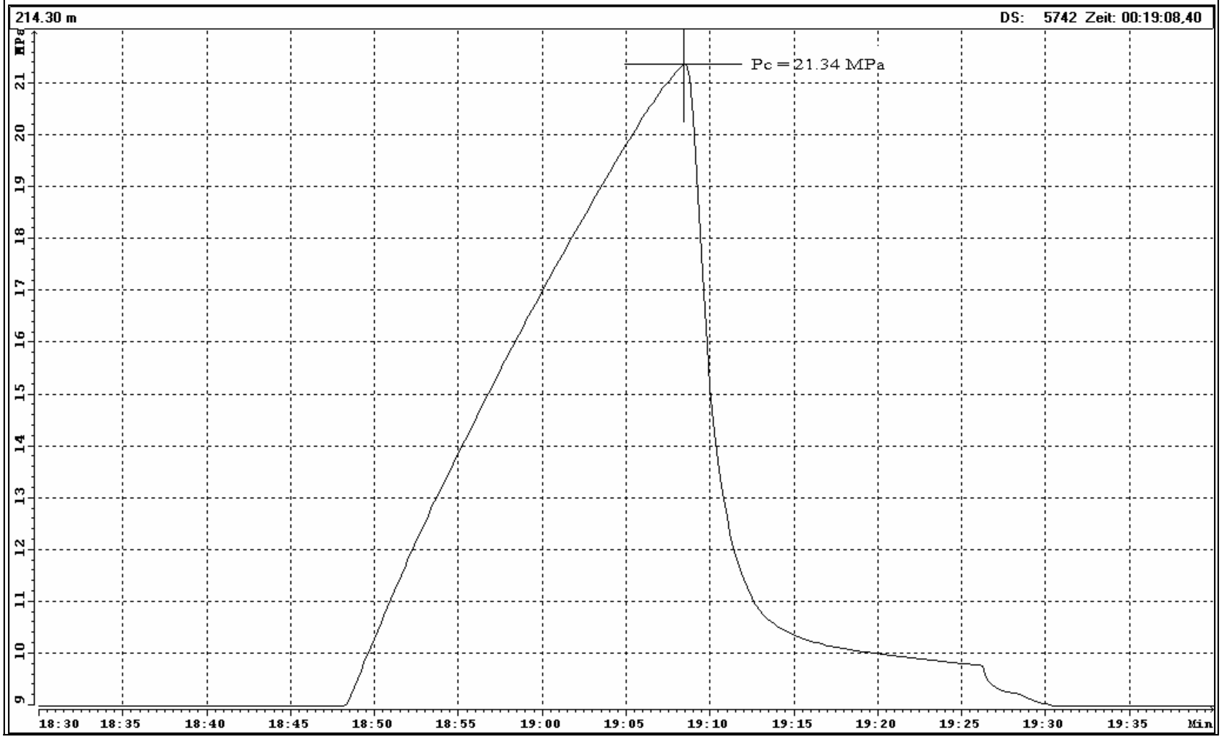
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.38 MPa in 956 sec.		
Frac - cycle	Qi (lpm) = 1.2	Vi (l) = 1.0	Vr (l) = 0.4
1. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.7	Vr (l) = 0.6
2. Refrac - cycle	Qi (lpm) = 2.5	Vi (l) = 2.6	Vr (l) = 0.6
3. Refrac - cycle	Qi (lpm) = 2.1	Vi (l) = 3.2	Vr (l) = 0.5
4. Refrac - cycle	Qi (lpm) = 2.1	Vi (l) = 2.3	Vr (l) = 0.3
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 11.0	Vr (l) = 0.4

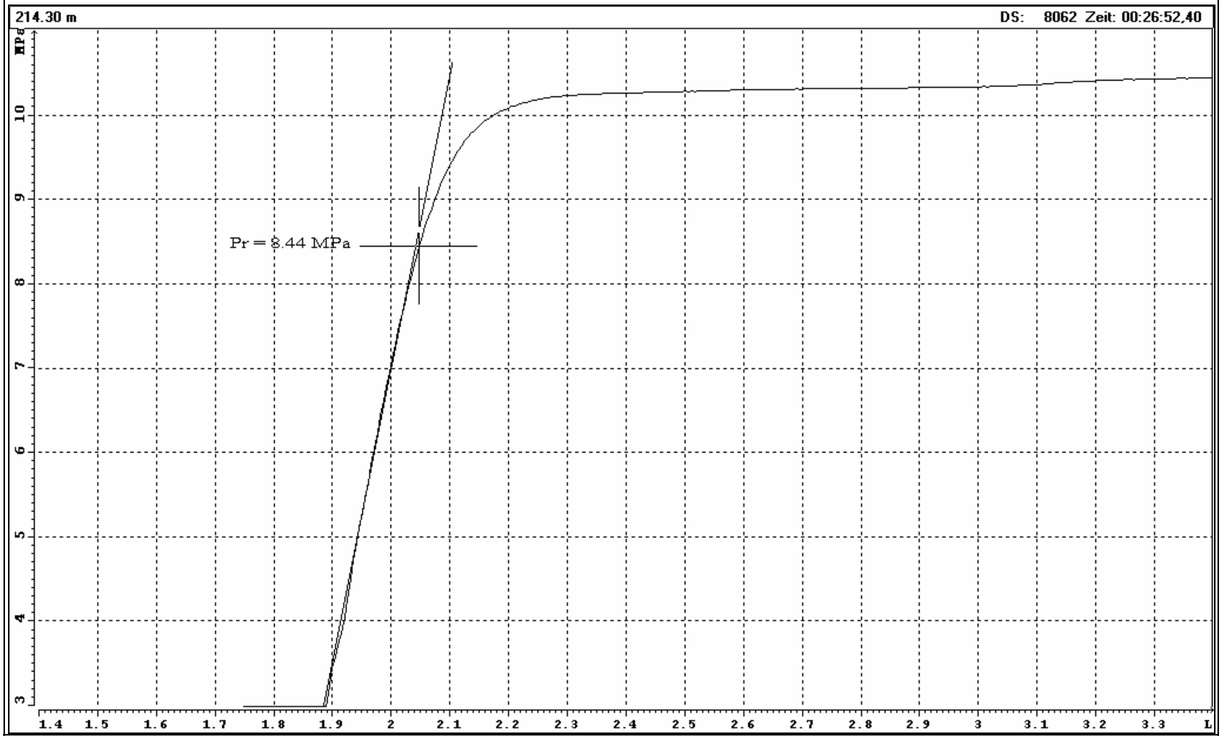
total injected volume (l): 21.8 recovered volume (l): 2.8 or 12.8 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- A significant increase of the injection pressure was observed between the 1. and 2. refrac - cycle as well as during the slow - pump / step-rate test.
- The refrac - pressure was determined from the 1. and 4. refrac - cycle, since the later cycle with slightly higher injection flow-rate yield a higher and more distinct fracture re-opening pressure.
- The shut-in phases yield distinct shut-in pressure values, which, however, increased from 8.2 MPa during the 3. refrac - cycle to 9.1 MPa during the 4. refrac - cycle. Therefore, the shut - in pressure of the 3. refrac - cycle was used for the stress analysis.

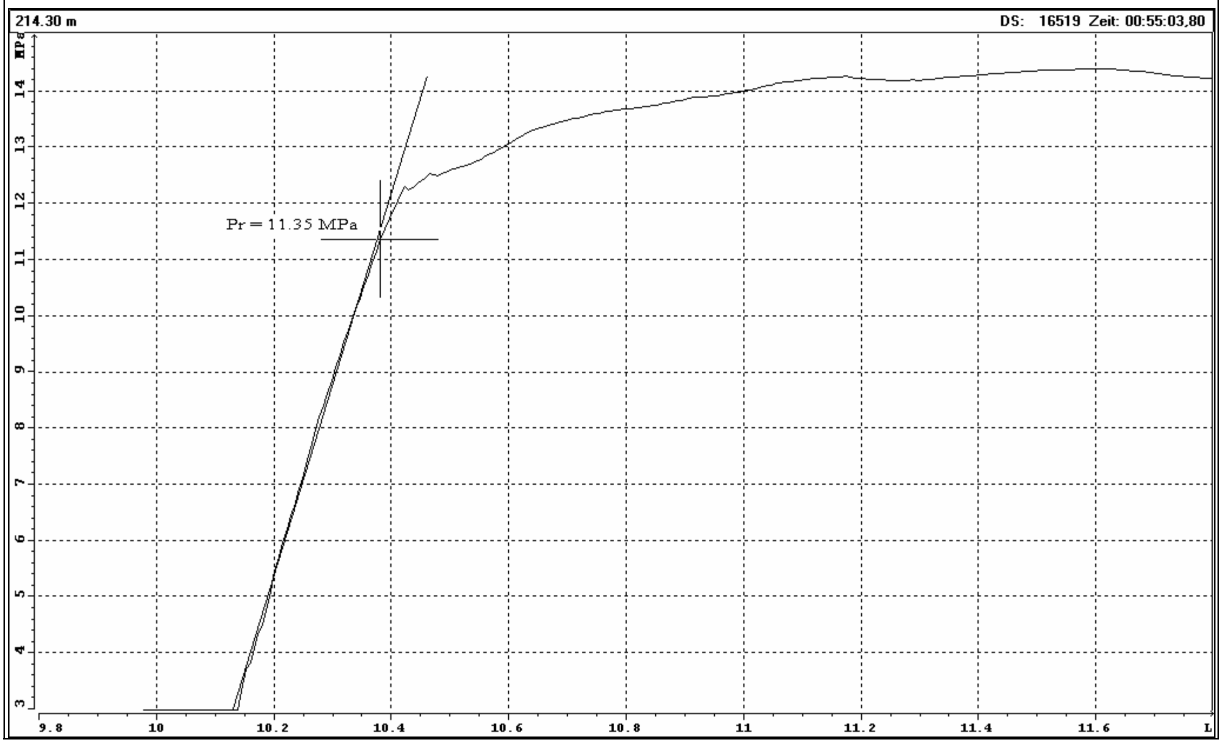
Test at 214.30 m MD: Estimation of P_c (Frac - Cycle)



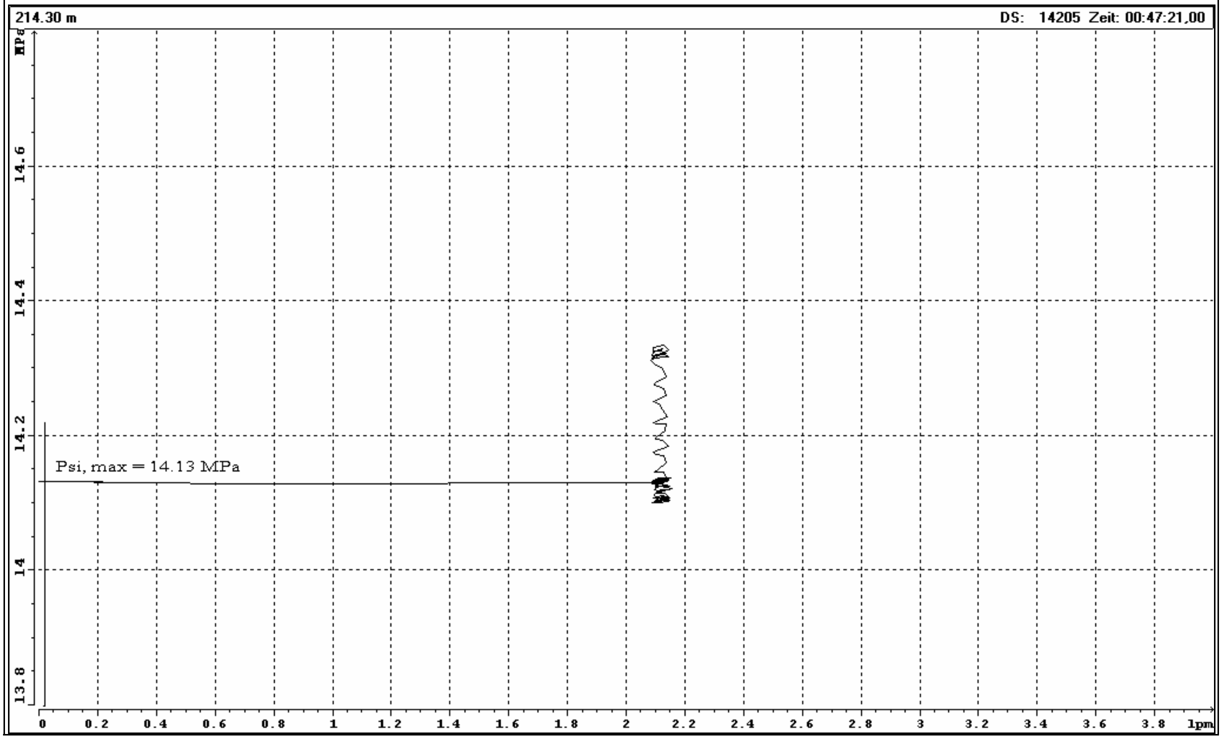
Test at 214.30 m MD: Estimation of P_r (1. Refrac - Cycle)



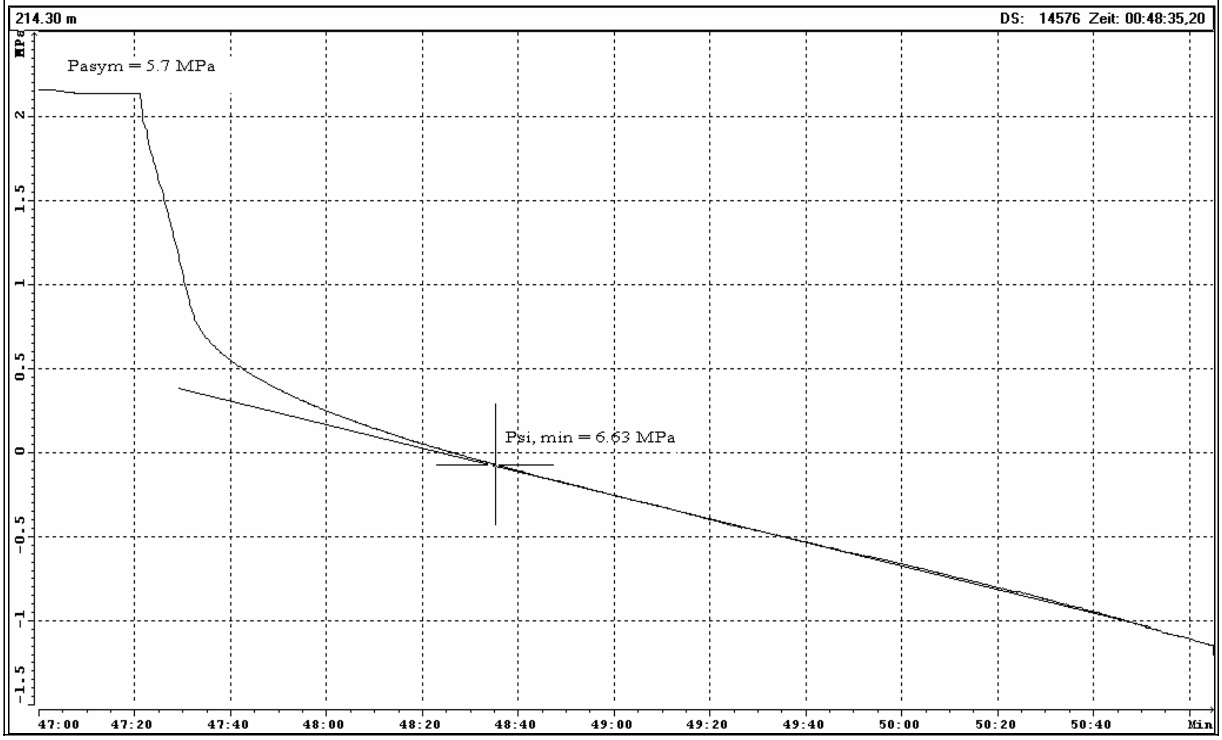
Test at 214.30 m MD: Estimation of P_r (4. Refrac - Cycle)



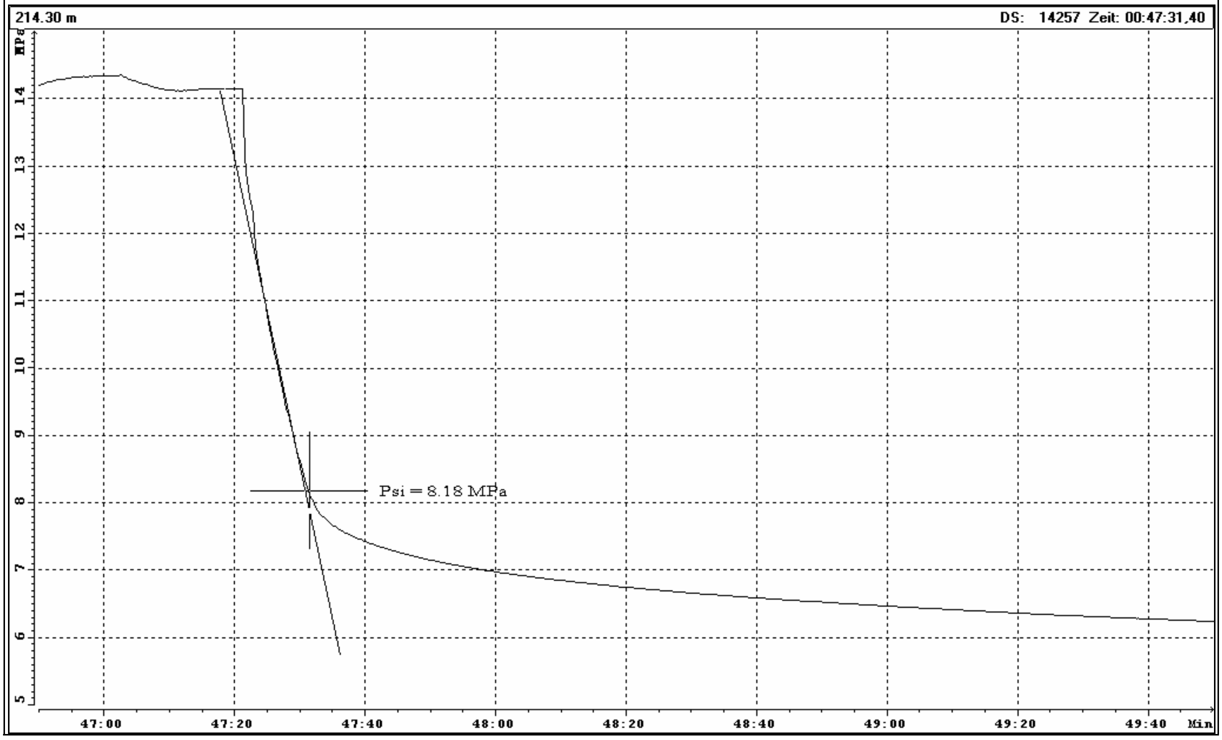
Test at 214.30 m MD: Estimation of $P_{si,\,max}$ (3. Refrac - Cycle)



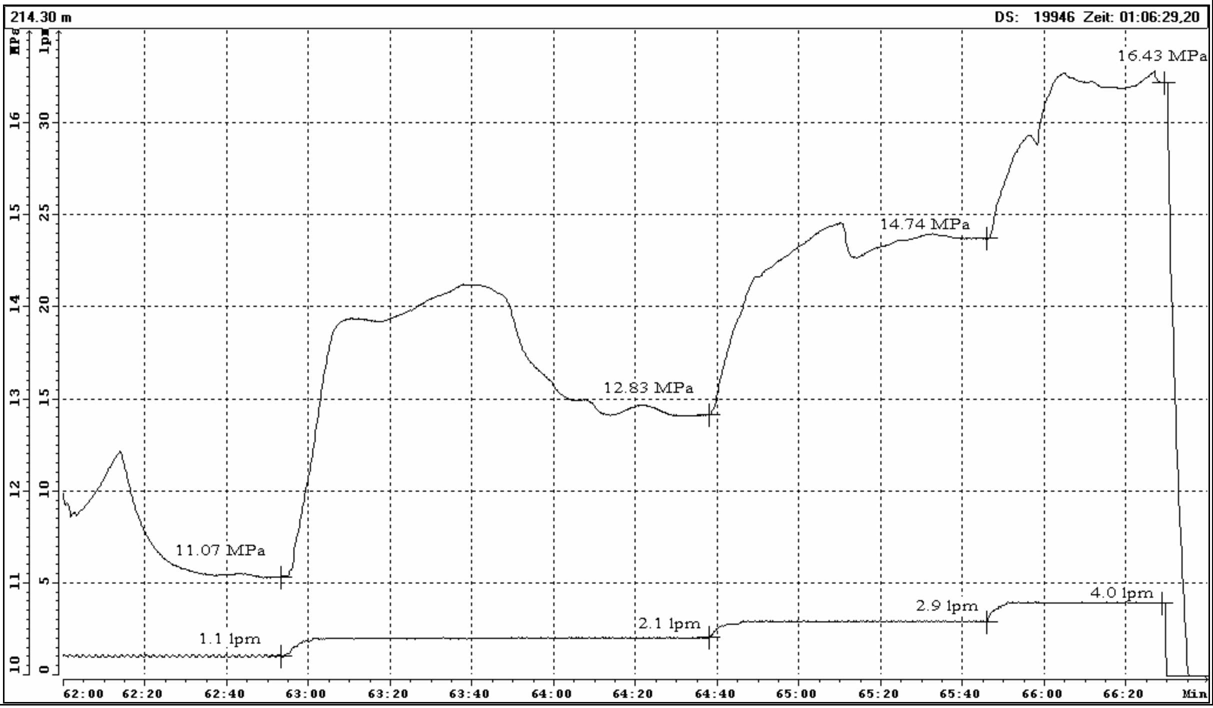
Test at 214.30 m MD: Estimation of $P_{si,\,min}$ (3. Refrac - Cycle)



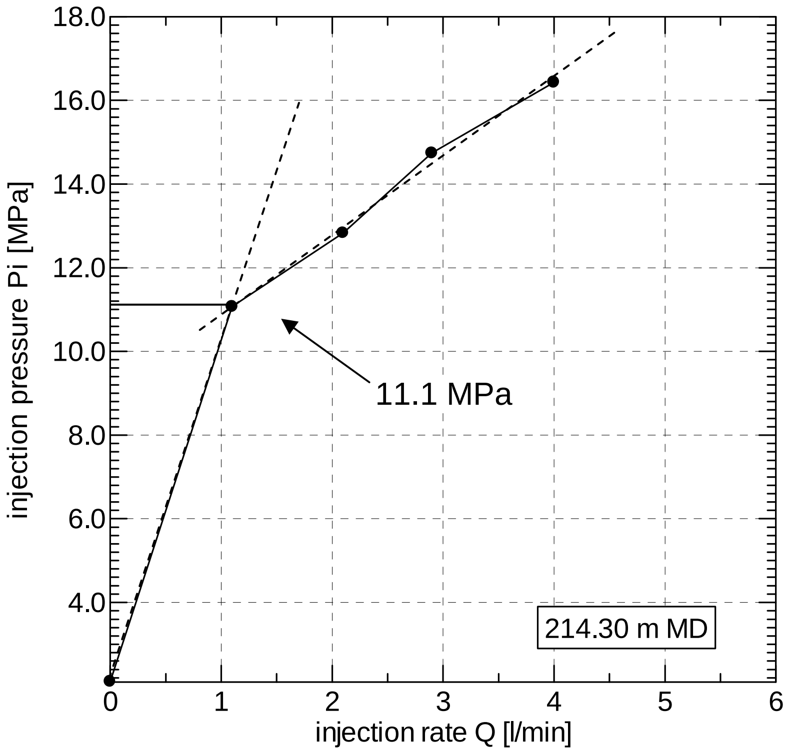
Test at 214.30 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 214.30 m MD: Analysis of Slow - Pump / Step - Rate - Test

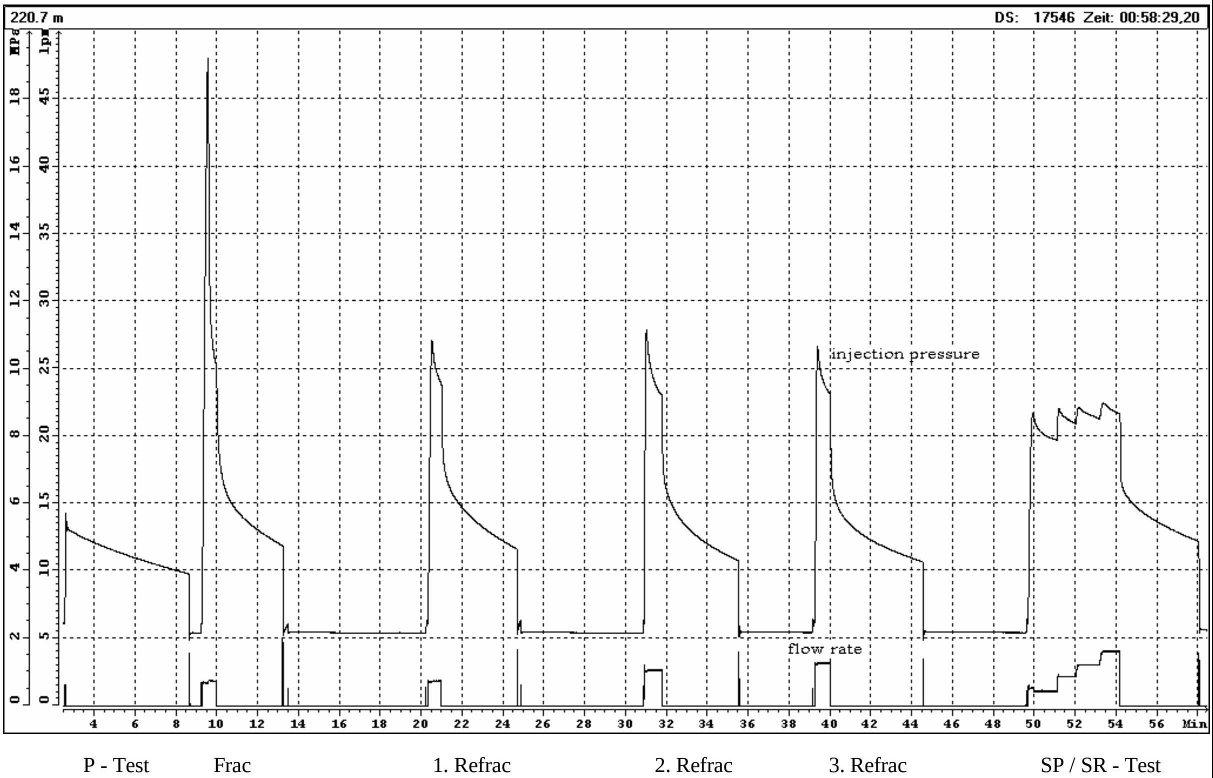


Test at 214.30 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 35 AT 220.7 m MD / 220.09 m TVD

Test at 220.7 m MD: Overview - Plot



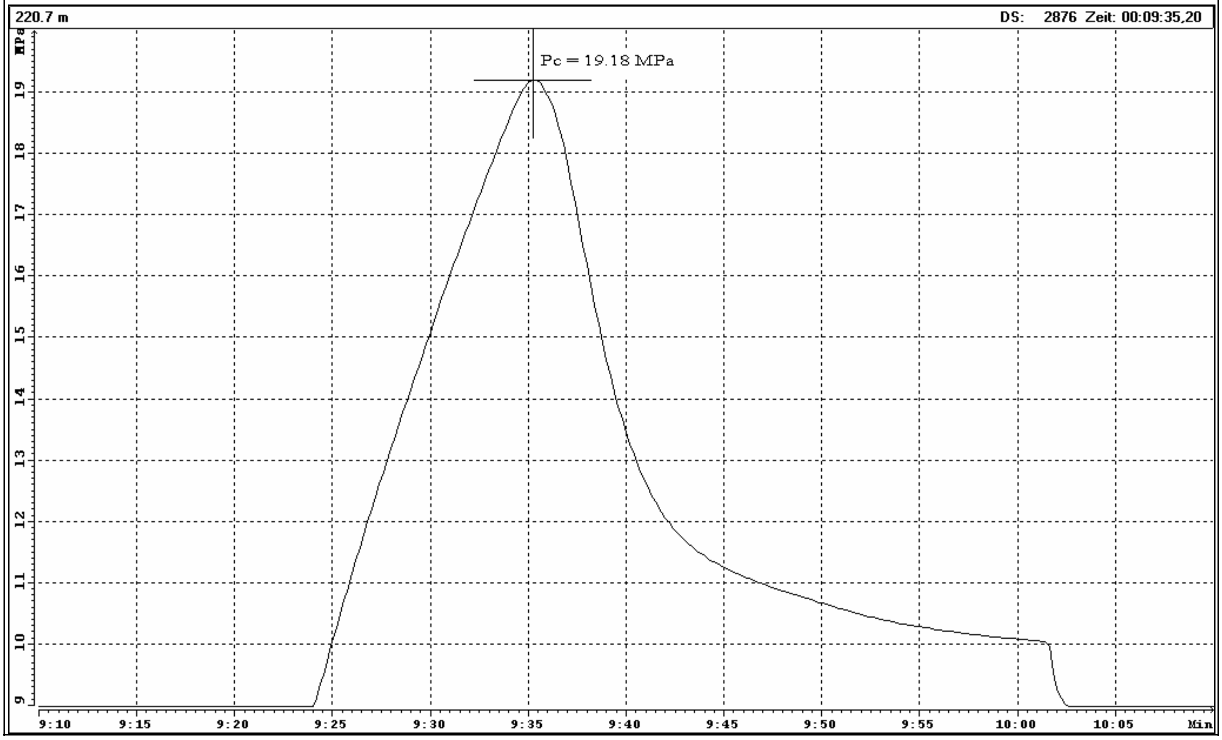
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.31 MPa in 353 sec.		
Frac - cycle	Qi (lpm) = 1.7	Vi (l) = 1.3	Vr (l) = 0.2
1. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 1.2	Vr (l) = 0.3
2. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 2.35	Vr (l) = 0.2
3. Refrac - cycle	Qi (lpm) = 3.2	Vi (l) = 2.4	Vr (l) = 0.3
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 11.1	Vr (l) = 1.1

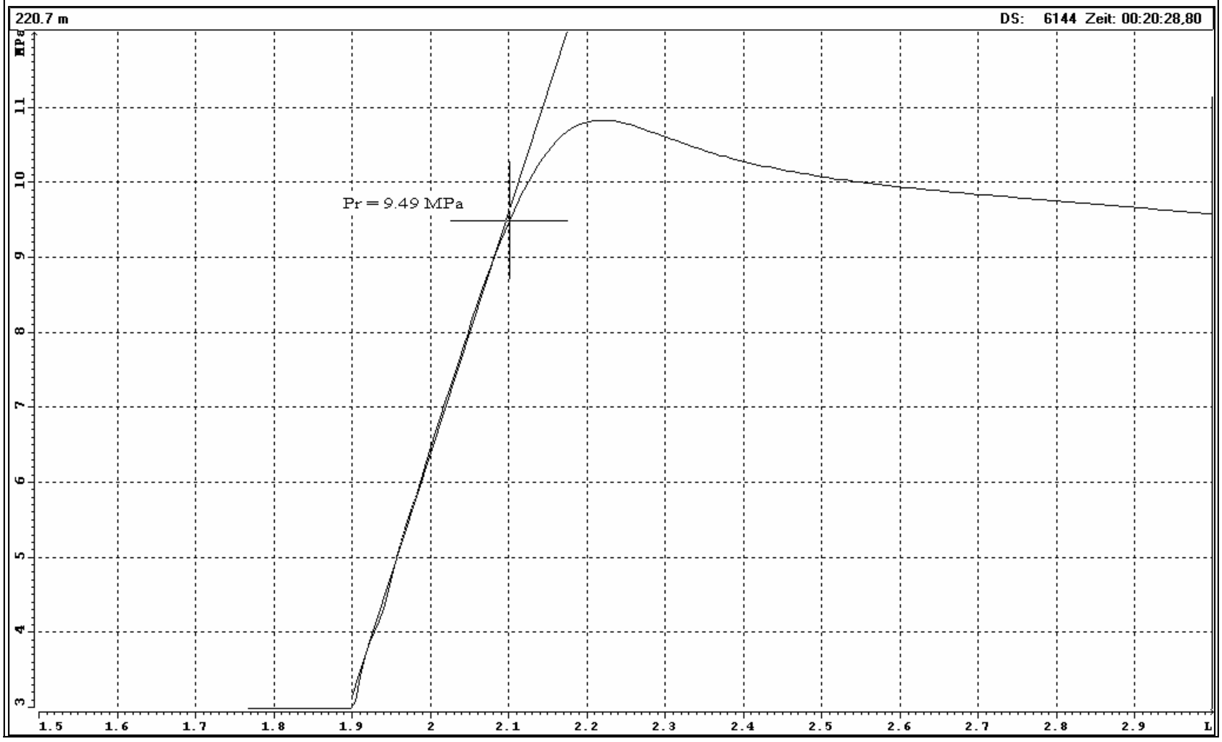
total injected volume (l): 18.35 recovered volume (l): 2.1 or 11.4 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (distinct breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield nearly identical fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

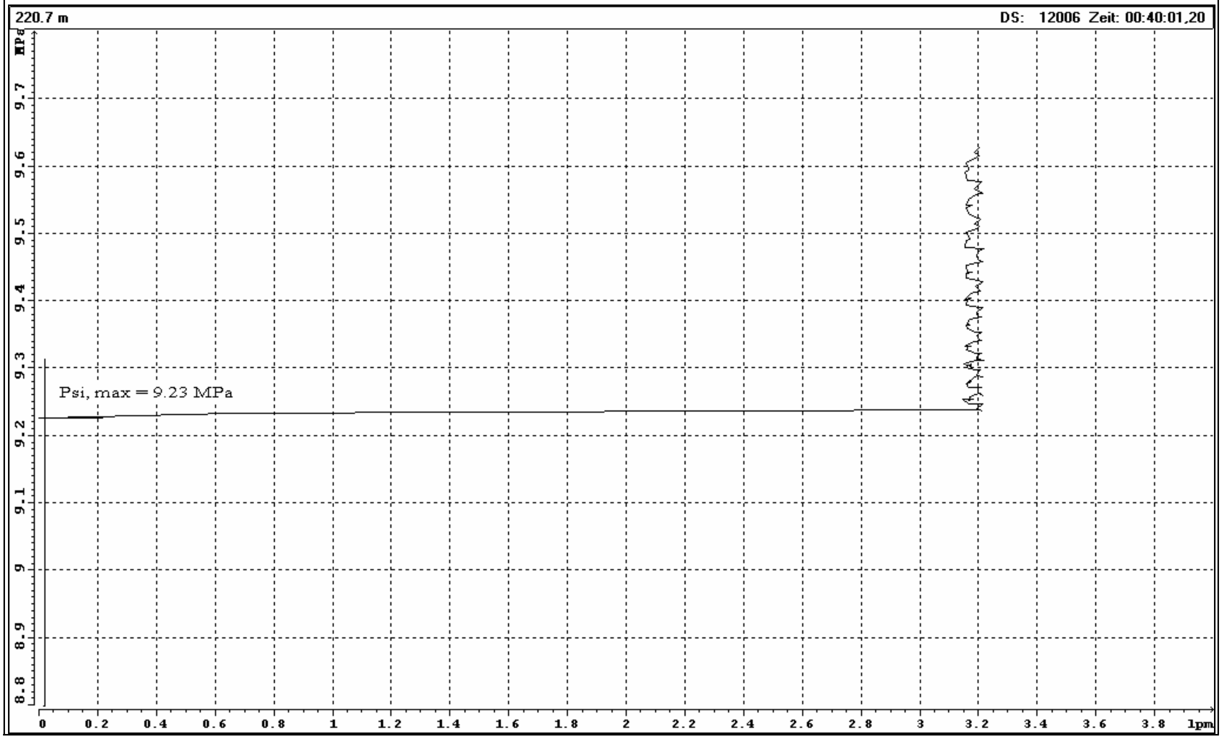
Test at 220.7 m MD: Estimation of P_c (Frac - Cycle)



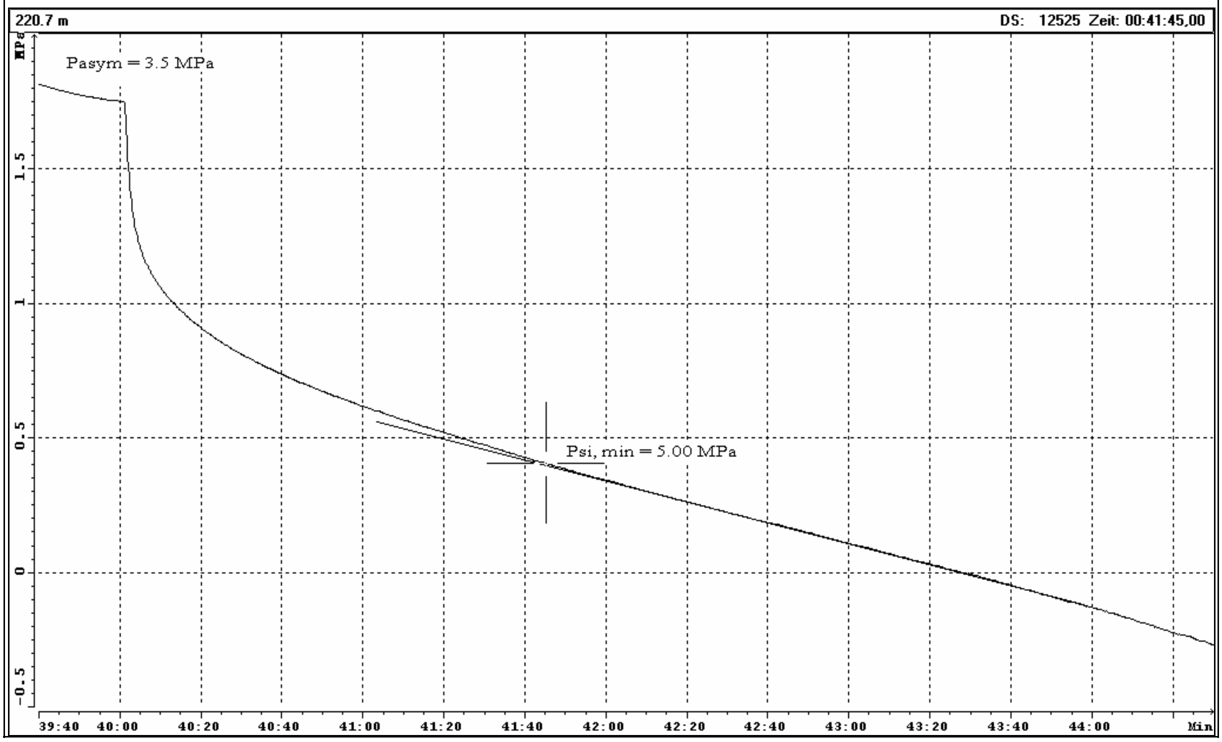
Test at 220.7 m MD: Estimation of P_r (1. Refrac - Cycle)



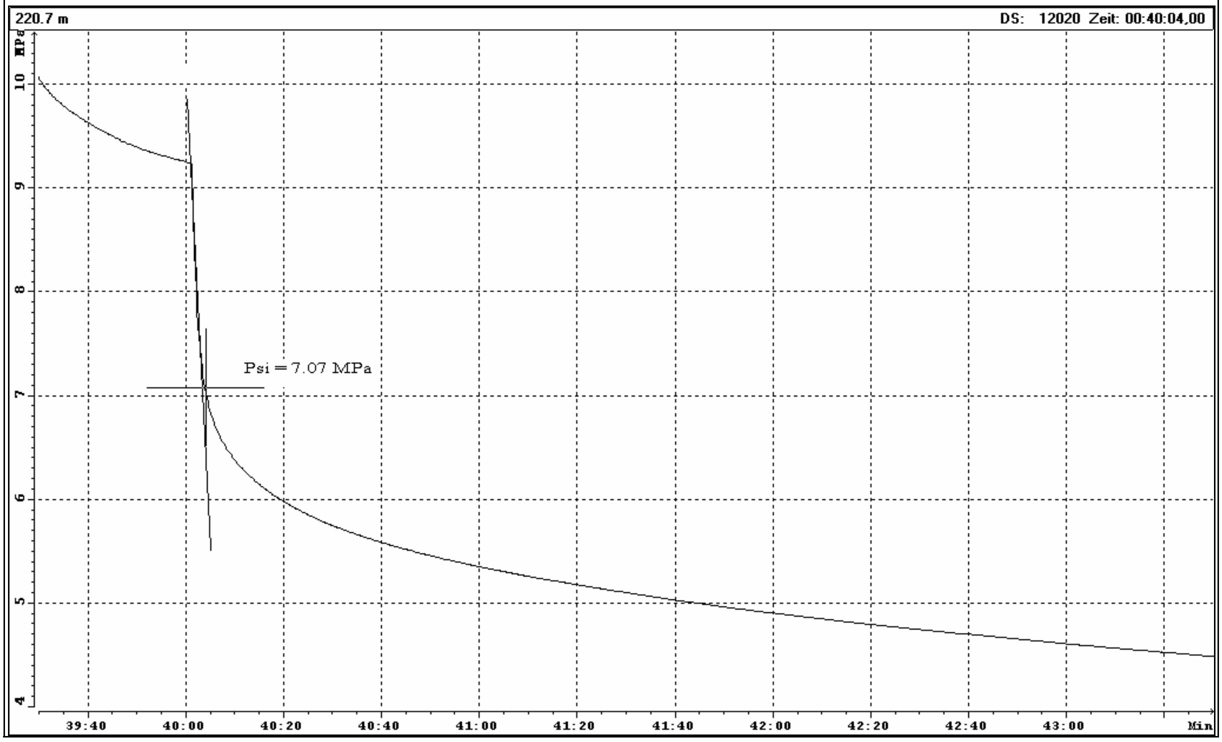
Test at 220.7 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



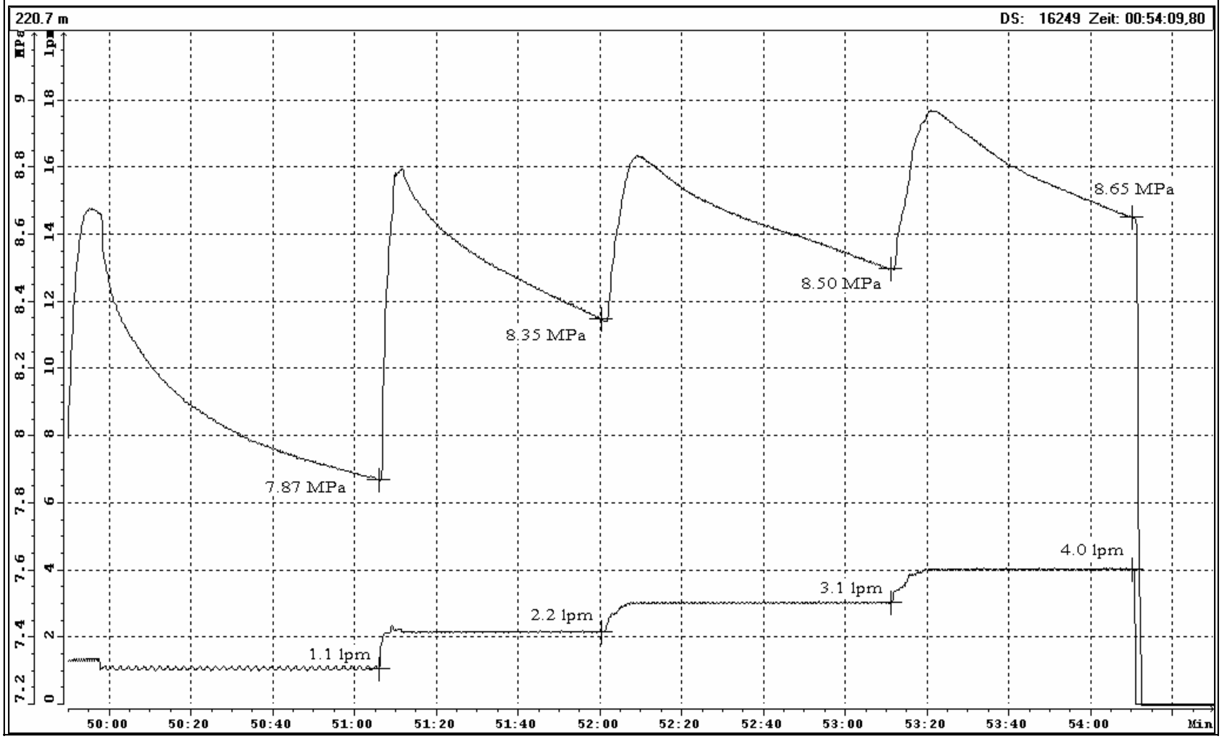
Test at 220.7 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



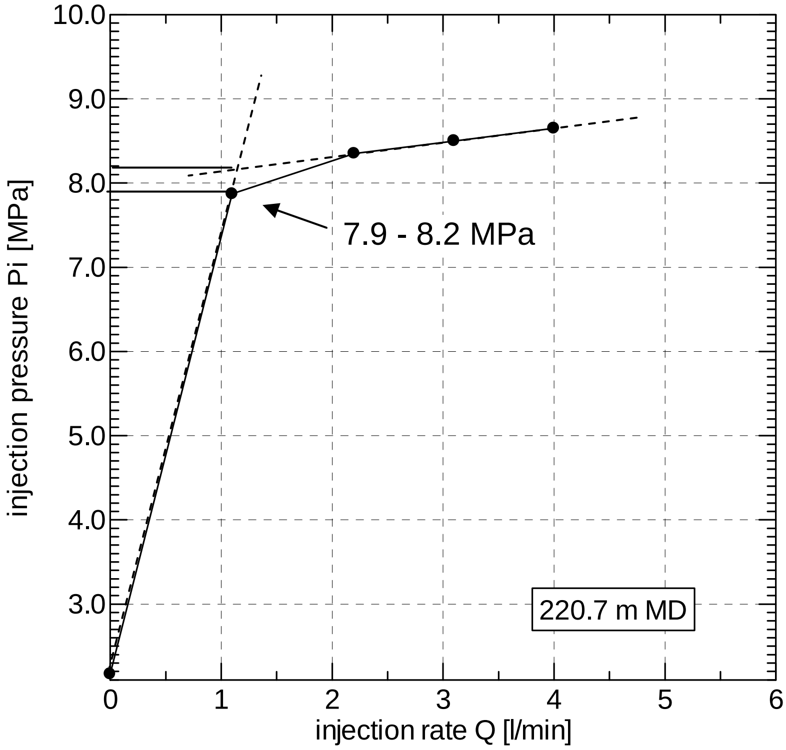
Test at 220.7 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 220.7 m MD: Analysis of Slow - Pump / Step - Rate - Test

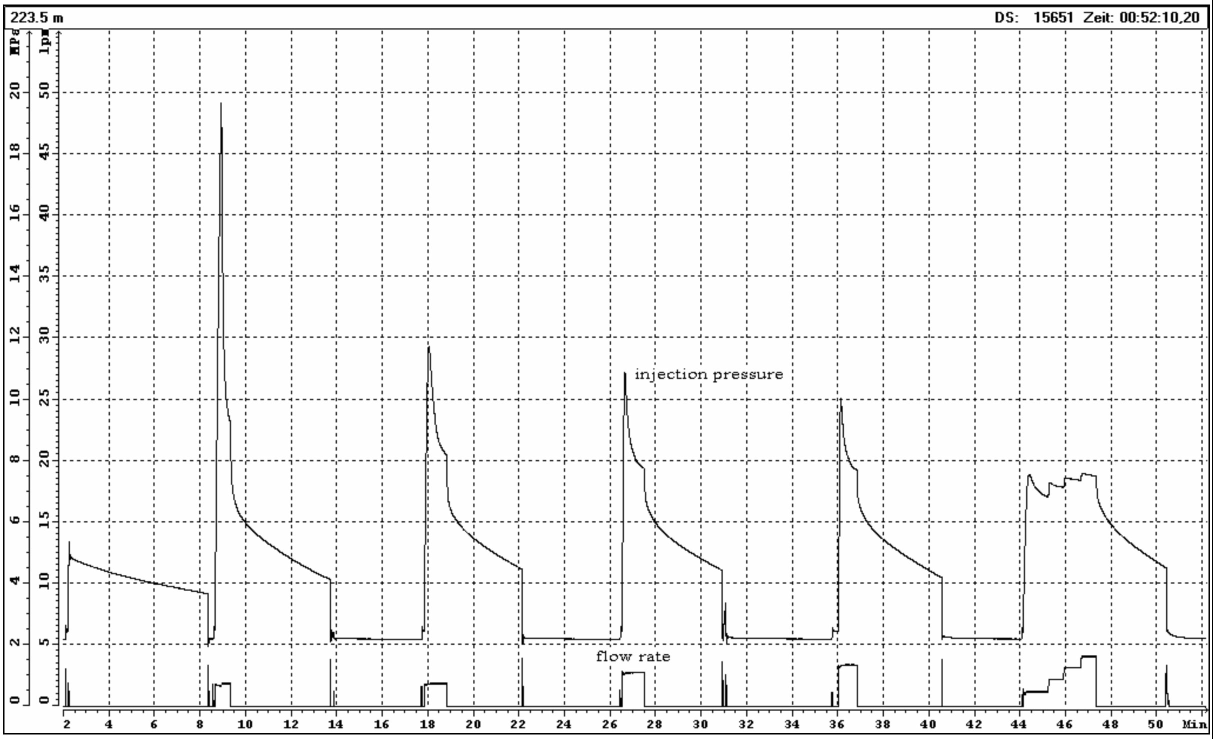


Test at 220.7 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 34 AT 223.5 m MD / 222.88 m TVD

Test at 223.5 m MD : Overview - Plot



P - Test   Frac   1. Refrac   2. Refrac   3. Refrac   Slow-Pump/Step-Rate Test

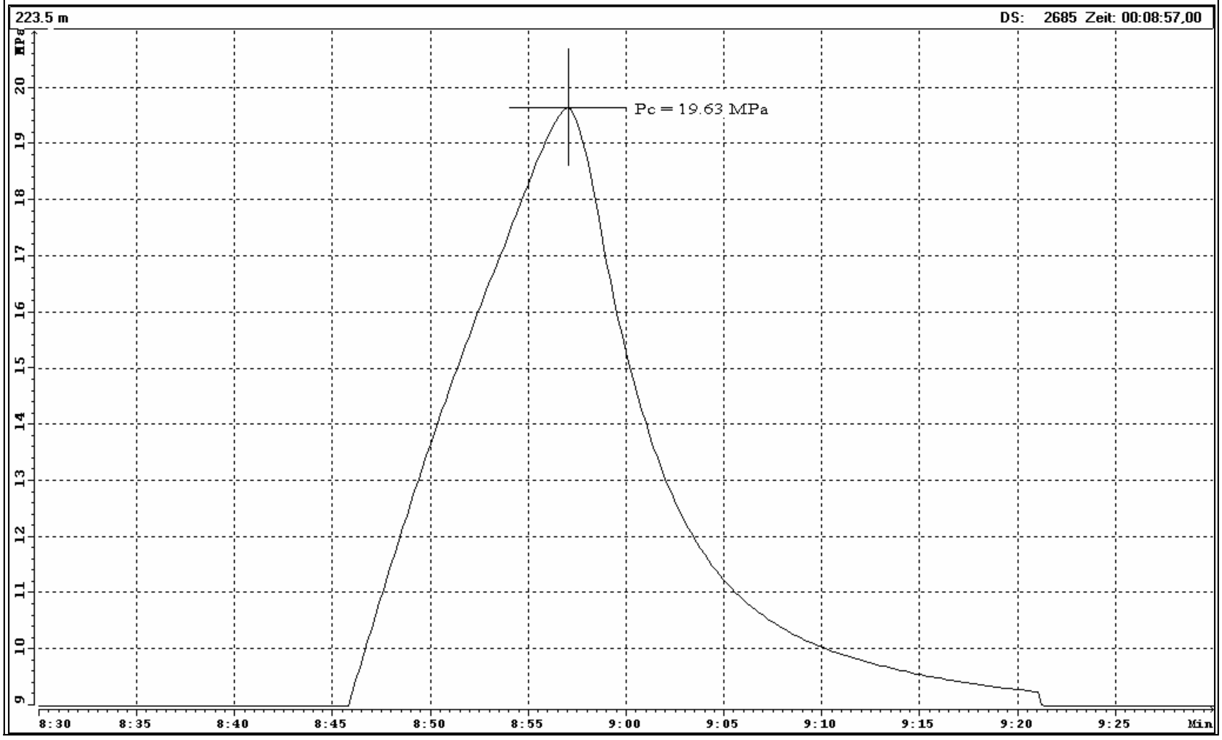
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 1.14 MPa in 359 sec.		
Frac - cycle	Qi (lpm) = 1.7	Vi (l) = 1.2	Vr (l) = 0.15
1. Refrac - cycle	Qi (lpm) = 1.9	Vi (l) = 1.9	Vr (l) = 0.2
2. Refrac - cycle	Qi (lpm) = 2.8	Vi (l) = 2.7	Vr (l) = 0.4
3. Refrac - cycle	Qi (lpm) = 3.4	Vi (l) = 2.8	Vr (l) = 0.3
SP/SR - test	Qi (lpm) = 1.2-4.1	Vi (l) = 7.9	Vr (l) = 0.8

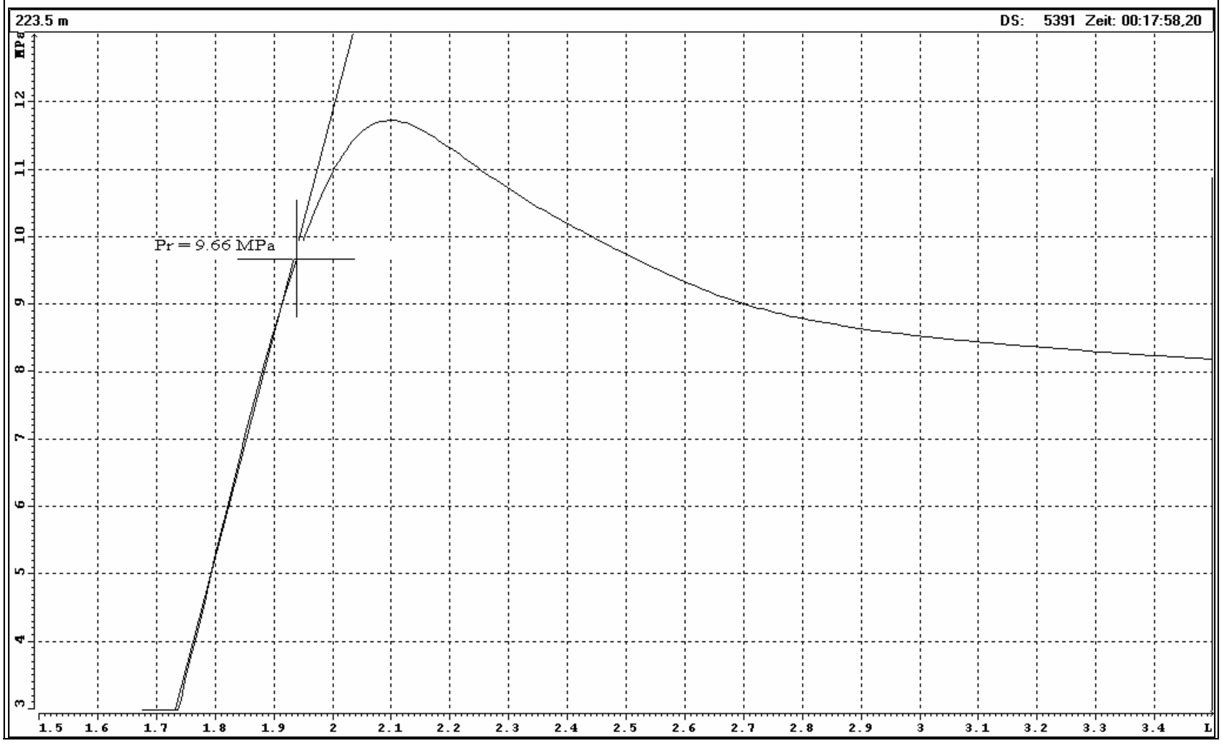
total injected volume (l): 16.5   recovered volume (l): 1.85 or 11.2 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV at 9.7 MPa, followed by a pressure increase up to 11.7 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

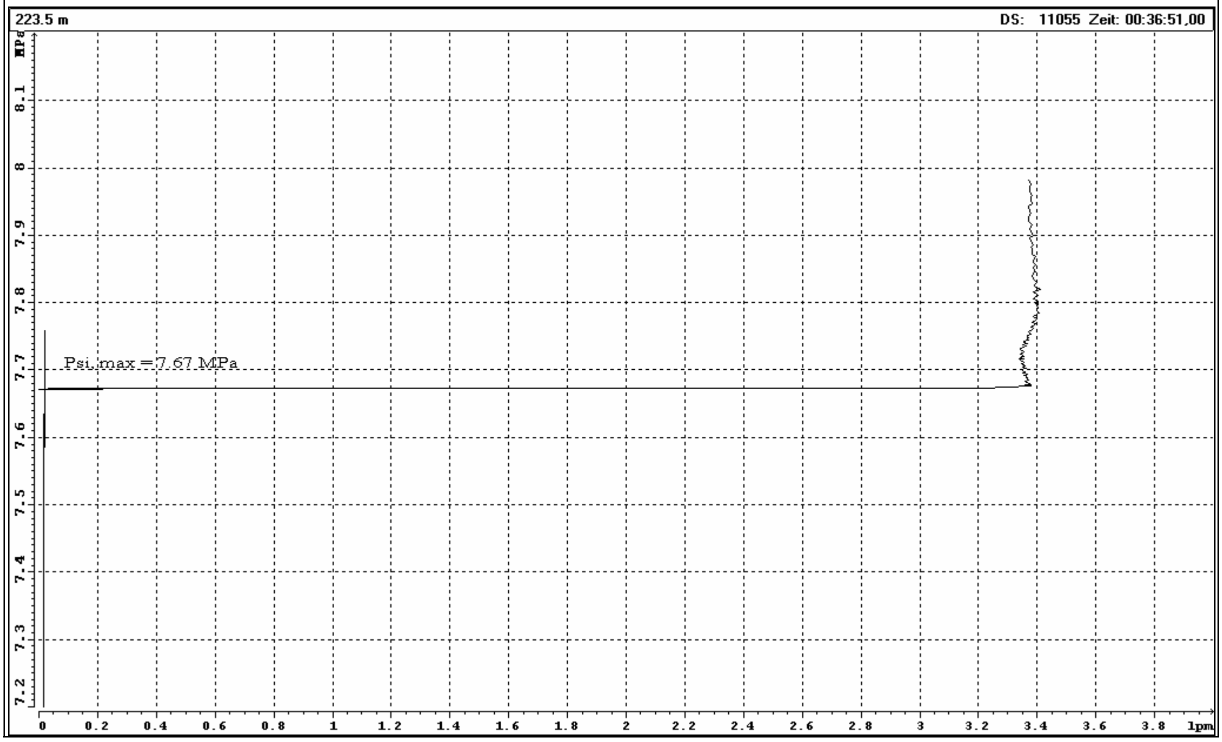
Test at 223.5 m MD: Estimation of P_c (Frac - Cycle)



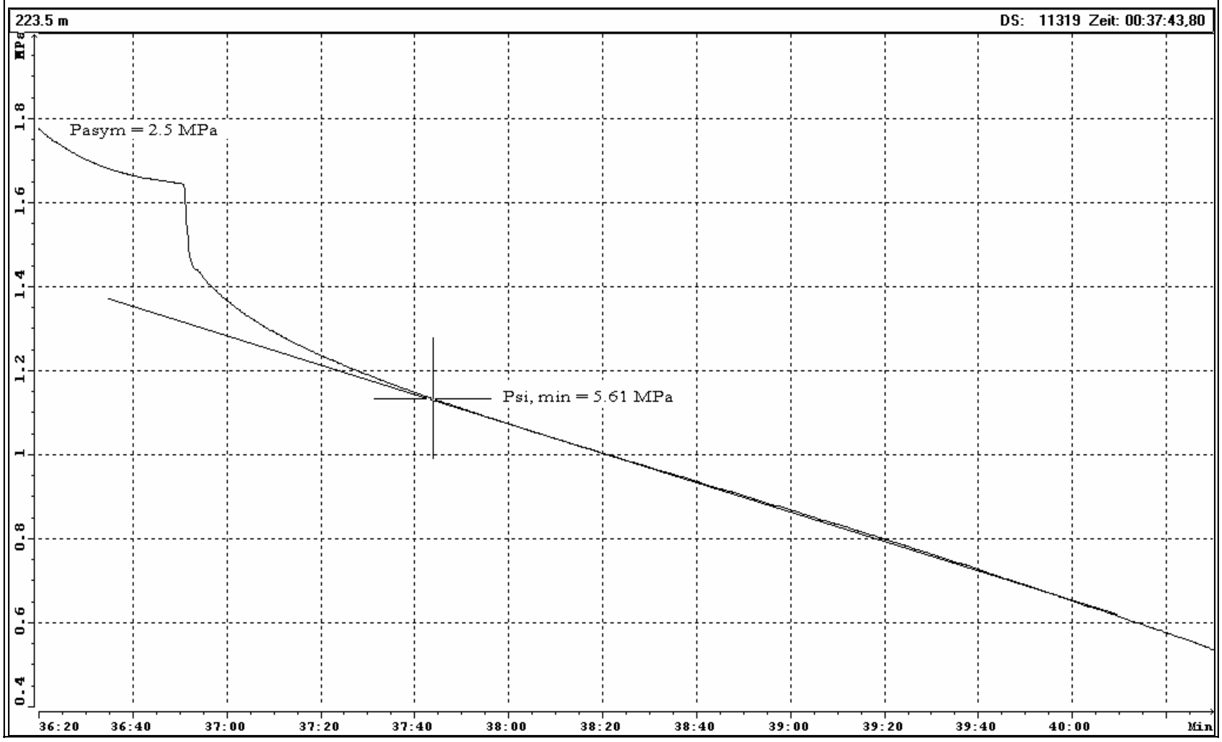
Test at 223.5 m MD: Estimation of P_r (1. Refrac) - Cycle)



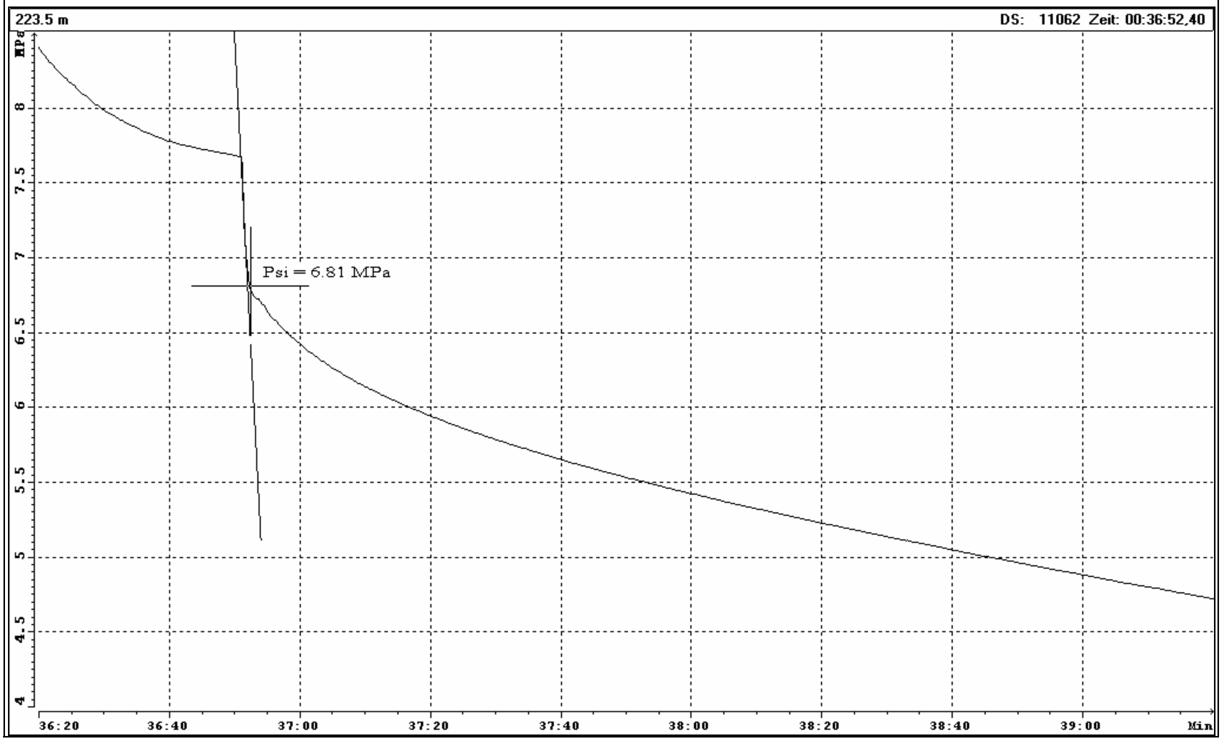
Test at 223.5 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



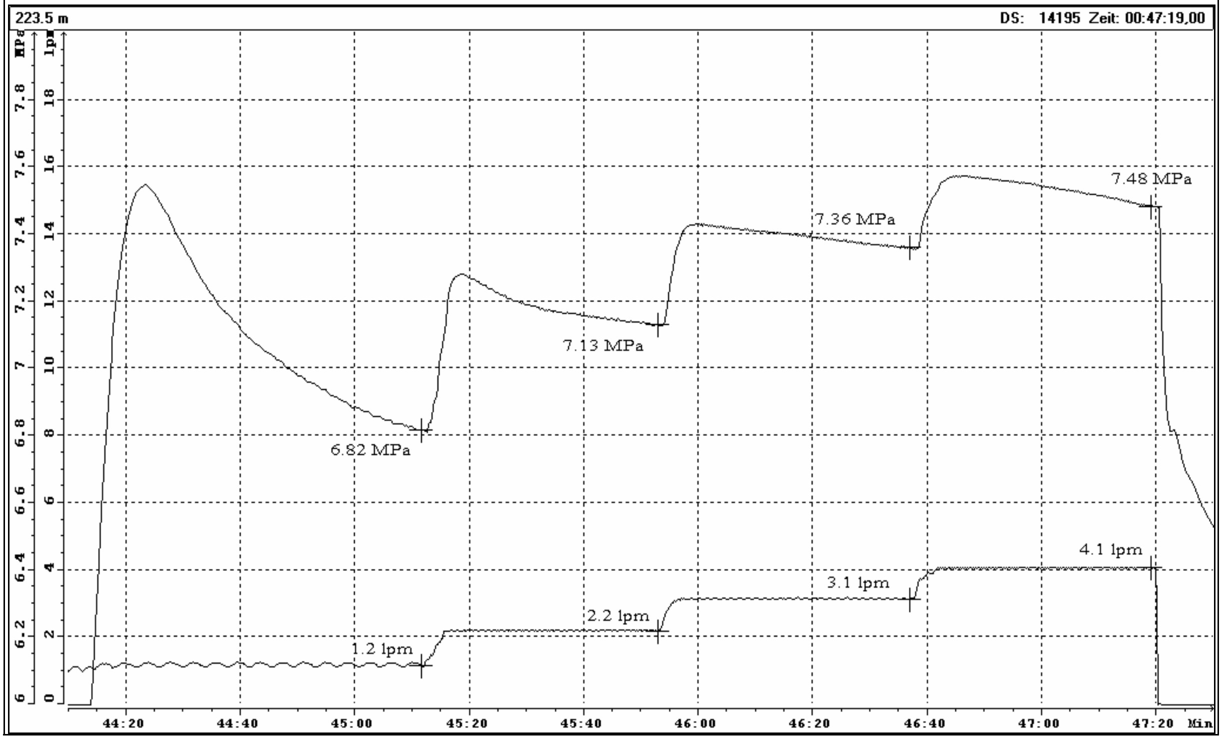
Test at 223.5 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



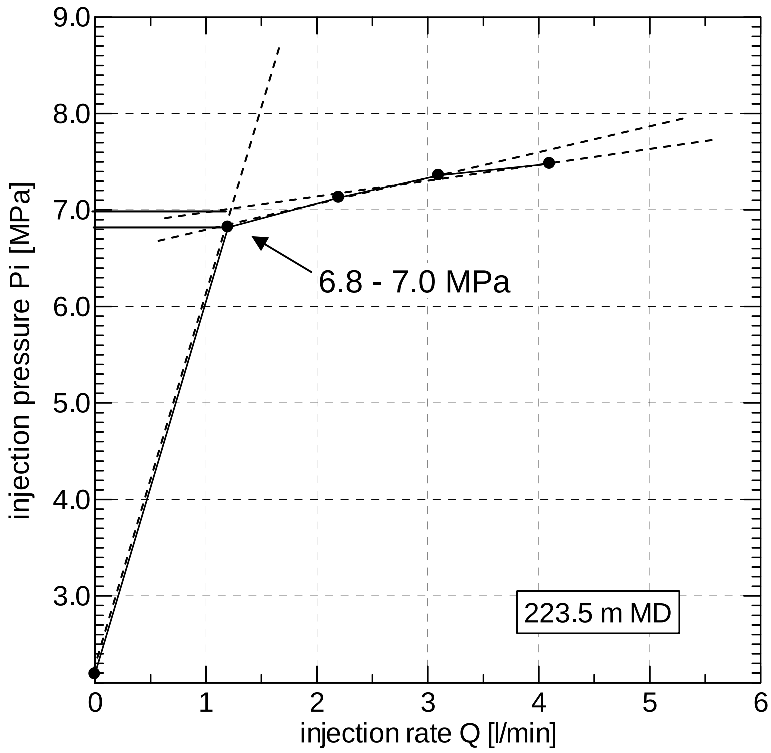
Test at 223.5 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 223.5 m MD: Analysis of Slow - Pump / Step - Rate - Test

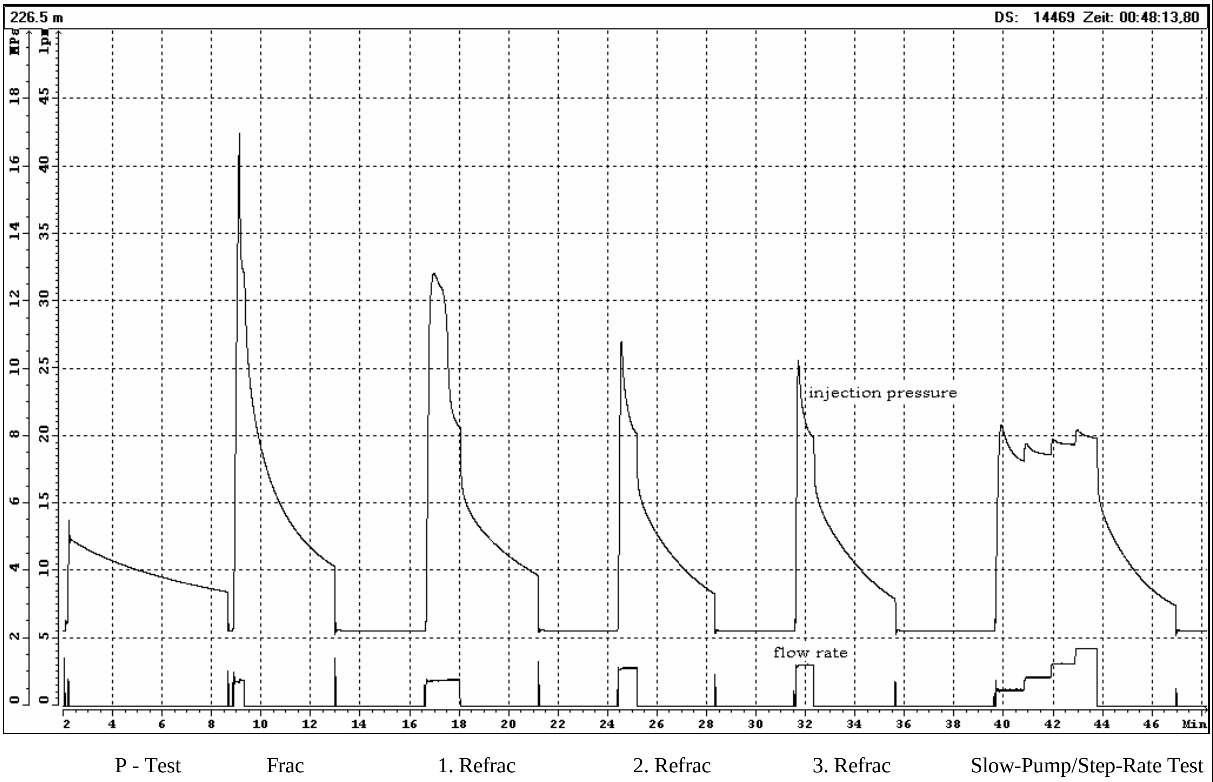


Test at 223.5 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 33 AT 226.5 m MD / 225.87 m TVD

Test at 226.5 m MD : Overview - Plot



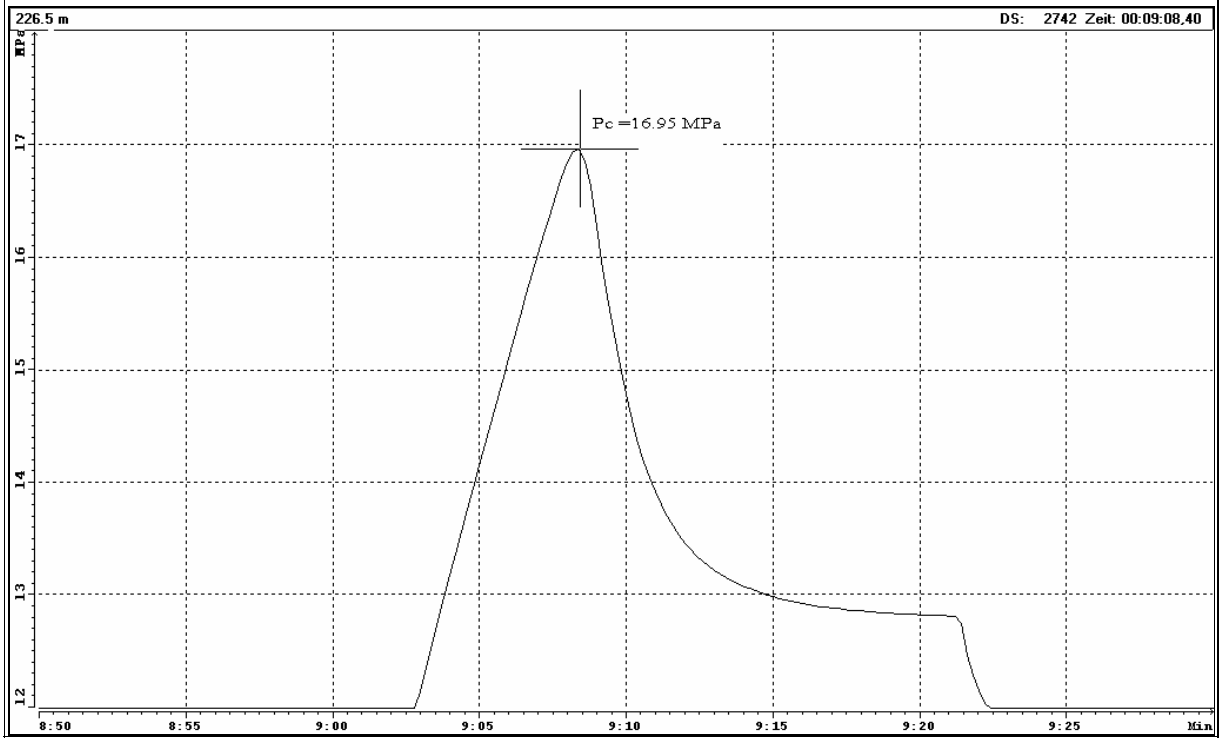
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.53 MPa in 378 sec.		
Frac - cycle	Qi (lpm) = 1.8	Vi (l) = 0.9	Vr (l) = 0.1
1. Refrac - cycle	Qi (lpm) = 1.9	Vi (l) = 2.7	Vr (l) = 0.1
2. Refrac - cycle	Qi (lpm) = 2.8	Vi (l) = 2.1	Vr (l) = 0.1
3. Refrac - cycle	Qi (lpm) = 3.1	Vi (l) = 2.3	Vr (l) = 0.1
SP/SR - test	Qi (lpm) = 1.2-4.3	Vi (l) = 10.6	Vr (l) = 0.1

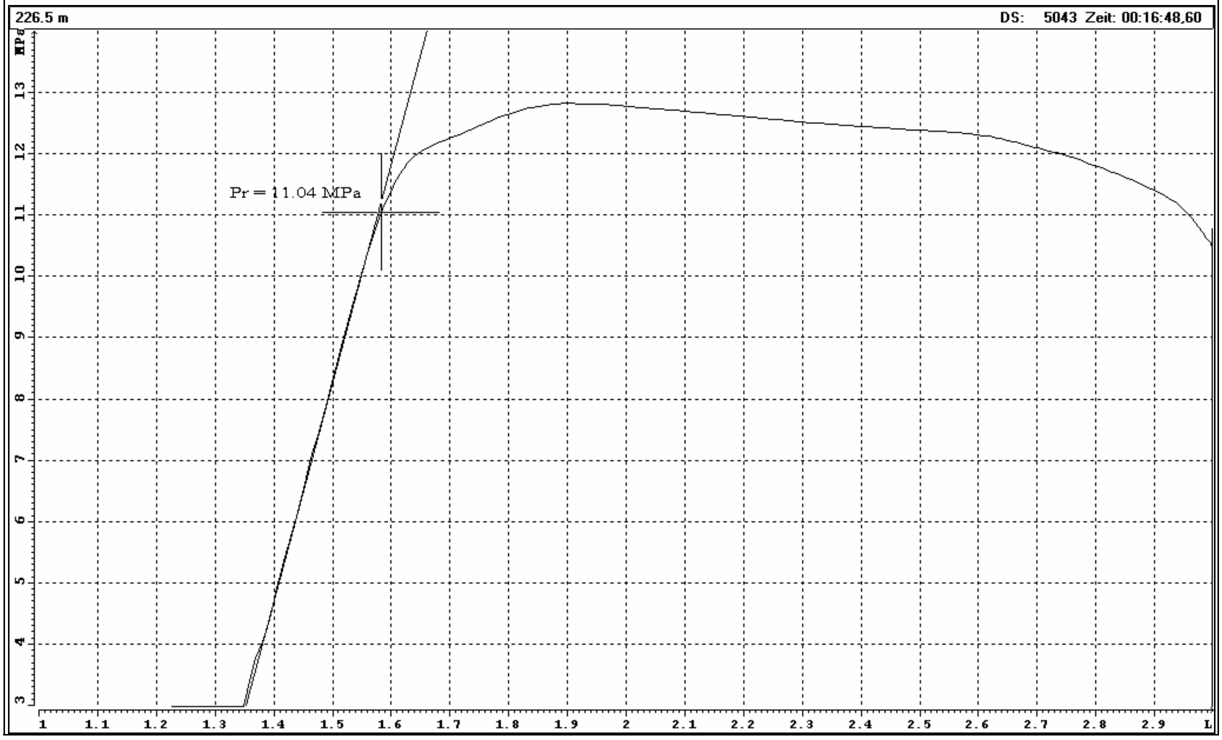
total injected volume (l): 18.6 recovered volume (l): 0.5 or 2.7 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (weak breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

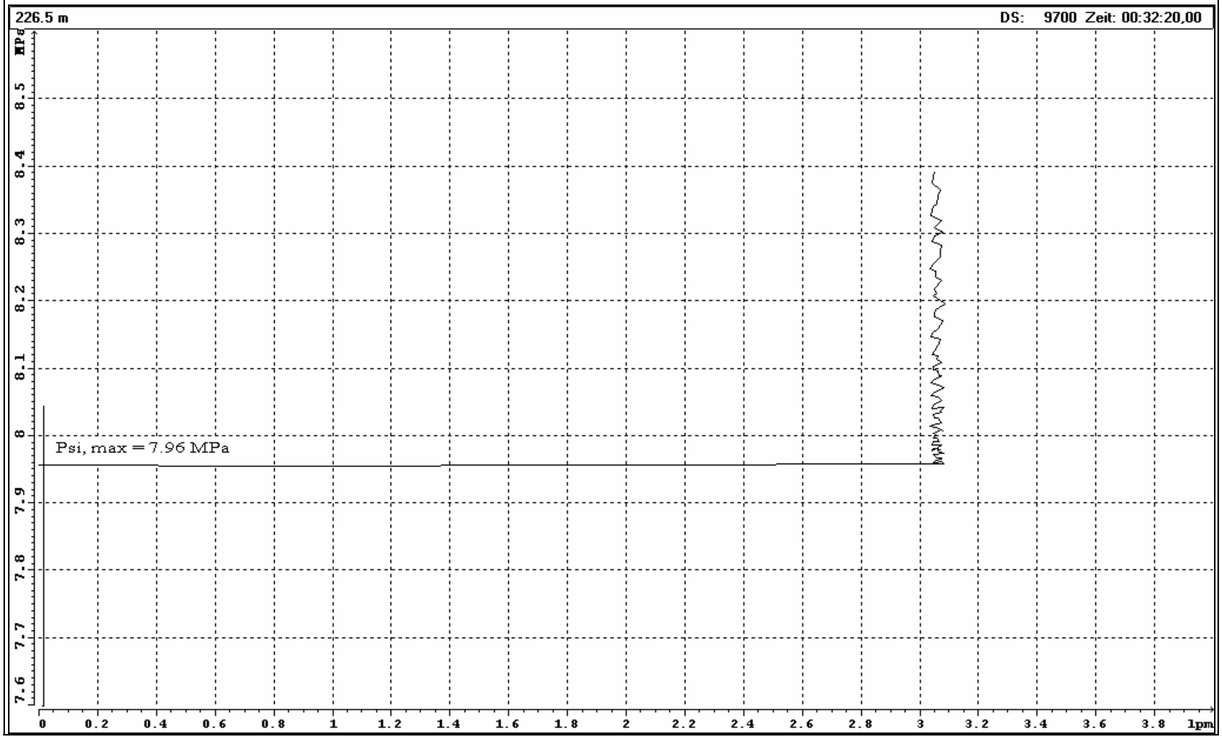
Test at 226.5 m MD: Estimation of P_c (Frac - Cycle)



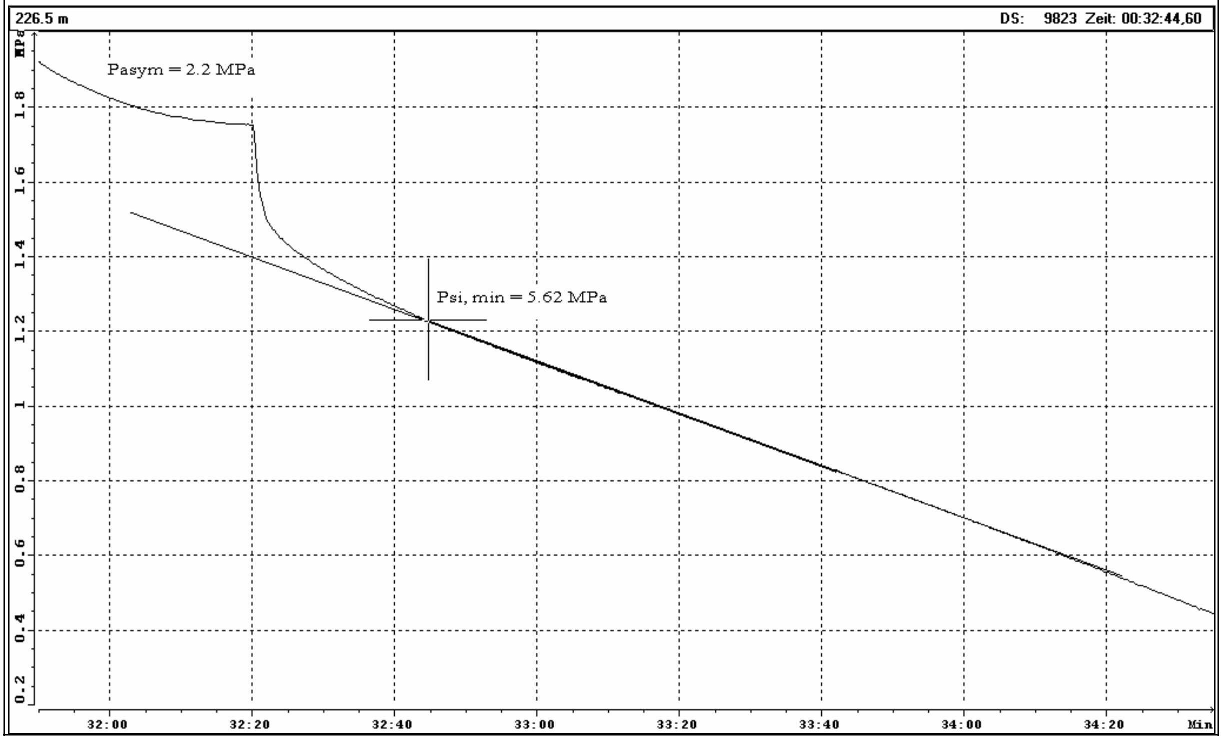
Test at 226.5 m MD: Estimation of P_r (1. Refrac) - Cycle)



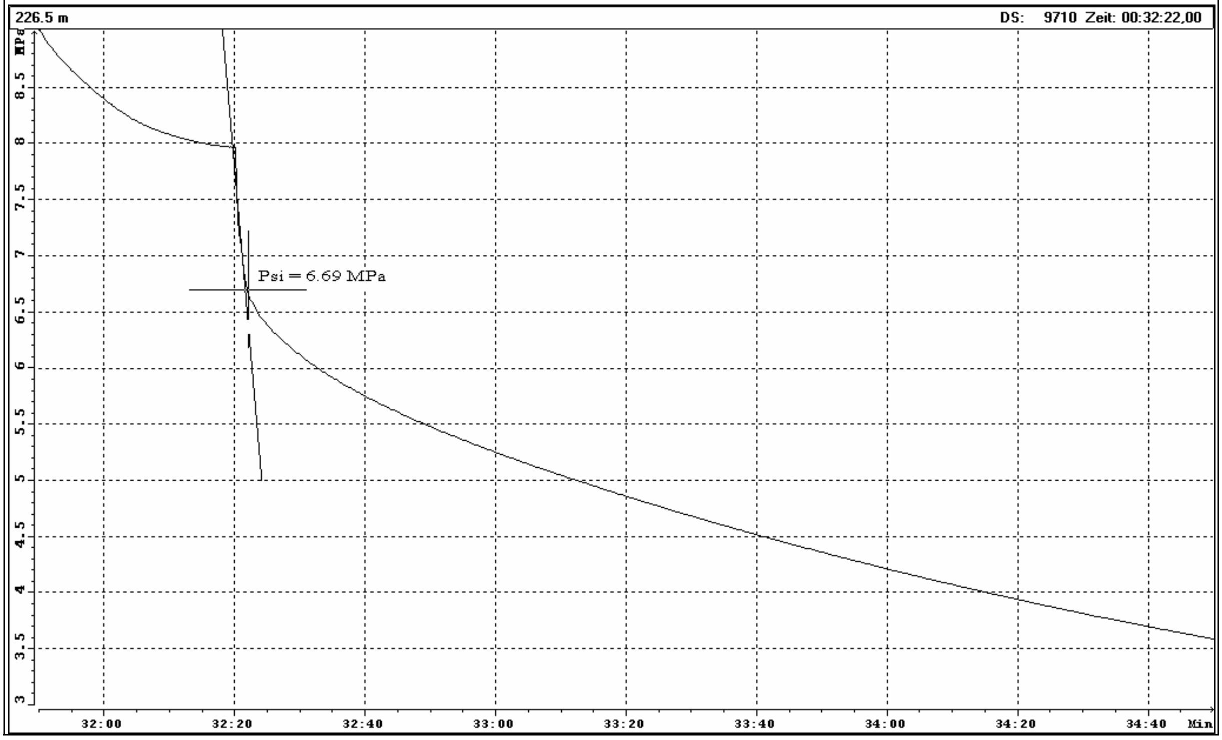
Test at 226.5 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



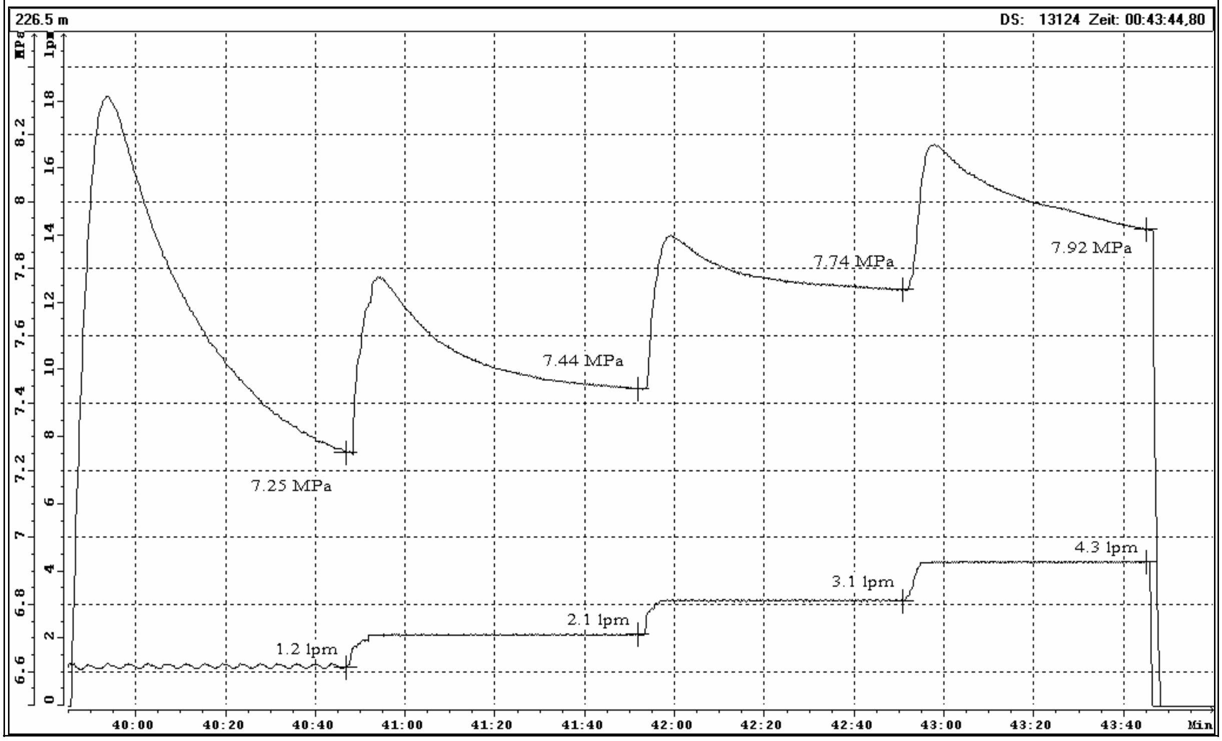
Test at 226.5 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



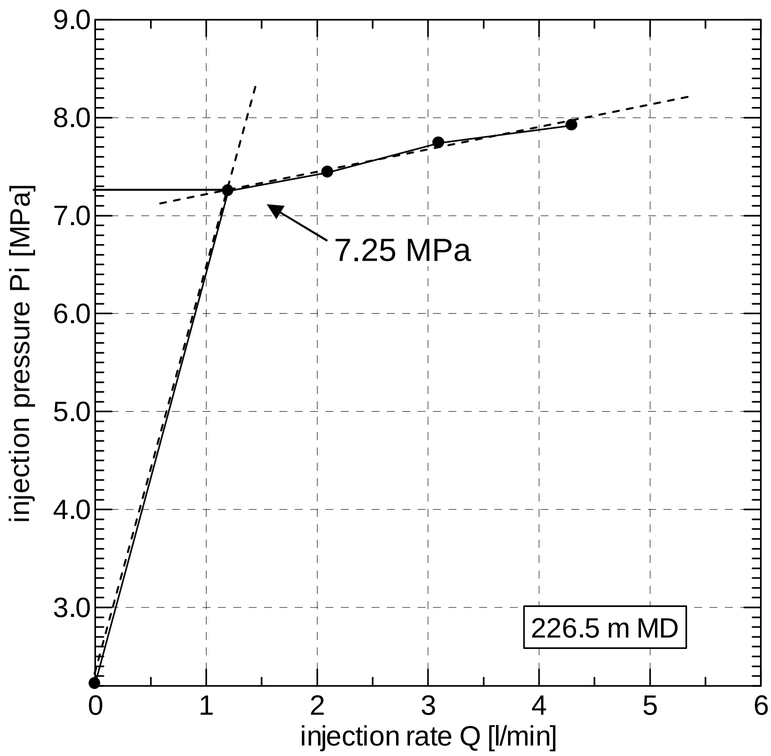
Test at 226.5 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 226.5 m MD: Analysis of Slow - Pump / Step - Rate - Test

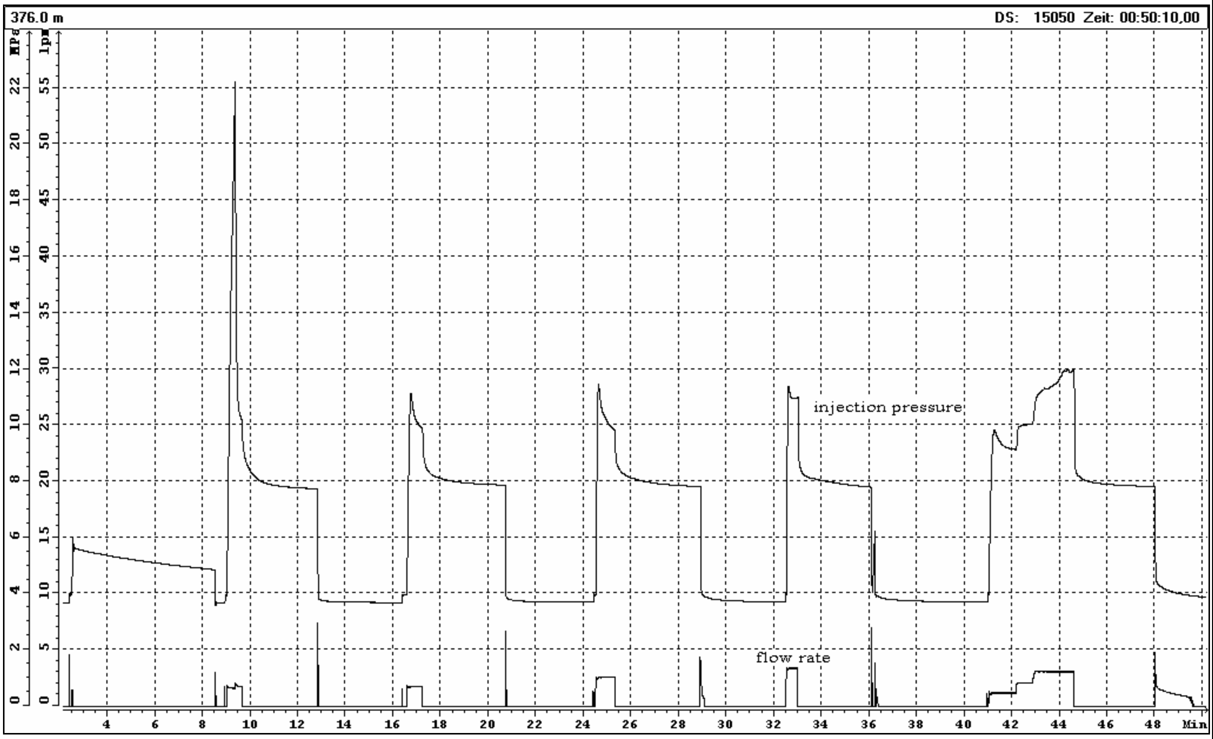


Test at 226.5 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 32 AT 376.0 m MD / 374.78 m TVD

Test at 376.0 m MD : Overview - Plot



P - Test | Frac | 1. Refrac | 2. Refrac | 3. Refrac | Slow-Pump/Step-Rate Test

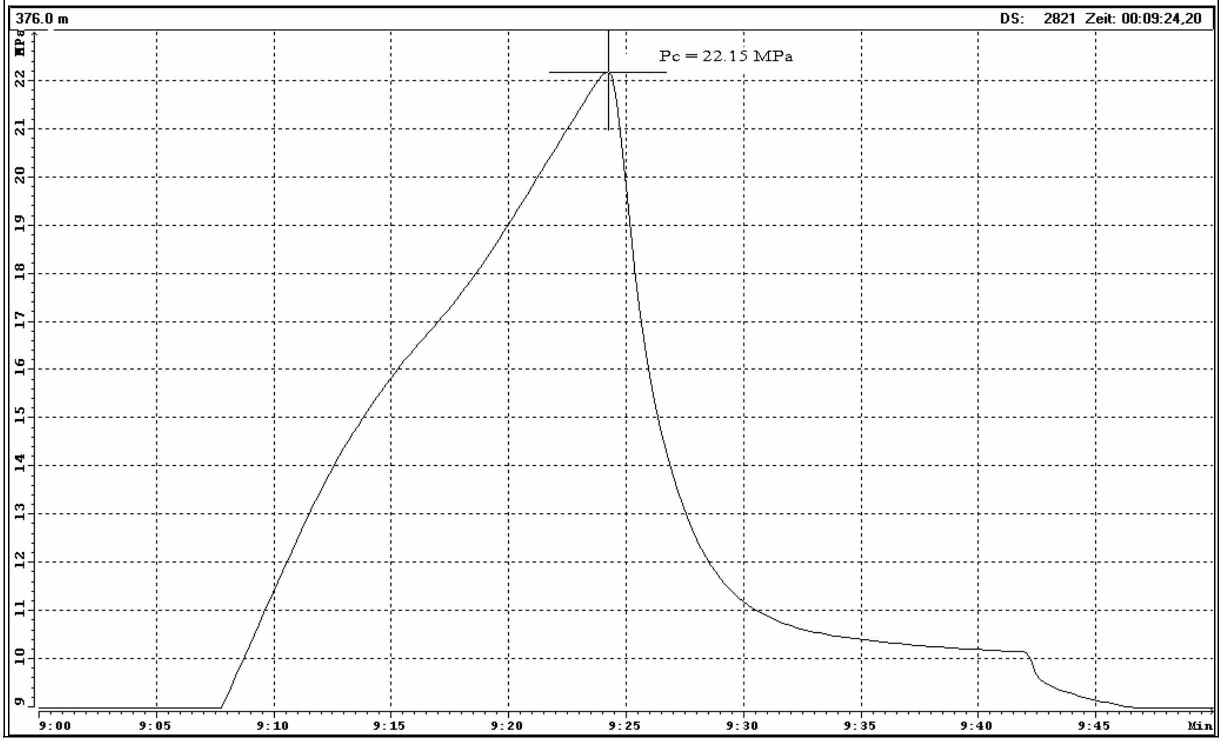
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.75 MPa in 350 sec.		
Frac - cycle	Qi (lpm) = 1.7	Vi (l) = 1.15	Vr (l) = 0.6
1. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 1.2	Vr (l) = 0.9
2. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 2.1	Vr (l) = 1.1
3. Refrac - cycle	Qi (lpm) = 3.4	Vi (l) = 1.7	Vr (l) = 1.4
SP/SR - test	Qi (lpm) = 1.2-3.1	Vi (l) = 8.2	Vr (l) = 3.4

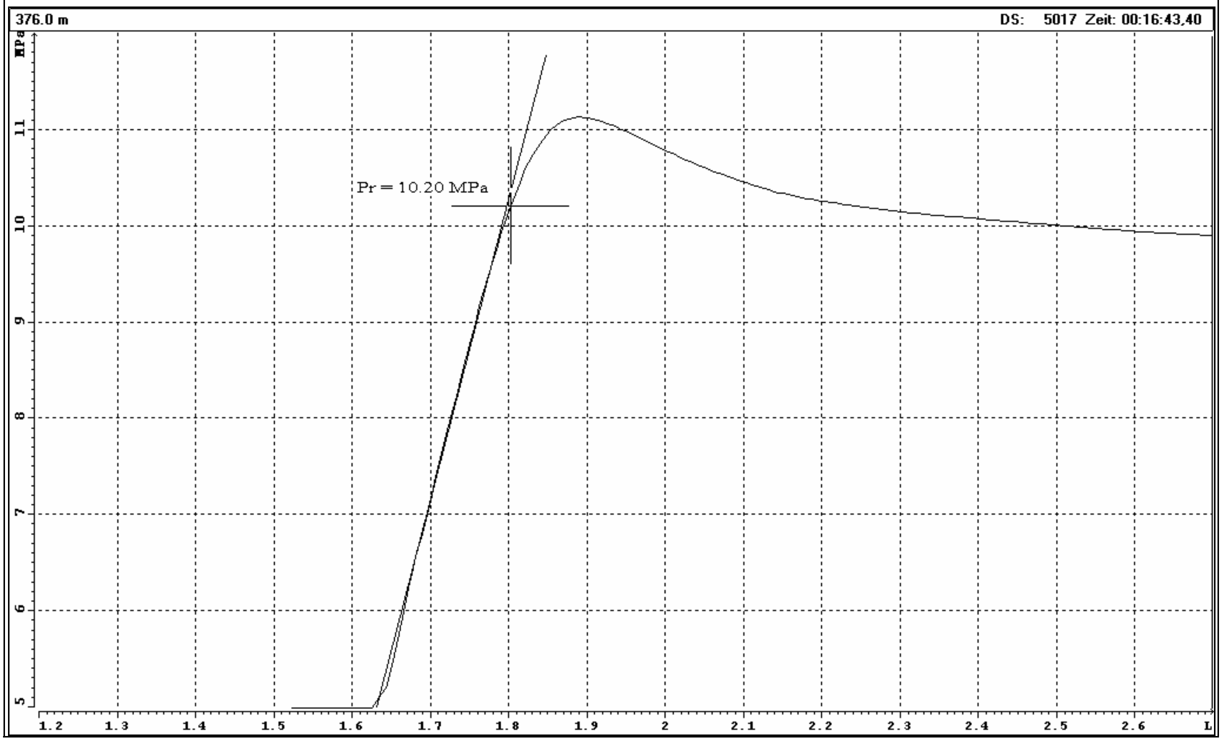
total injected volume (l): 14.35 recovered volume (l): 7.4 or 51.6 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (distinct breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield nearly the same fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.
- A pronounced pressure increase was observed during the final stage of the slow-pump / step-rate test.

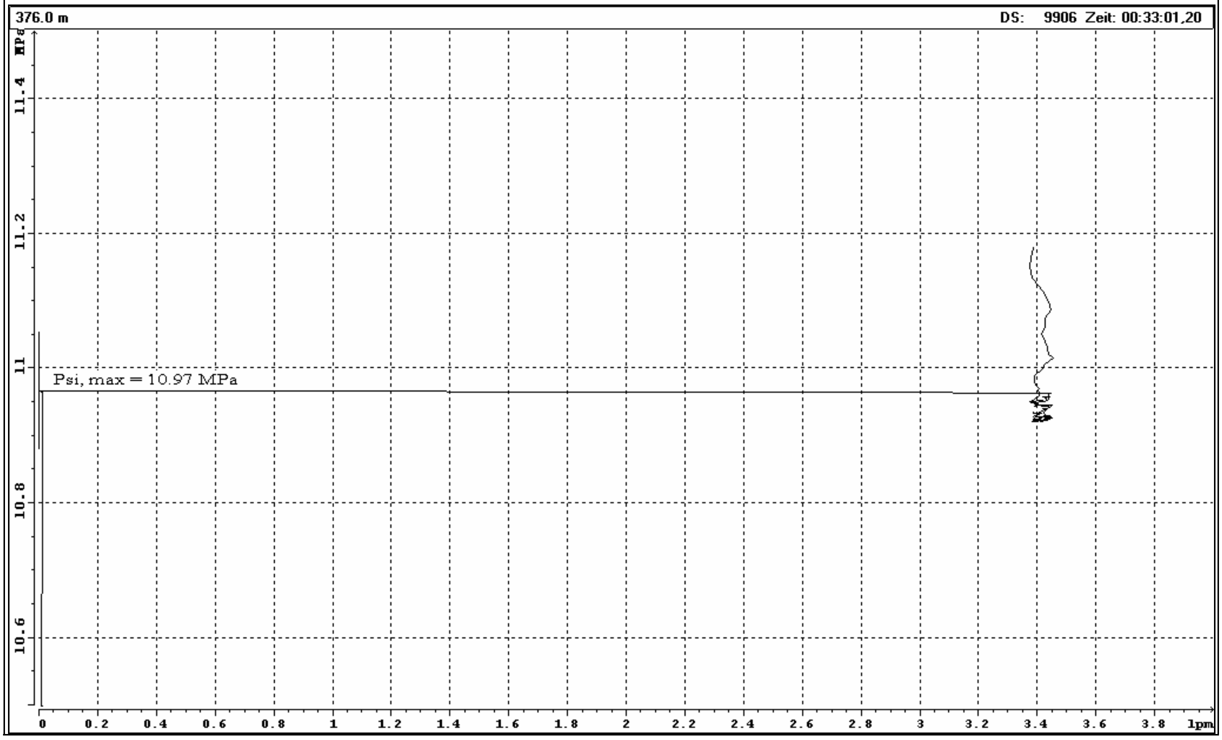
Test at 376.0 m MD: Estimation of P_c (Frac - Cycle)



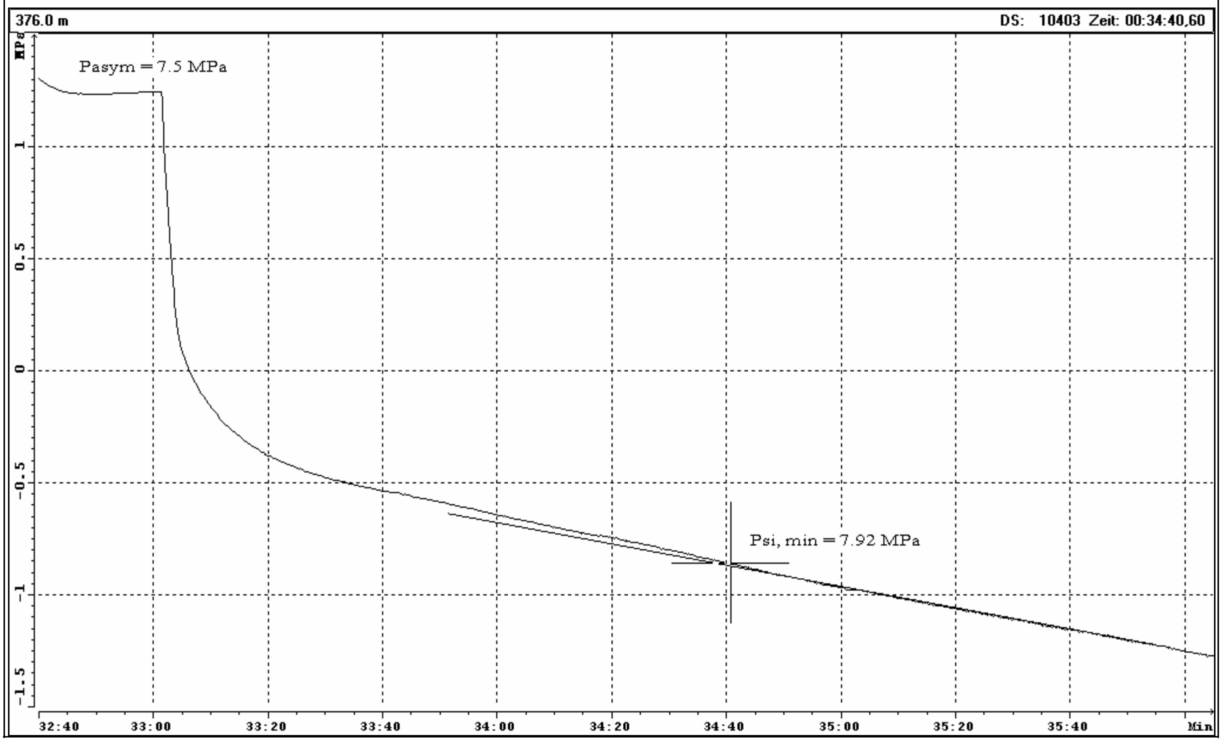
Test at 376.0 m MD: Estimation of P_r (1. Refrac) - Cycle)



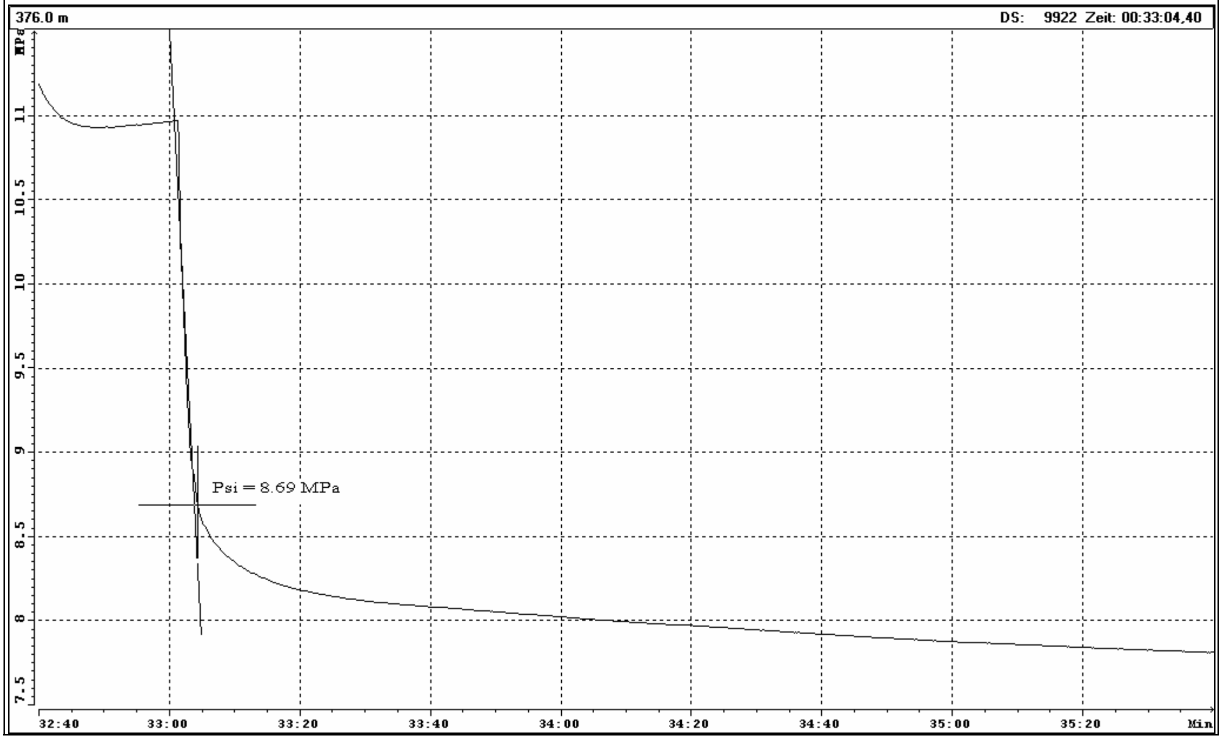
Test at 376.0 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



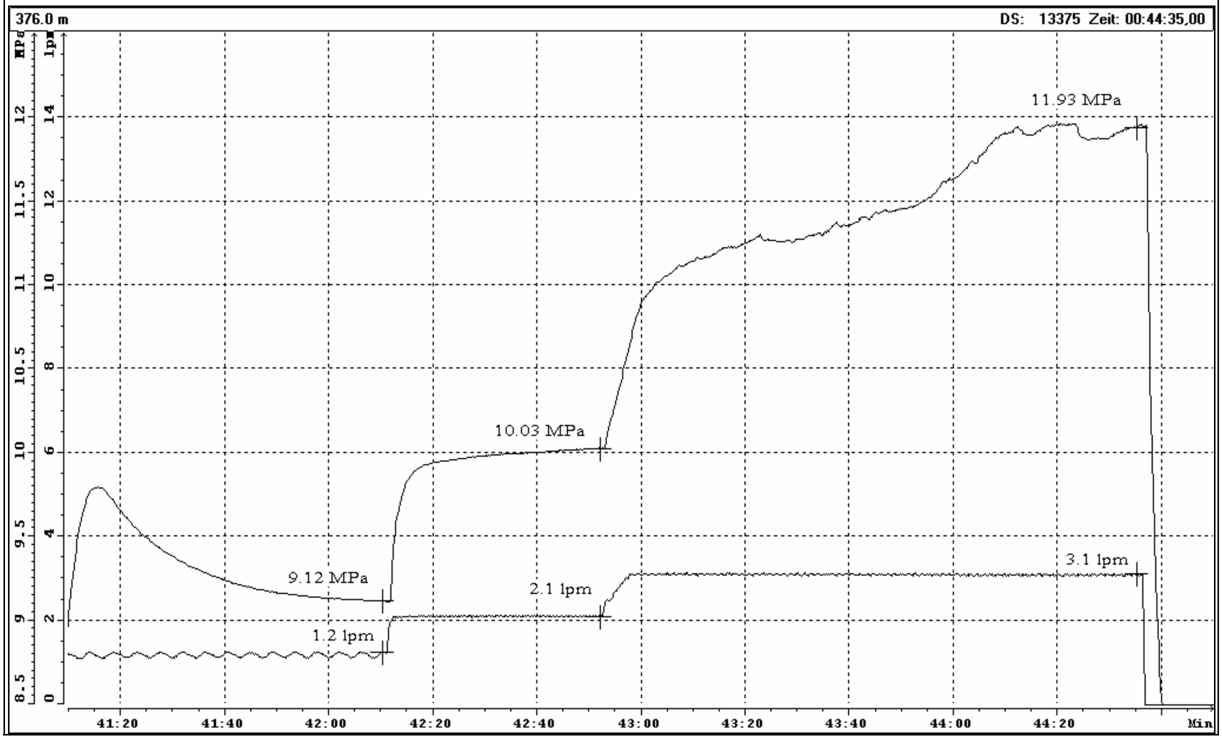
Test at 376.0 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



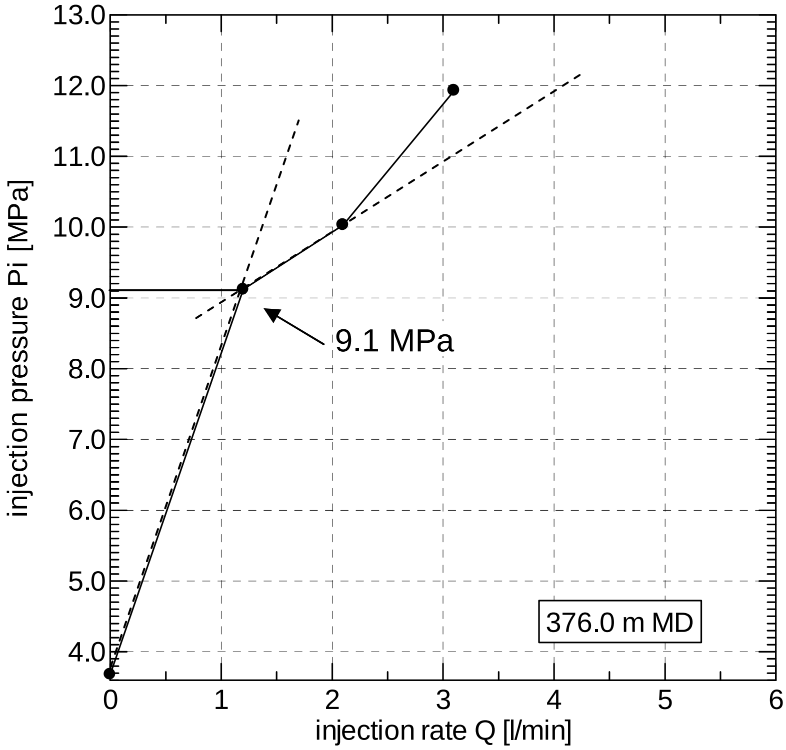
Test at 376.0 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 376.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

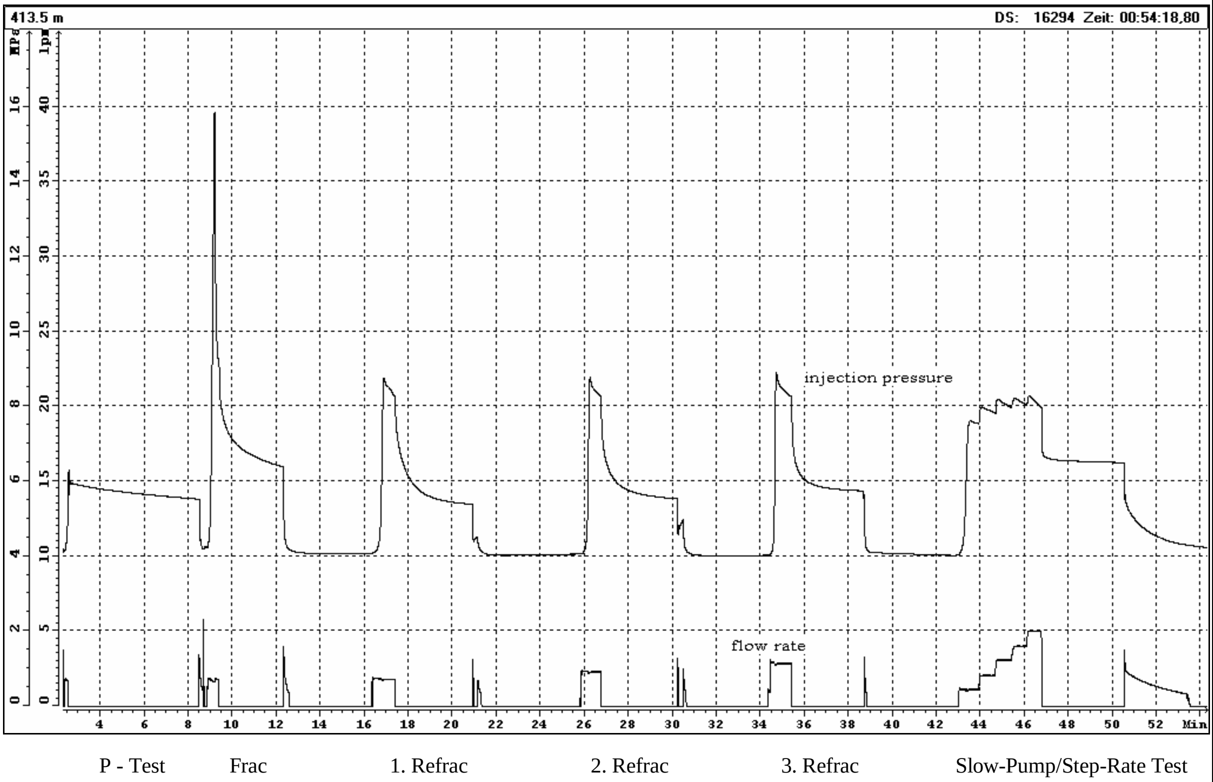


Test at 376.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 31 AT 413.5 m MD / 412.12 m TVD

Test at 413.5 m MD : Overview - Plot



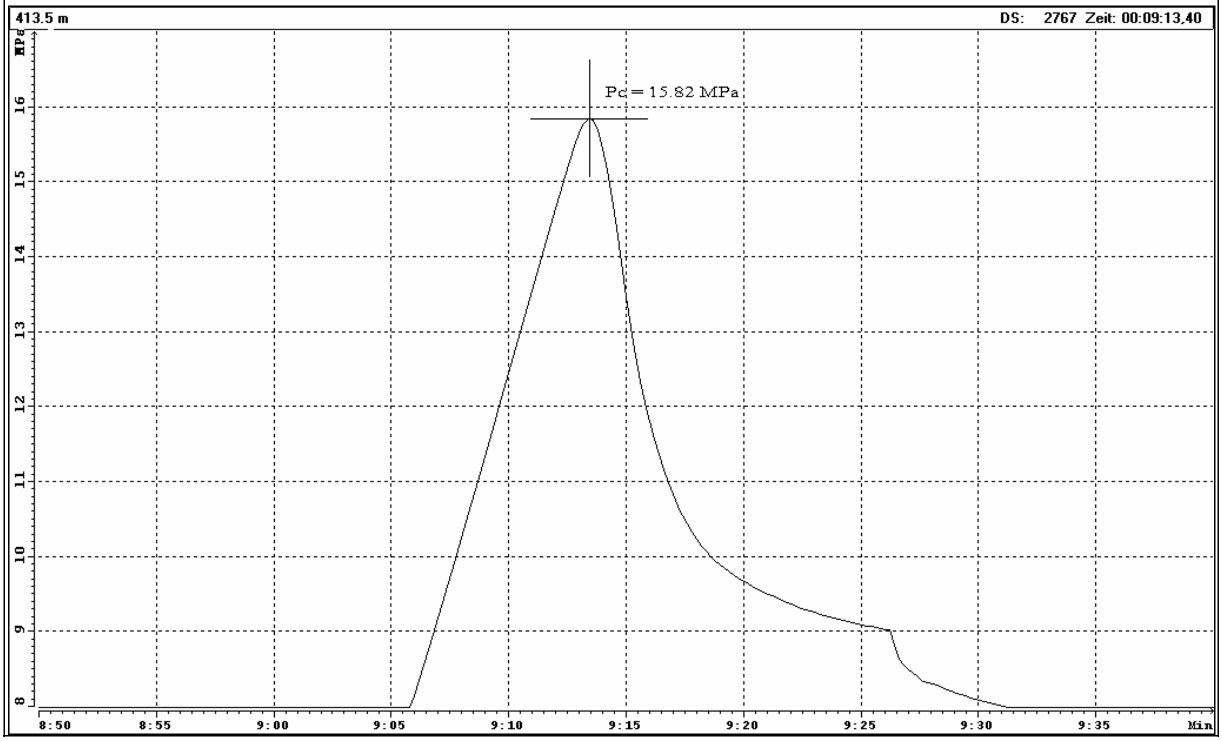
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.41 MPa in 347 sec.		
Frac - cycle	Qi (lpm) = 1.8	Vi (l) = 0.9	Vr (l) = 0.9
1. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 1.9	Vr (l) = 1.1
2. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 2.1	Vr (l) = 1.4
3. Refrac - cycle	Qi (lpm) = 2.8	Vi (l) = 2.9	Vr (l) = 1.5
SP/SR - test	Qi (lpm) = 1.1-5.0	Vi (l) = 10.8	Vr (l) = 8.0

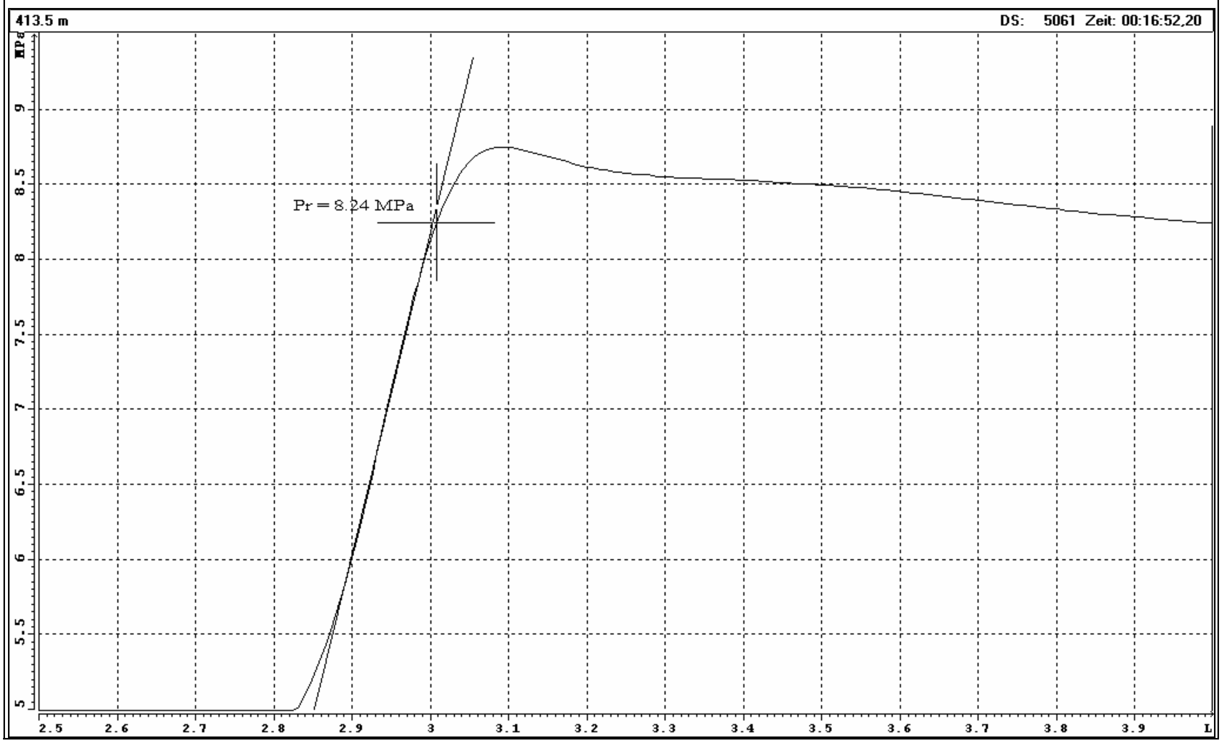
total injected volume (l): 18.6 recovered volume (l): 12.9 or 69.4 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (distinct breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield nearly the same fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

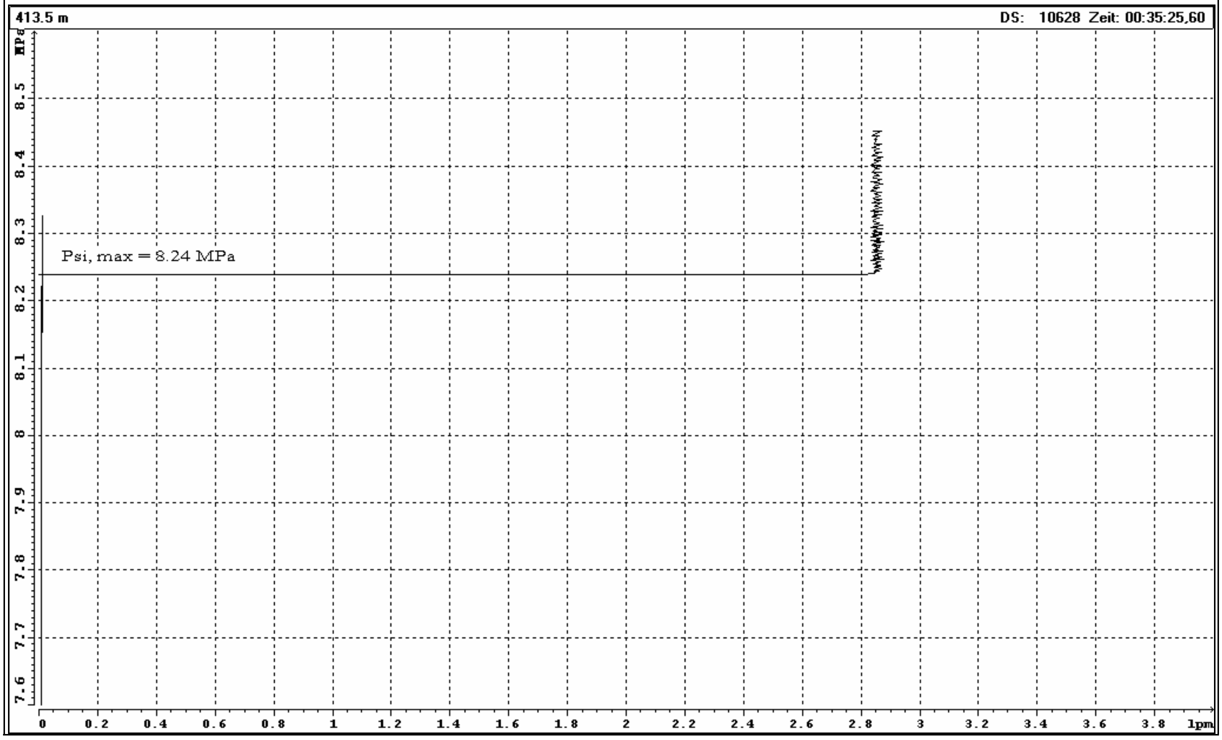
Test at 413.5 m MD: Estimation of P_c (Frac - Cycle)



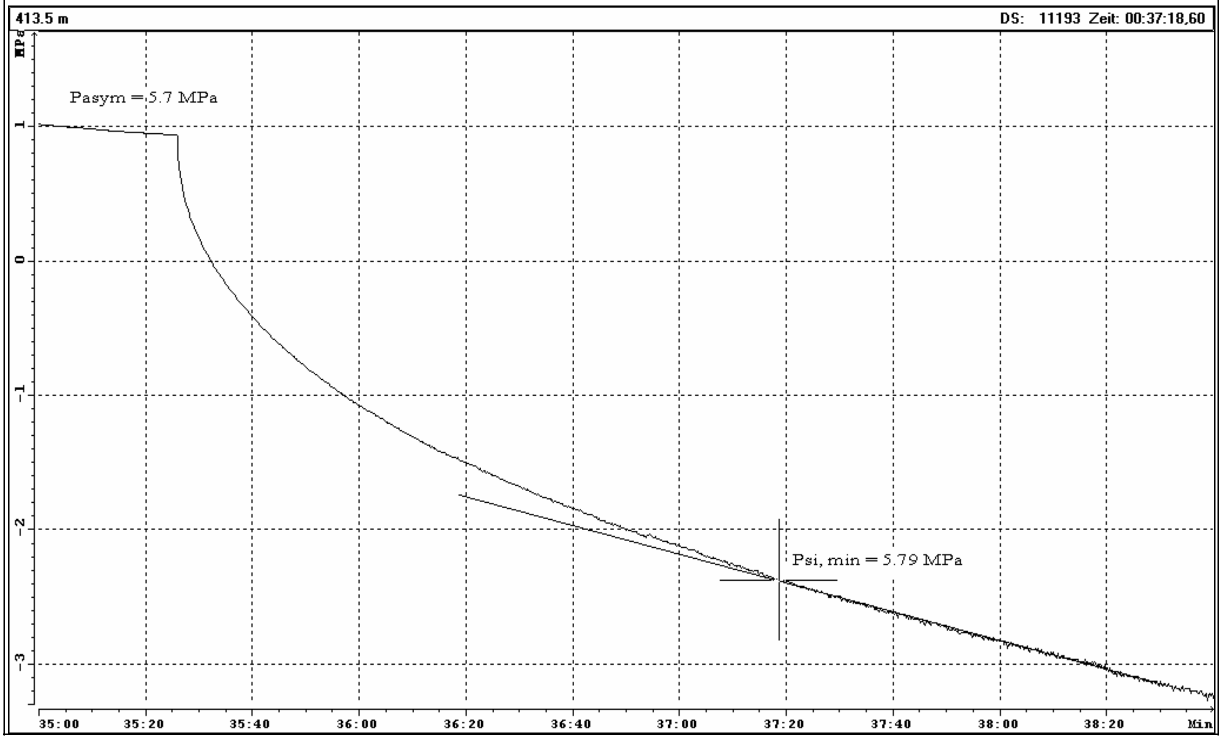
Test at 413.5 m MD: Estimation of P_r (1. Refrac) - Cycle)



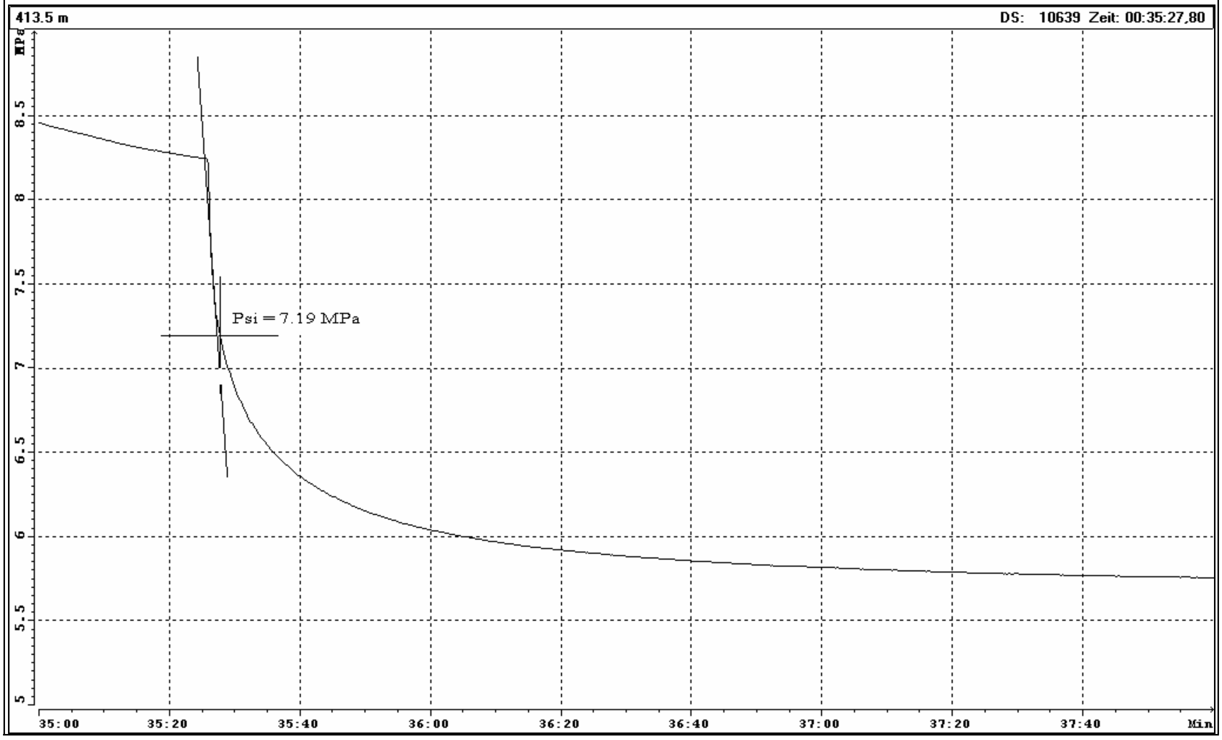
Test at 413.5 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



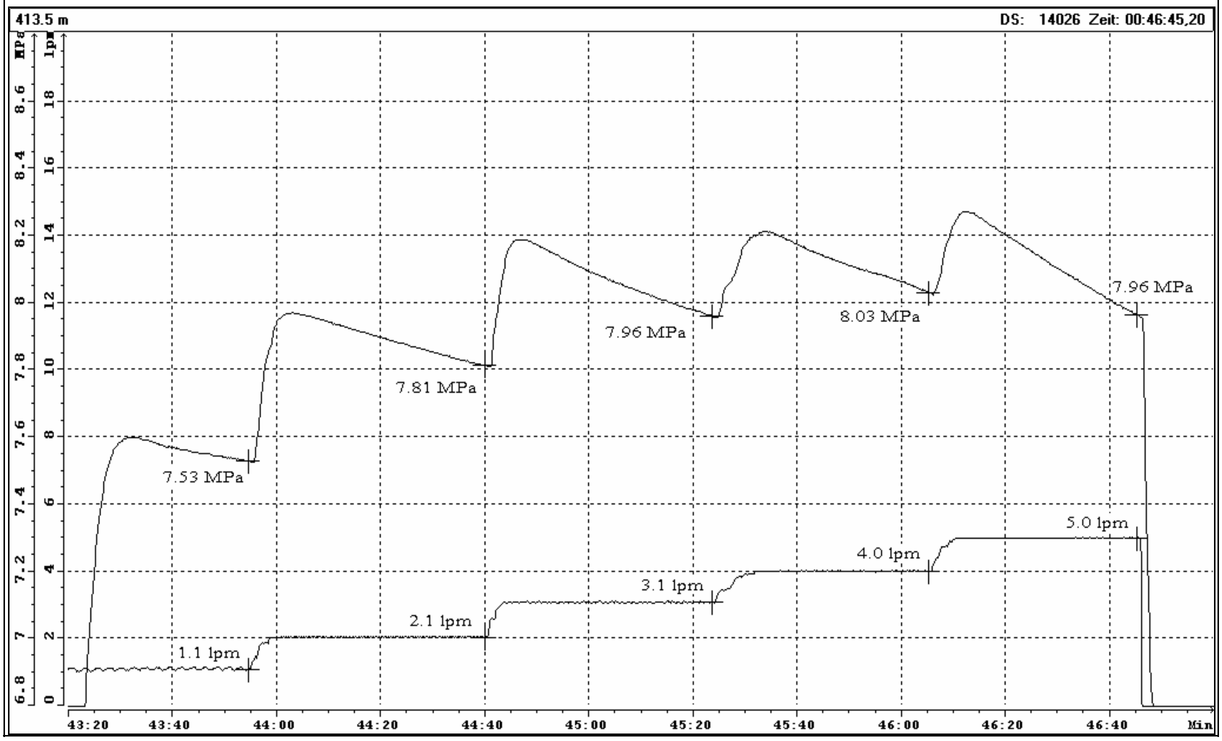
Test at 413.5 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



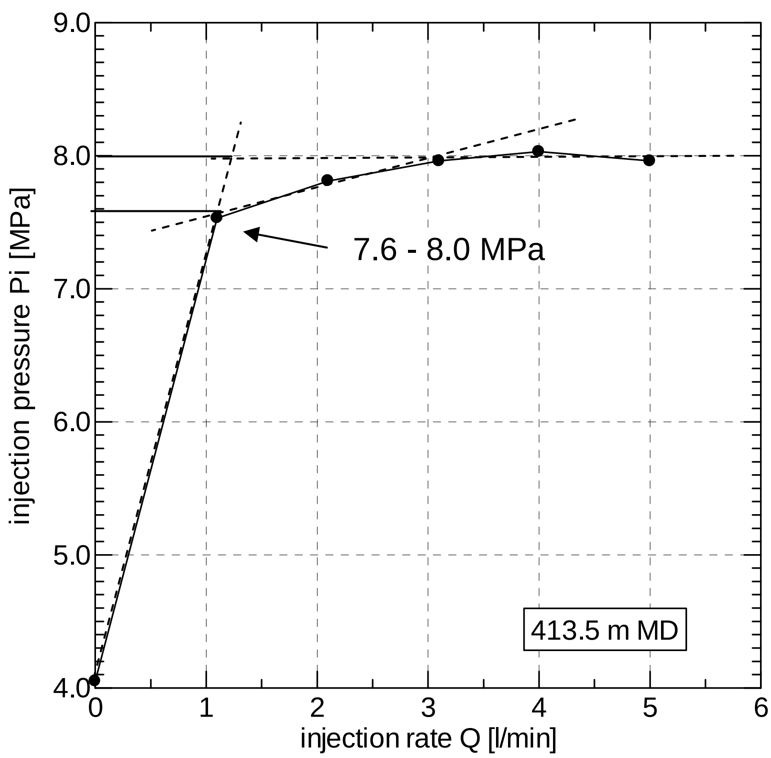
Test at 413.5 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 413.5 m MD: Analysis of Slow - Pump / Step - Rate - Test

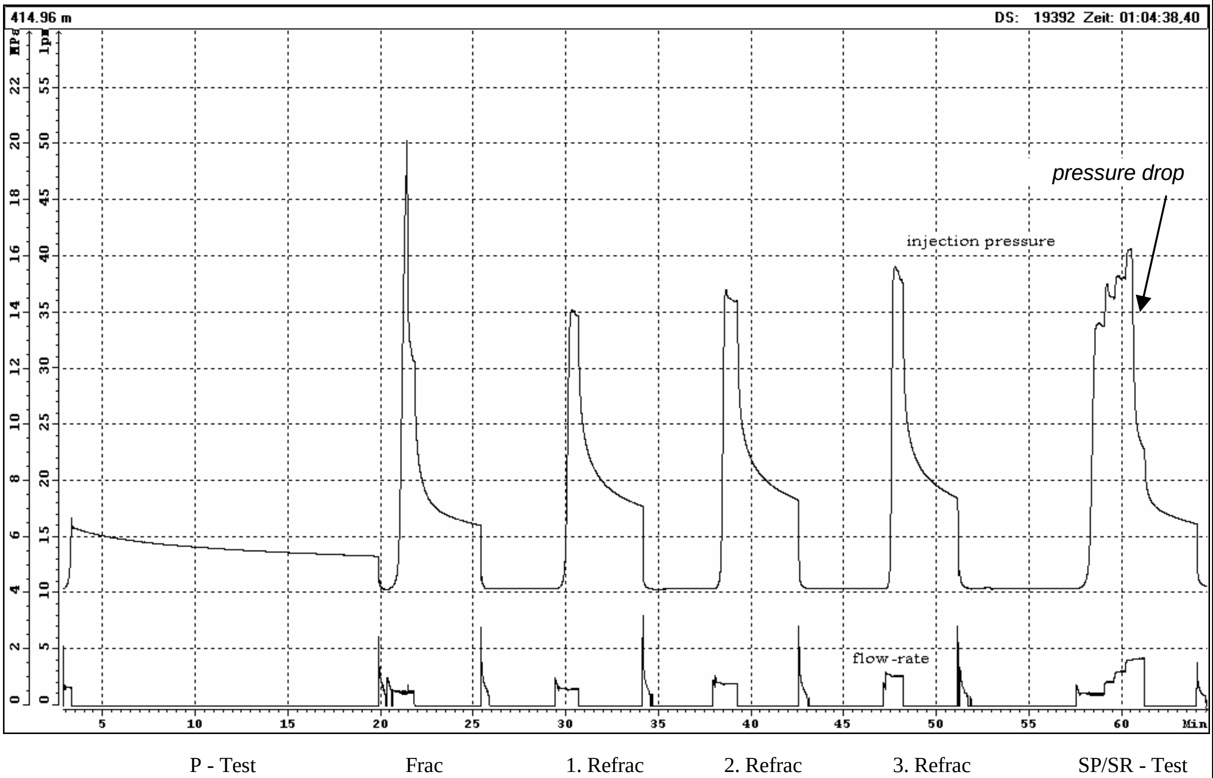


Test at 413.5 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 30 AT 414.96 m MD / 413.57 m TVD

Test at 414.96 m MD: Overview - Plot



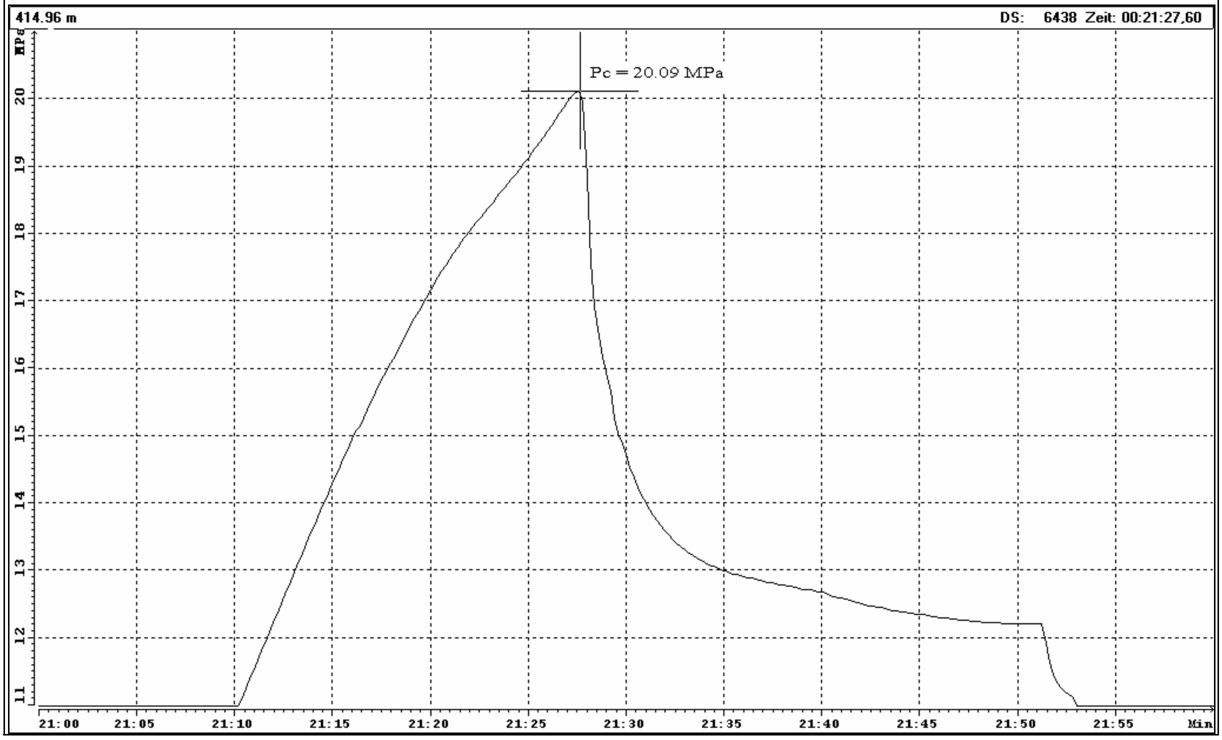
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 1.01 MPa in 987 sec.		
Frac - cycle	Qi (lpm) = 1.2	Vi (l) = 2.0	Vr (l) = 1.2
1. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 2.0	Vr (l) = 1.3
2. Refrac - cycle	Qi (lpm) = 2.0	Vi (l) = 2.65	Vr (l) = 1.4
3. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 2.7	Vr (l) = 1.5
SP/SR - test	Qi (lpm) = 1.1-4.2	Vi (l) = 9.0	Vr (l) = 1.7

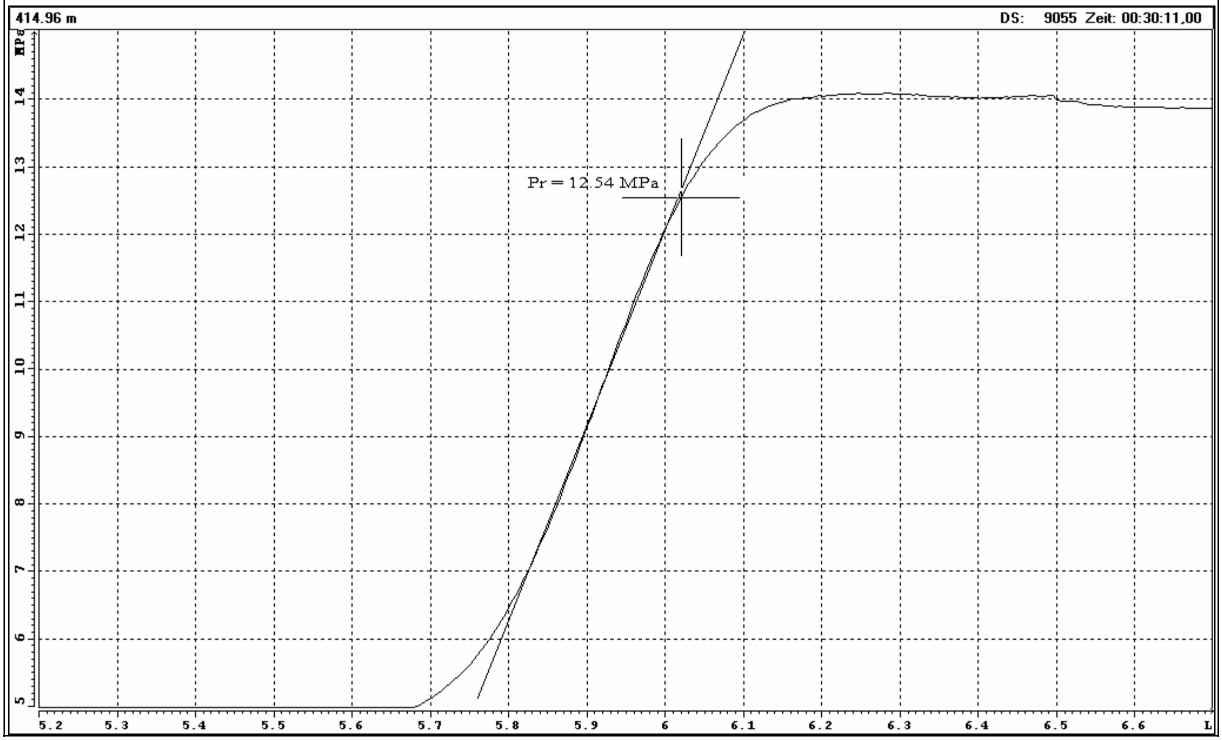
total injected volume (l): 18.35 recovered volume (l): 7.1 or 38.7 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. and 3. refrac - cycle, since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- During the final stage of the slow-pump / step-rate test, the injection pressure dropped from 16.2 MPa to 9.1 MPa.
- The shut-in phases of the 1., 2, and 3. refrac - cycle yield distinct and consistent shut-in pressure values of about 12 MPa which, however, decreased to about 8 MPa during the slow-pump / step-rate test. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

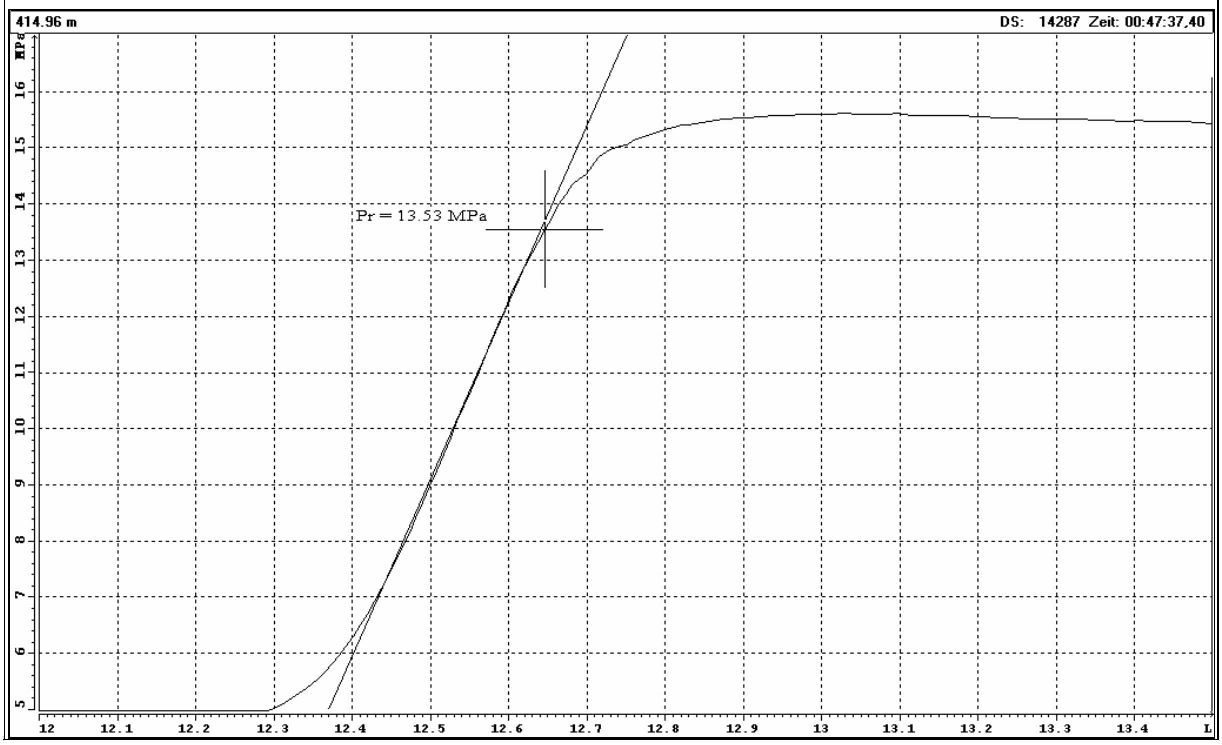
Test at 414.96 m MD: Estimation of P_c (Frac - Cycle)



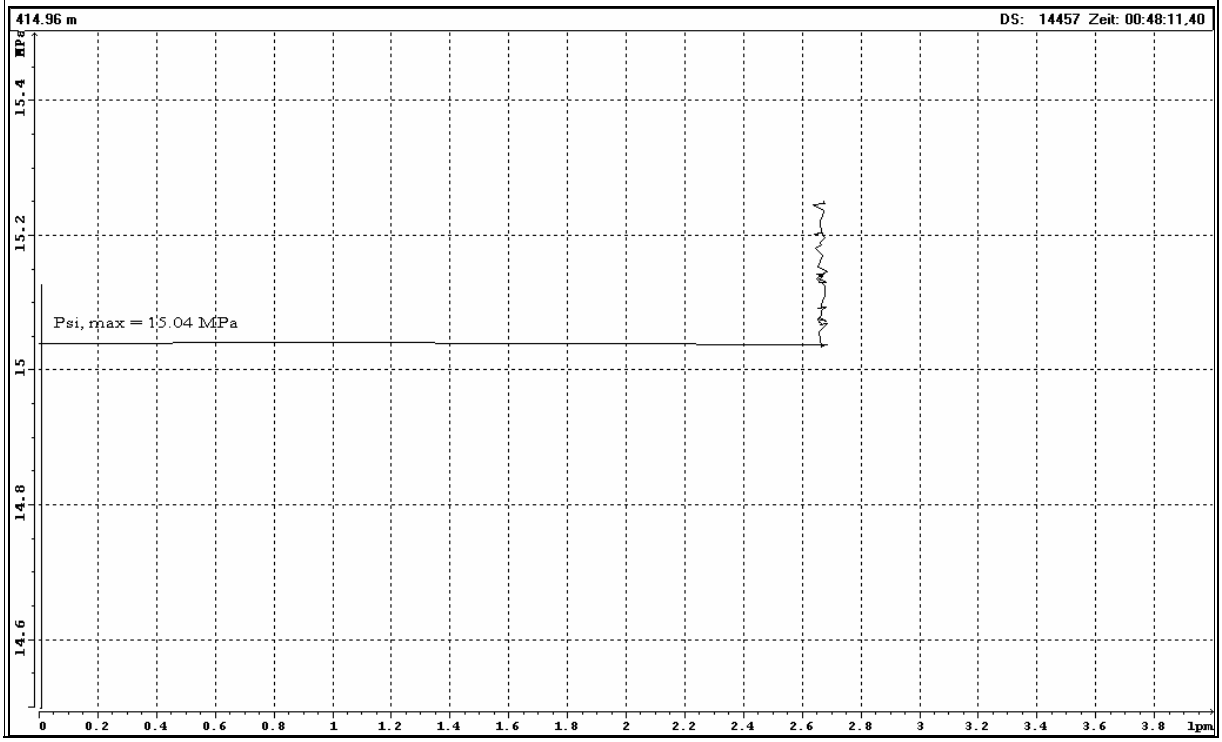
Test at 414.96 m MD: Estimation of P_r (1. Refrac - Cycle)



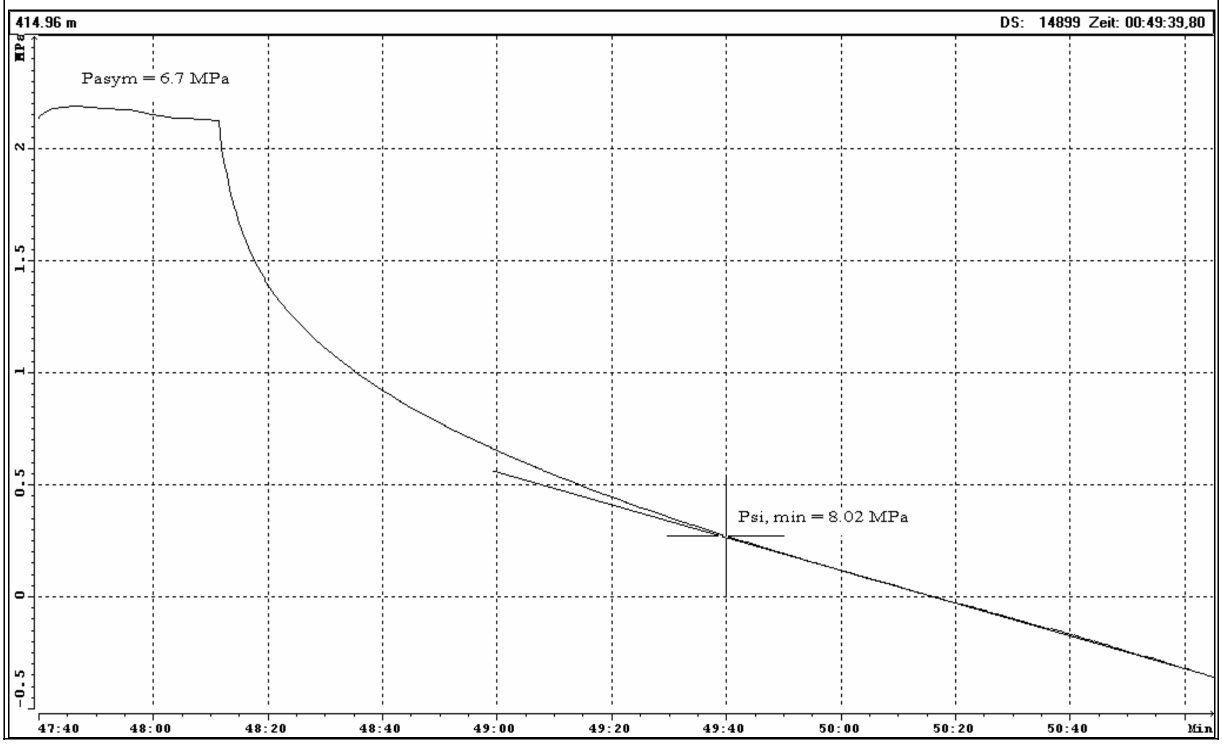
Test at 414.96 m MD: Estimation of P_r (3. Refrac - Cycle)



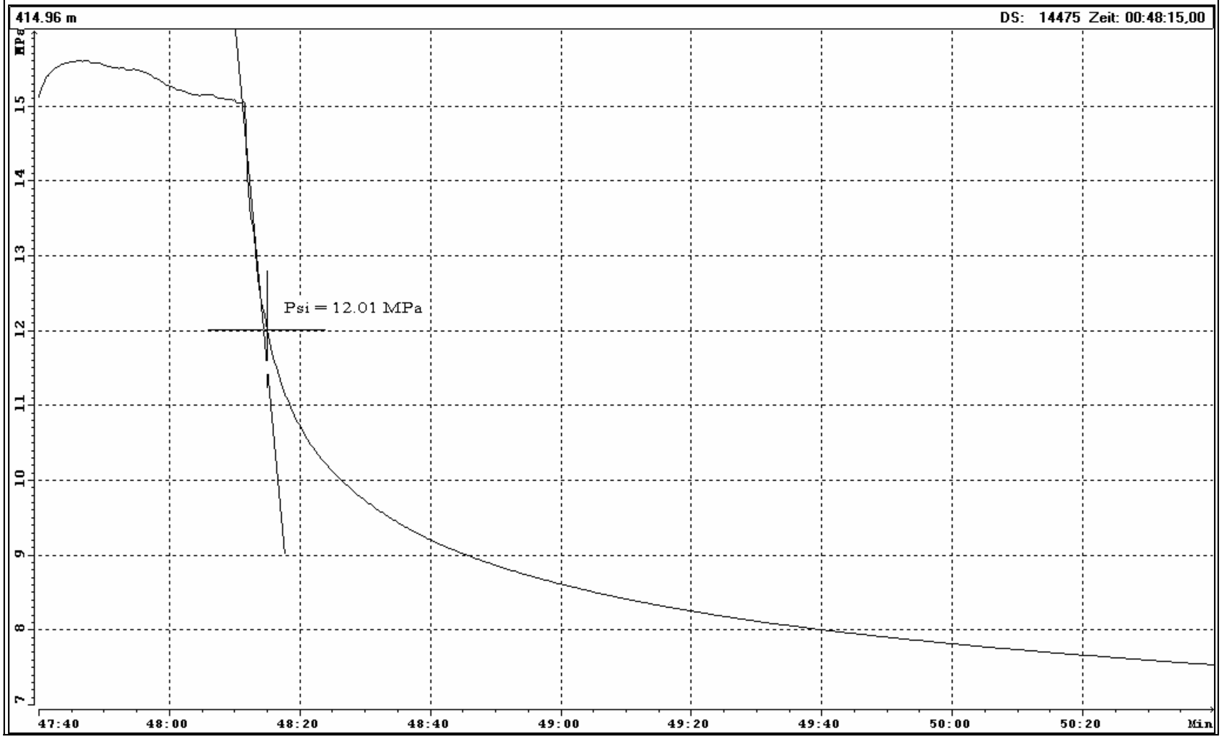
Test at 414.96 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



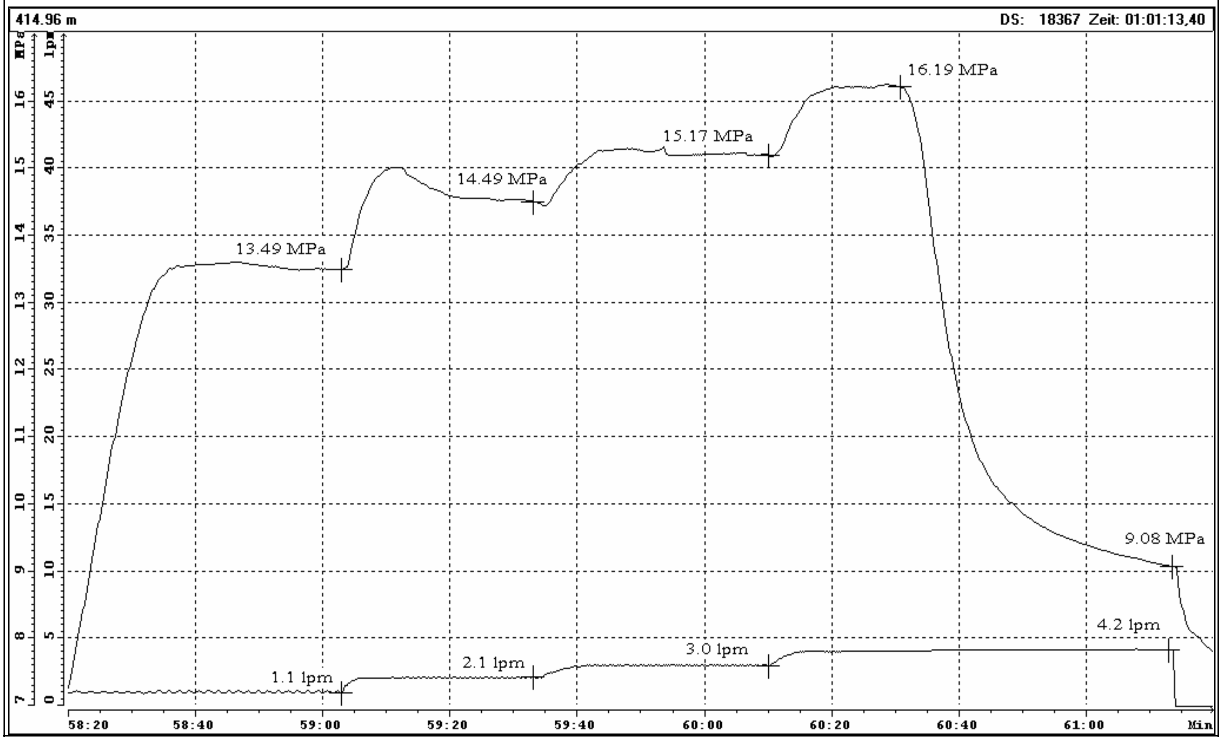
Test at 414.96 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



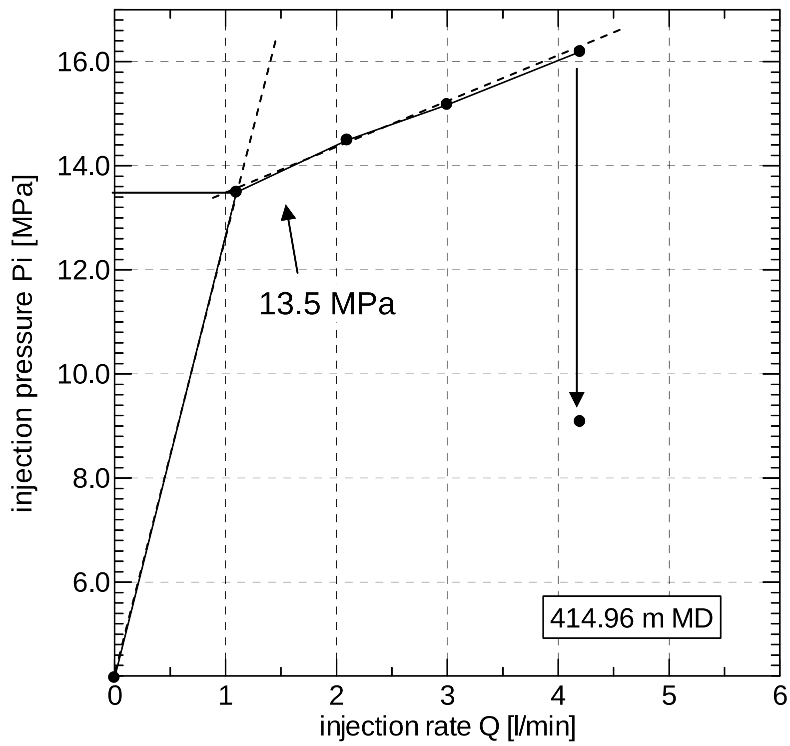
Test at 414.96 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 414.96 m MD: Analysis of Slow - Pump / Step - Rate - Test

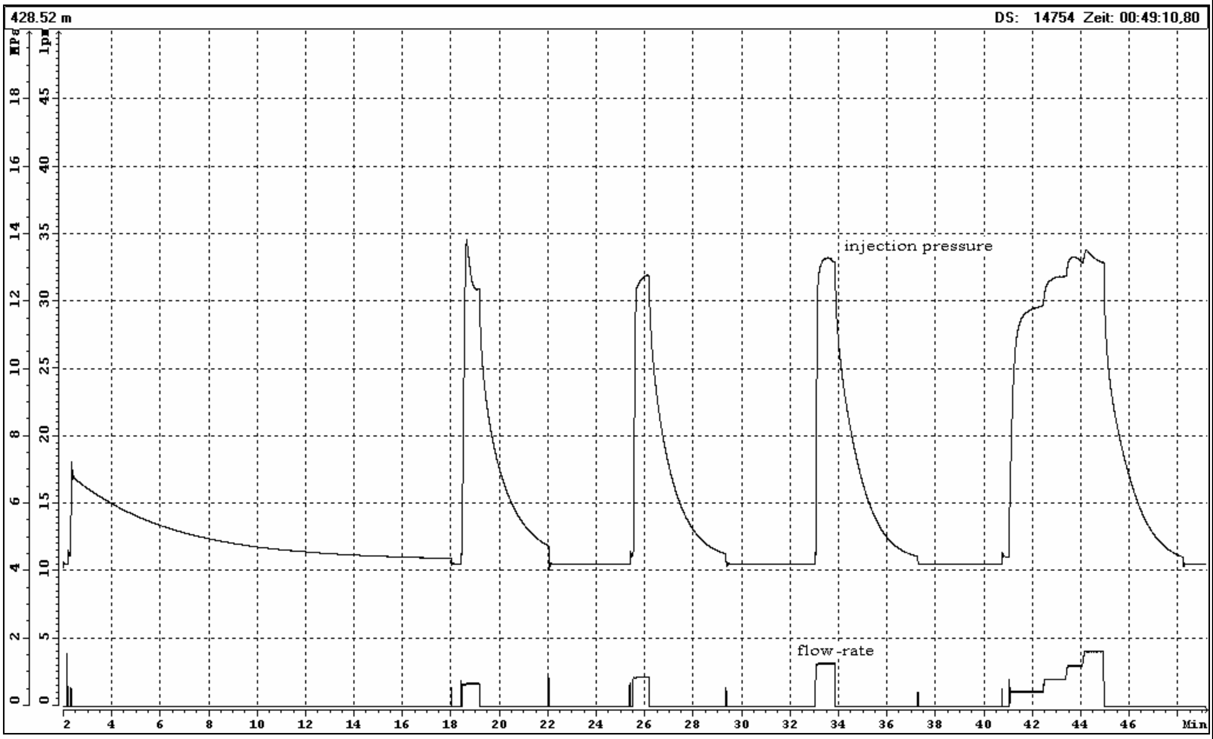


Test at 414.96 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 29 AT 428.52 m MD / 434.78 m TVD

Test at 428.52 m MD: Overview - Plot



P - Test　Frac (1. Refrac)　2. Refrac　3. Refrac　SP/SR - Test

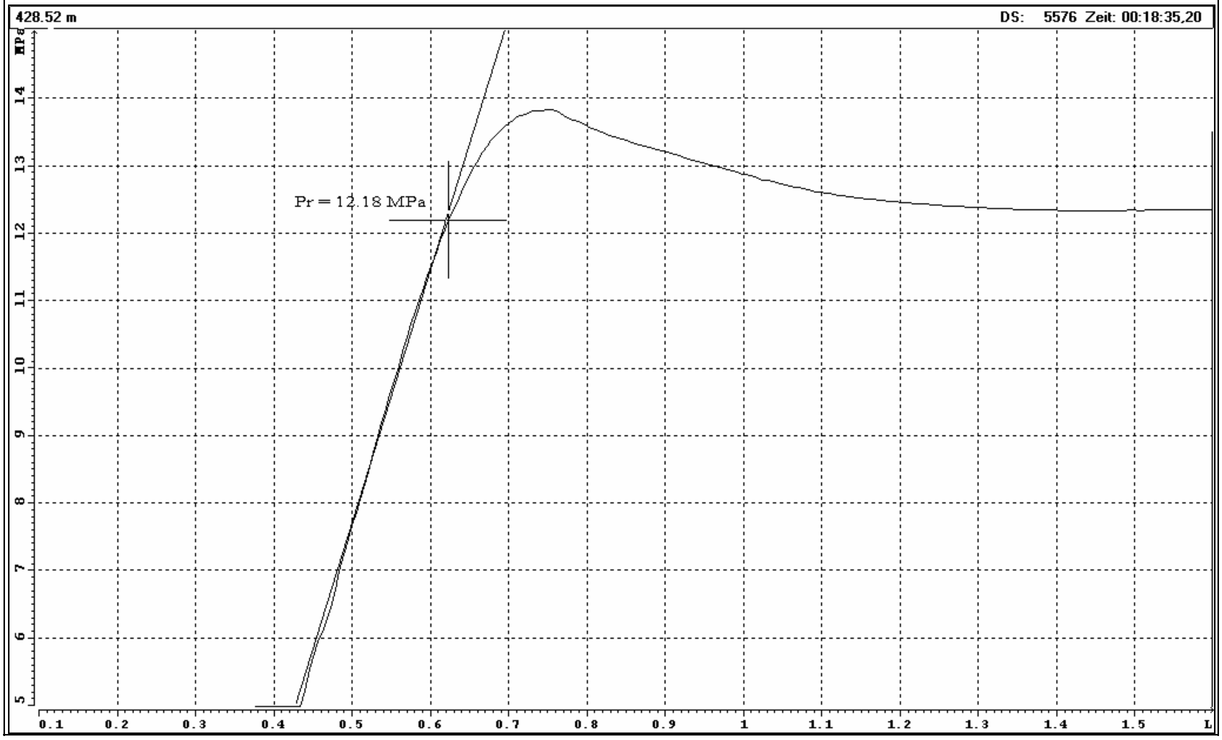
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 2.38 MPa in 932 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.7	Vi (l) = 1.2	Vr (l) = 0.05
2. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 1.5	Vr (l) = 0.0
3. Refrac - cycle	Qi (lpm) = 3.2	Vi (l) = 2.6	Vr (l) = 0.05
SP/SR - test	Qi (lpm) = 1.1-4.1	Vi (l) = 9.0	Vr (l) = 0.0

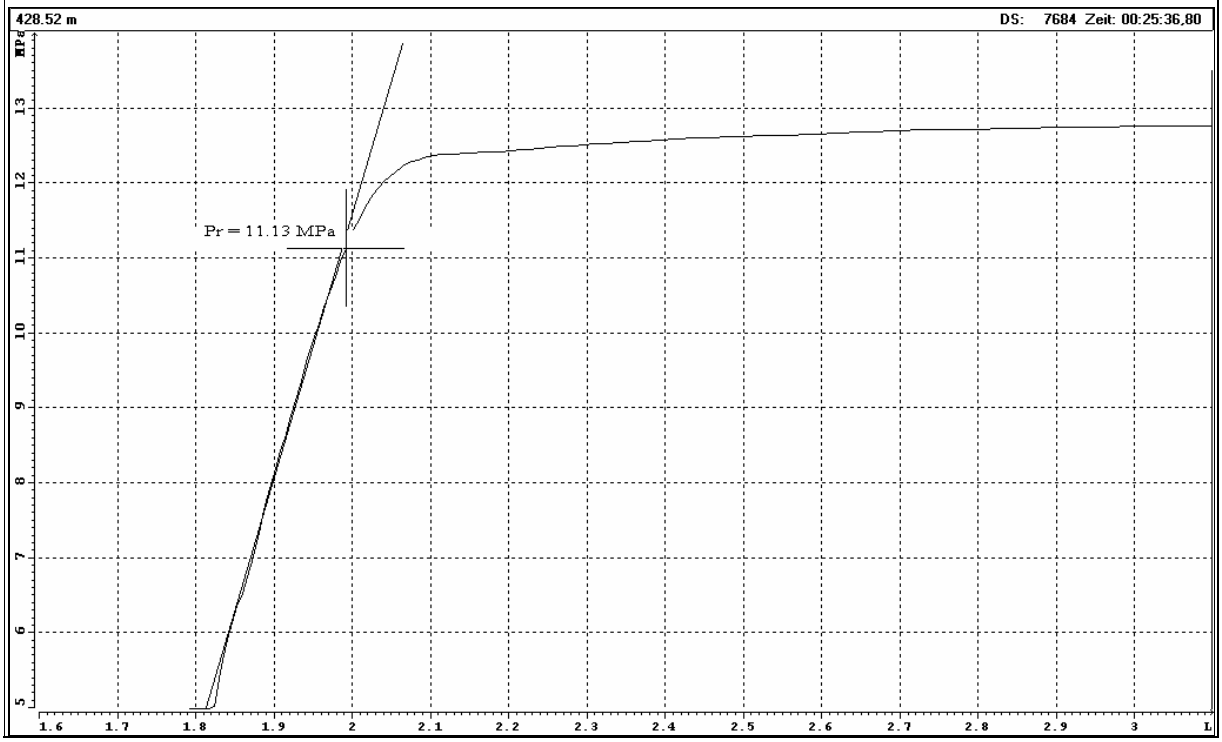
total injected volume (l): 14.3　recovered volume (l): 0.1 or 0.7 %

- Initial test type: HTPF-h
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct shut-in pressure values, however, which increased slightly from 11.4 MPa during the 1. refrac - cycle to 11.9 MPa during the 3. refrac - cycle. Therefore, the shut - in pressure of the 1. refrac - cycle was used for the stress analysis.

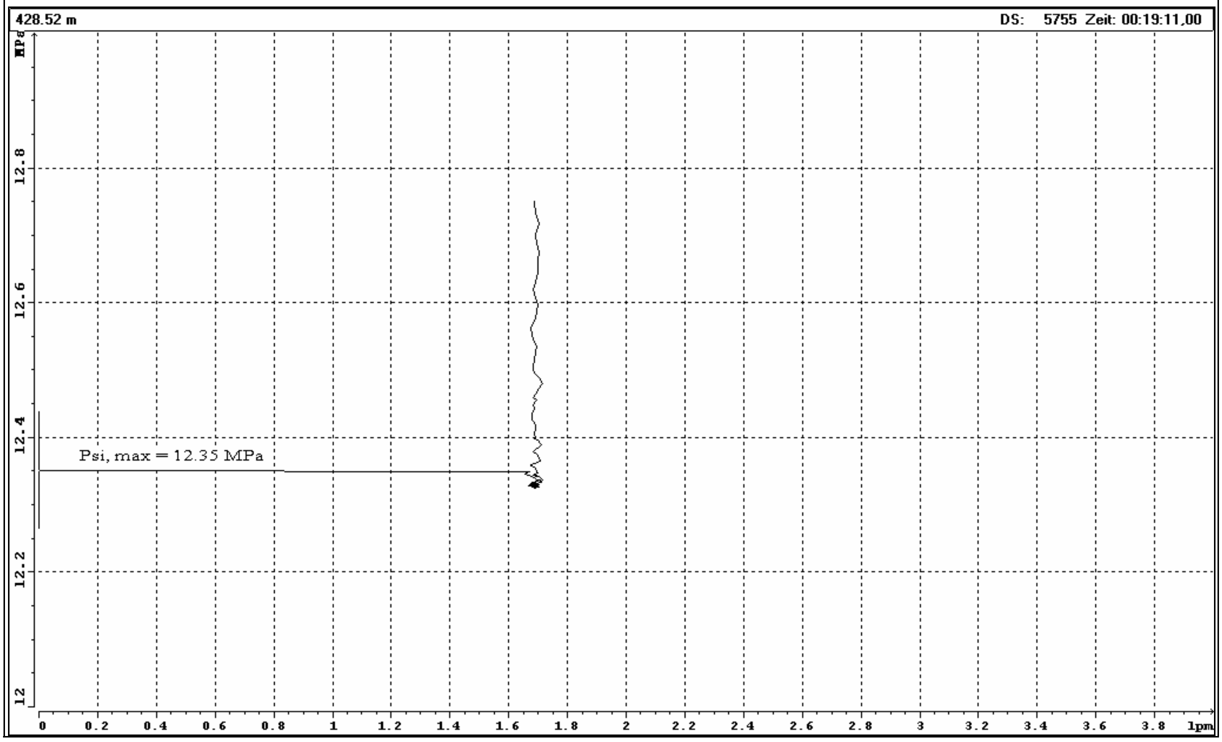
Test at 428.52 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



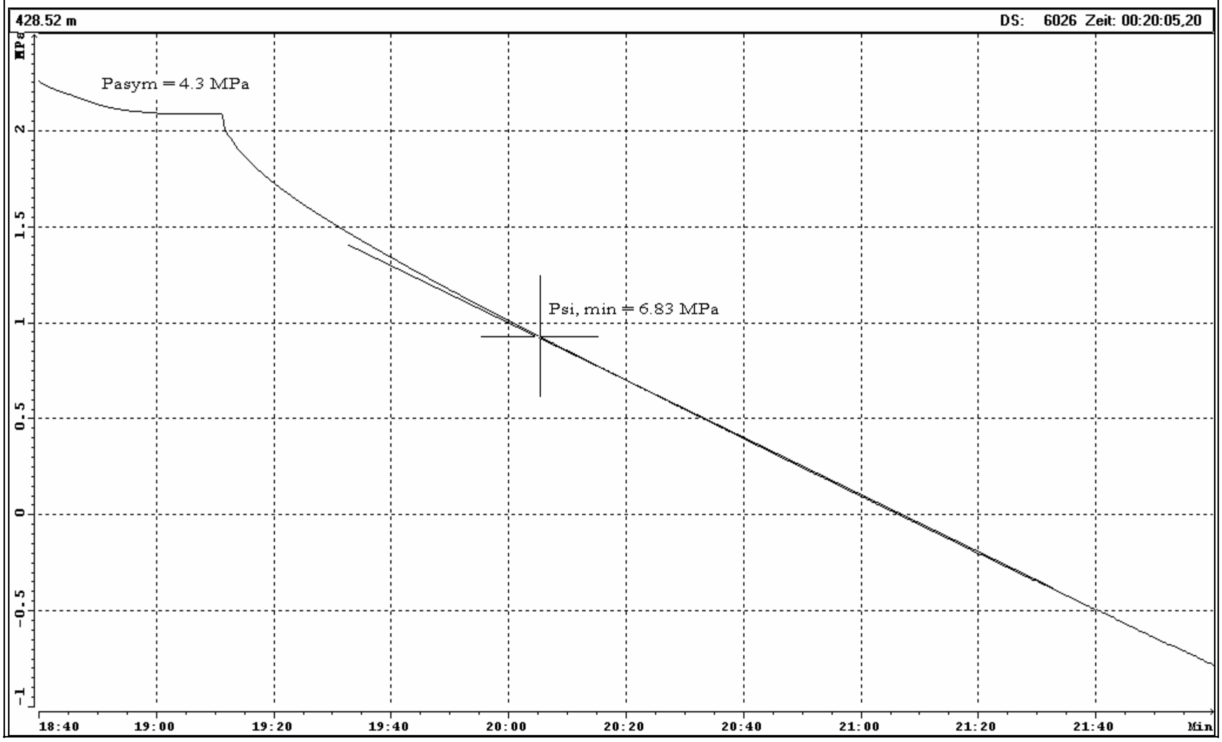
Test at 428.52 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



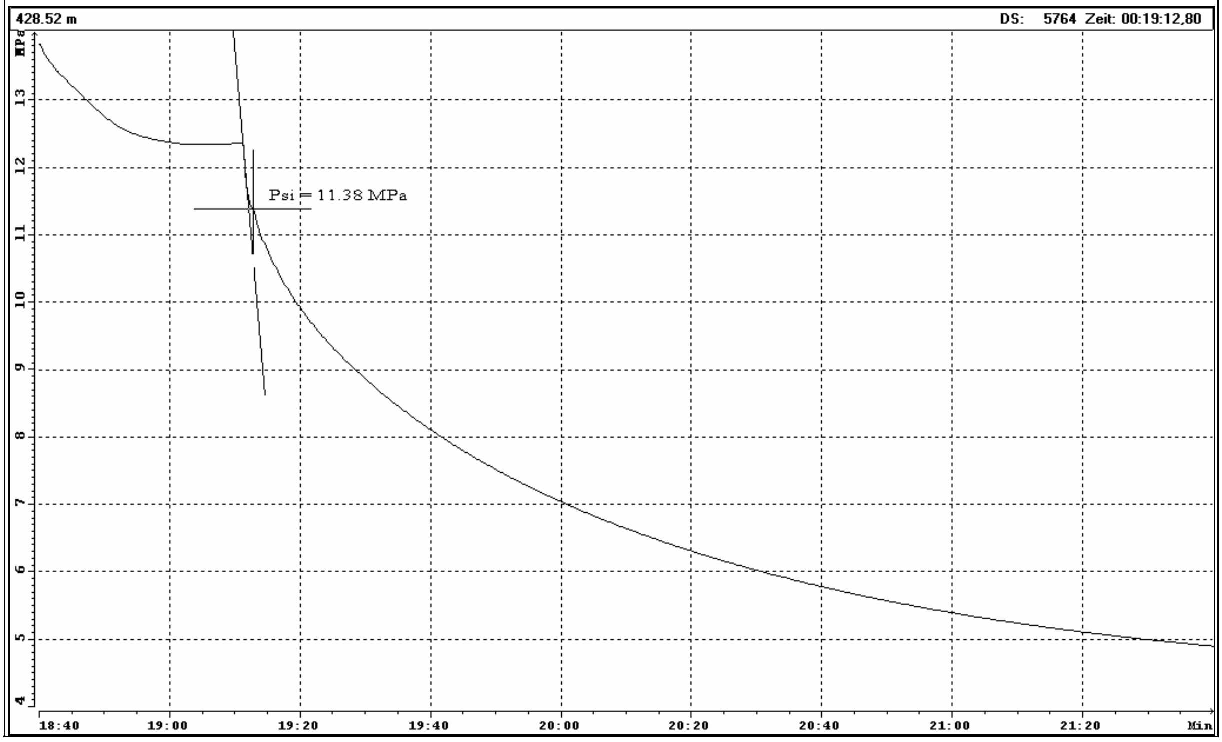
Test at 428.52 m MD: Estimation of $P_{si, max}$ (1. Refrac - Cycle)



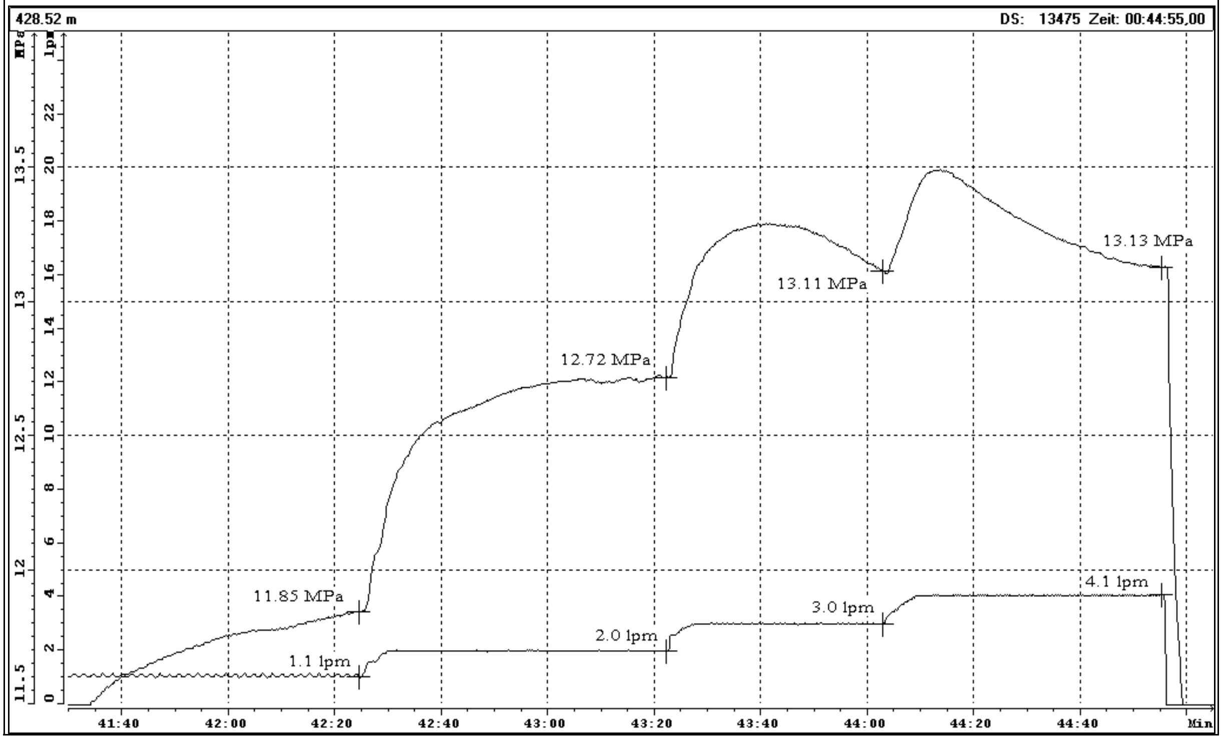
Test at 428.52 m MD: Estimation of $P_{si, min}$ (1. Refrac - Cycle)



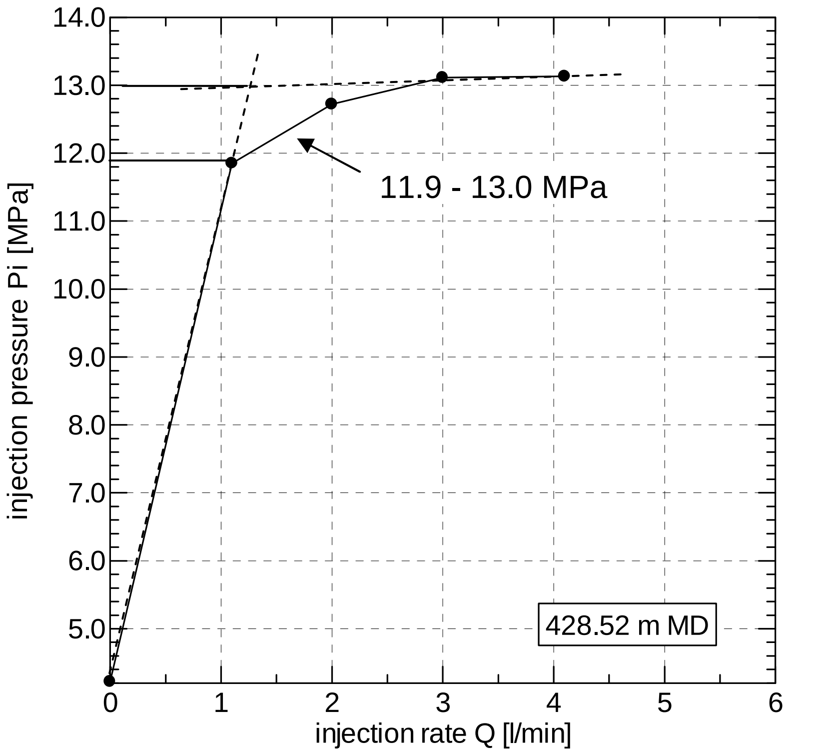
Test at 428.52 m MD: Estimation of P_{si} (1. Refrac - Cycle)



Test at 428.52 m MD: Analysis of Slow - Pump / Step - Rate - Test

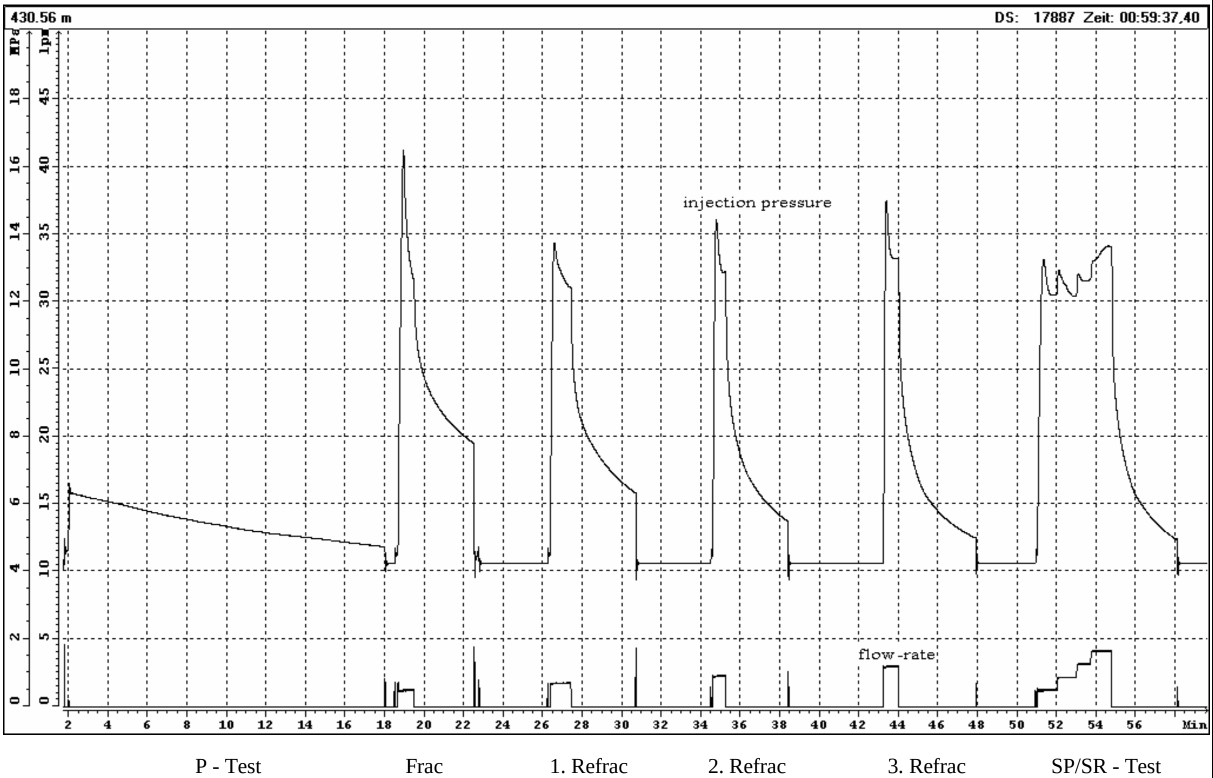


Test at 428.52 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 28 AT 430.56 m MD / 428.66 m TVD

Test at 430.56 m MD : Overview - Plot



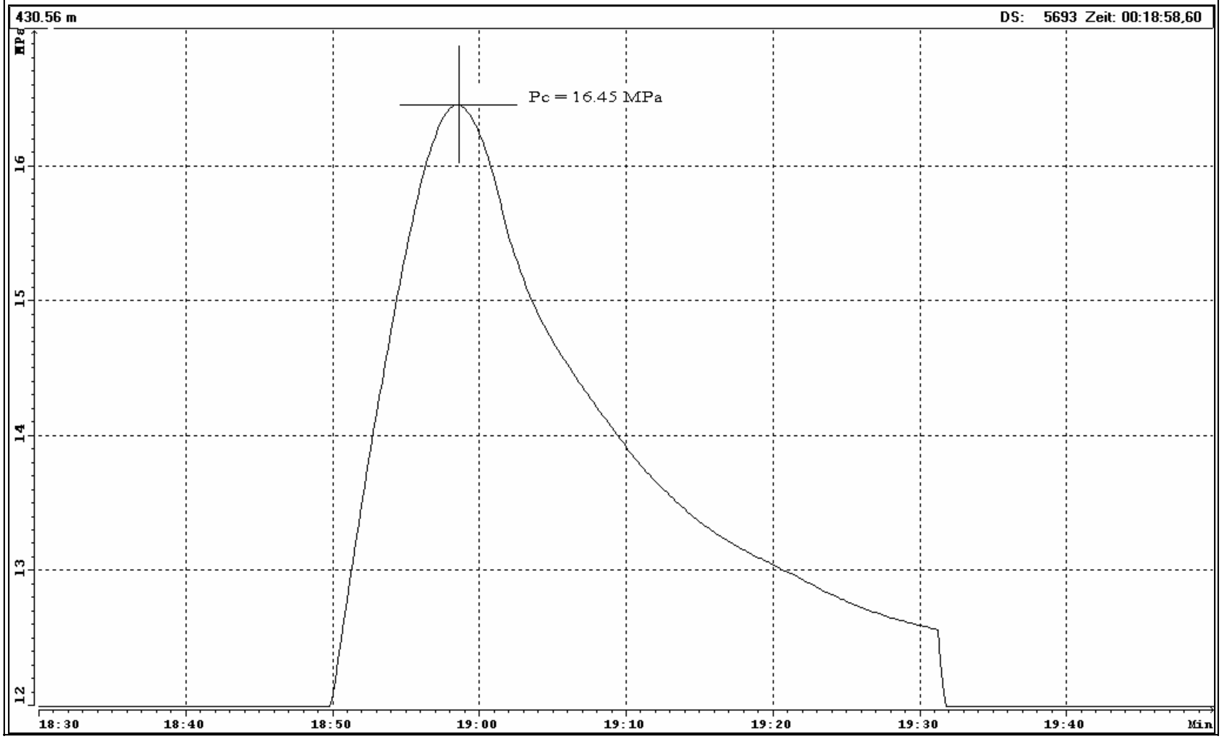
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.58 MPa in 949 sec.		
Frac - cycle	Qi (lpm) = 1.2	Vi (l) = 1.1	Vr (l) = 0.15
1. Refrac - cycle	Qi (lpm) = 1.7	Vi (l) = 1.9	Vr (l) = 0.15
2. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 1.5	Vr (l) = 0.1
3. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 2.3	Vr (l) = 0.05
SP/SR - test	Qi (lpm) = 1.3-4.1	Vi (l) = 10.0	Vr (l) = 0.1

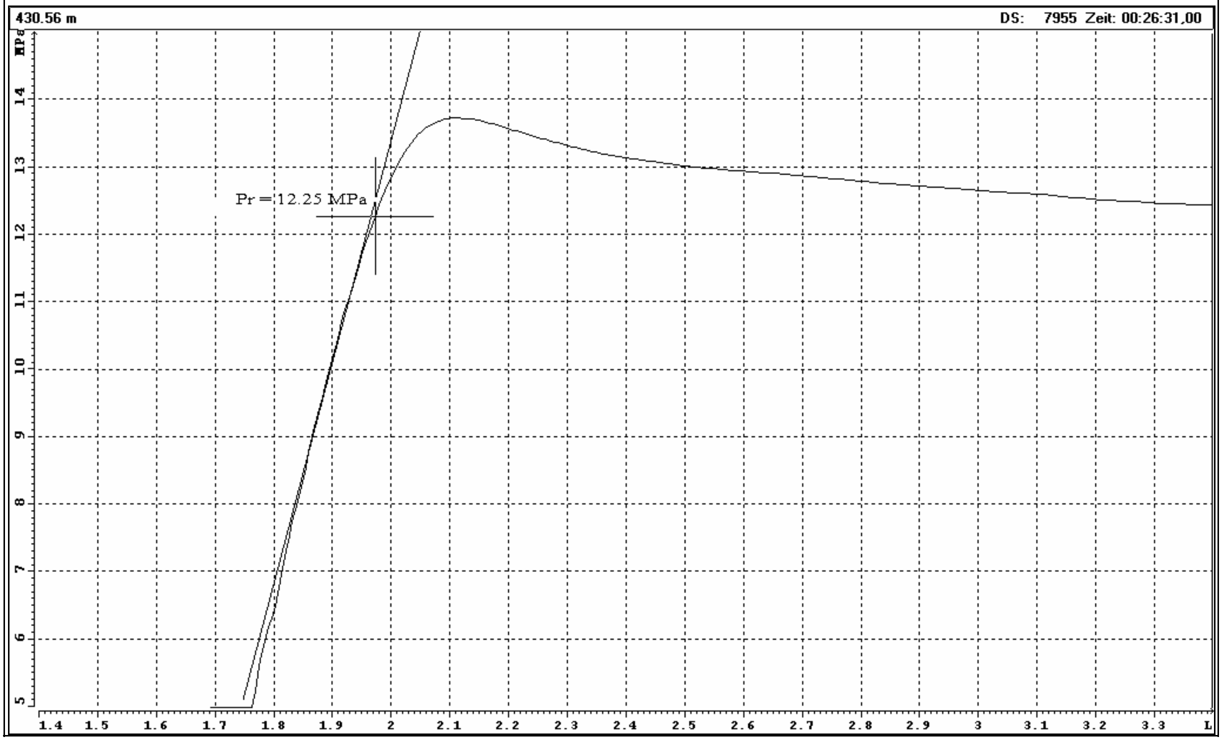
total injected volume (l): 16.8 recovered volume (l): 0.55 or 3.3 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a weak breakdown event.
- The refrac - pressure was determined from the 1. and 2. refrac - cycle, since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- The shut-in phases yield consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

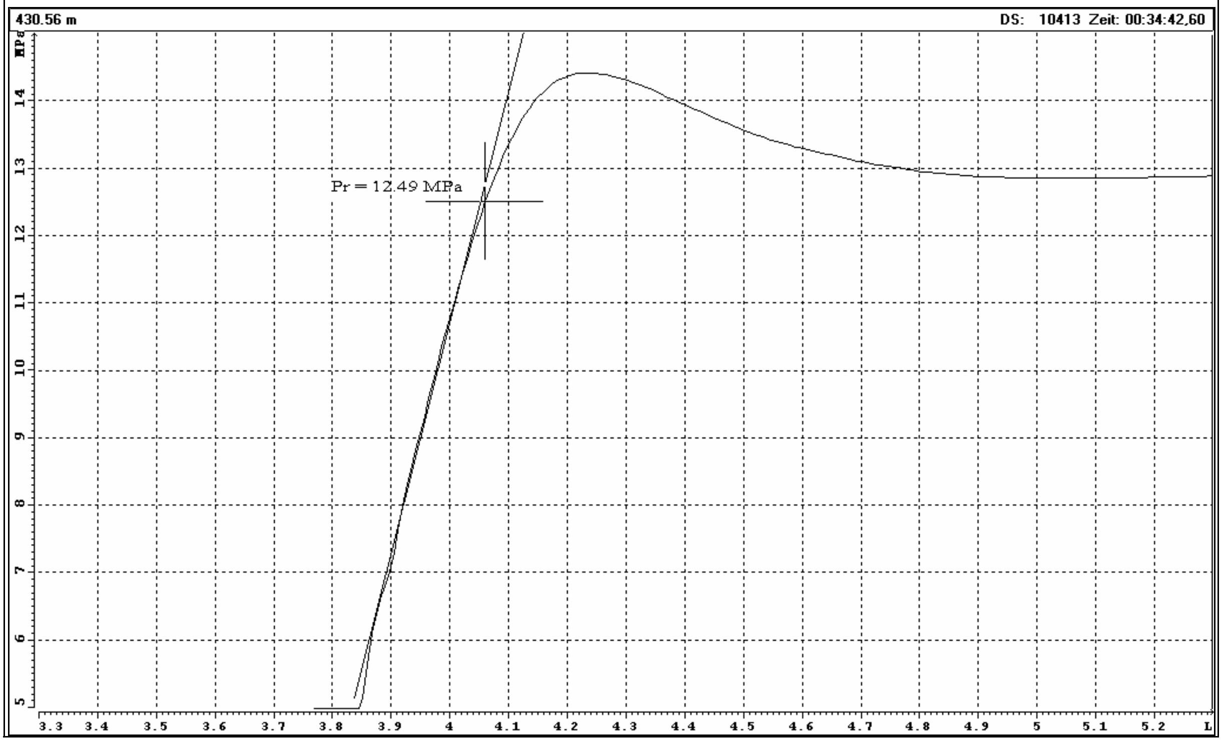
Test at 430.56 m MD: Estimation of P_c (Frac - Cycle)



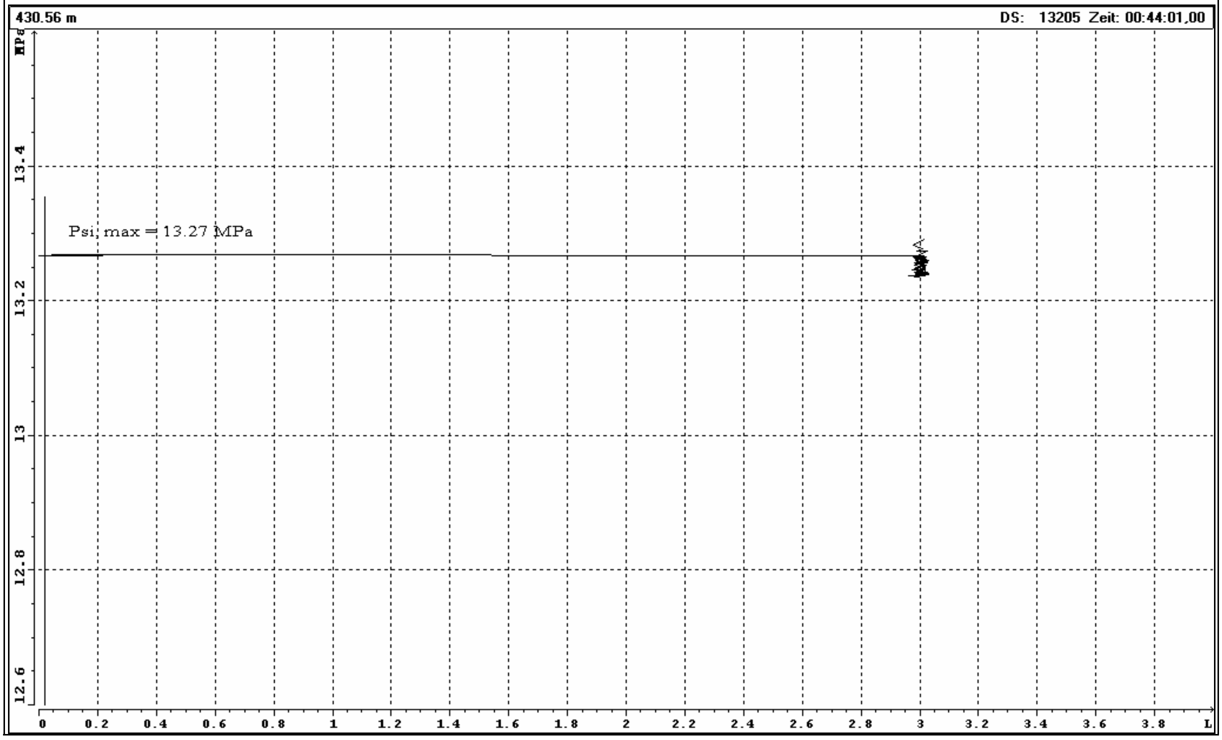
Test at 430.56 m MD: Estimation of P_r (1. Refrac) - Cycle)



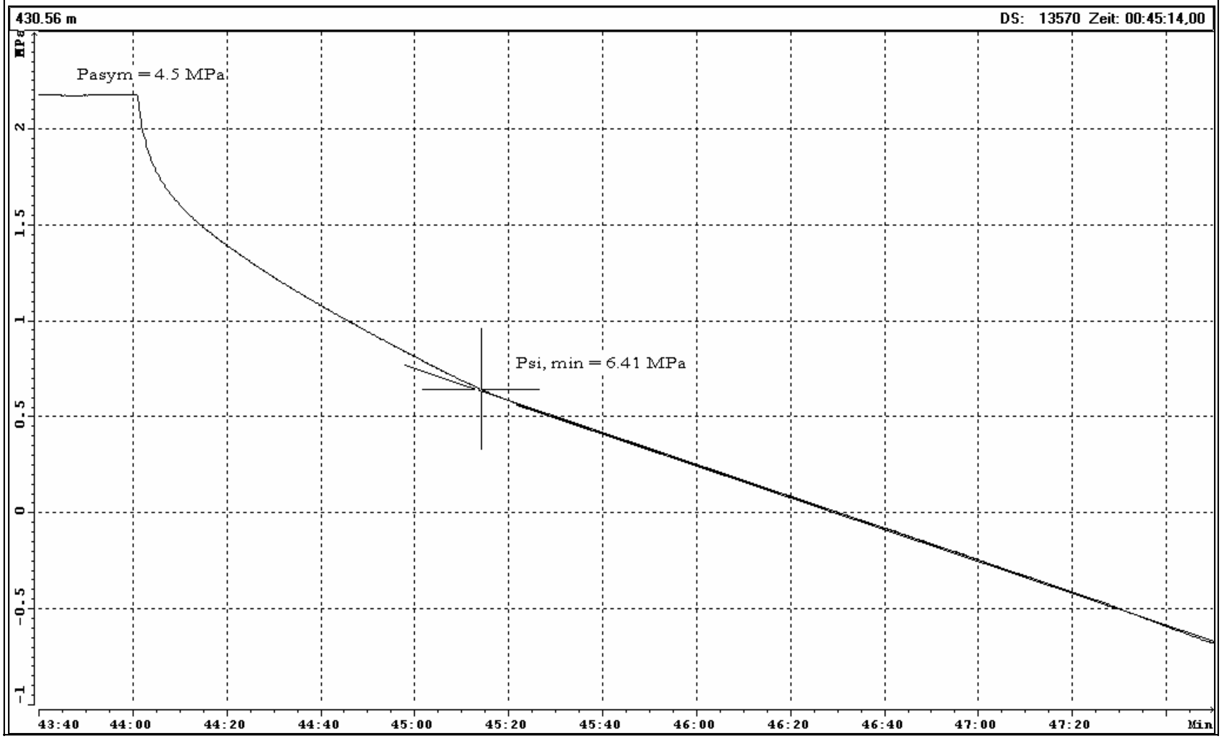
Test at 430.56 m MD: Estimation of P_r (2. Refrac - Cycle)



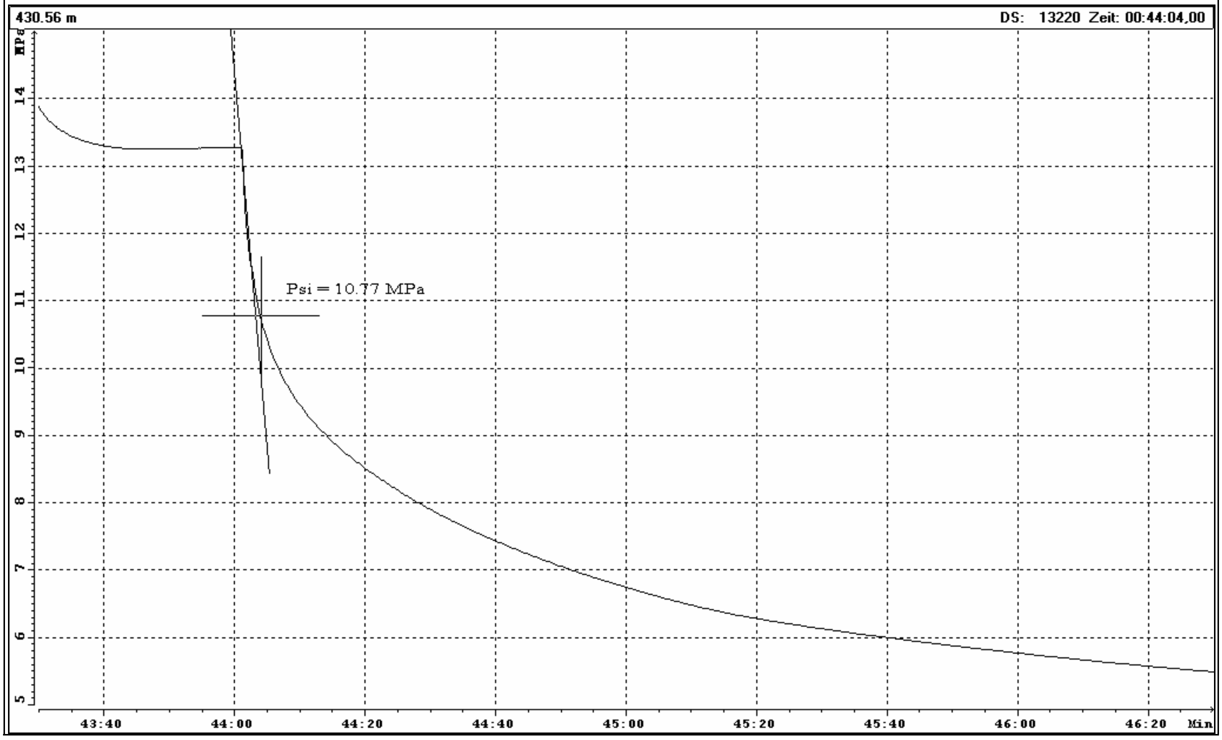
Test at 430.56 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



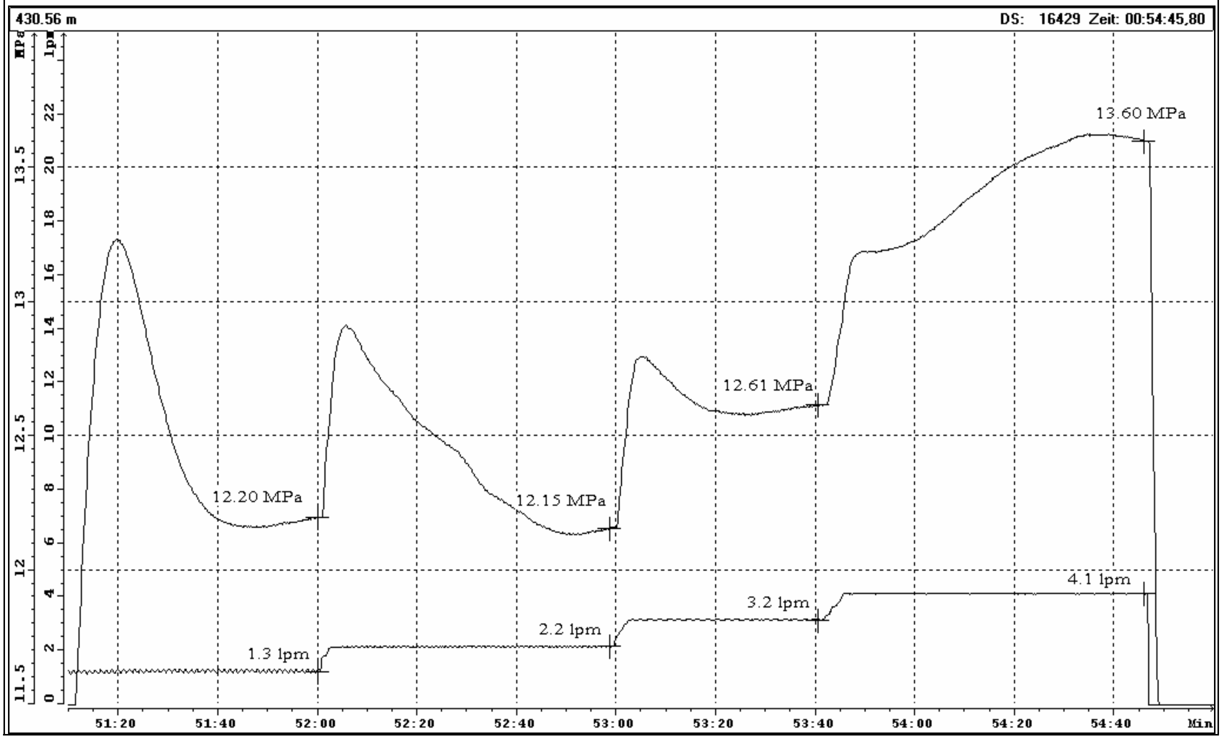
Test at 430.56 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



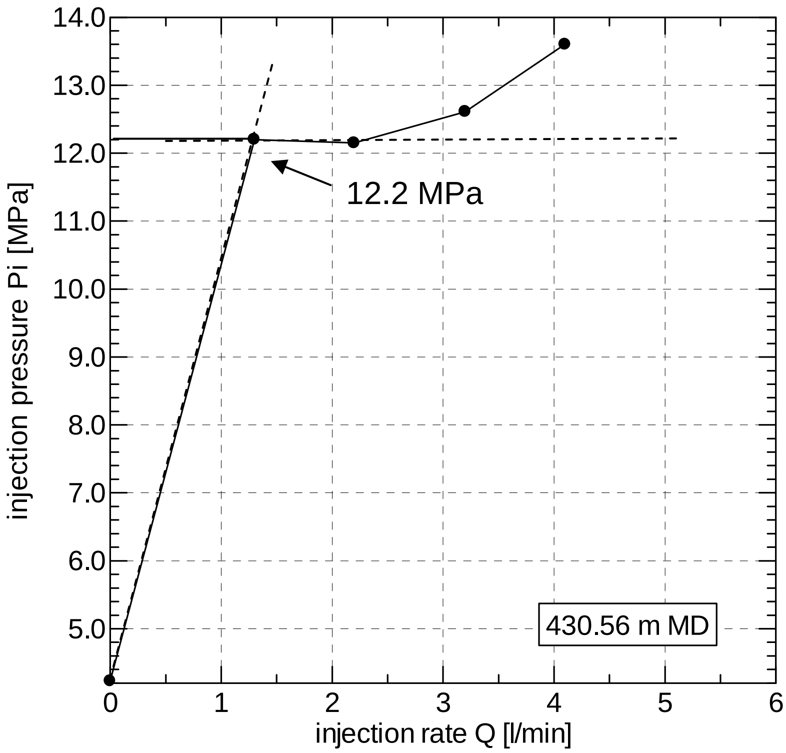
Test at 430.56 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 430.56 m MD: Analysis of Slow - Pump / Step - Rate - Test

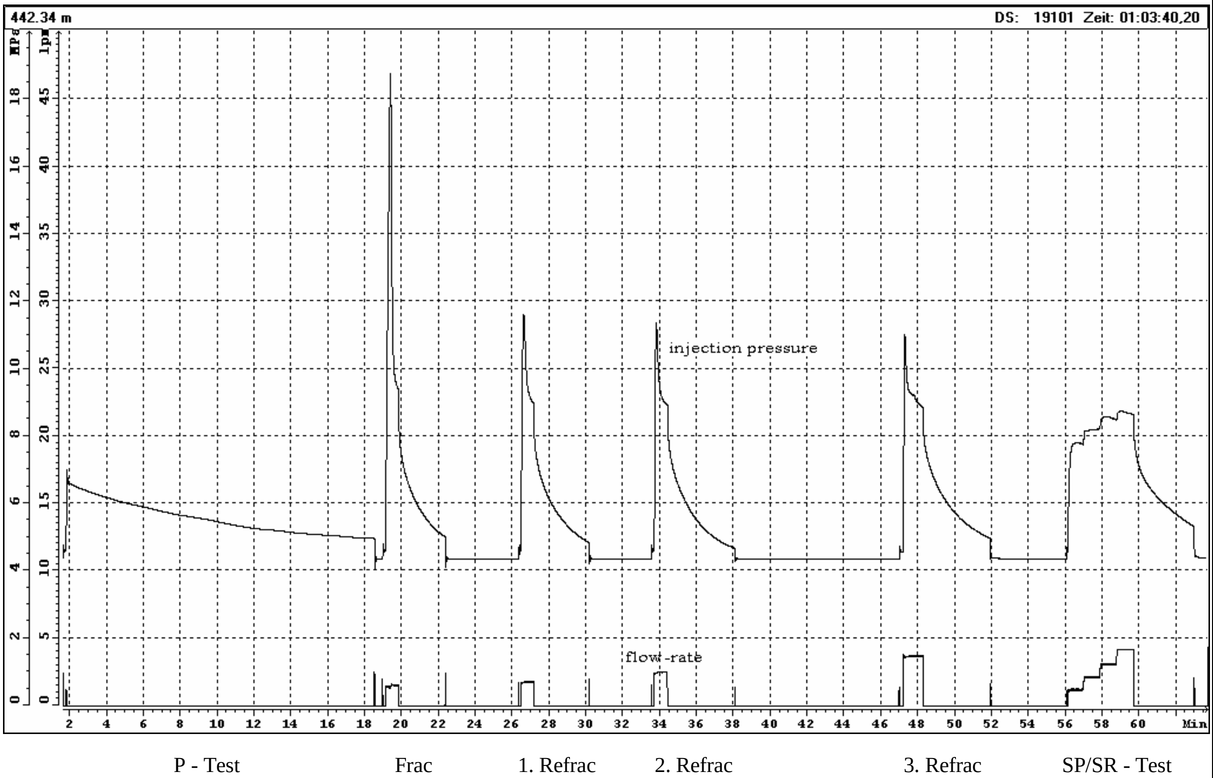


Test at 430.56 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 27 AT 442.34 m MD / 440.83 m TVD

Test at 442.34 m MD : Overview - Plot



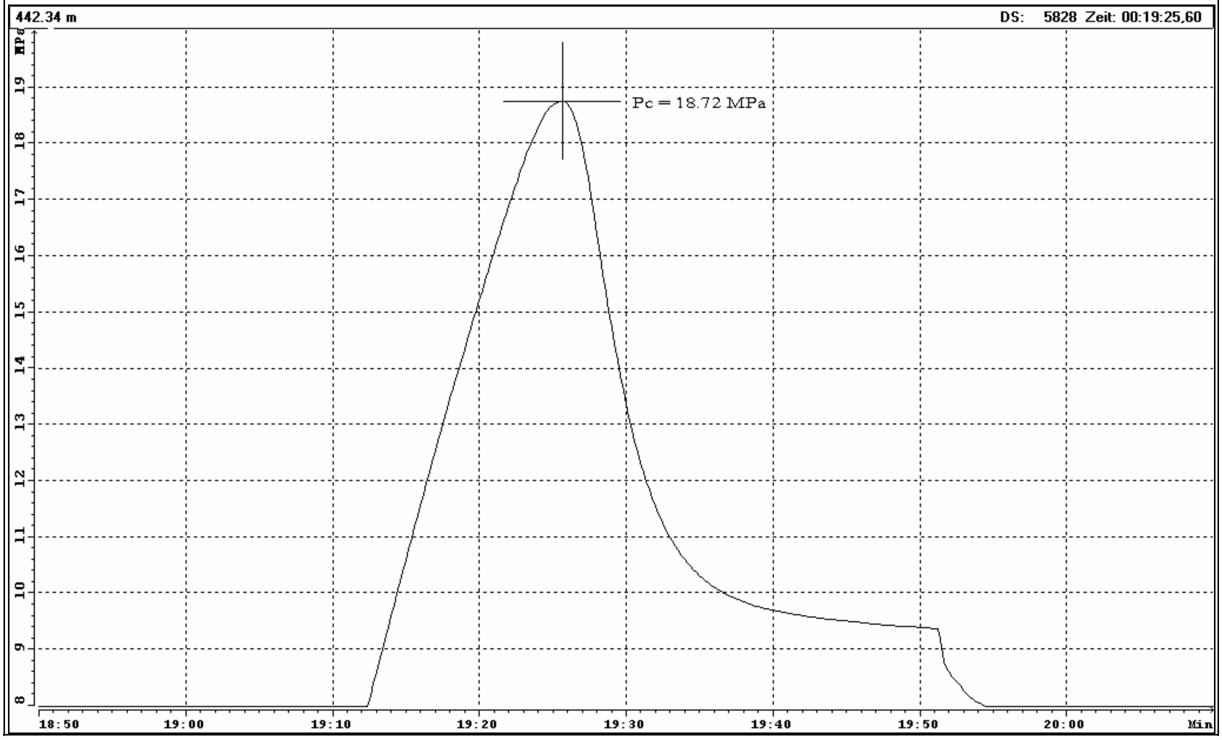
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.64 MPa in 991 sec.		
Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.1	Vr (l) = 0.1
1. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 1.25	Vr (l) = 0.05
2. Refrac - cycle	Qi (lpm) = 2.5	Vi (l) = 1.8	Vr (l) = 0.05
3. Refrac - cycle	Qi (lpm) = 3.7	Vi (l) = 3.9	Vr (l) = 0.15
SP/SR - test	Qi (lpm) = 1.2-4.2	Vi (l) = 9.5	Vr (l) = 0.5

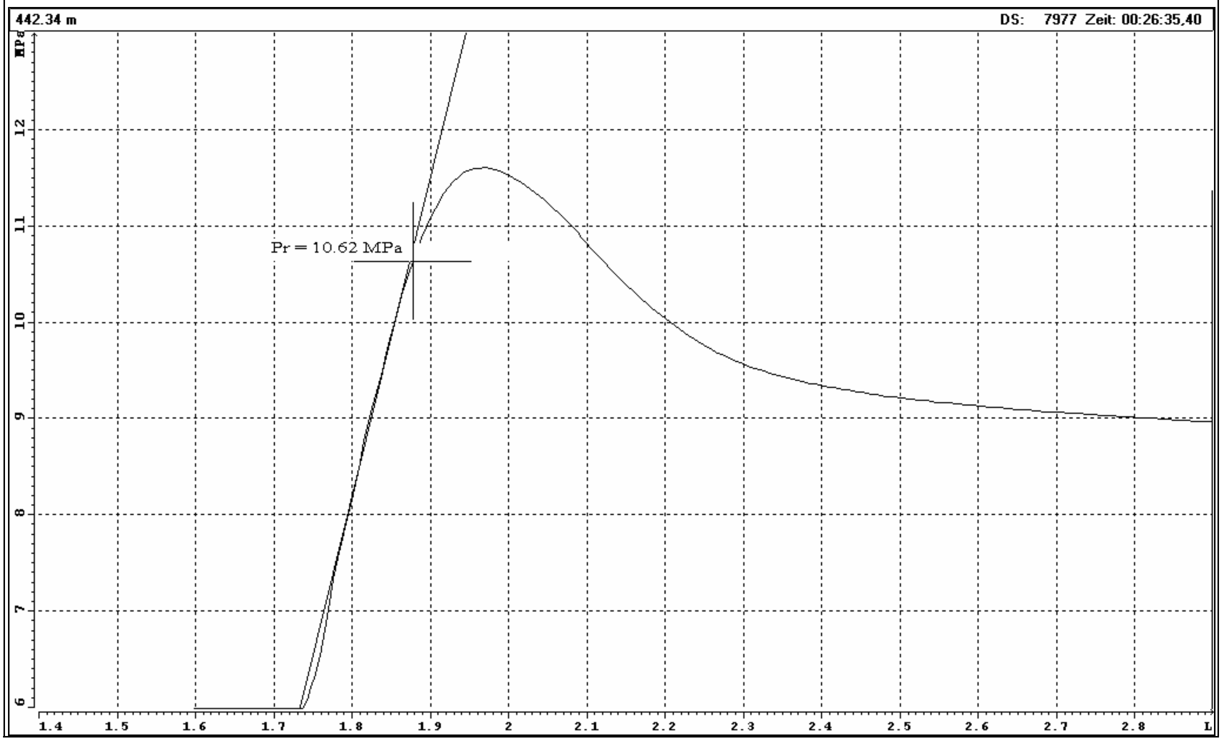
total injected volume (l): 17.55 recovered volume (l): 0.85 or 4.8 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

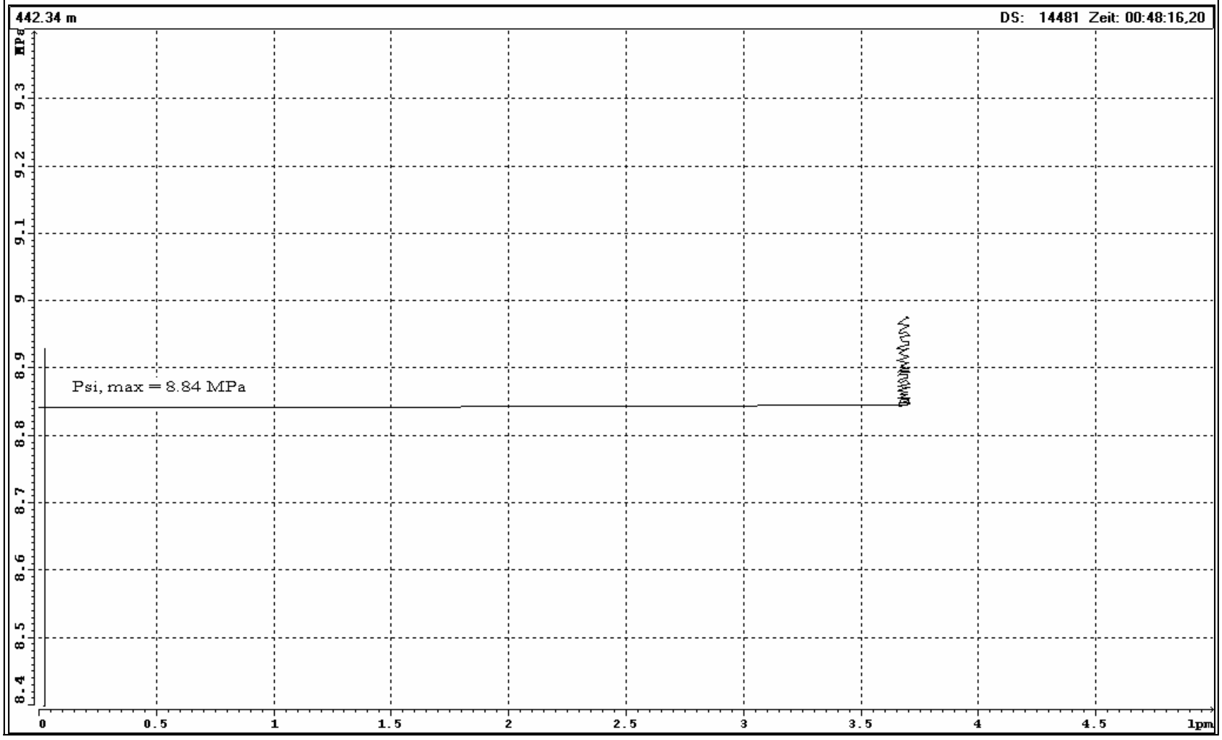
Test at 442.34 m MD: Estimation of P_c (Frac - Cycle)



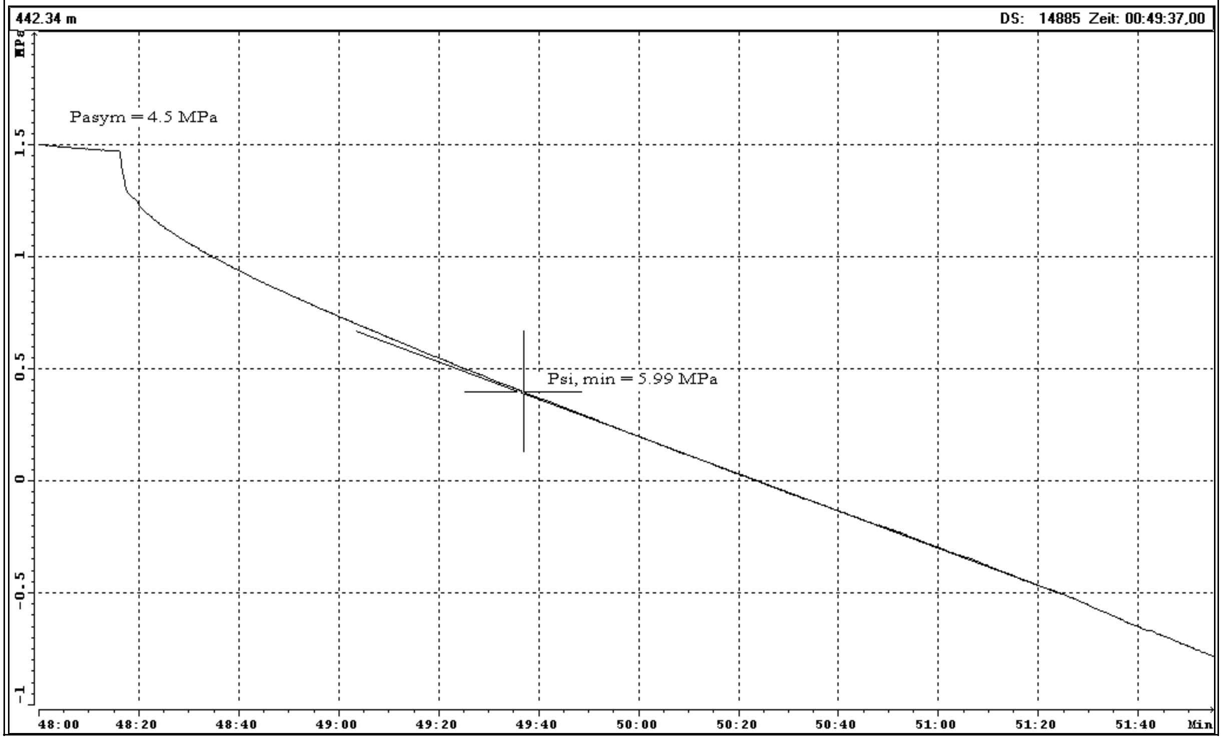
Test at 442.34 m MD: Estimation of P_r (1. Refrac - Cycle)



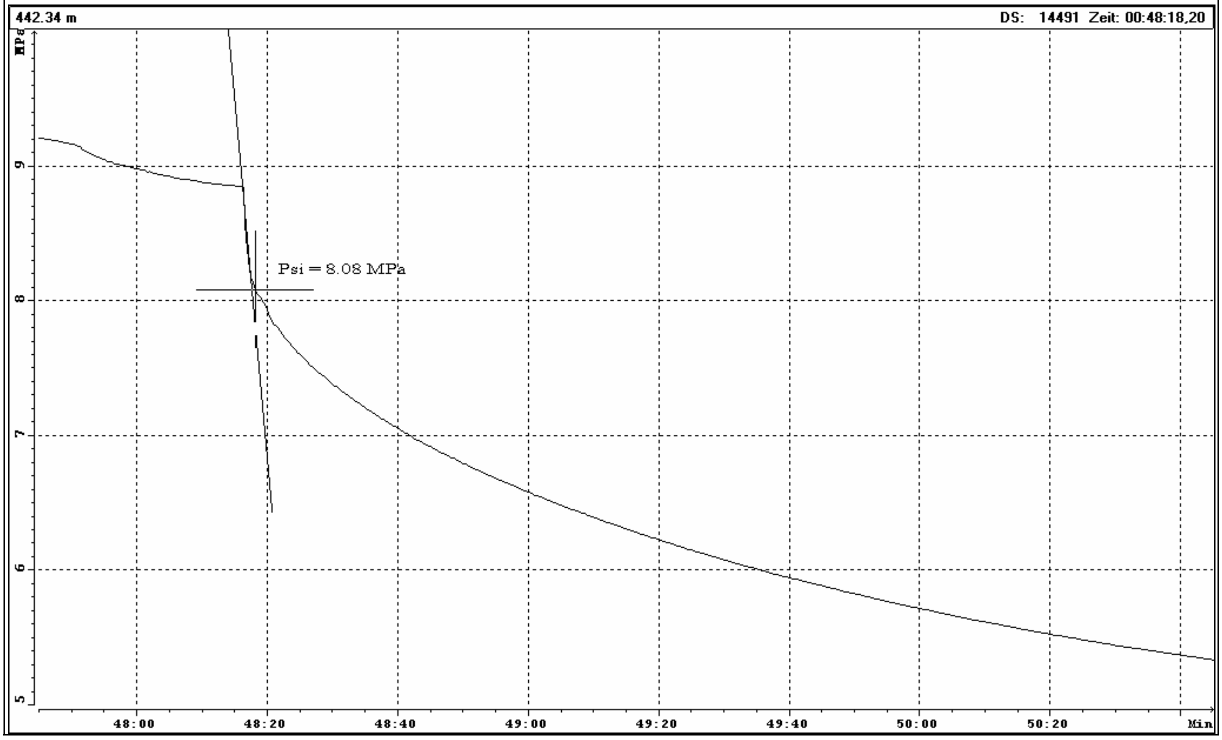
Test at 442.34 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



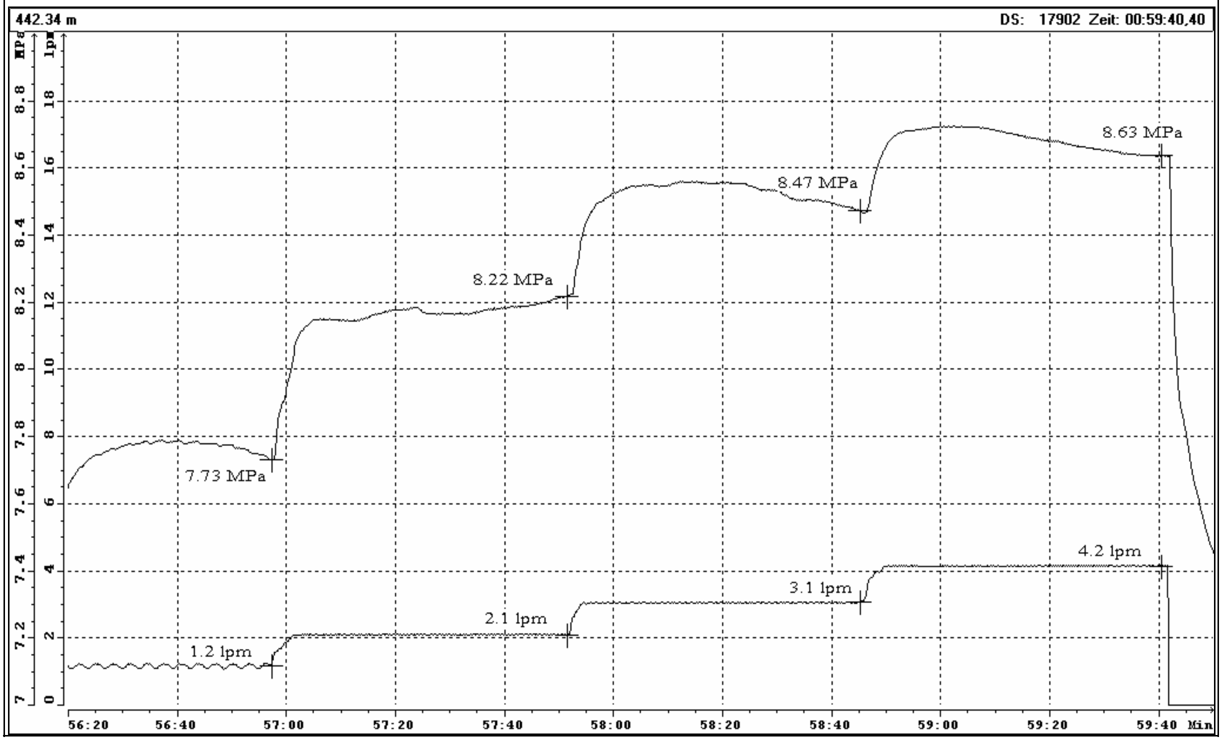
Test at 442.34 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



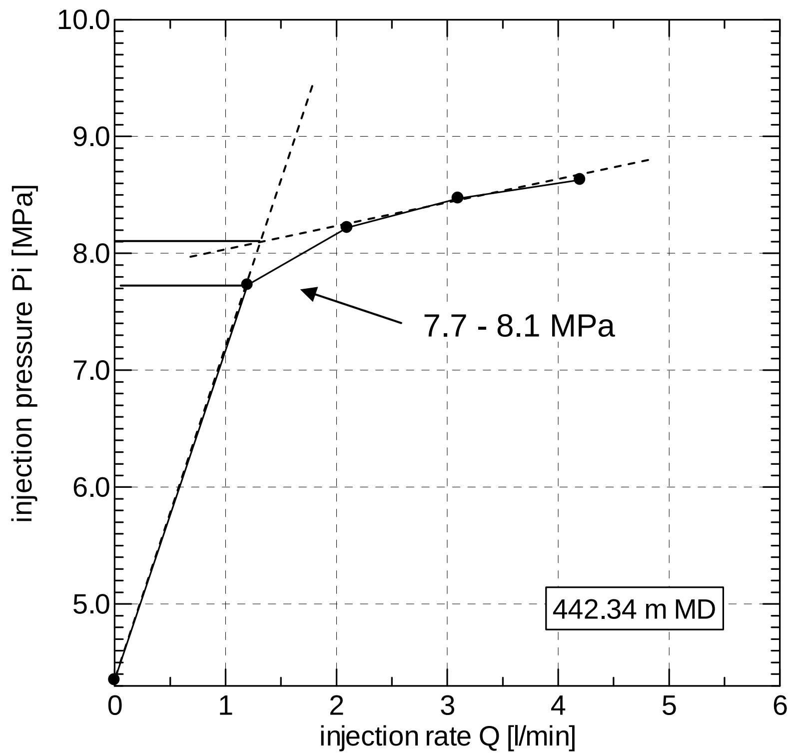
Test at 442.34 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 442.34 m MD: Analysis of Slow - Pump / Step - Rate - Test

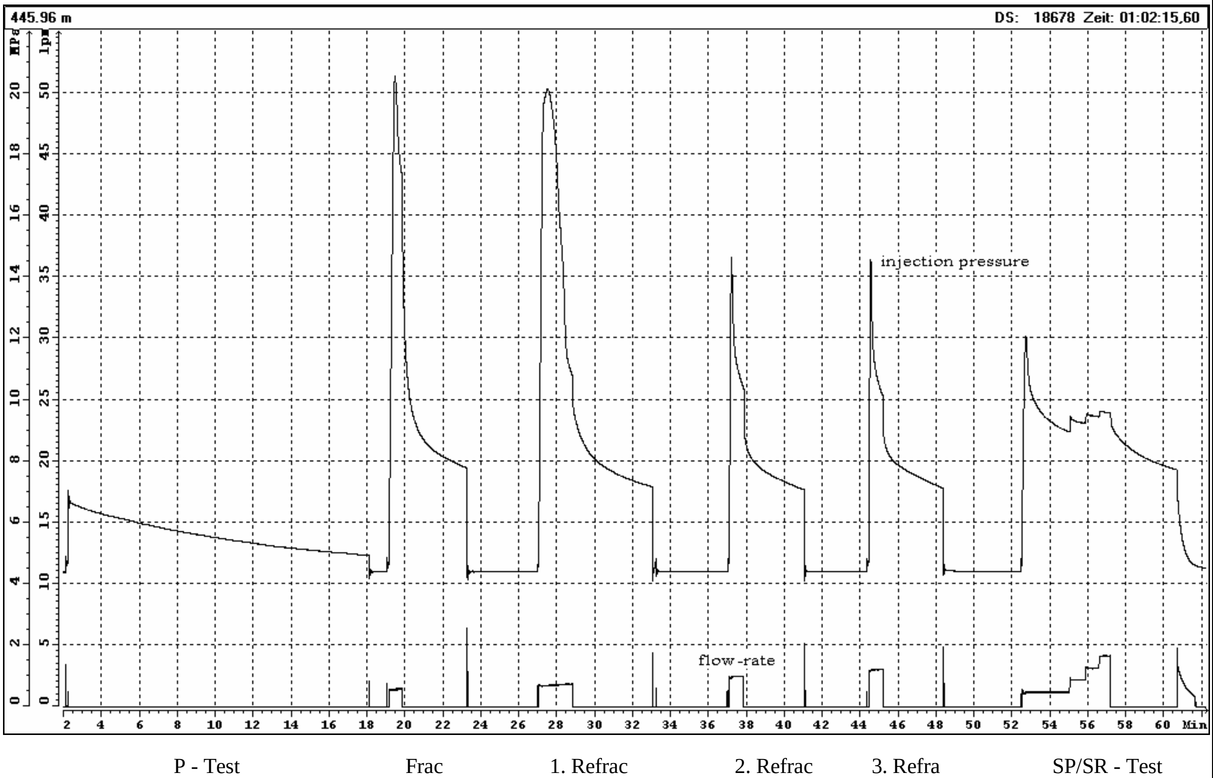


Test at 442.34 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 26 AT 445.96 m MD / 444.44 m TVD

Test at 445.96 m MD: Overview - Plot



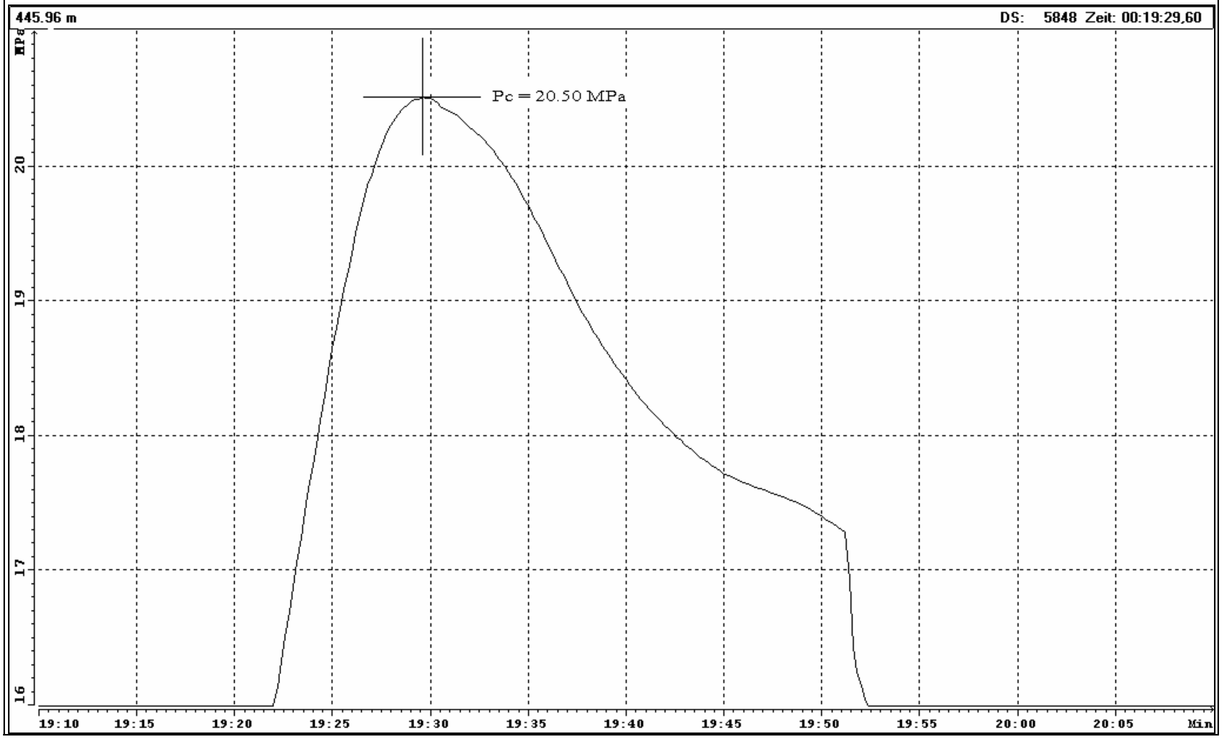
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.71 MPa in 942 sec.		
Frac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.0	Vr (l) = 0.1
1. Refrac - cycle	Qi (lpm) = 1.7	Vi (l) = 3.2	Vr (l) = 0.3
2. Refrac - cycle	Qi (lpm) = 2.5	Vi (l) = 1.9	Vr (l) = 0.35
3. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 2.3	Vr (l) = 0.6
SP/SR - test	Qi (lpm) = 1.2-4.1	Vi (l) = 9.6	Vr (l) = 3.4

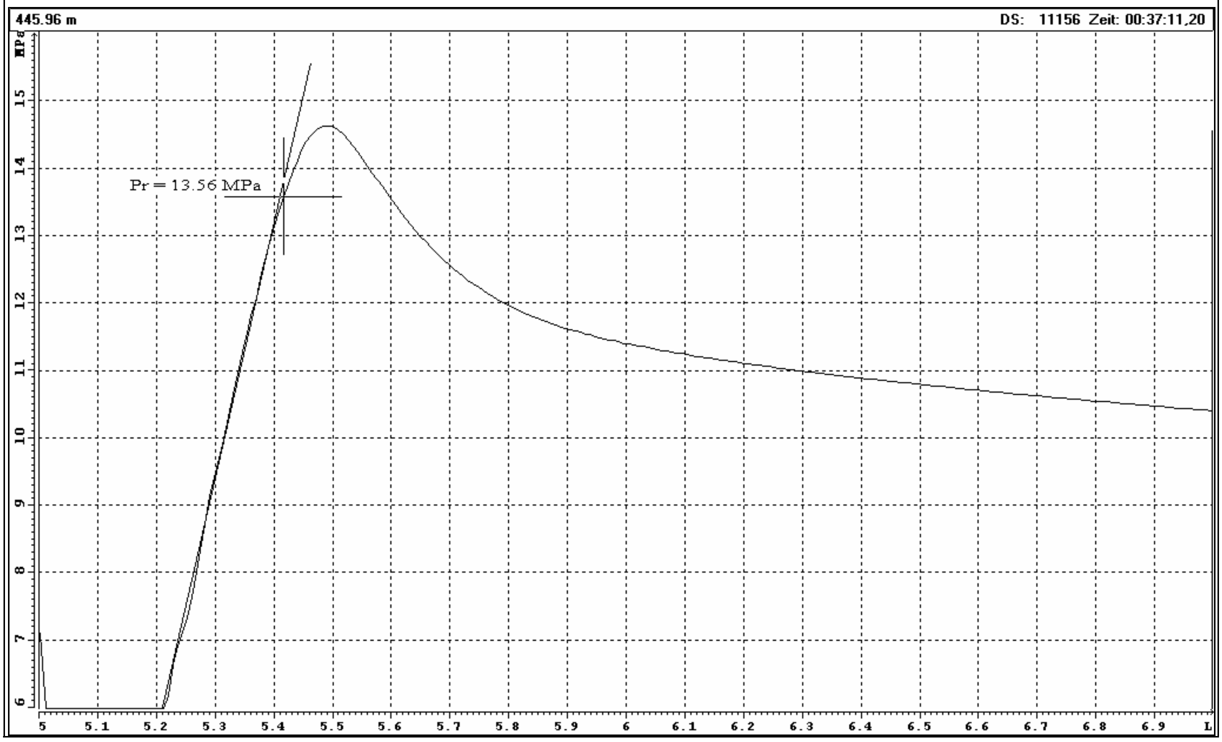
total injected volume (l): 18.0 recovered volume (l): 4.8 or 26.5 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a weak breakdown event.
- The subsequent 1. refrac - cycle demonstrates further fracture initiation. Therefore, the re-frac - pressure was determined from the 2. refrac - cycle. The final 3. refrac - cycles confirms the fracture re-opening pressure value.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the analysis, the shut - in pressure of the 3. refrac - cycle was used.

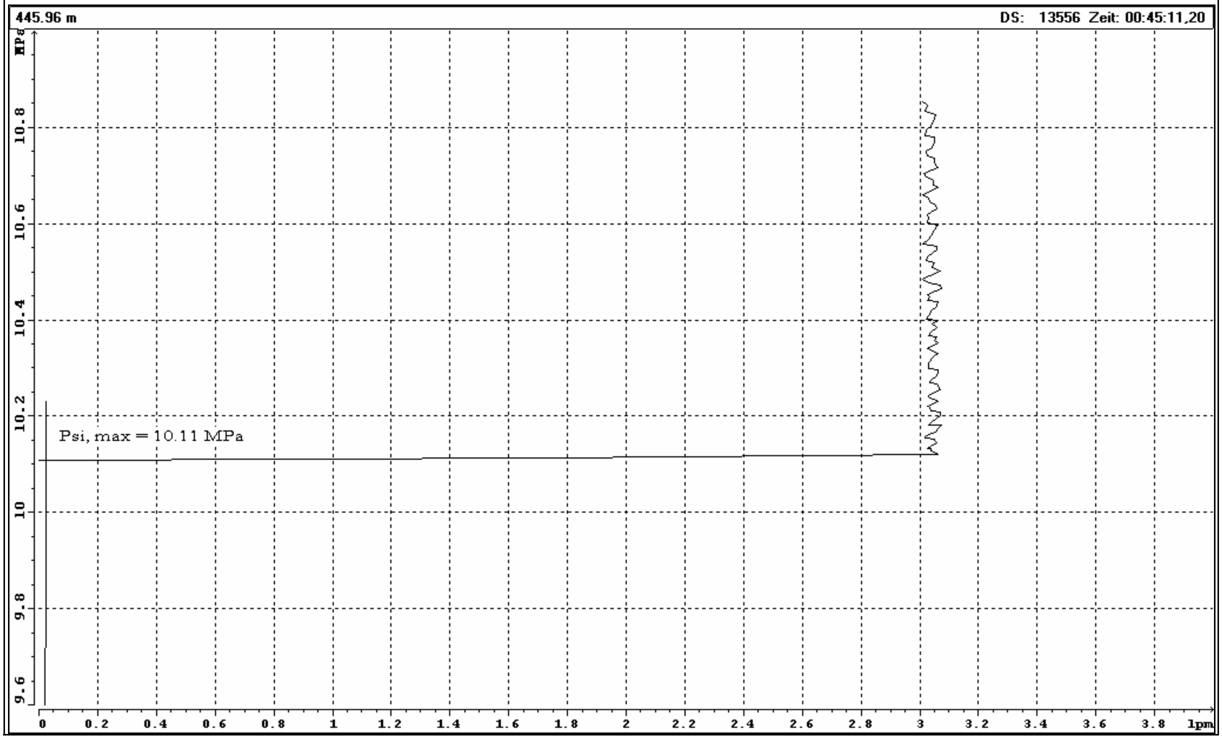
Test at 445.96 m MD: Estimation of P_c (Frac - Cycle)



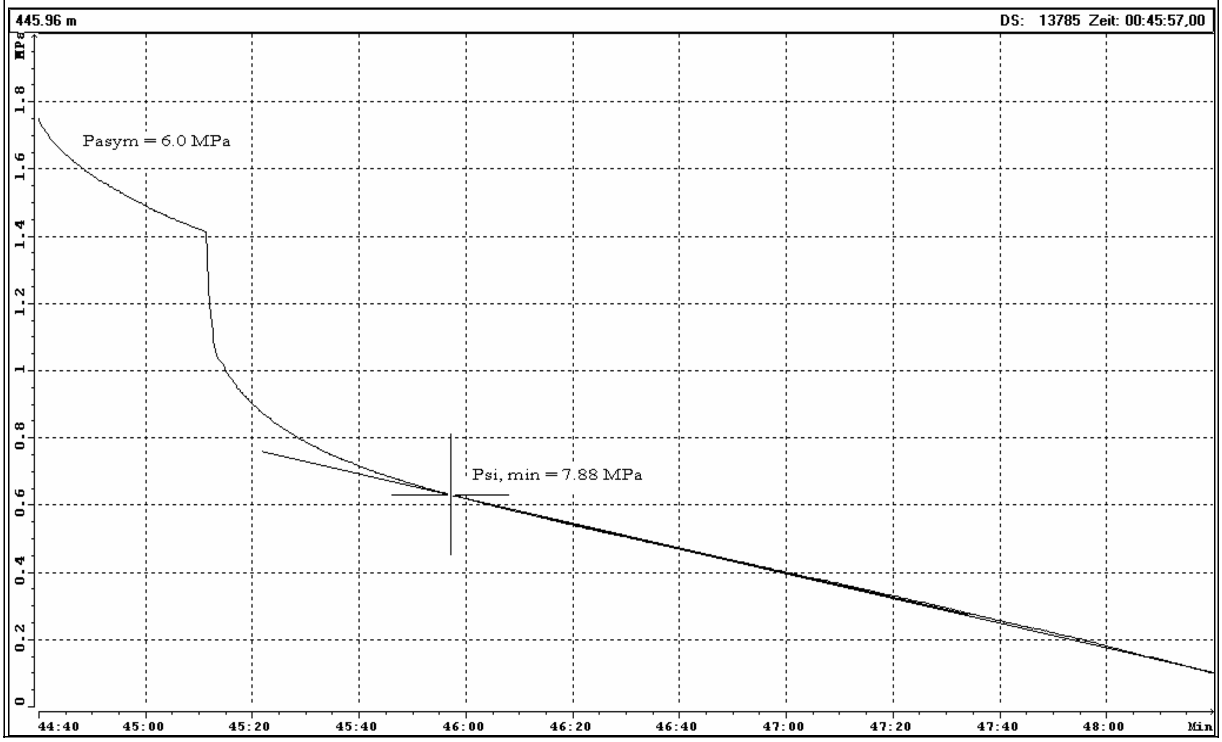
Test at 445.96 m MD: Estimation of P_r (2. Refrac - Cycle)



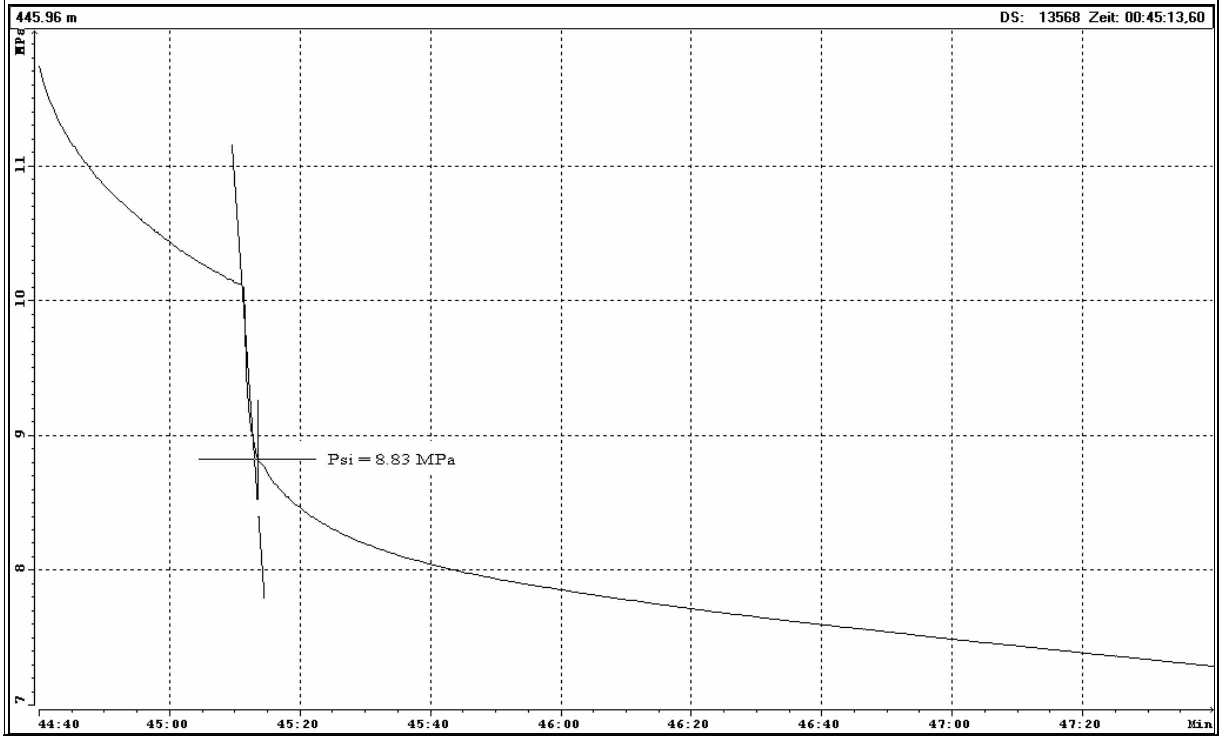
Test at 445.96 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



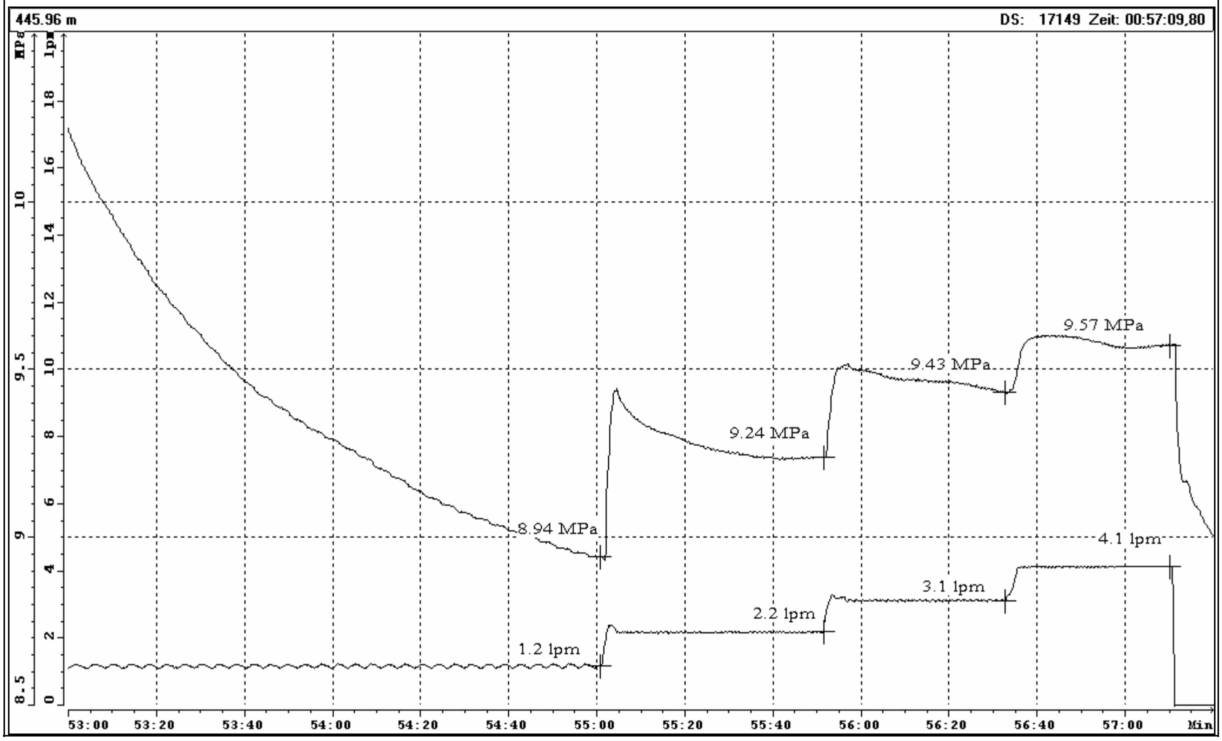
Test at 445.96 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



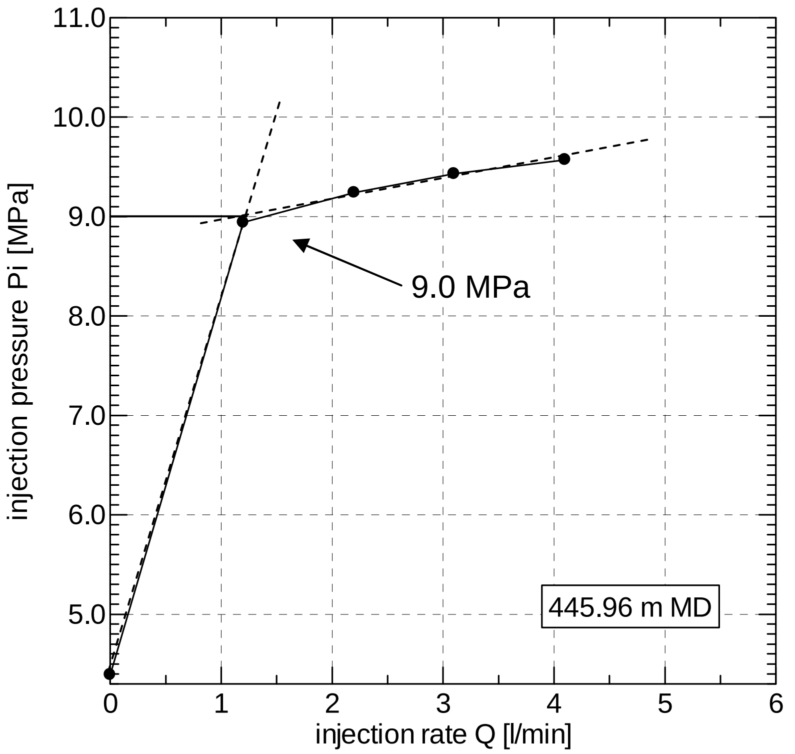
Test at 445.96 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 445.96 m MD: Analysis of Slow - Pump / Step - Rate - Test

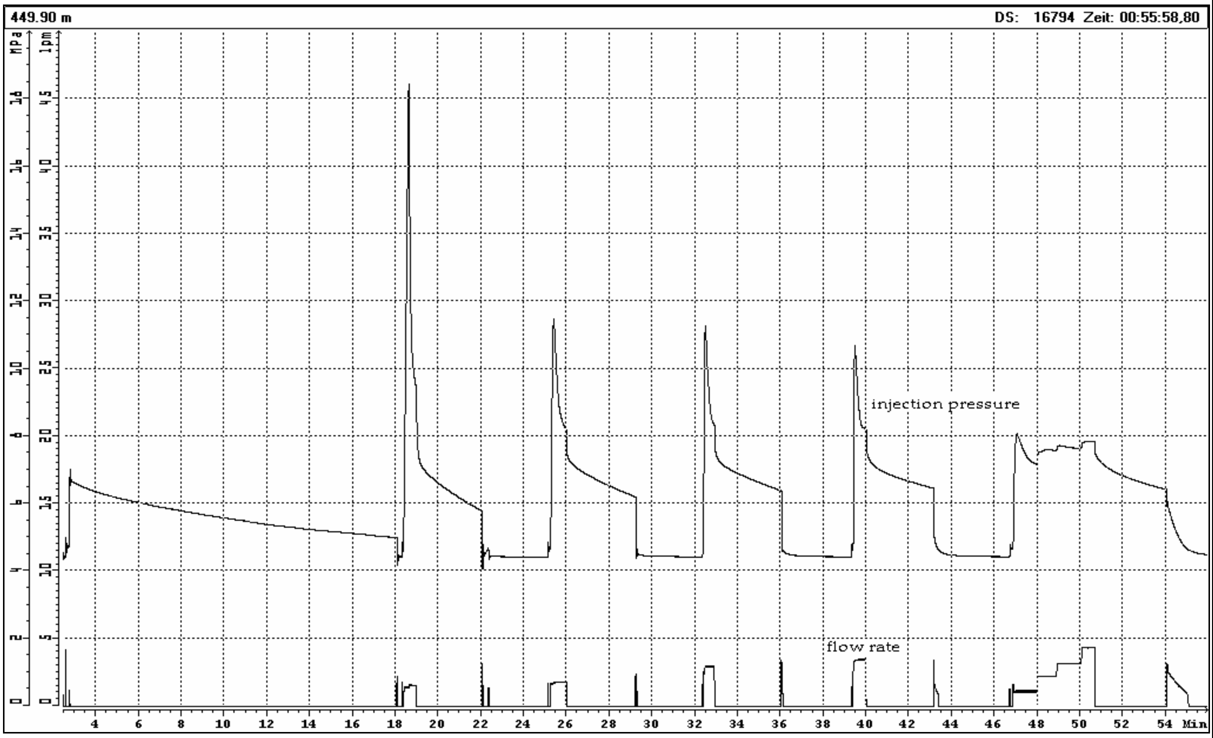


Test at 445.96 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 25 AT 449.90 m MD / 448.36 m TVD

Test at 449.90 m MD : Overview - Plot



P - Test Frac 1. Refrac 2. Refrac 3. Refrac SP/SR - Test

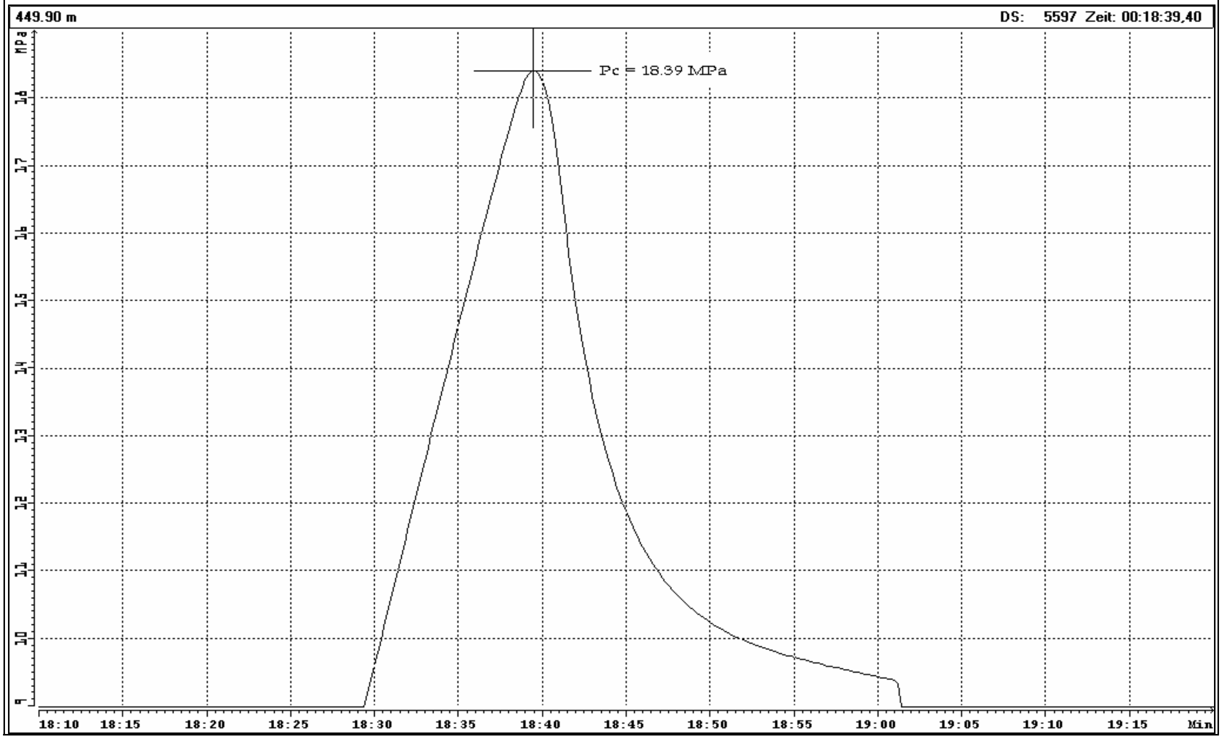
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.64 MPa in 907 sec.		
Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 0.9	Vr (l) = 0.1
1. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 1.3	Vr (l) = 0.25
2. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 1.55	Vr (l) = 0.7
3. Refrac - cycle	Qi (lpm) = 3.5	Vi (l) = 2.1	Vr (l) = 0.9
SP/SR - test	Qi (lpm) = 1.1-4.4	Vi (l) = 9.6	Vr (l) = 3.3

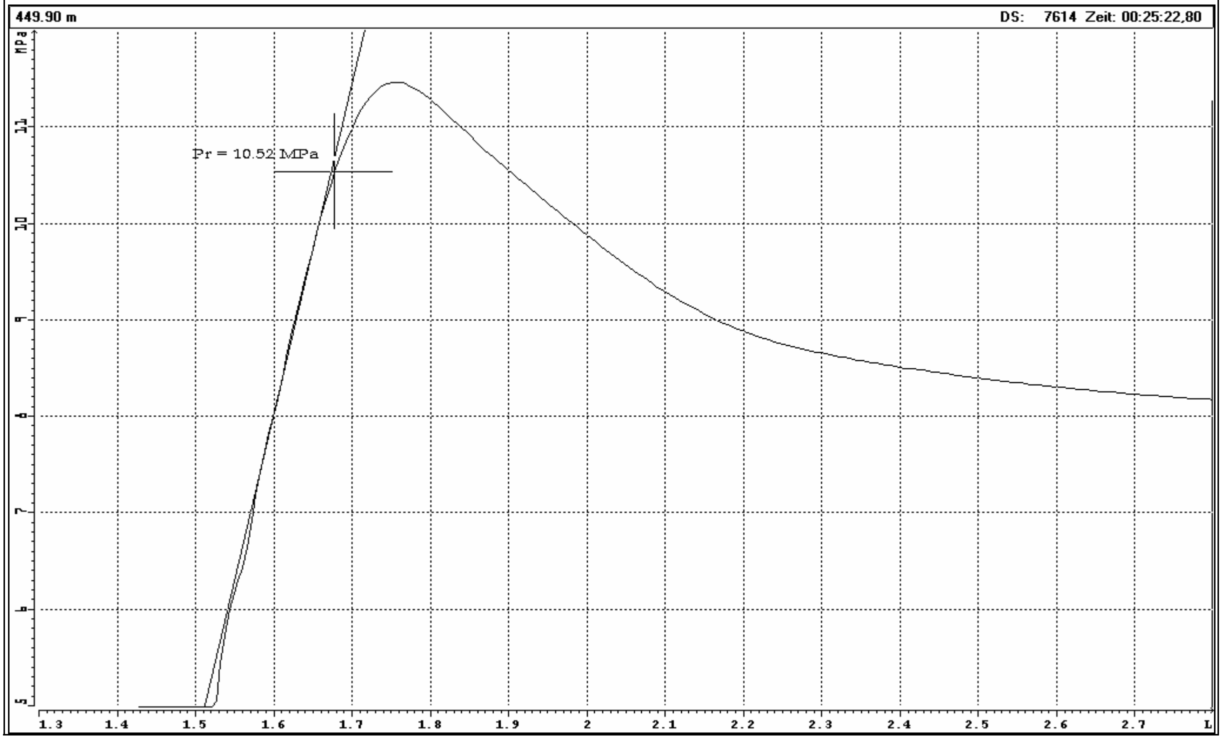
total injected volume (l): 15.45 recovered volume (l): 5.25 or 34.0 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

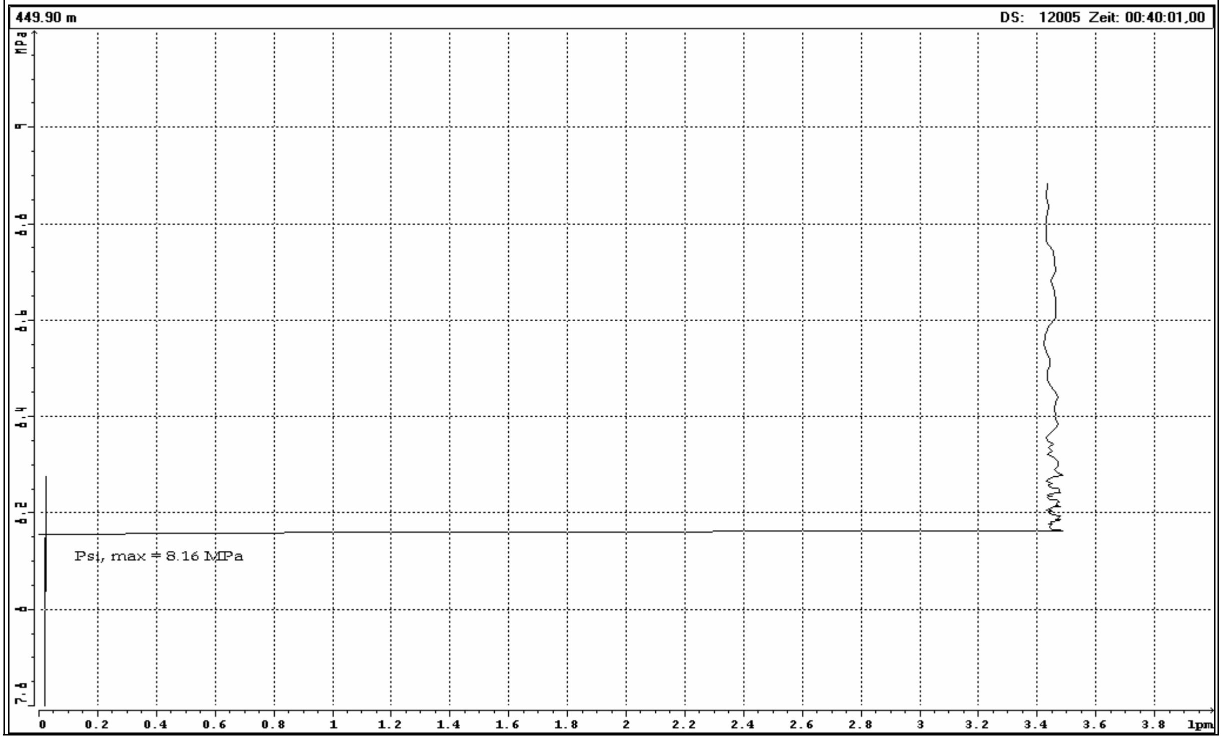
Test at 449.90 m MD: Estimation of P_c (Frac - Cycle)



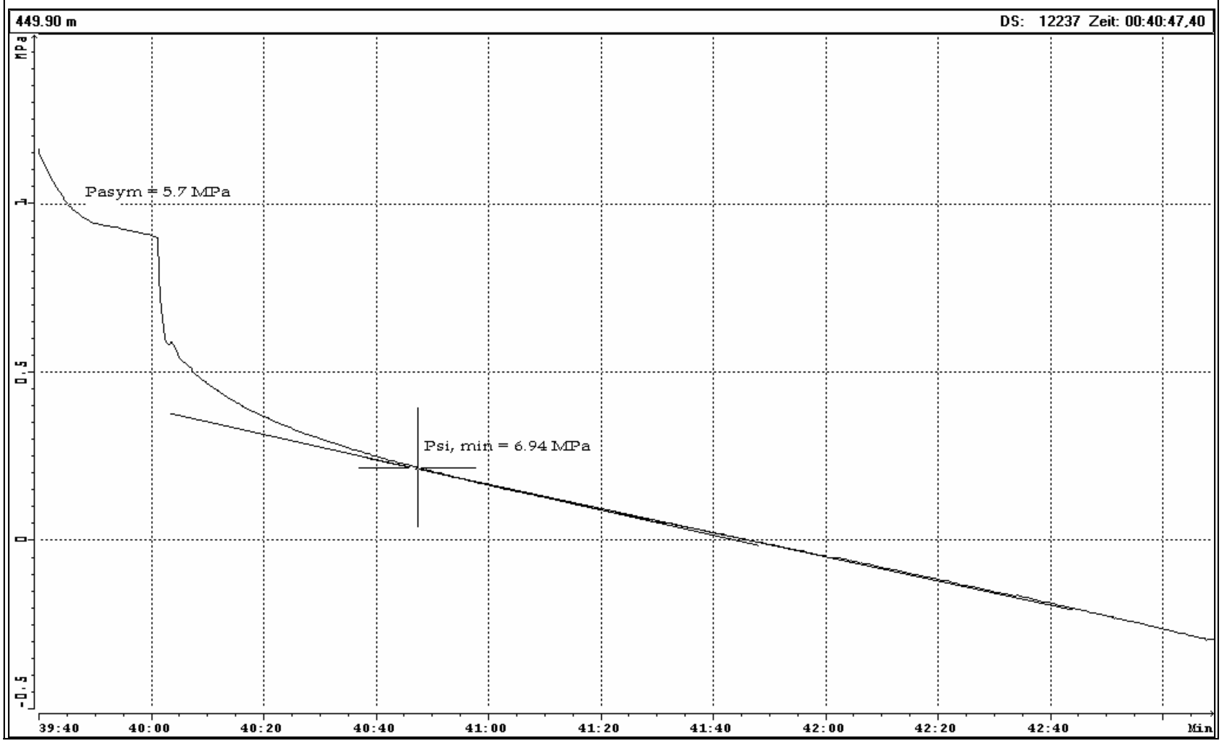
Test at 449.90 m MD: Estimation of P_r (1. Refrac - Cycle)



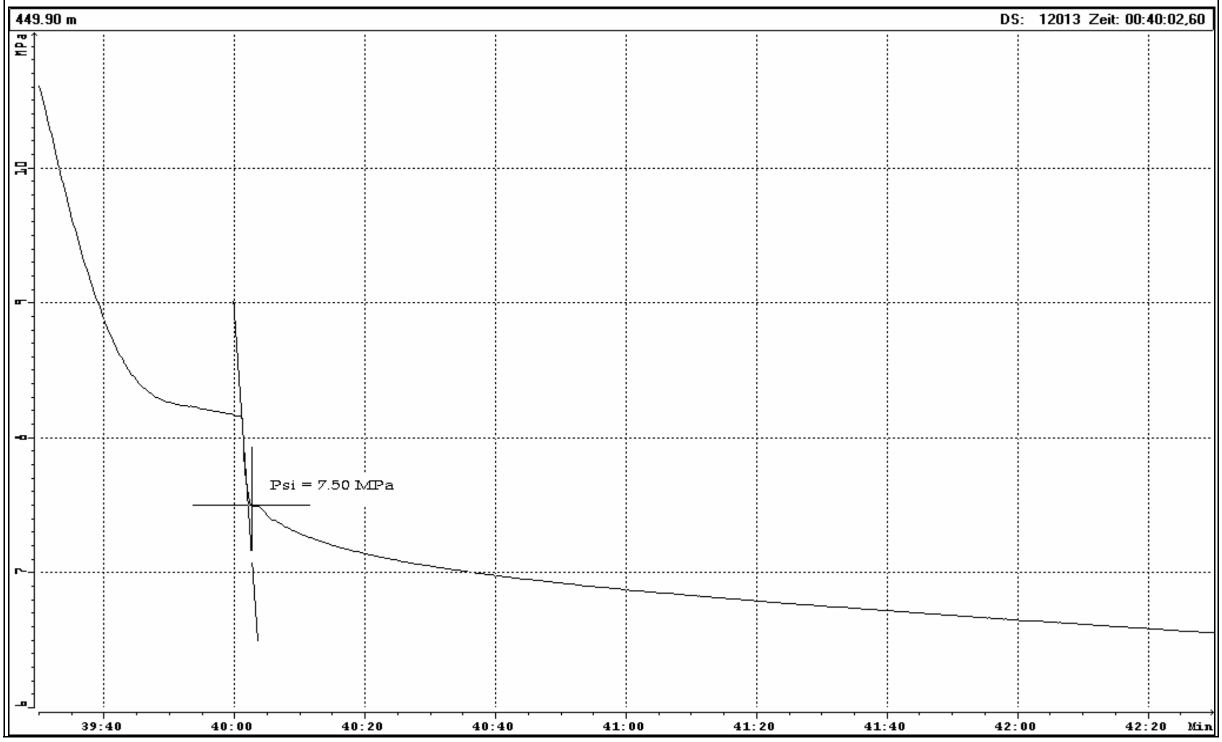
Test at 449.90 m MD: Estimation of $P_{si,\,max}$ (3. Refrac - Cycle)



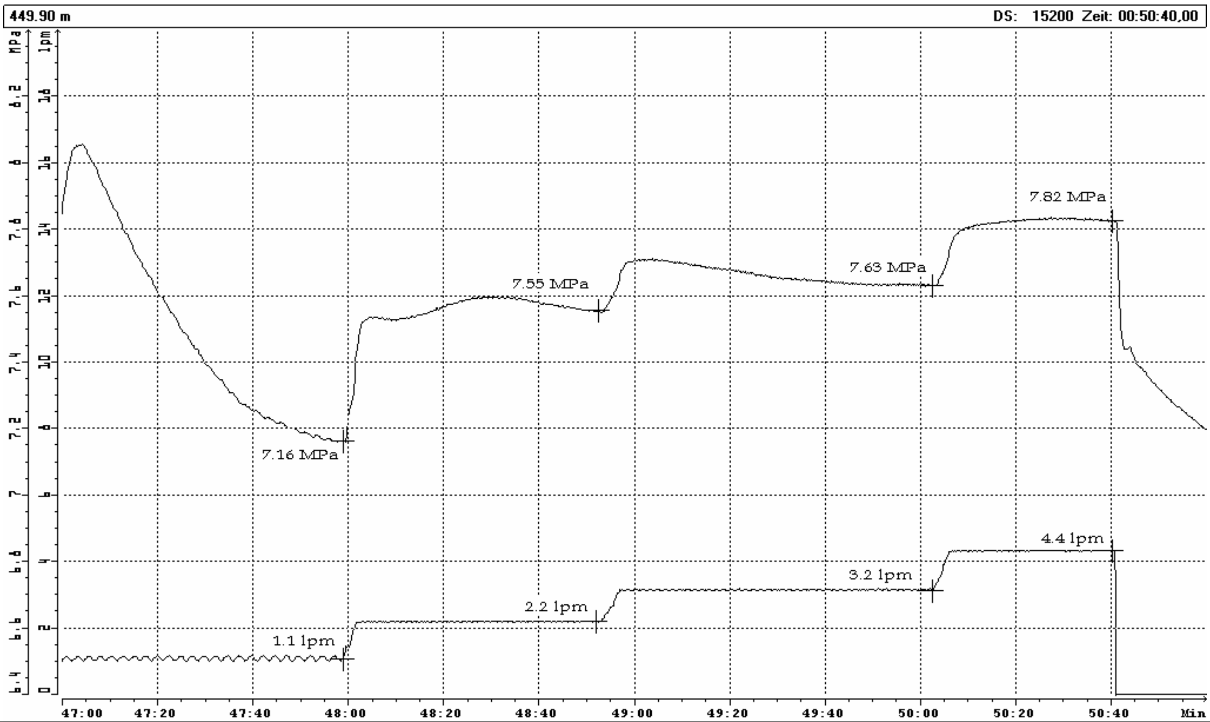
Test at 449.90 m MD: Estimation of $P_{si,\,min}$ (3. Refrac - Cycle)



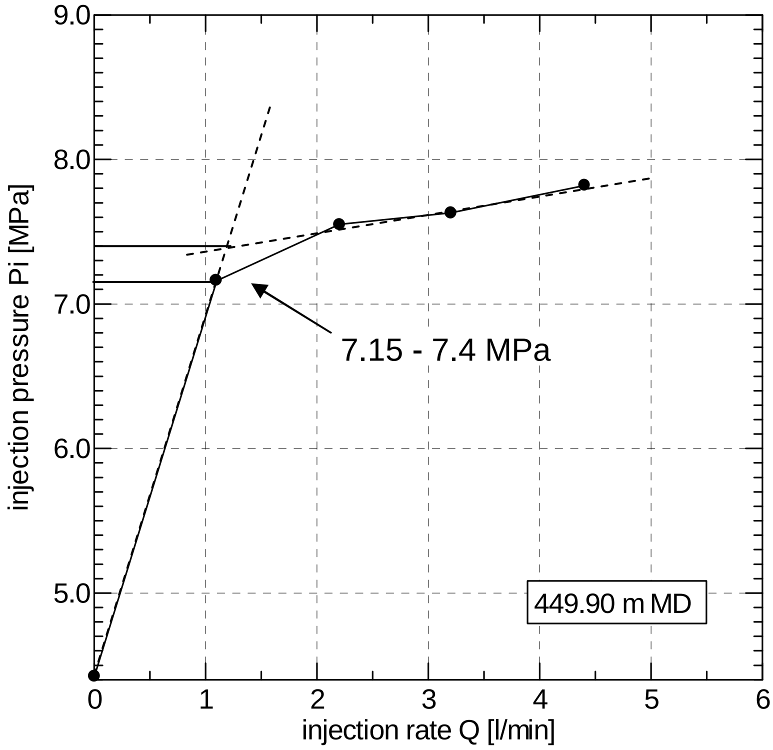
Test at 449.90 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 449.90 m MD: Analysis of Slow - Pump / Step - Rate - Test

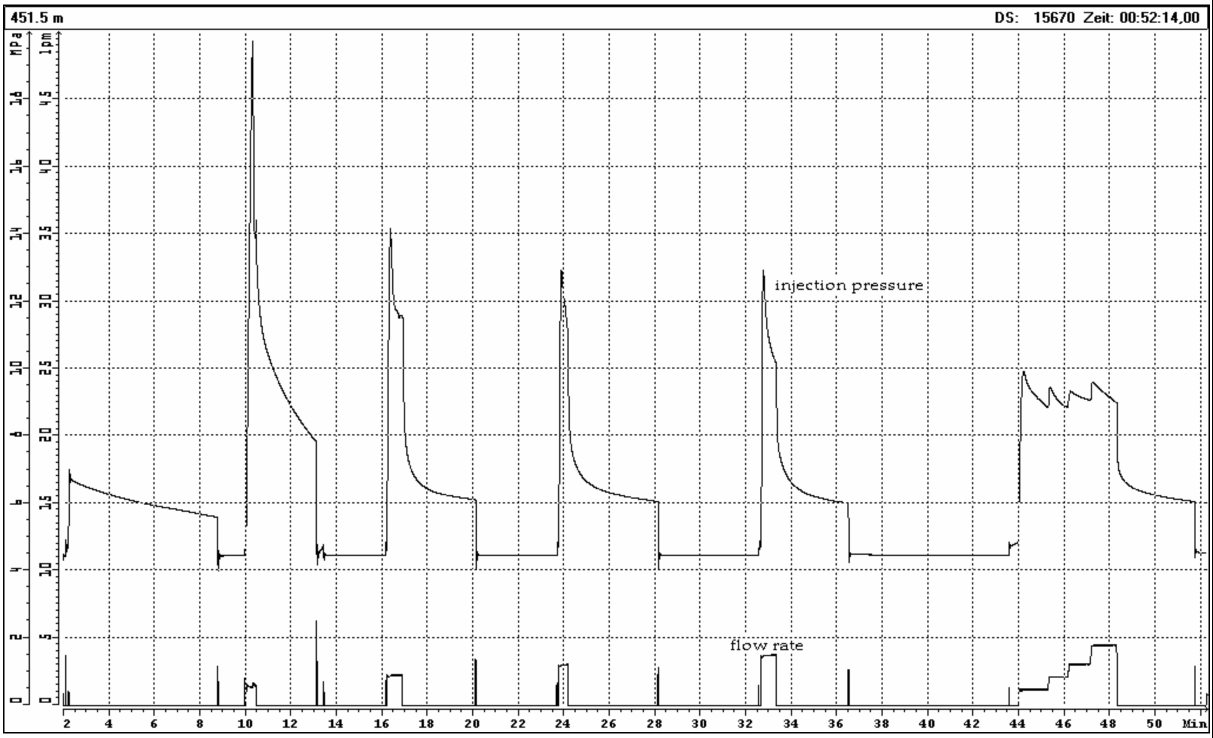


Test at 449.90 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 24 AT 451.5 m MD / 449.15 m TVD

Test at 451.5 m MD: Overview - Plot



P - Test Frac 1. Refrac 2. Refrac 3. Refrac Slow-Pump / Step-Rate - Test

TEST SUMMARY / ANALYSIS / REMARKS

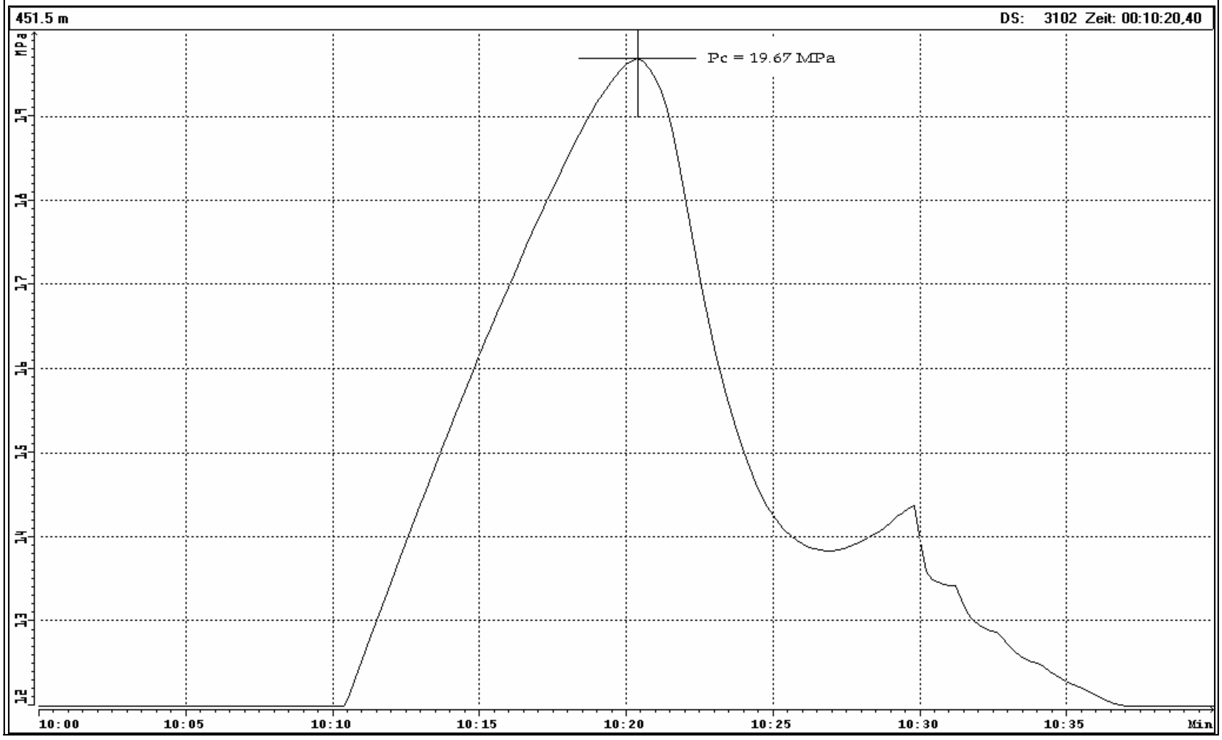
P - Test : pressure decrease: 1.09 MPa in 382 sec.

Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 0.7	Vr (l) = 0.2
1. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 1.6	Vr (l) = 0.25
2. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 1.2	Vr (l) = 0.4
3. Refrac - cycle	Qi (lpm) = 3.7	Vi (l) = 2.5	Vr (l) = 0.7
SP/SR - test	Qi (lpm) = 1.2-4.5	Vi (l) = 11.55	Vr (l) = 1.7

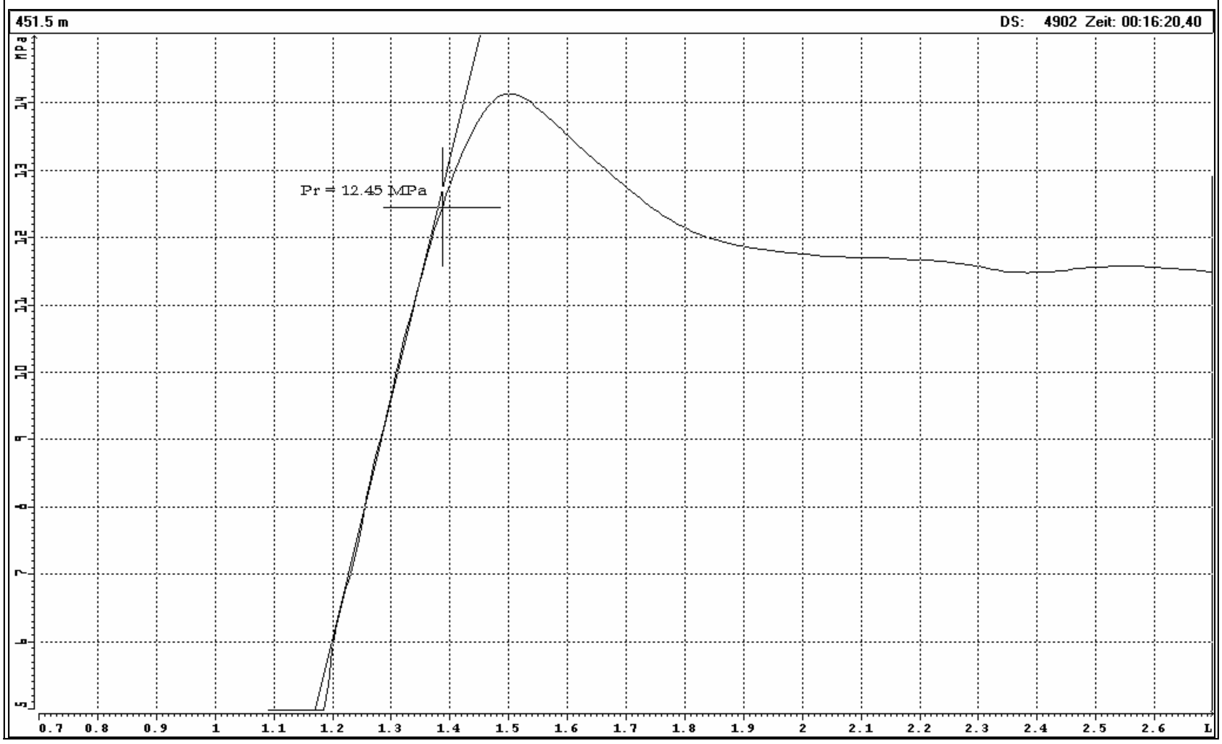
total injected volume (l): 17.55 recovered volume (l): 3.25 or 18.5 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

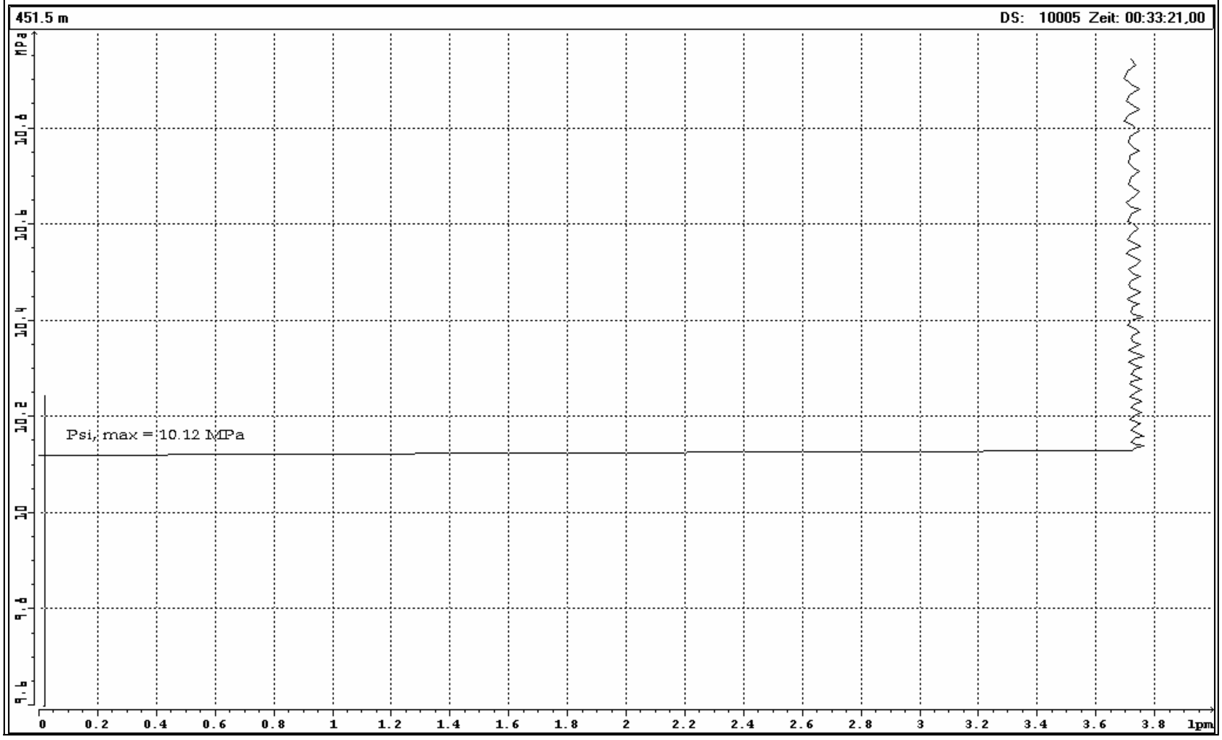
Test at 451.5 m MD: Estimation of P_c (Frac - Cycle)



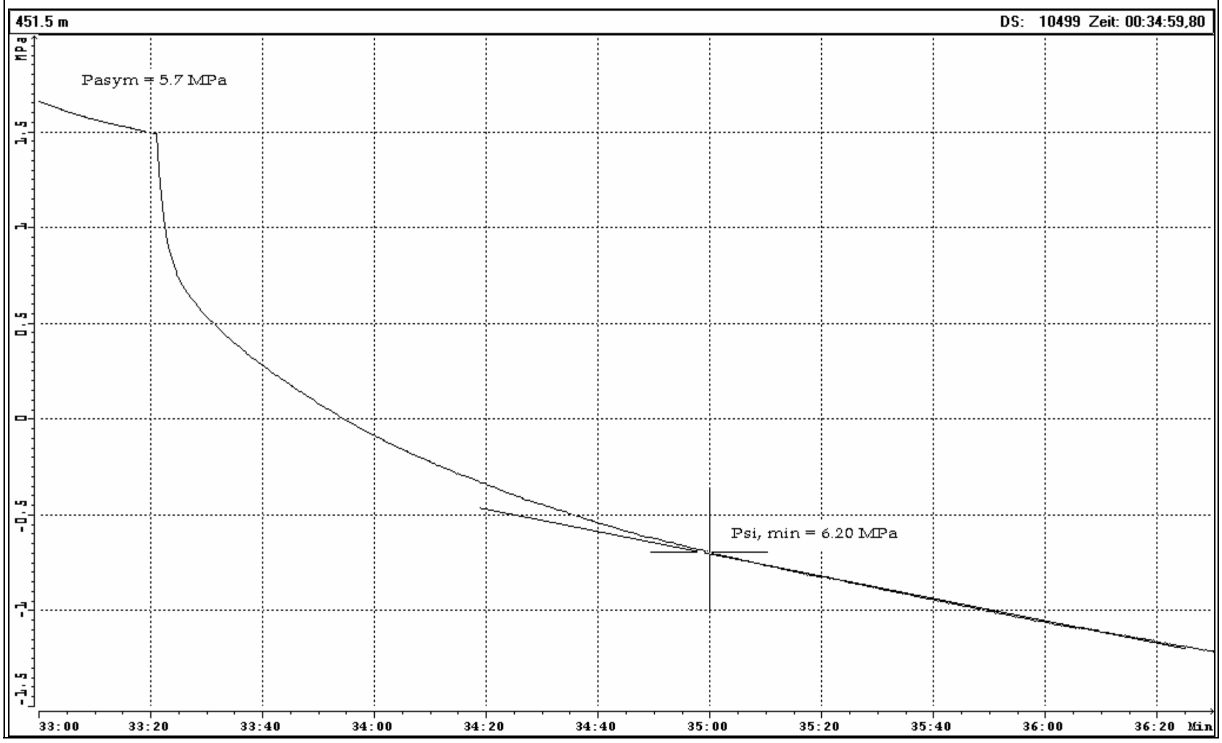
Test at 451.5 m MD: Estimation of P_r (1. Refrac - Cycle)



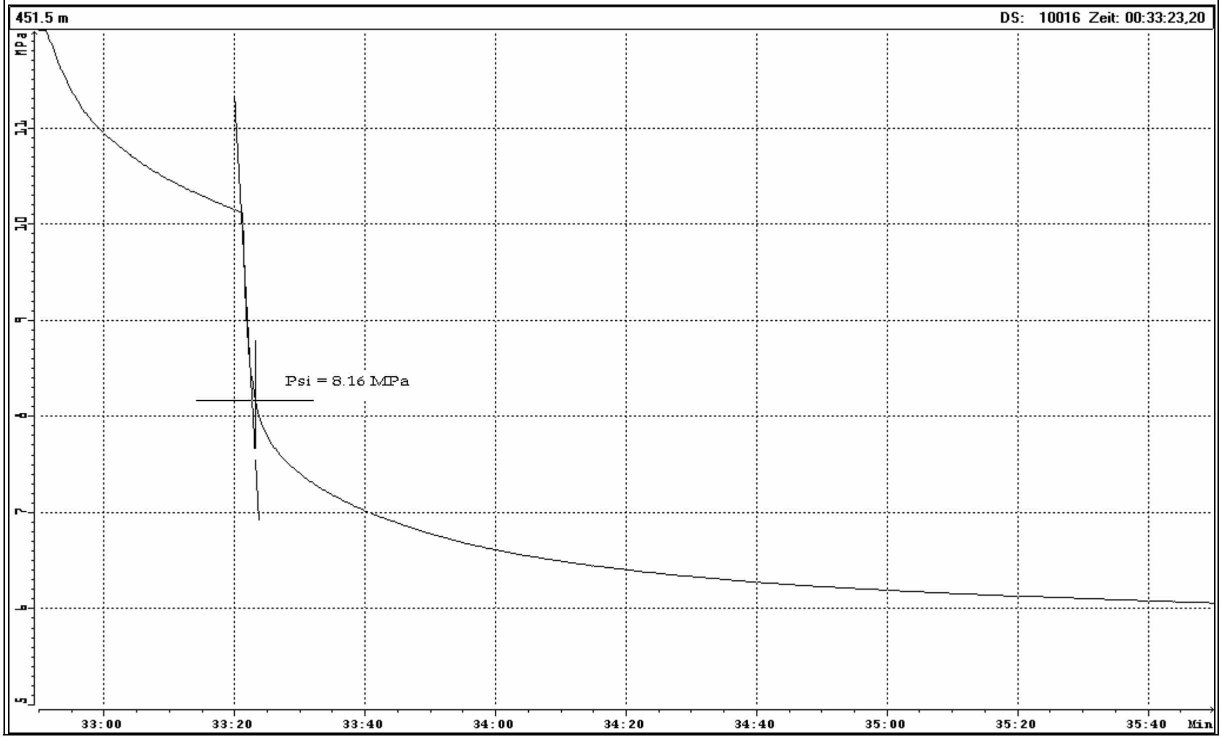
Test at 451.5 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



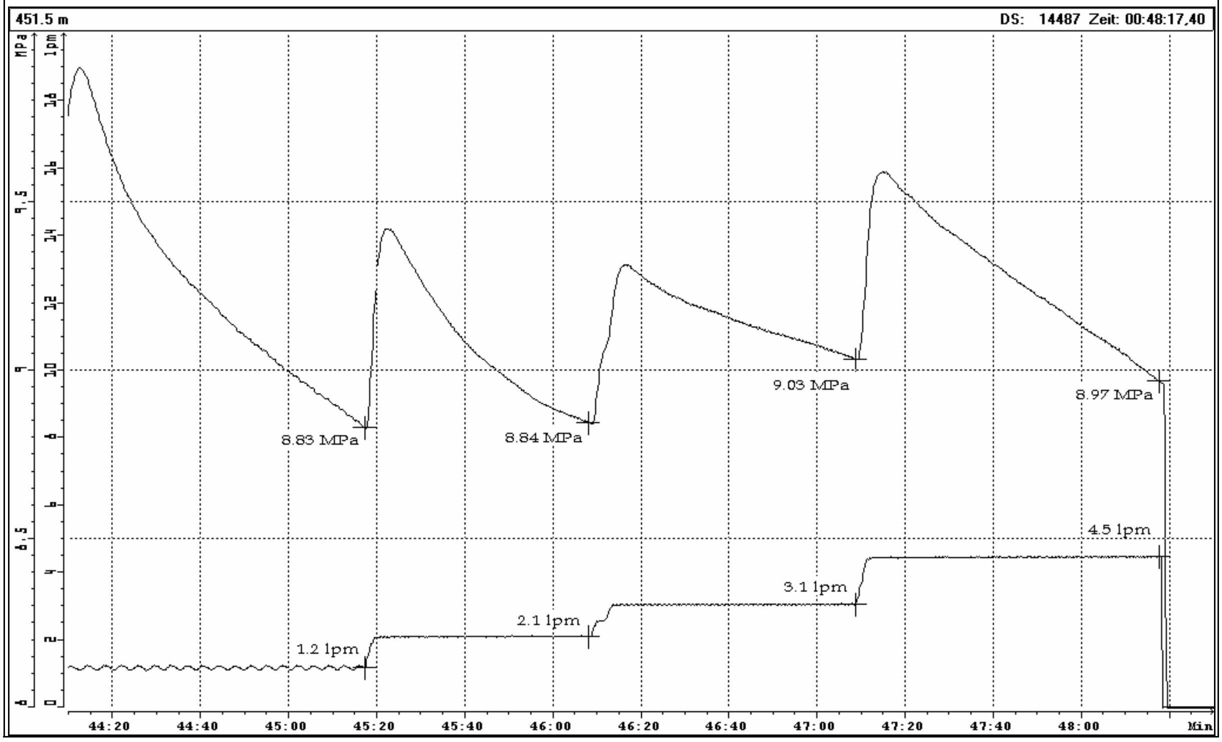
Test at 451.5 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



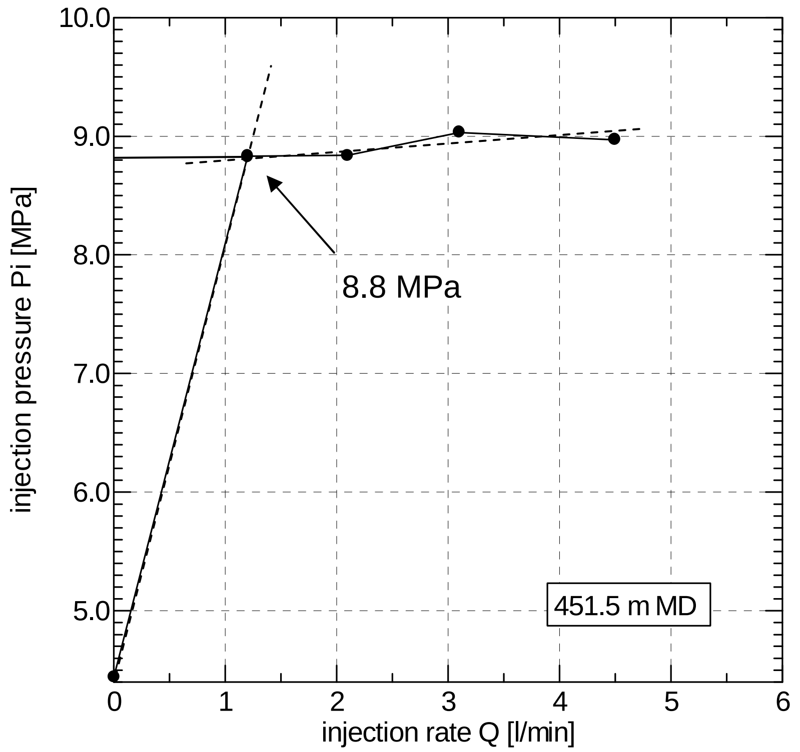
Test at 451.5 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 451.5 m MD: Analysis of Slow - Pump / Step - Rate - Test

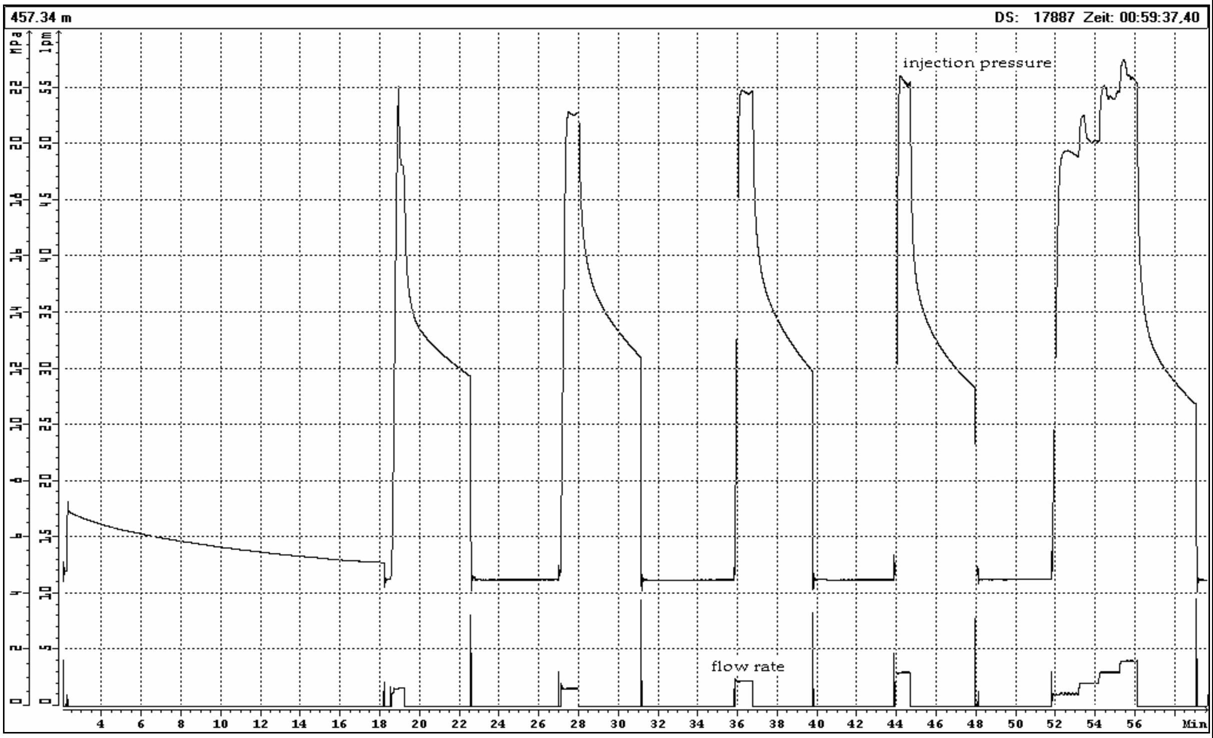


Test at 451.5 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 23 AT 457.34 m MD / 455.77 m TVD

Test at 457.34 m MD : Overview - Plot



P - Test | Frac (1. Refrac) | 2. Refrac | 3. Refrac | 4. Refrac | SP/SR - Test

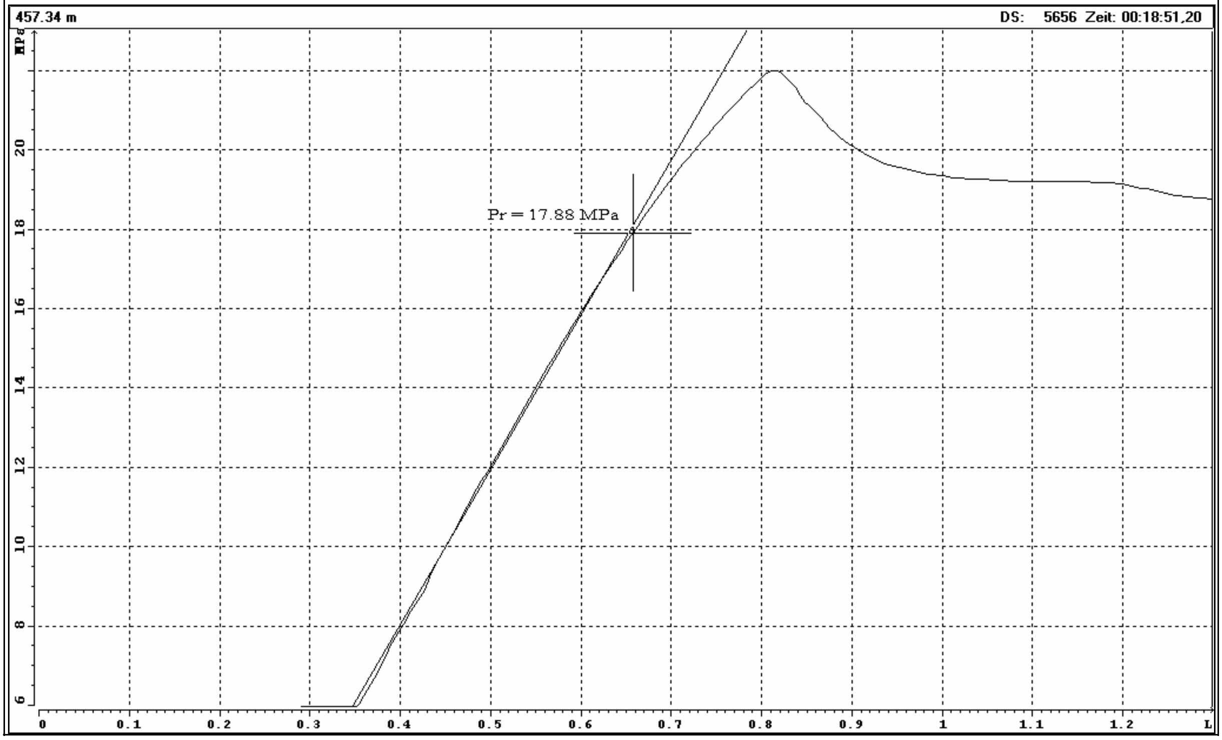
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.79 MPa in 948 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.5	Vi (l) = 1.0	Vr (l) = 0.2
2. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.5	Vr (l) = 0.2
3. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 2.1	Vr (l) = 0.2
4. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 2.2	Vr (l) = 0.2
SP/SR - test	Qi (lpm) = 1.0-4.0	Vi (l) = 10.2	Vr (l) = 0.15

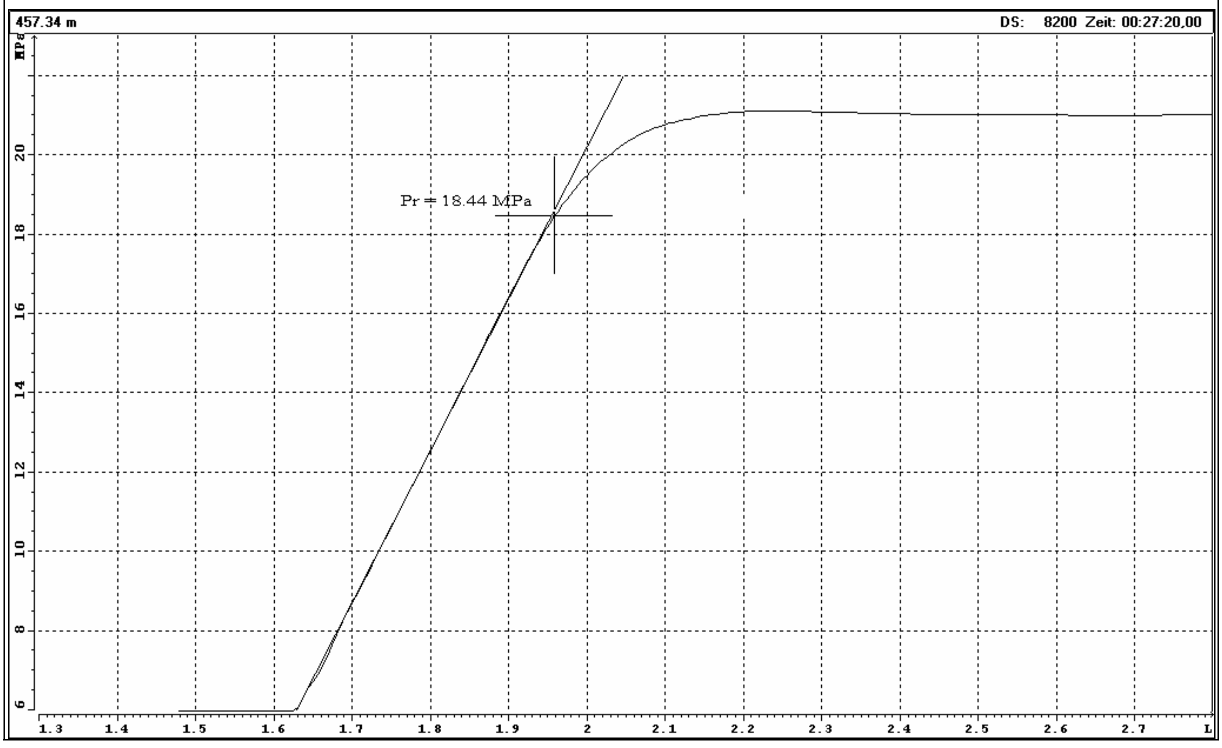
total injected volume (l): 17.0 recovered volume (l): 0.95 or 5.6 %

- Initial test type: HTPF-v
- The frac (1. refrac) - cycle is characterized by the stimulation of a pre - existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. and 2. refrac - cycle. The analysis of the fracture opening phases show a decrease of system stiffness dP/dV already at 17.9 and 18.4 MPa, followed by a pressure increase up to 22 and 21 MPa, respectively. In comparison to the first cycles, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

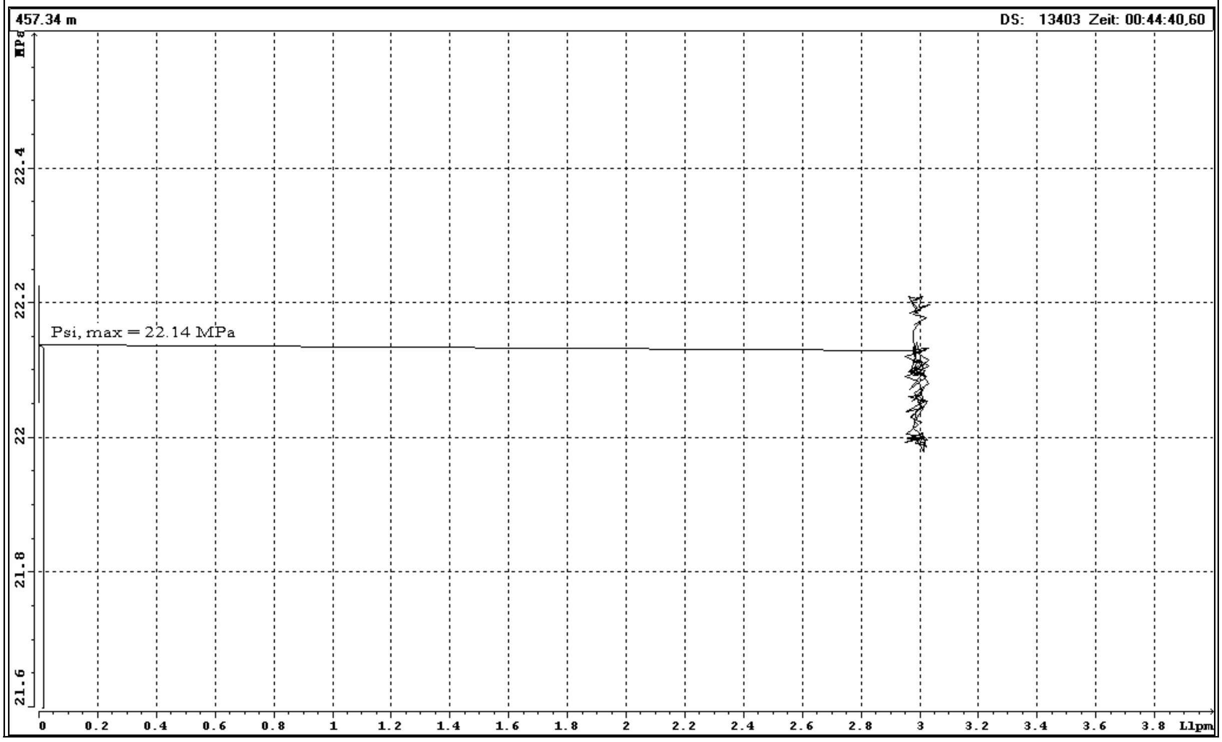
Test at 457.34 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



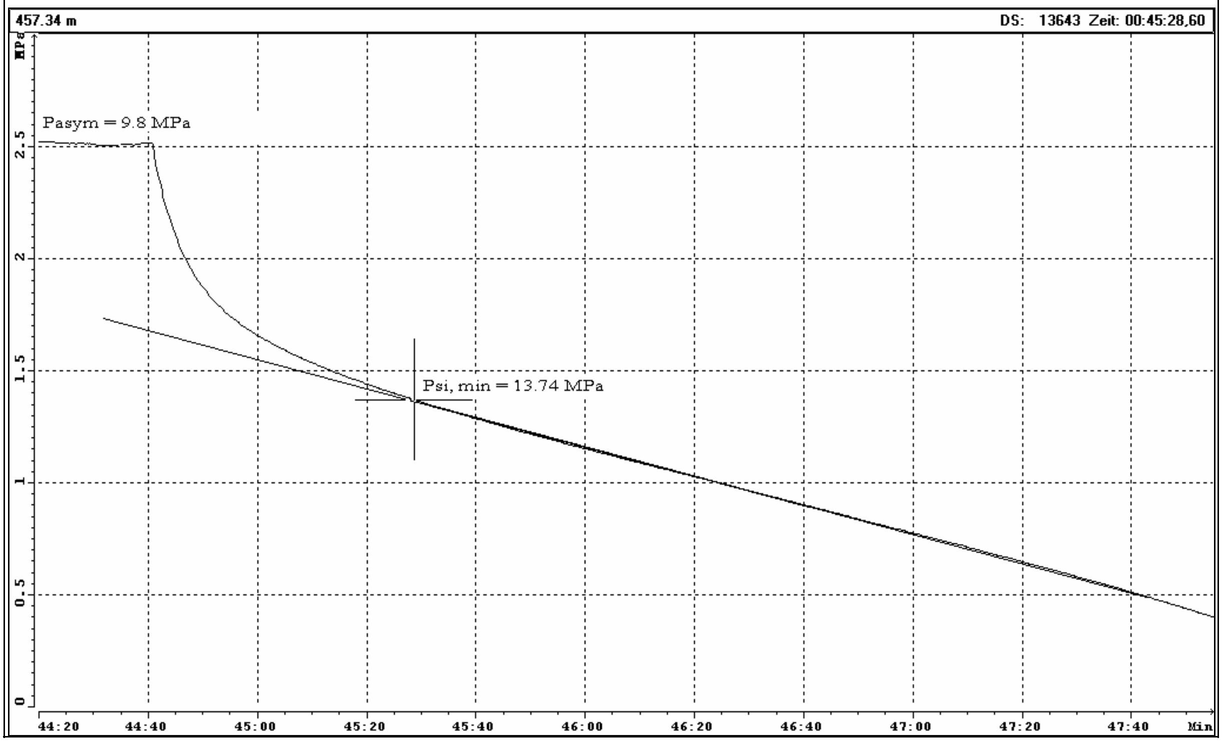
Test at 457.34 m MD: Estimation of P_r (2. Refrac - Cycle)



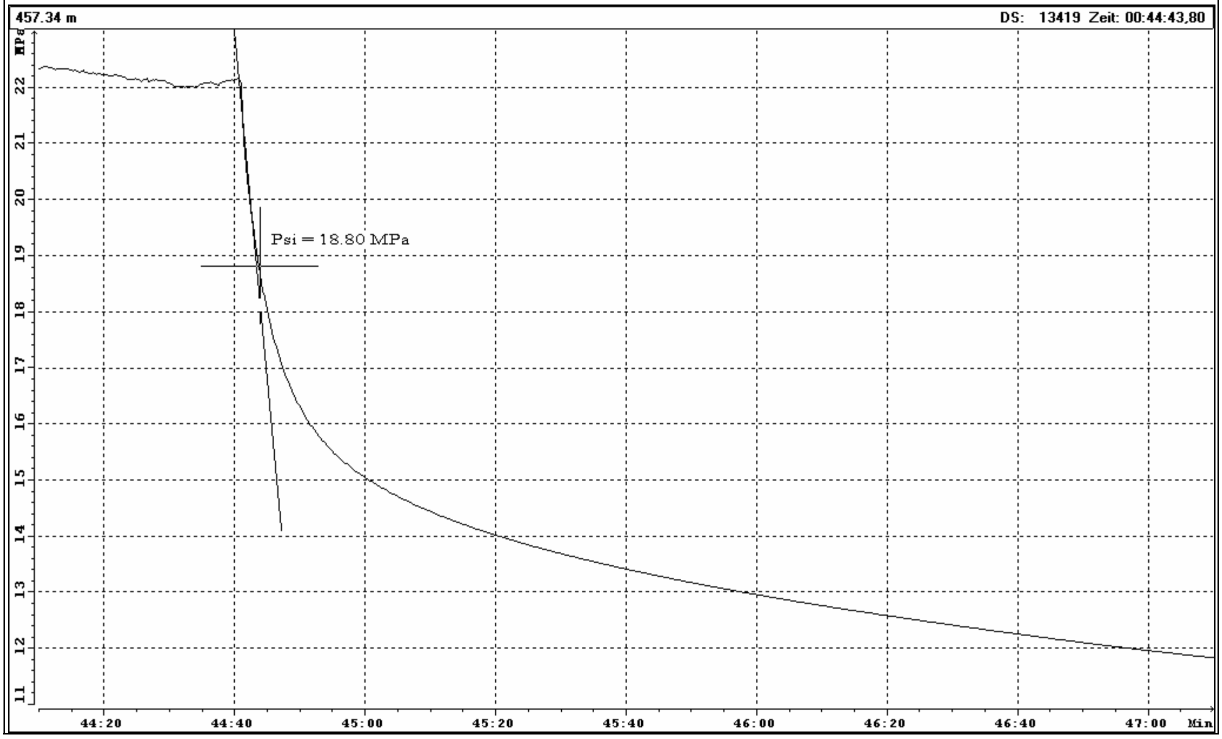
Test at 457.34 m MD: Estimation of $P_{si,\,max}$ (4. Refrac - Cycle)



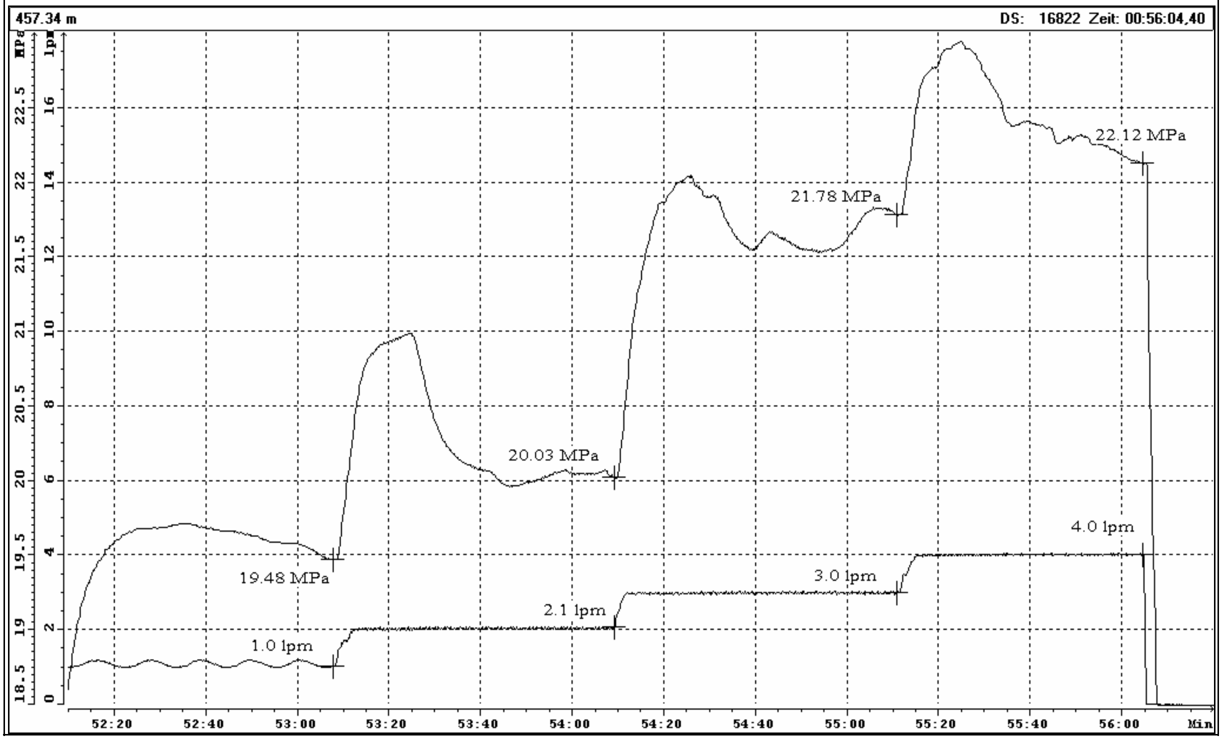
Test at 457.34 m MD: Estimation of $P_{si,\,min}$ (4. Refrac - Cycle)



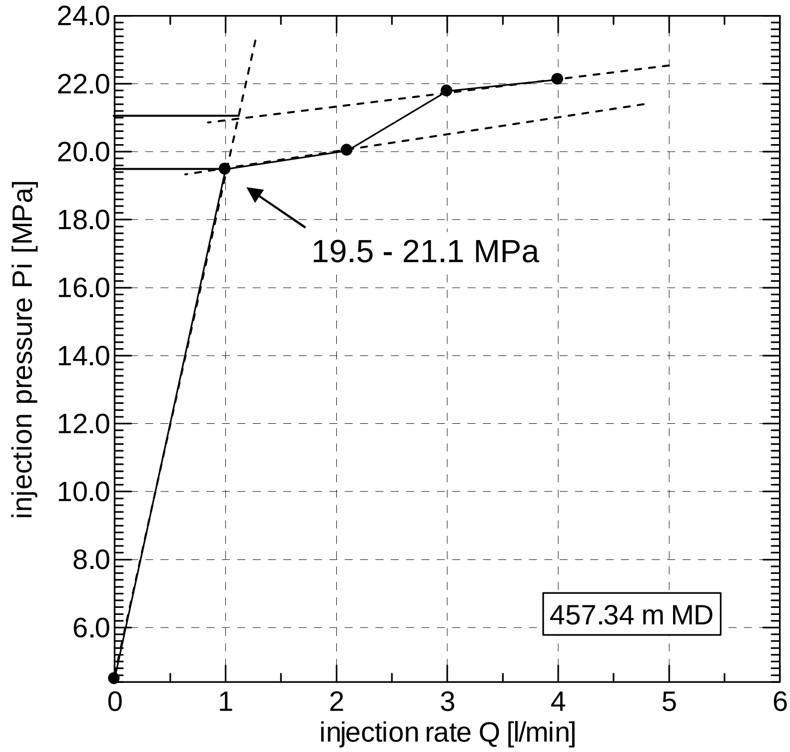
Test at 457.34 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 457.34 m MD: Analysis of Slow - Pump / Step - Rate - Test

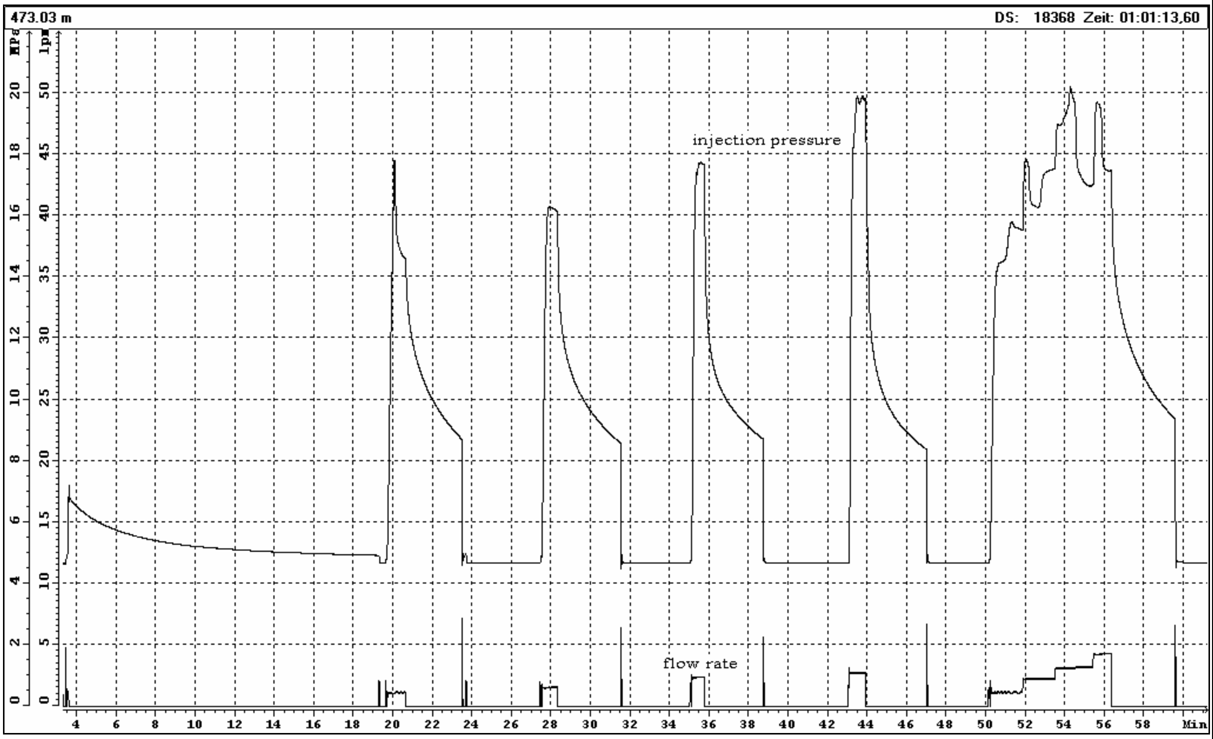


Test at 457.34 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 22 AT 473.03 m MD / 471.39 m TVD

Test at 473.03 m MD : Overview - Plot



P - Test | Frac (1. Refrac) | 2. Refrac | 3. Refrac | 4. Refrac | SP/SR - Test

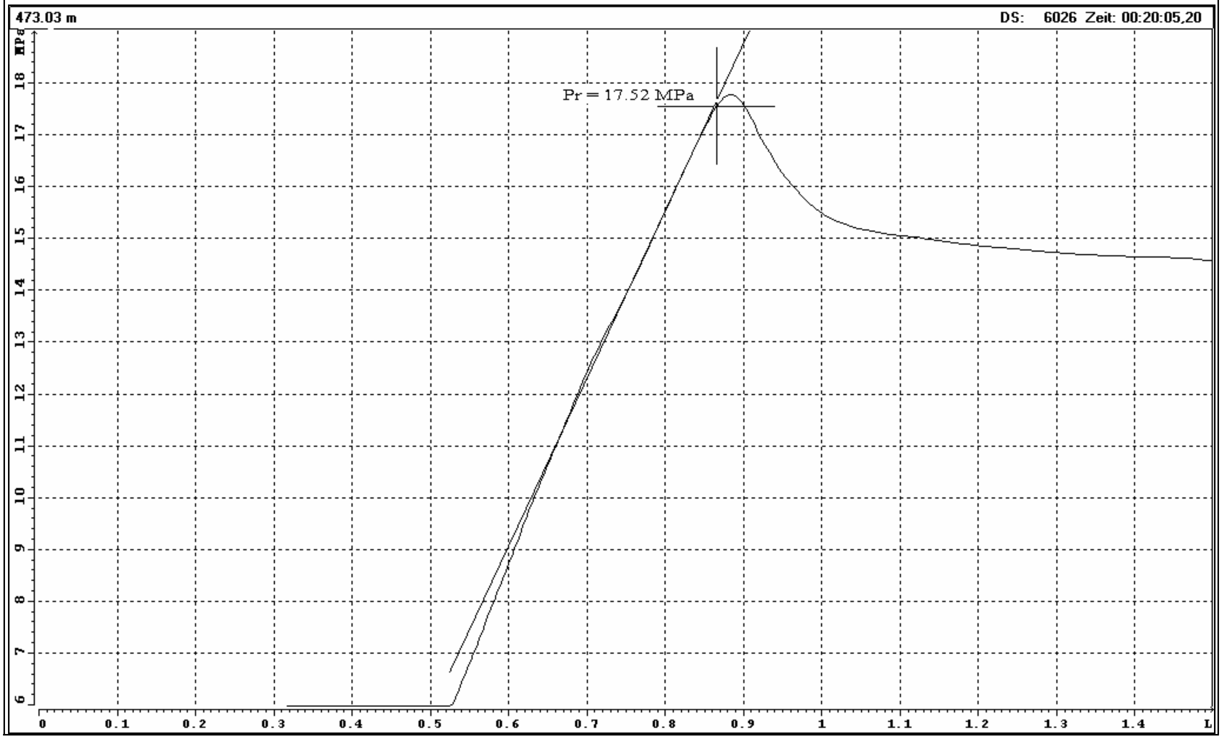
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 1.80 MPa in 933 sec.			
Frac (1. Refrac) - cycle	Qi (lpm) = 1.1	Vi (l) = 1.2	Vr (l) = 0.15
2. Refrac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.3	Vr (l) = 0.25
3. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 1.65	Vr (l) = 0.3
4. Refrac - cycle	Qi (lpm) = 2.7	Vi (l) = 2.4	Vr (l) = 0.3
SP/SR - test	Qi (lpm) = 1.2-4.3	Vi (l) = 15.7	Vr (l) = 0.8

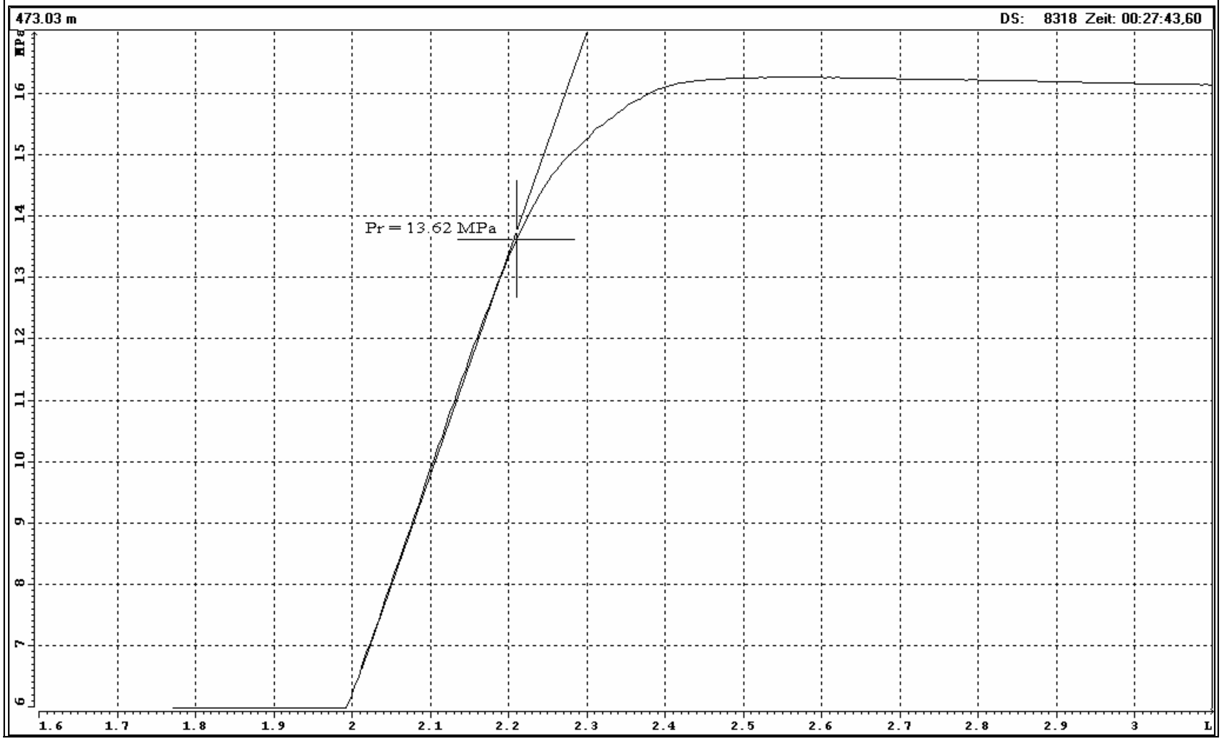
total injected volume (l): 22.25 recovered volume (l): 1.8 or 8.1 %

- Initial test type: HTPF-v
- The frac (1. refrac) - cycle is characterized by the stimulation of a pre - existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct shut-in pressure values, which, however, increased from 13.9 - 14.0 MPa during the 1., 2., and 3. refrac - cycle to 15.8 MPa during the 4. refrac - cycle. Therefore, the shut - in pressure of the 3. refrac - cycle was used for the stress analysis.

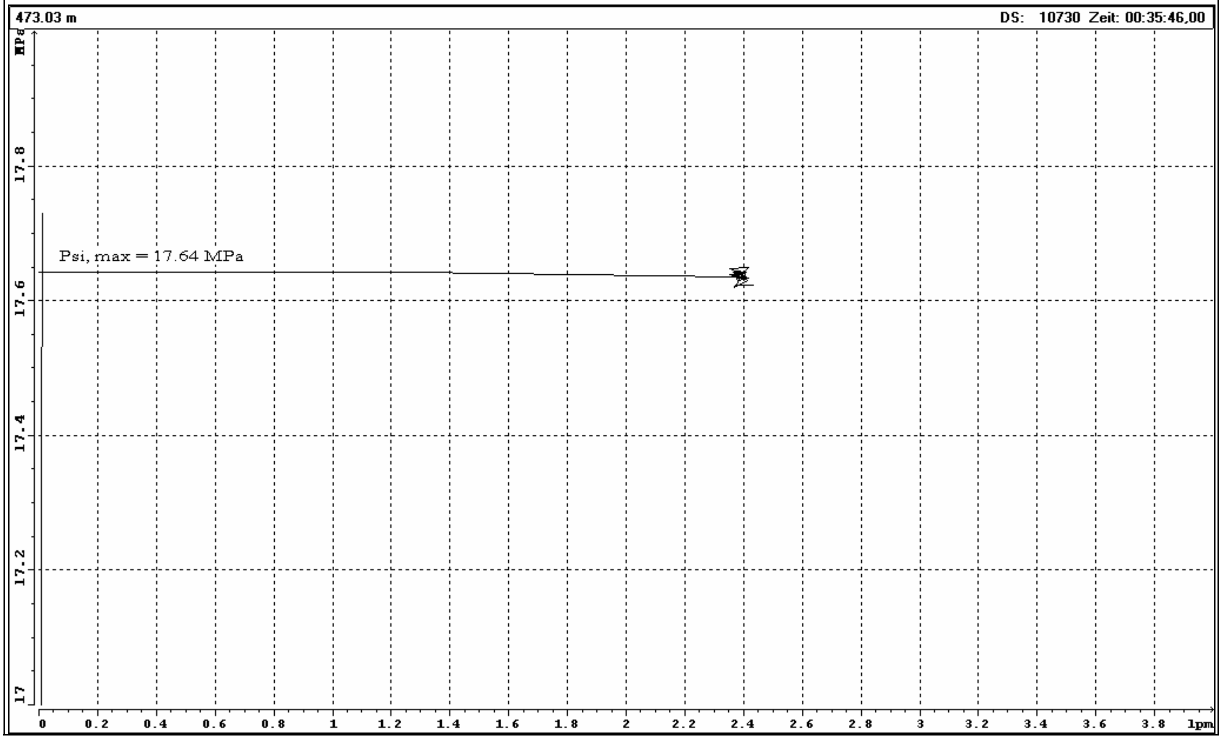
Test at 473.03 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



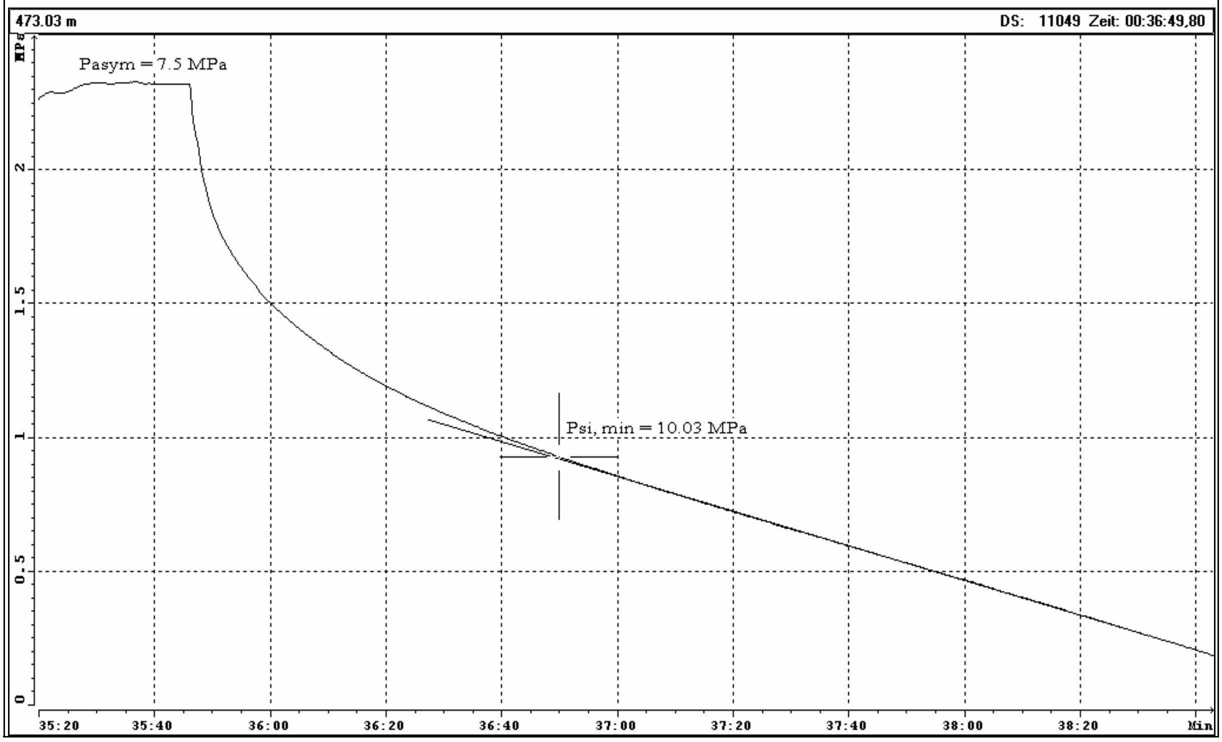
Test at 473.03 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



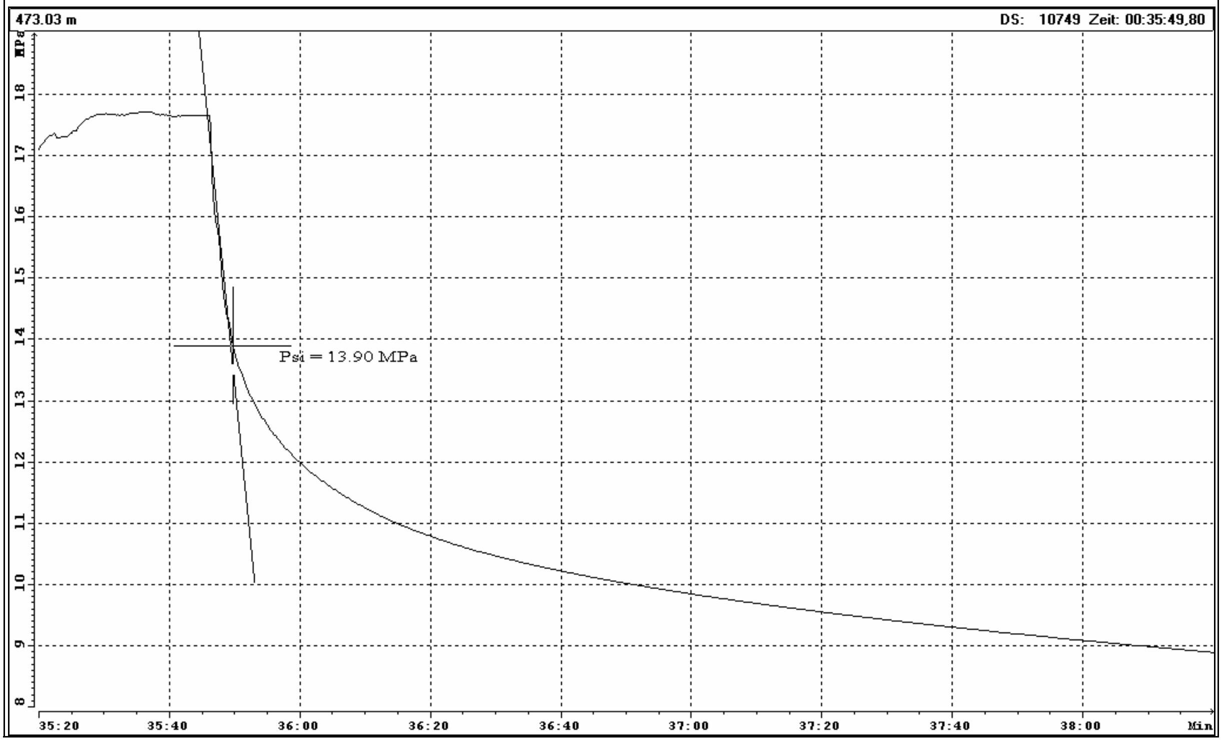
Test at 473.03 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



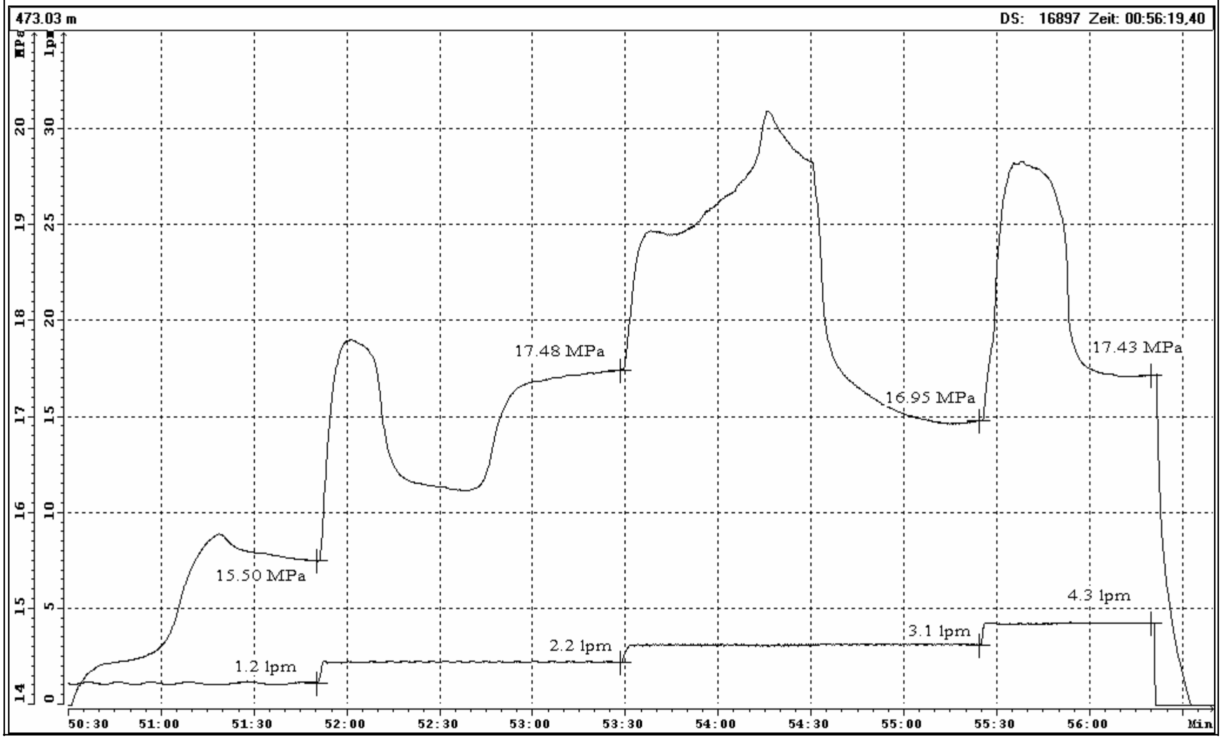
Test at 473.03 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



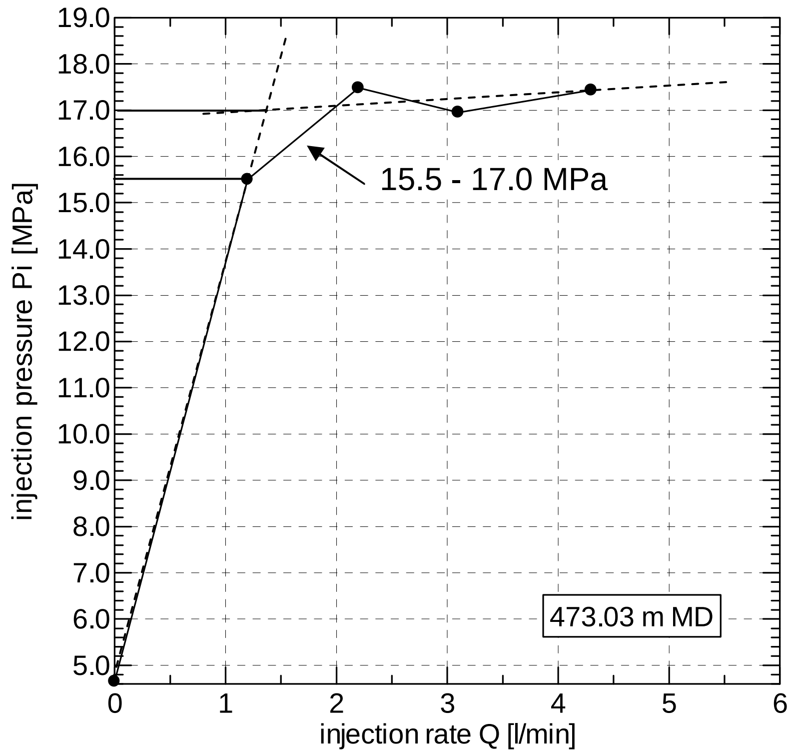
Test at 473.03 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 473.03 m MD: Analysis of Slow - Pump / Step - Rate - Test

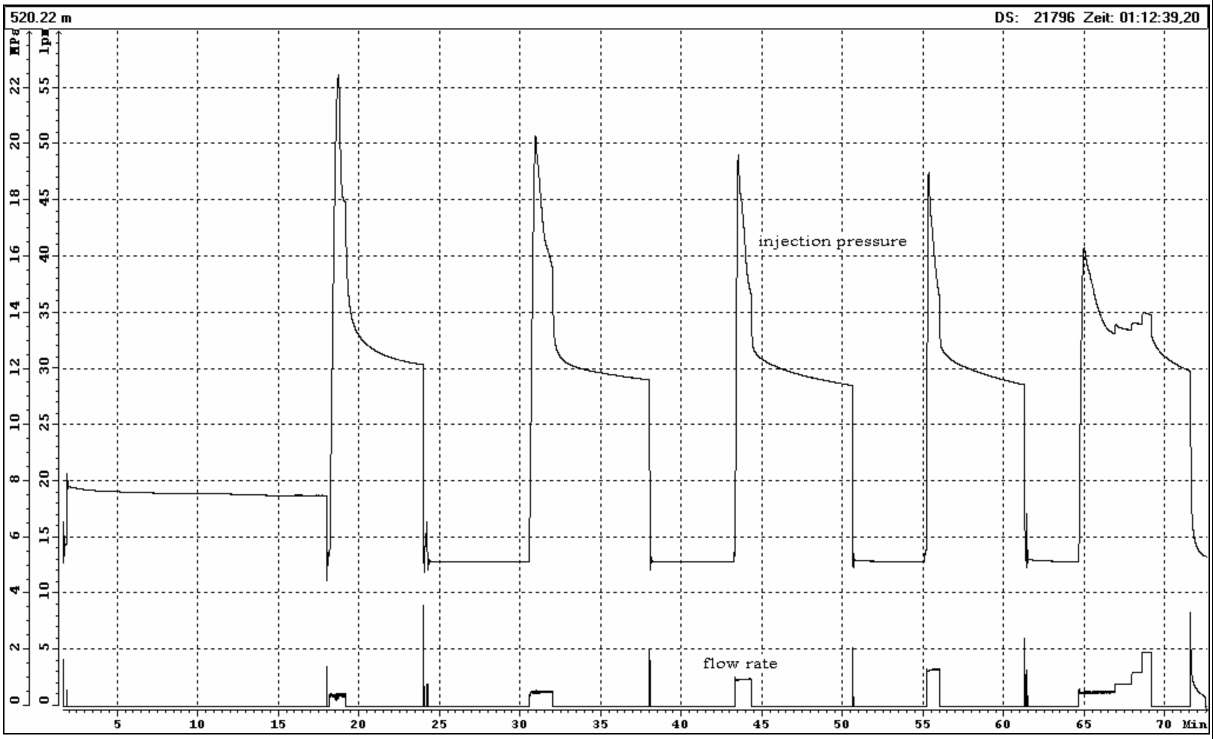


Test at 473.03 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 21 AT 520.22 m MD / 518.34 m TVD

Test at 520.22 m MD: Overview - Plot



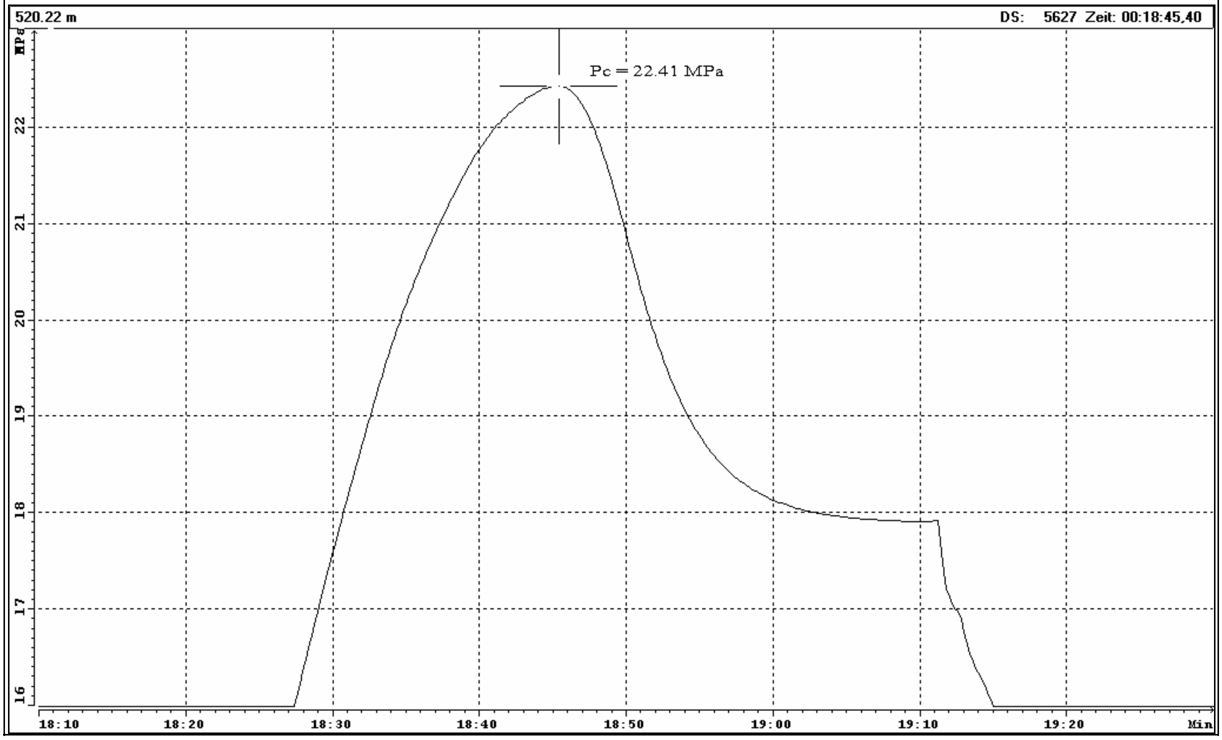
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.30 MPa in 955 sec.		
Frac - cycle	Qi (lpm) = 1.1	Vi (l) = 1.0	Vr (l) = 0.5
1. Refrac - cycle	Qi (lpm) = 1.3	Vi (l) = 1.85	Vr (l) = 0.75
2. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 2.4	Vr (l) = 0.8
3. Refrac - cycle	Qi (lpm) = 3.3	Vi (l) = 2.7	Vr (l) = 1.3
SP/SR - test	Qi (lpm) = 1.2-4.8	Vi (l) = 9.5	Vr (l) = 4.0

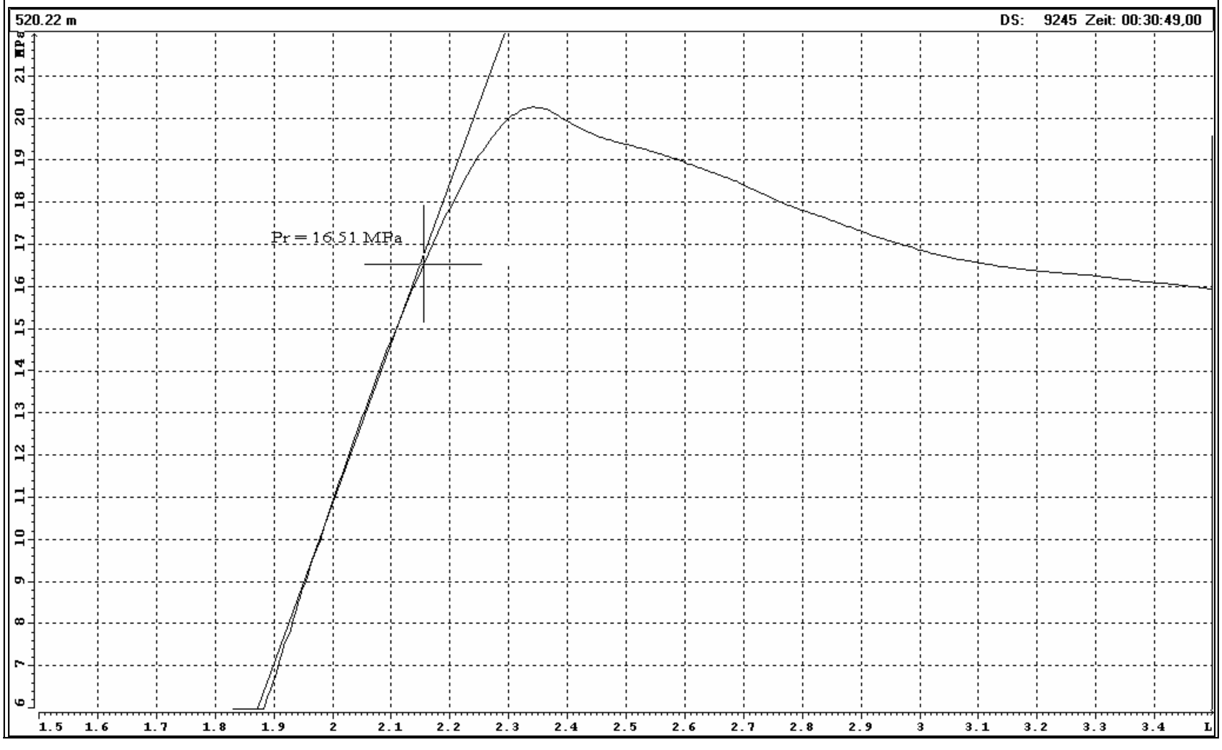
total injected volume (l): 17.45 recovered volume (l): 7.35 or 42.1 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a weak breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 16.5 MPa, followed by a pressure increase up to 20.2 MPa. In comparison to the first cycle, the subsequent re-frac - cycles yield nearly identical fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

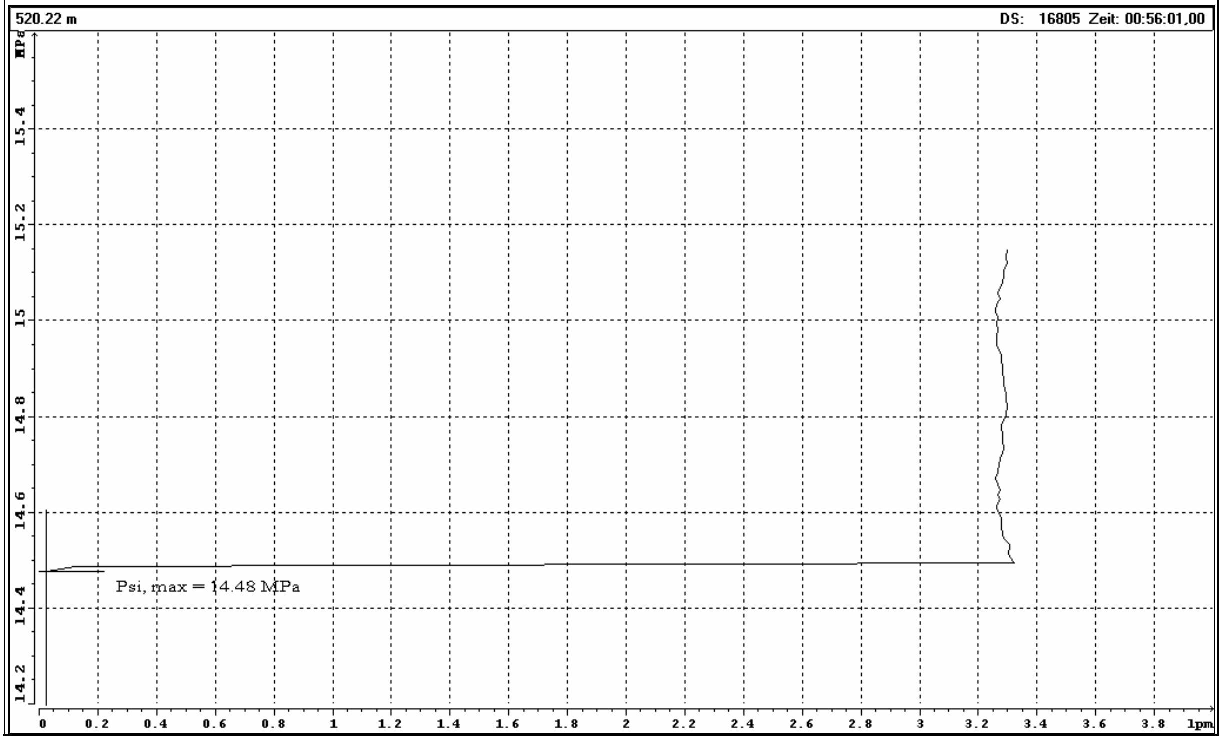
Test at 520.22 m MD: Estimation of P_c (Frac - Cycle)



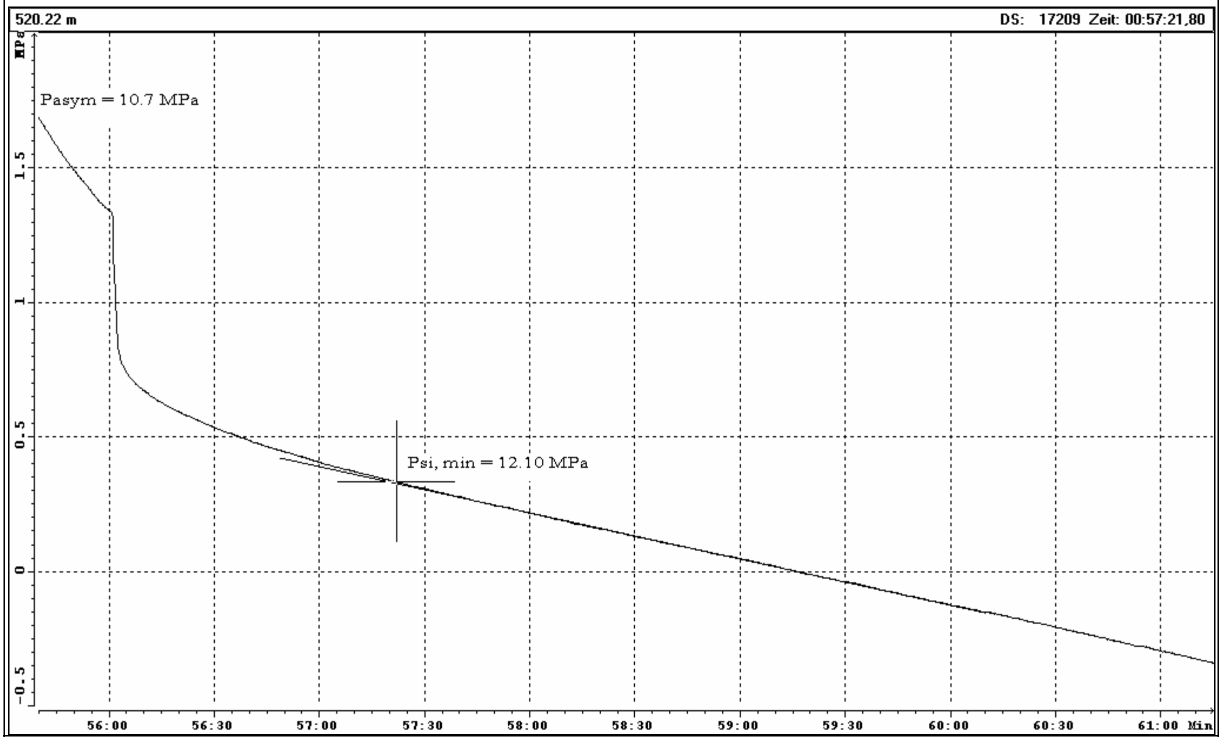
Test at 520.22 m MD: Estimation of P_r (1. Refrac - Cycle)



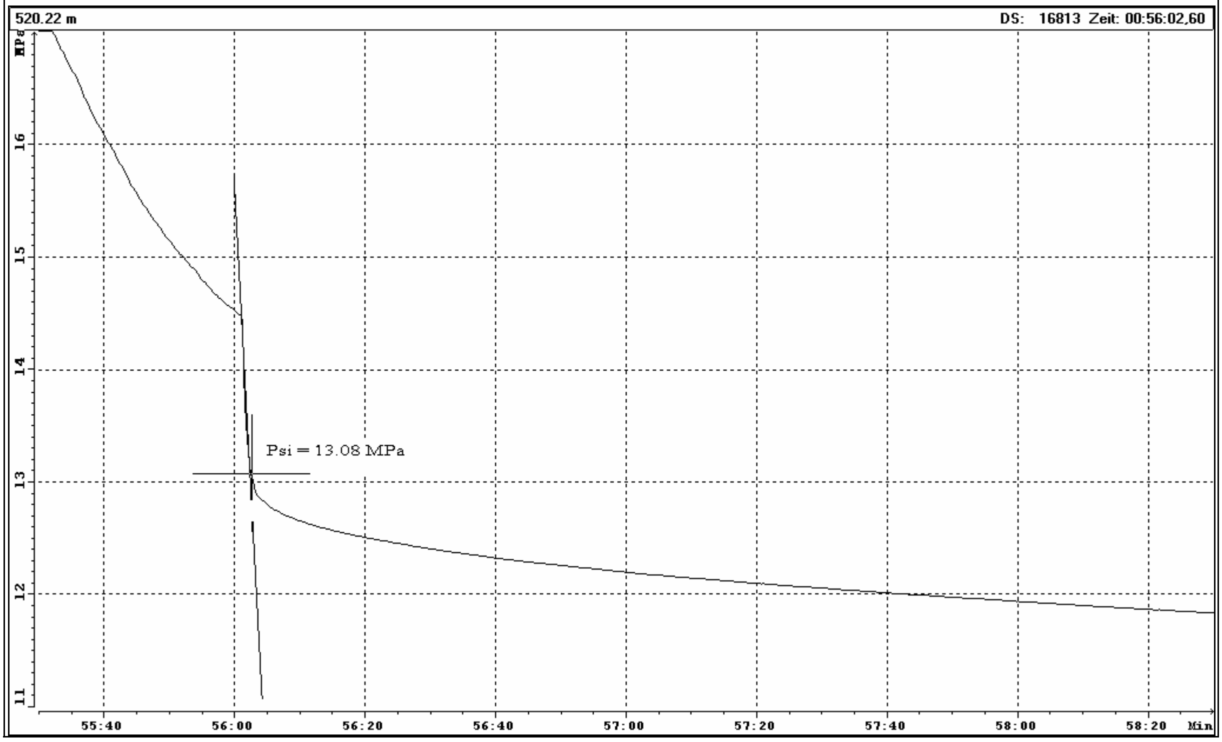
Test at 520.22 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



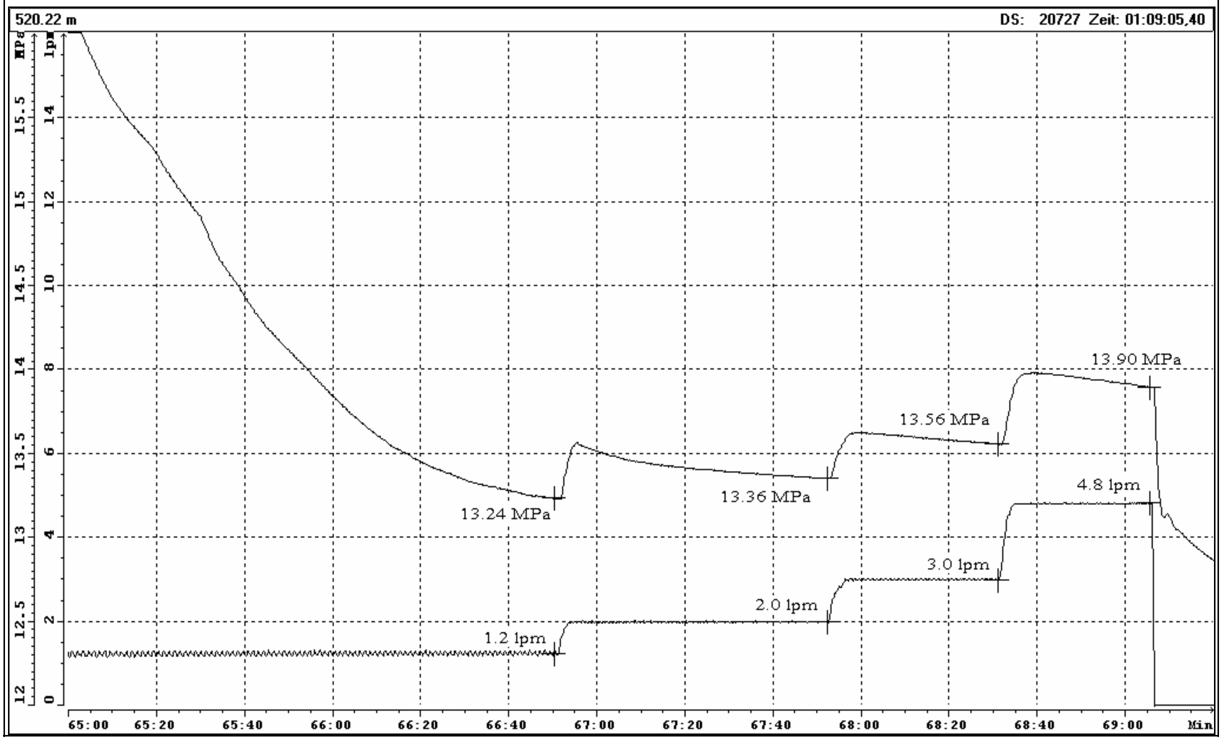
Test at 520.22 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



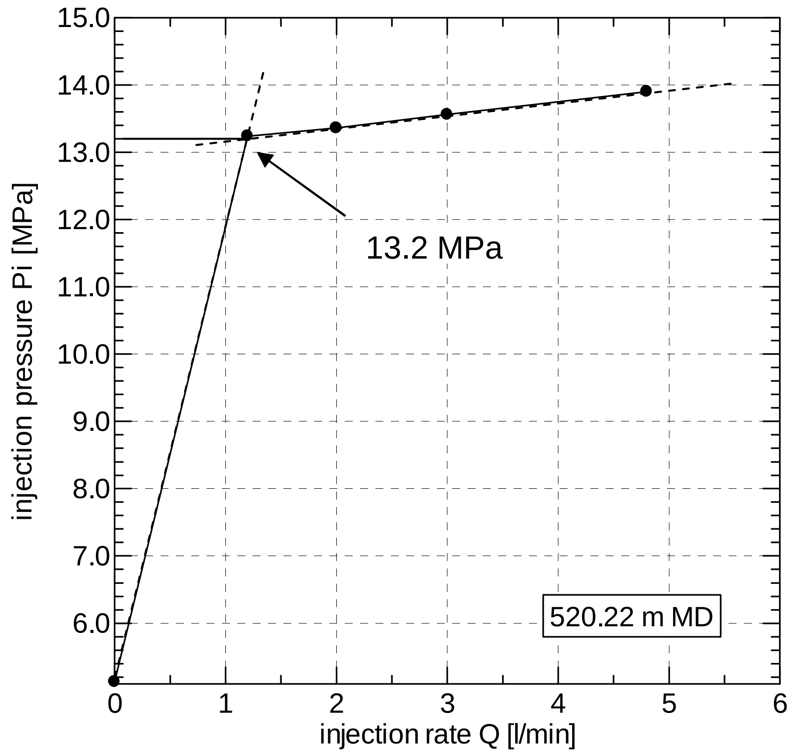
Test at 520.22 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 520.22 m MD: Analysis of Slow - Pump / Step - Rate - Test

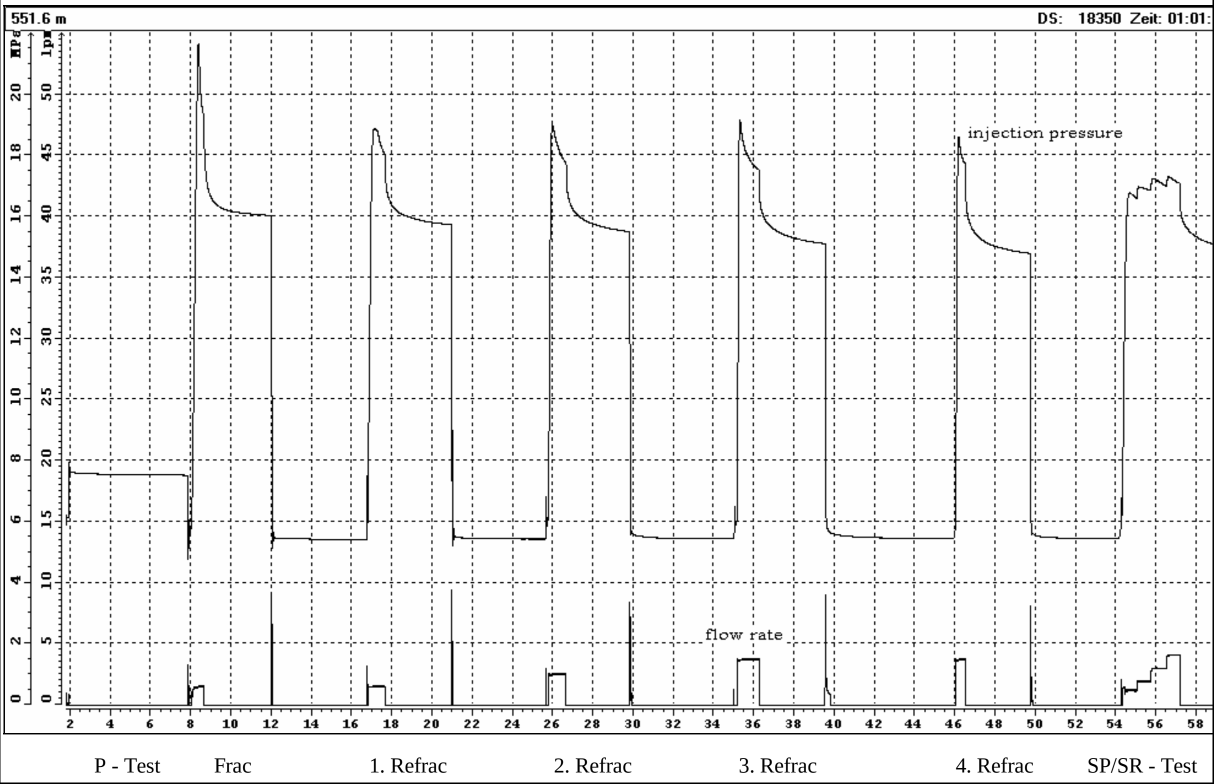


Test at 520.22 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 20 AT 551.6 m MD / 549.53 m TVD

Test at 551.6 m MD: Overview - Plot



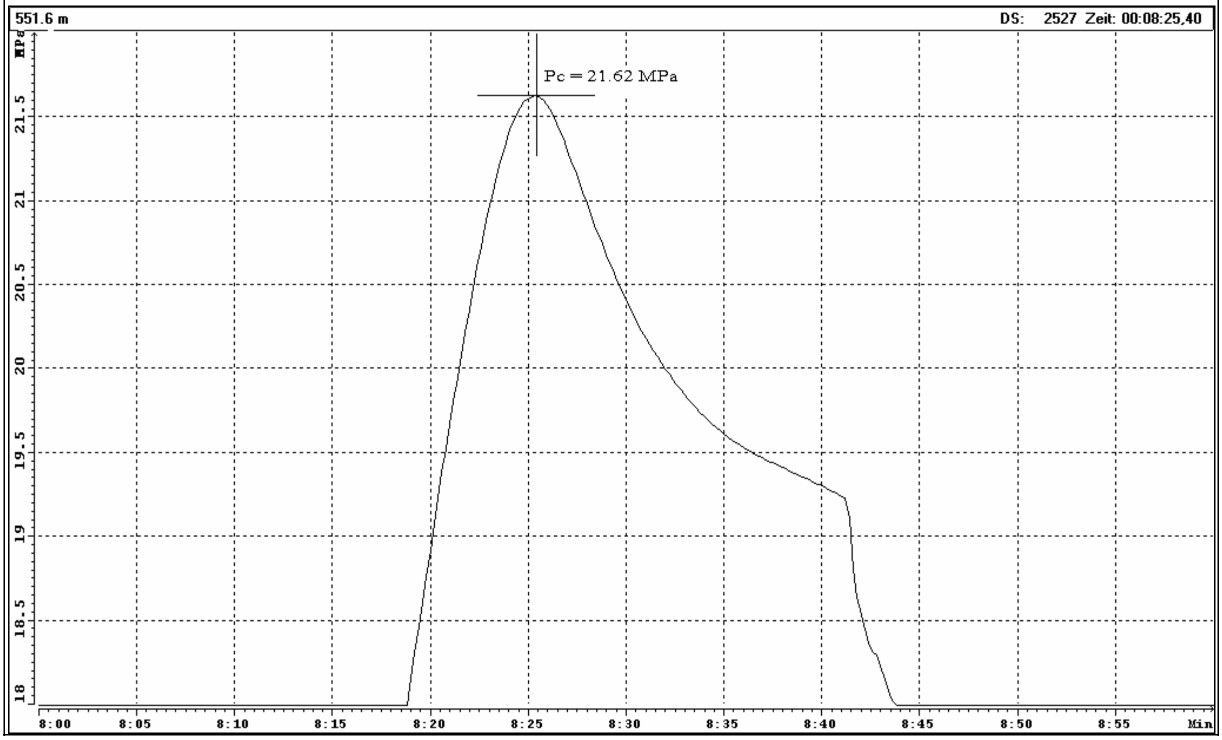
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.11 MPa in 346 sec.		
Frac - cycle	Qi (lpm) = 1.5	Vi (l) = 0.85	Vr (l) = 0.5
1. Refrac - cycle	Qi (lpm) = 1.5	Vi (l) = 1.3	Vr (l) = 0.8
2. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 2.2	Vr (l) = 1.5
3. Refrac - cycle	Qi (lpm) = 3.8	Vi (l) = 4.1	Vr (l) = 2.5
4. Refrac - cycle	Qi (lpm) = 3.8	Vi (l) = 1.8	Vr (l) = 1.5
SP/SR - test	Qi (lpm) = 1.2-4.1	Vi (l) = 7.4	Vr (l) = 2.1

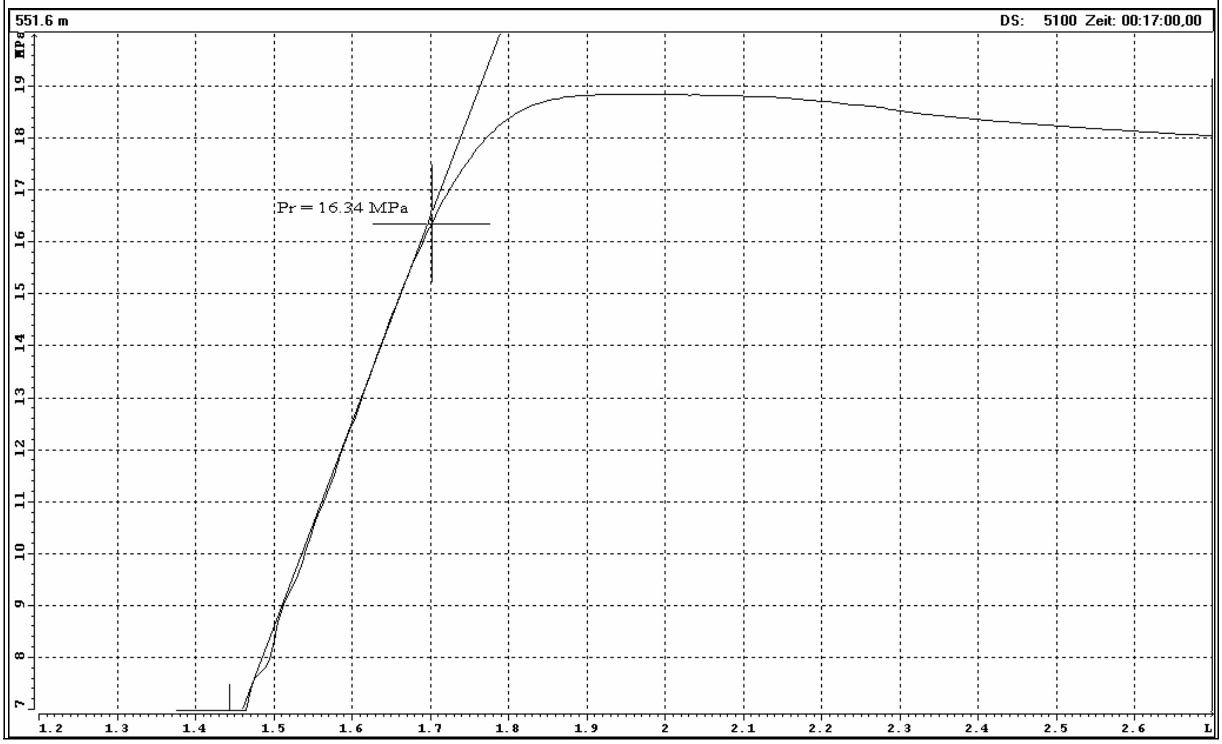
total injected volume (l): 17.65 recovered volume (l): 8.9 or 50.4 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. In comparison, the subsequent refrac - cycles yield nearly identical fracture re-opening pressures.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

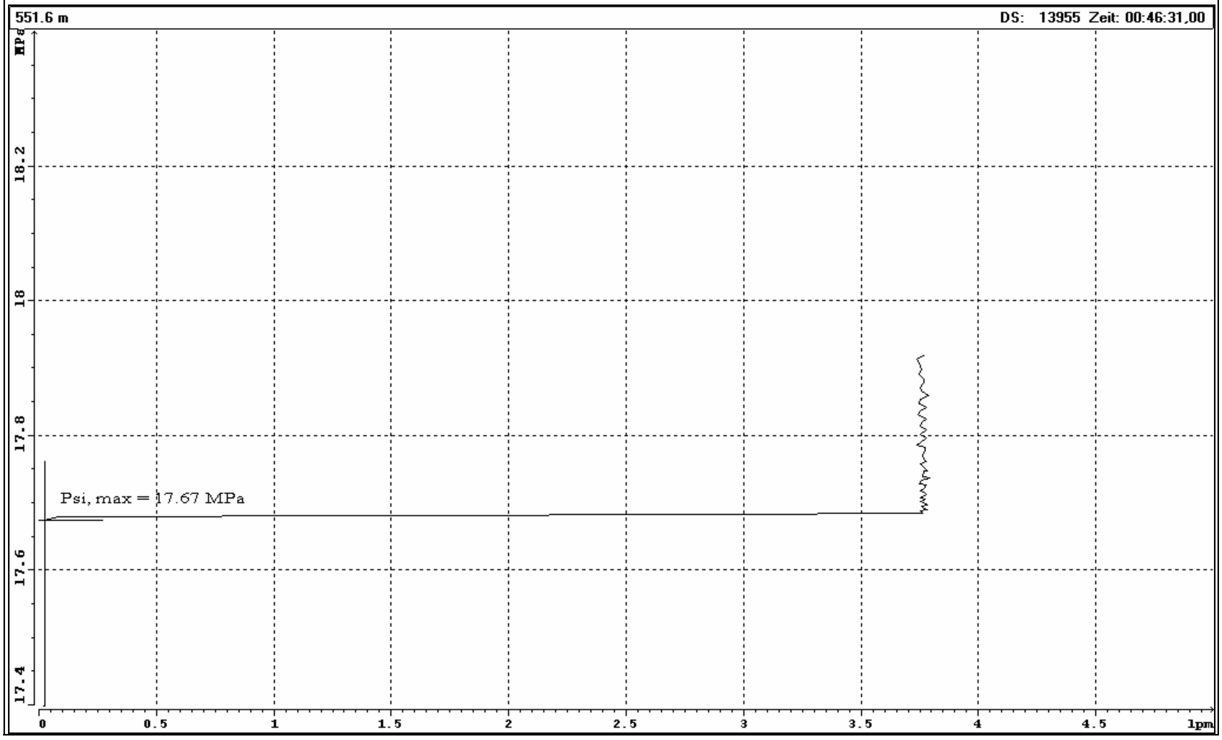
Test at 551.6 m MD: Estimation of P_c(Frac - Cycle)



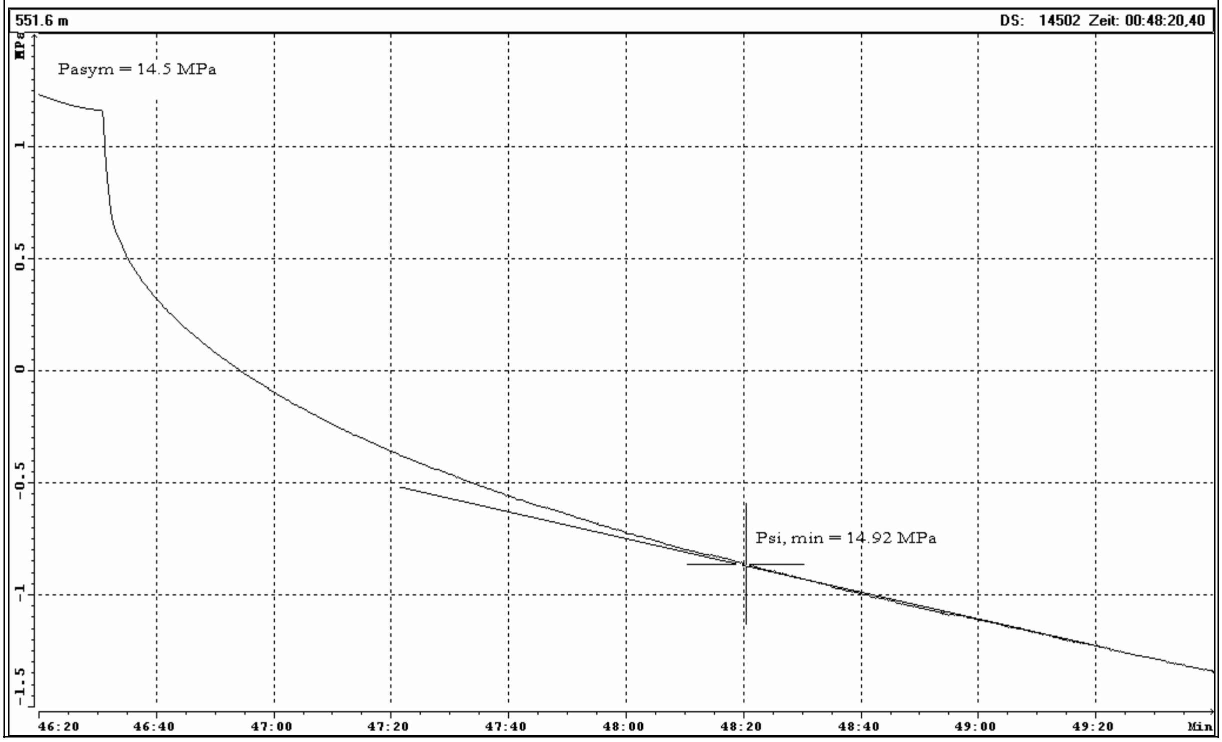
Test at 551.6 m MD: Estimation of P_r (1. Refrac - Cycle)



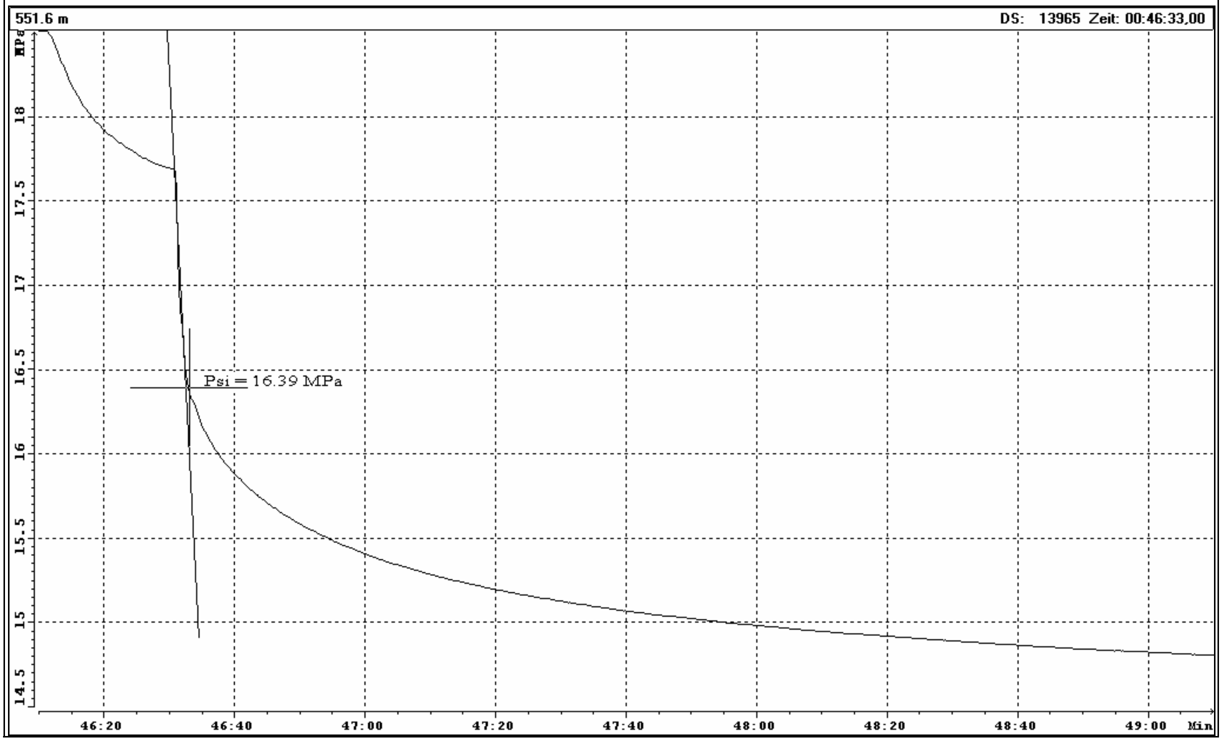
Test at 551.6 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



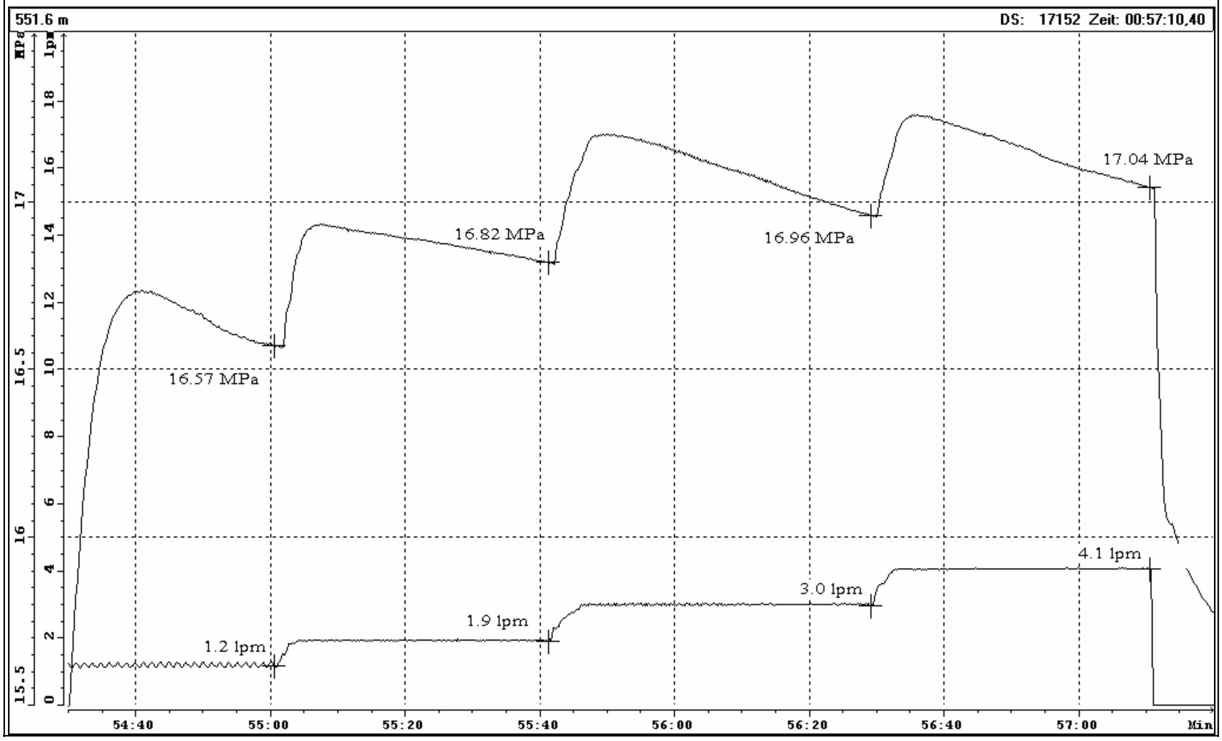
Test at 551.6 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



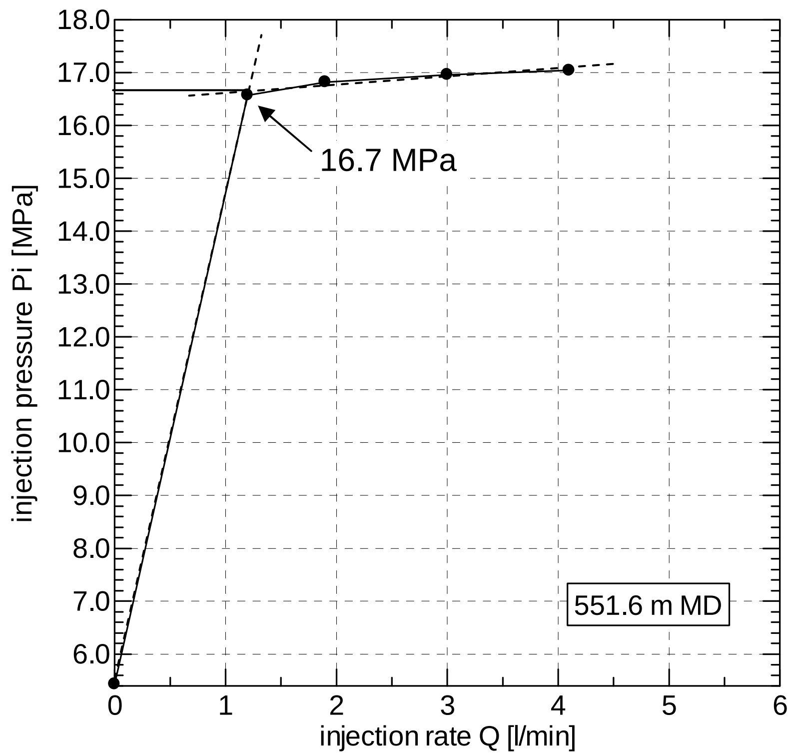
Test at 551.6 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 551.6 m MD: Analysis of Slow - Pump / Step - Rate - Test

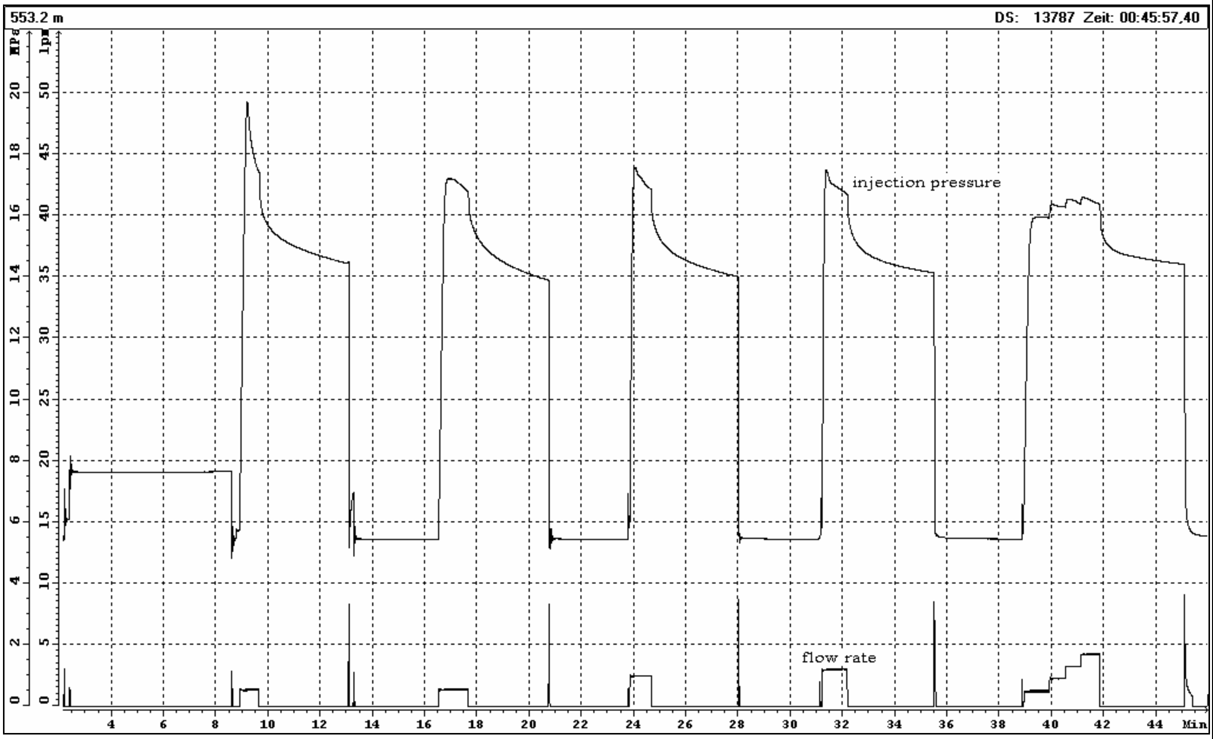


Test at 551.6 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 19 AT 553.2 m MD / 551.12 m TVD

Test at 553.2 m MD: Overview - Plot



P - Test | Frac | 1. Refrac | 2. Refrac | 3. Refrac | SP/SR - Test

TEST SUMMARY / ANALYSIS / REMARKS

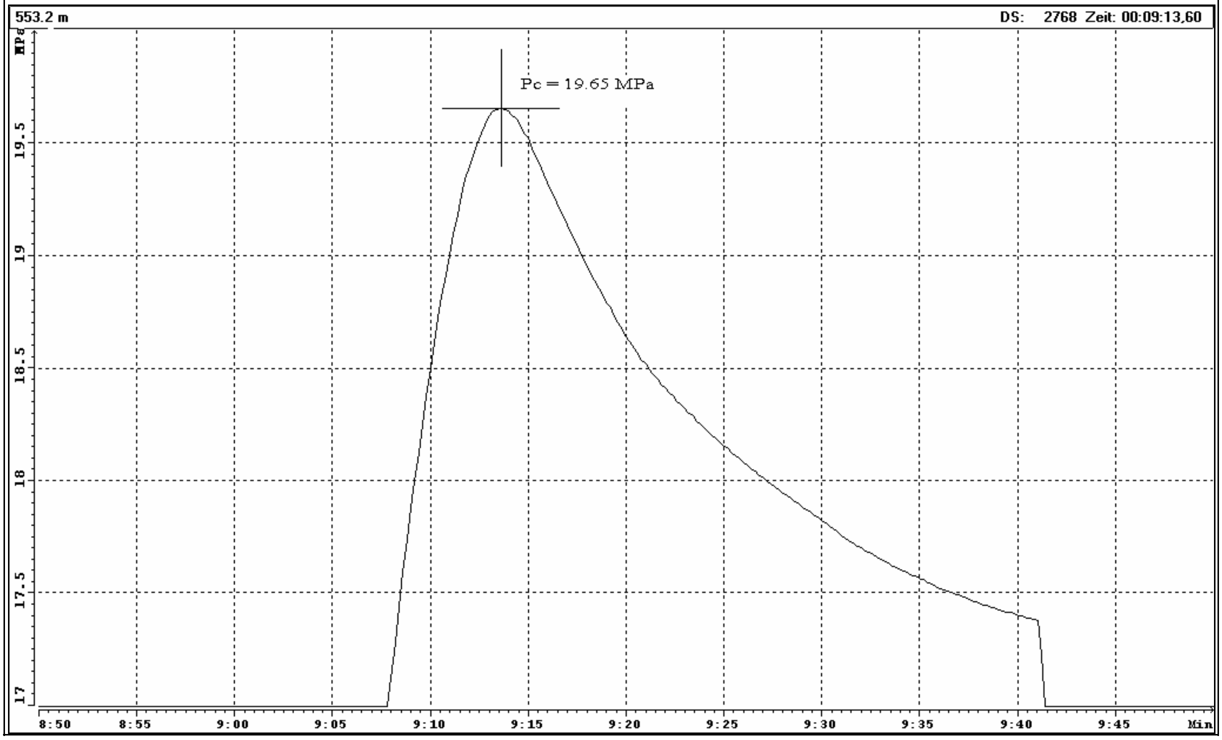
P - Test : pressure decrease of 0.02 MPa in 104 sec., followed by a pressure increase of 0.04 MPa in 255 sec.

Frac - cycle	Qi (lpm) = 1.3	Vi (l) = 1.0	Vr (l) = 0.25
1. Refrac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.6	Vr (l) = 0.25
2. Refrac - cycle	Qi (lpm) = 2.5	Vi (l) = 2.0	Vr (l) = 0.4
3. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 2.9	Vr (l) = 0.75
SP/SR - test	Qi (lpm) = 1.2-4.3	Vi (l) = 7.6	Vr (l) = 2.5

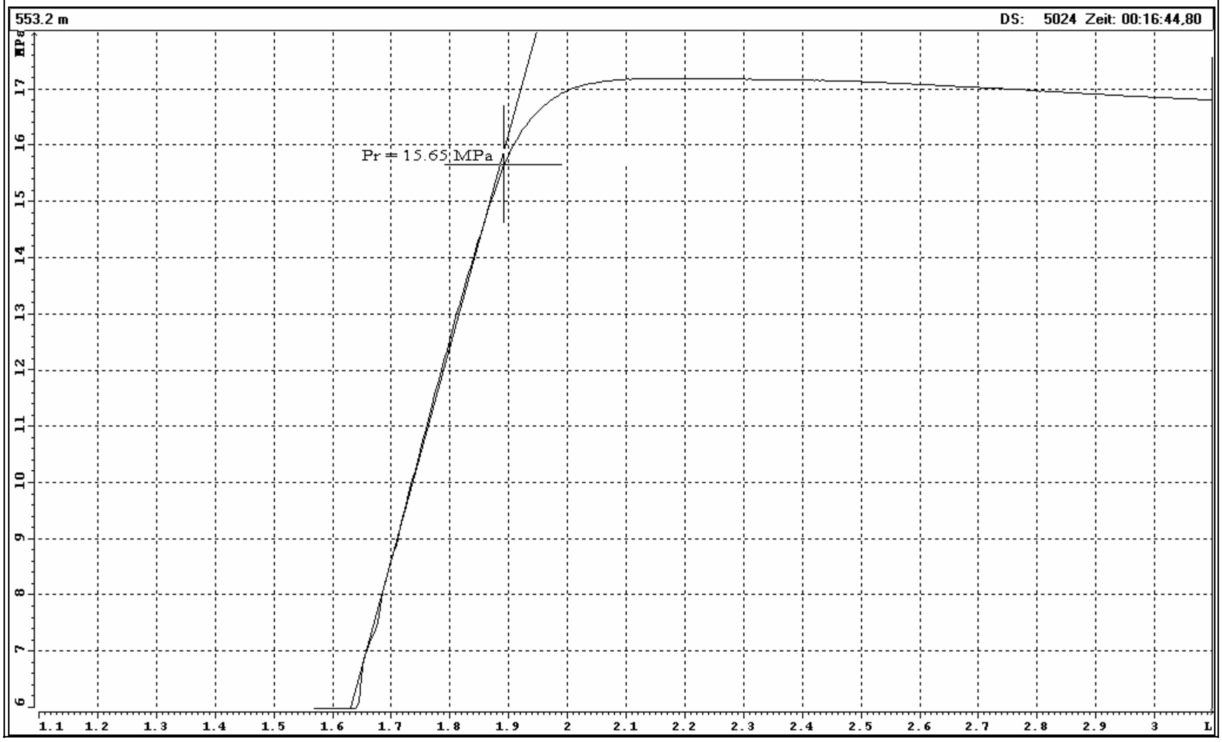
total injected volume (l): 15.1 recovered volume (l): 4.15 or 27.5 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. In comparison, the subsequent refrac - cycles yield slightly lower fracture re-opening pressures.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

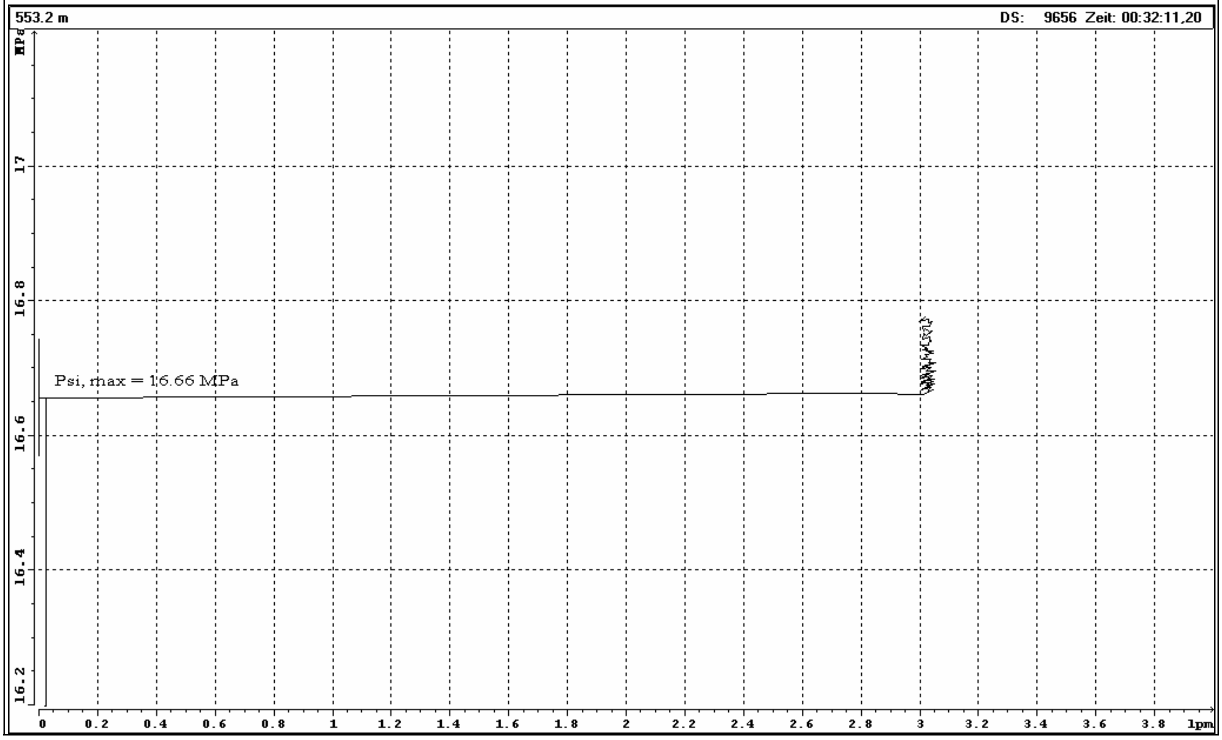
Test at 553.2 m MD: Estimation of P_c(Frac - Cycle)



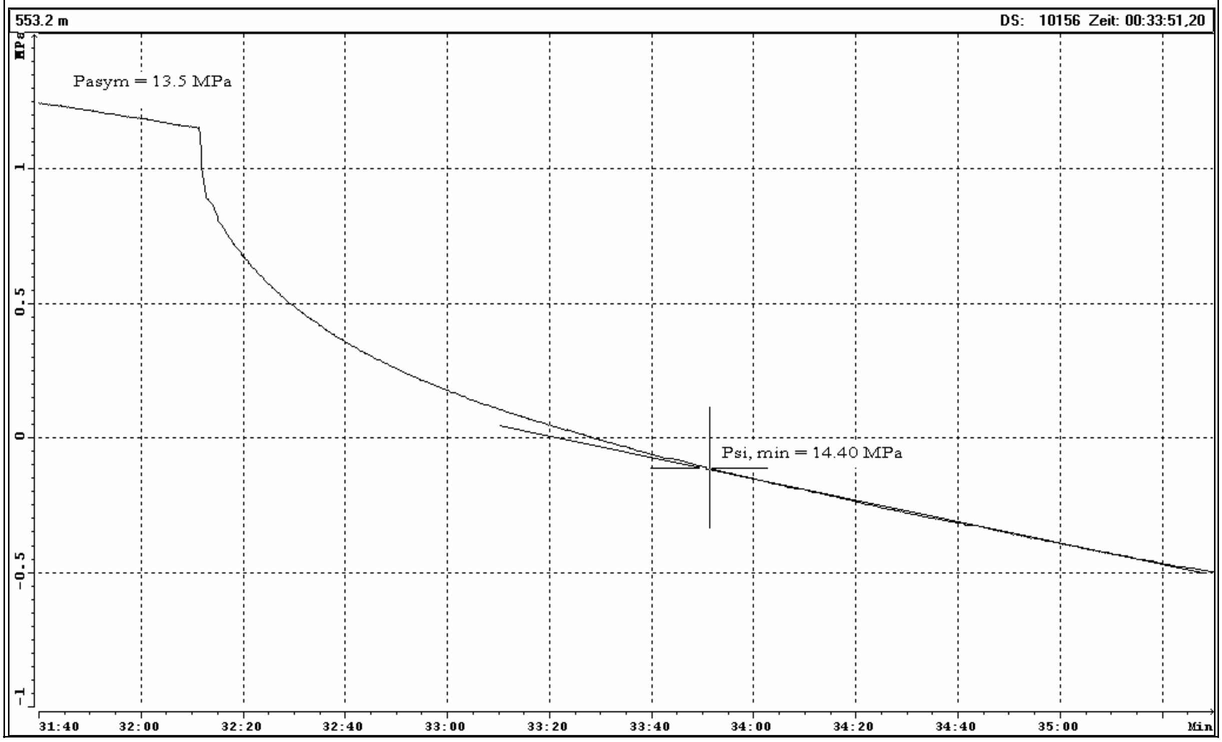
Test at 553.2 m MD: Estimation of P_r (1. Refrac - Cycle)



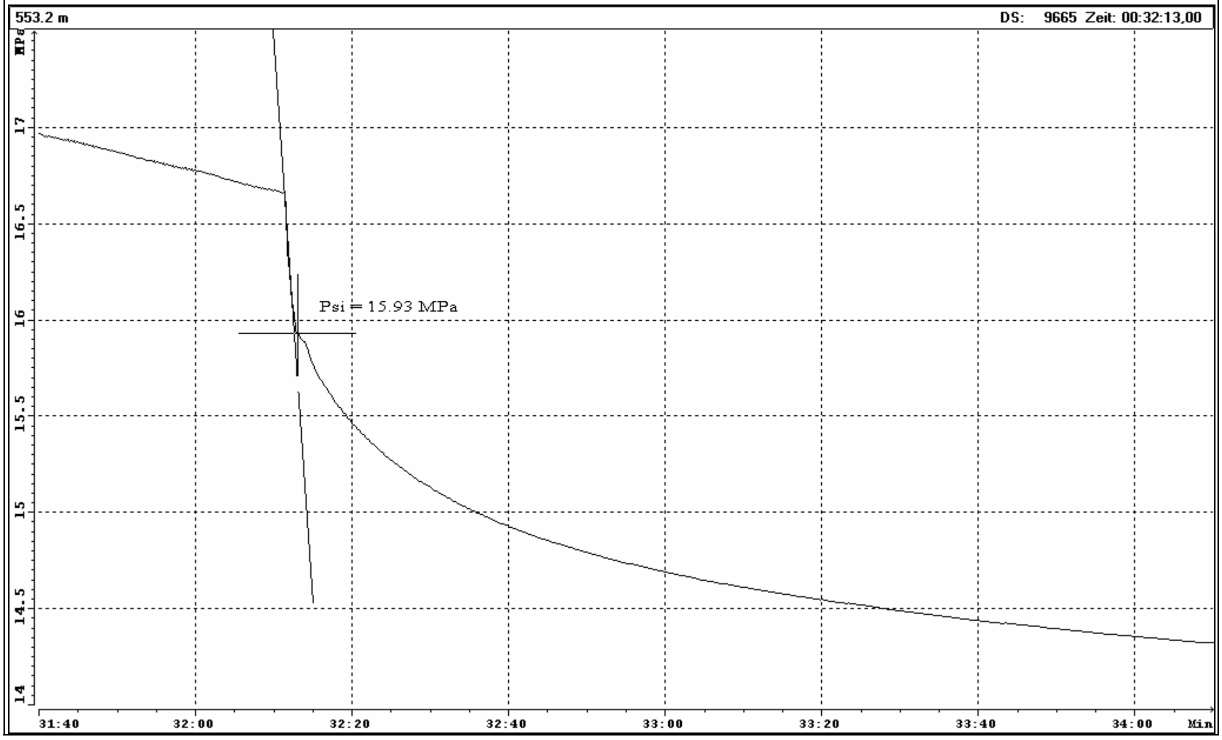
Test at 553.2 m MD: Estimation of $P_{si,\,max}$ (3. Refrac - Cycle)



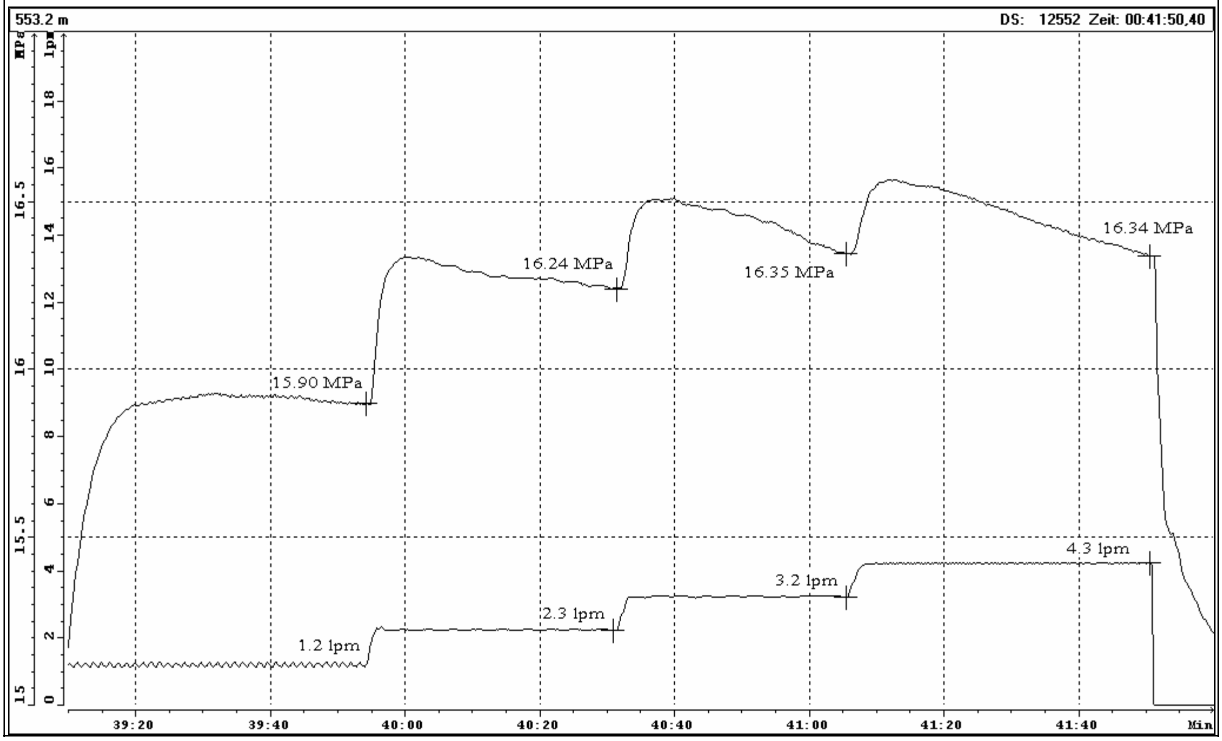
Test at 553.2 m MD: Estimation of $P_{si,\,min}$ (3. Refrac - Cycle)



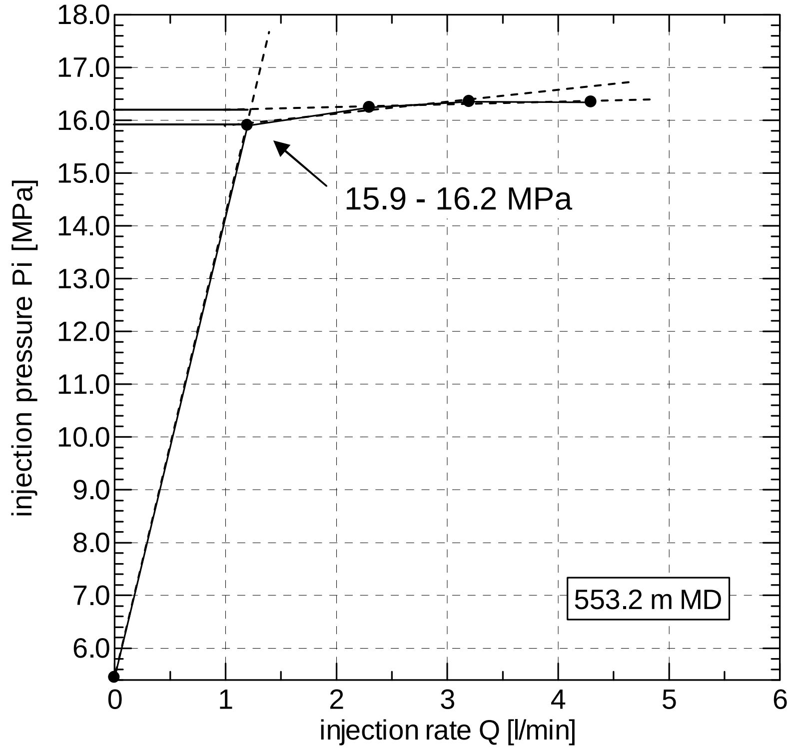
Test at 553.2 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 553.2 m MD: Analysis of Slow - Pump / Step - Rate - Test

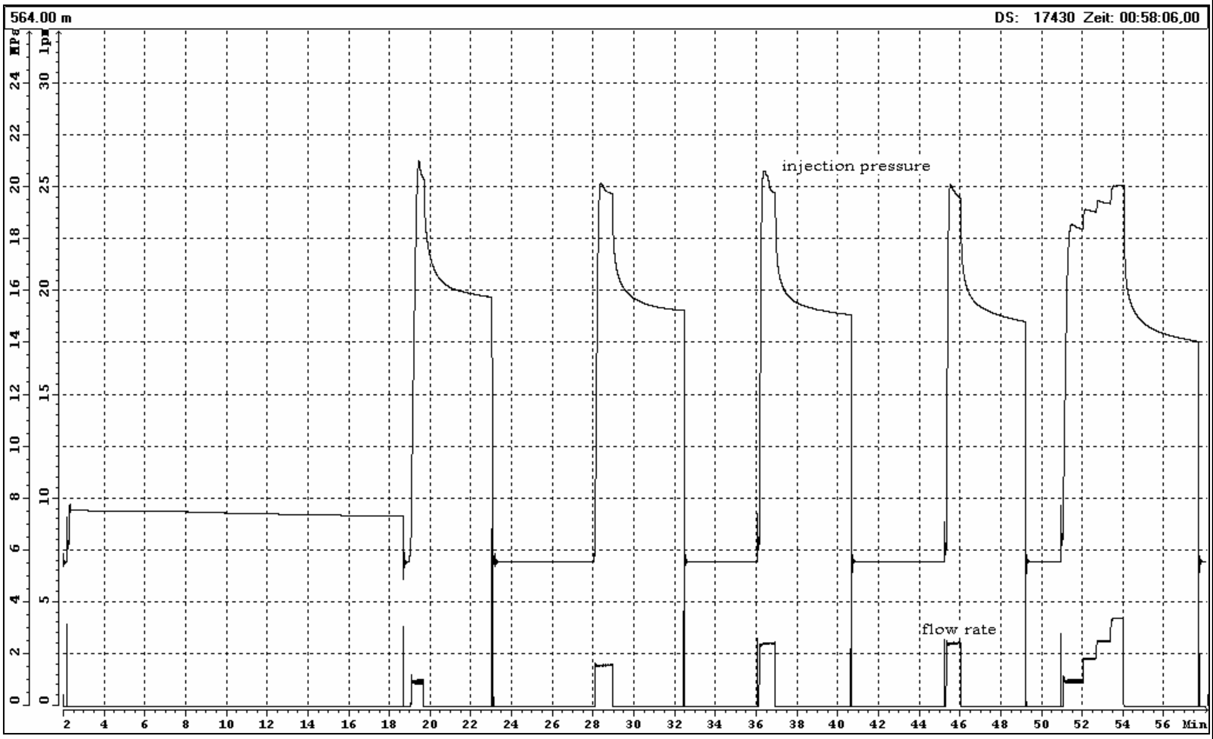


Test at 553.2 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 18 AT 564.00 m MD / 561.86 m TVD

Test at 564.00 m MD : Overview - Plot



P - Test Frac (1. Refrac) 2. Refrac 3. Refrac 4. Refrac SP/SR - Test

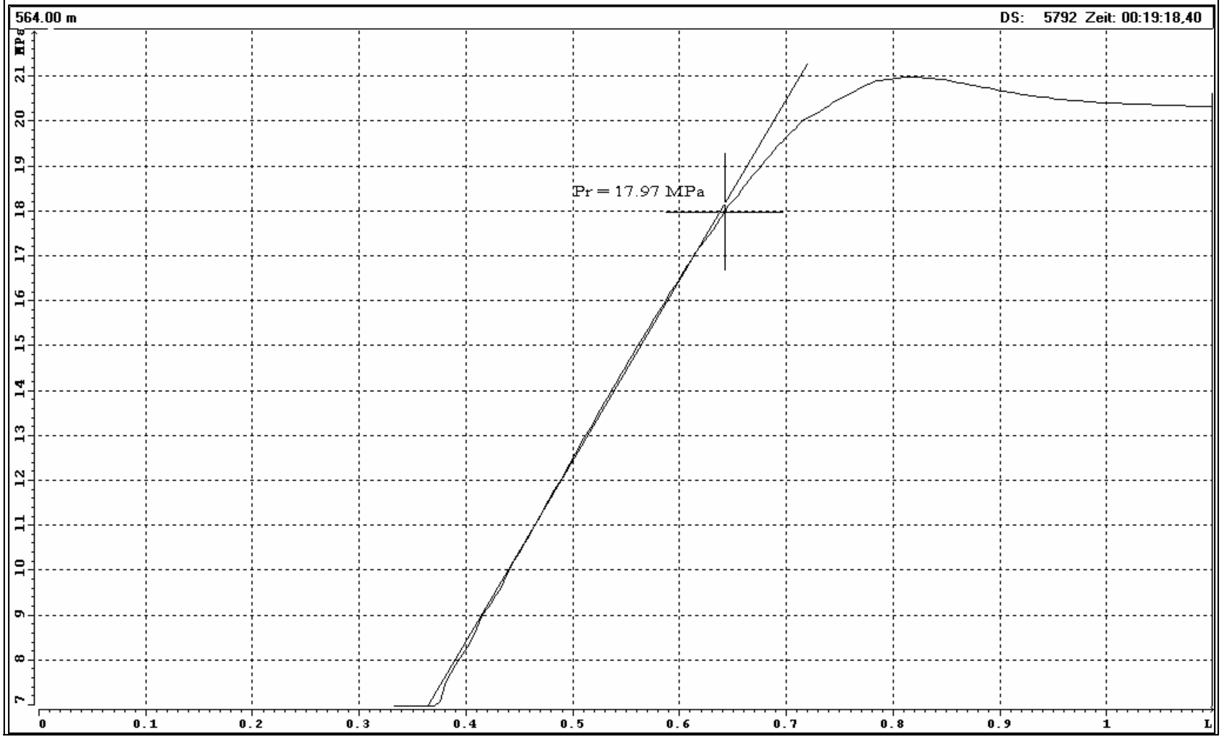
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.22 MPa in 970 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.1	Vi (l) = 0.8	Vr (l) = 0.25
2. Refrac - cycle	Qi (lpm) = 2.0	Vi (l) = 1.7	Vr (l) = 0.3
3. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 2.4	Vr (l) = 0.3
4. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 2.2	Vr (l) = 0.3
SP/SR - test	Qi (lpm) = 1.2-4.2	Vi (l) = 7.6	Vr (l) = 0.3

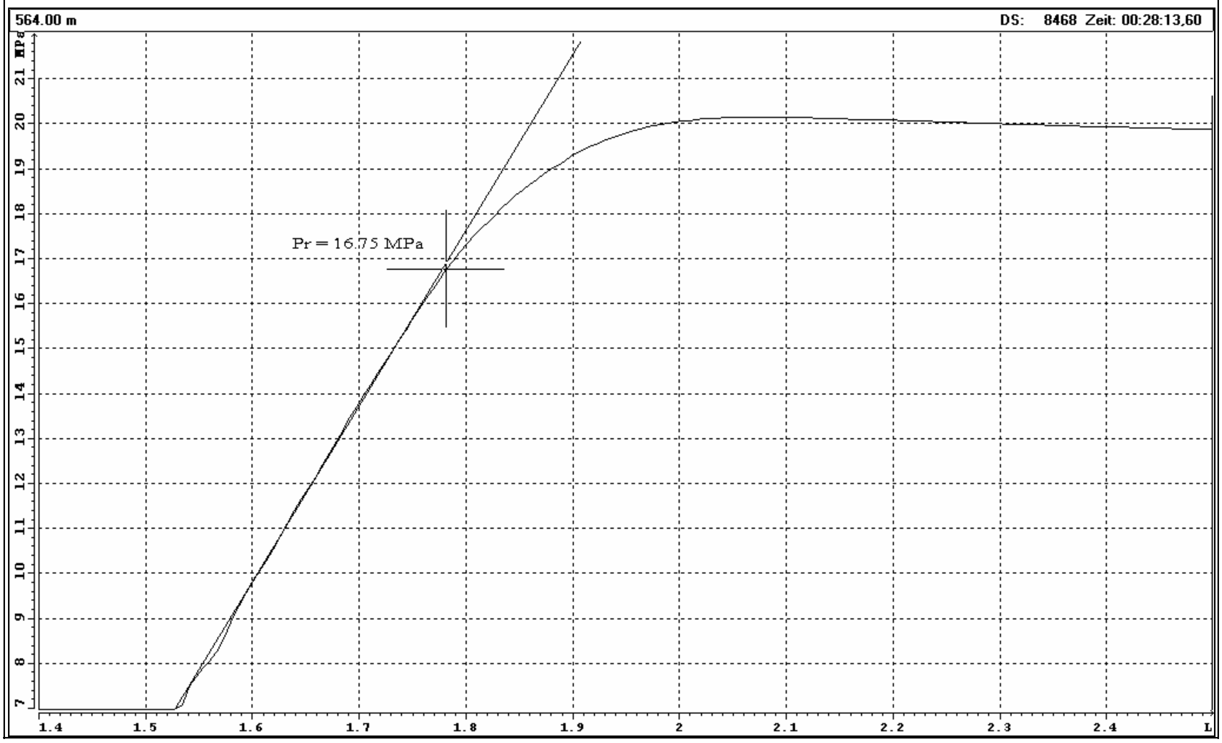
total injected volume (l): 14.7 recovered volume (l): 1.45 or 9.9 %

- Initial test type: HTPF-v
- The frac (1. refrac) - cycle is characterized by the stimulation of a pre - existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 18 MPa, followed by a pressure increase up to about 21 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

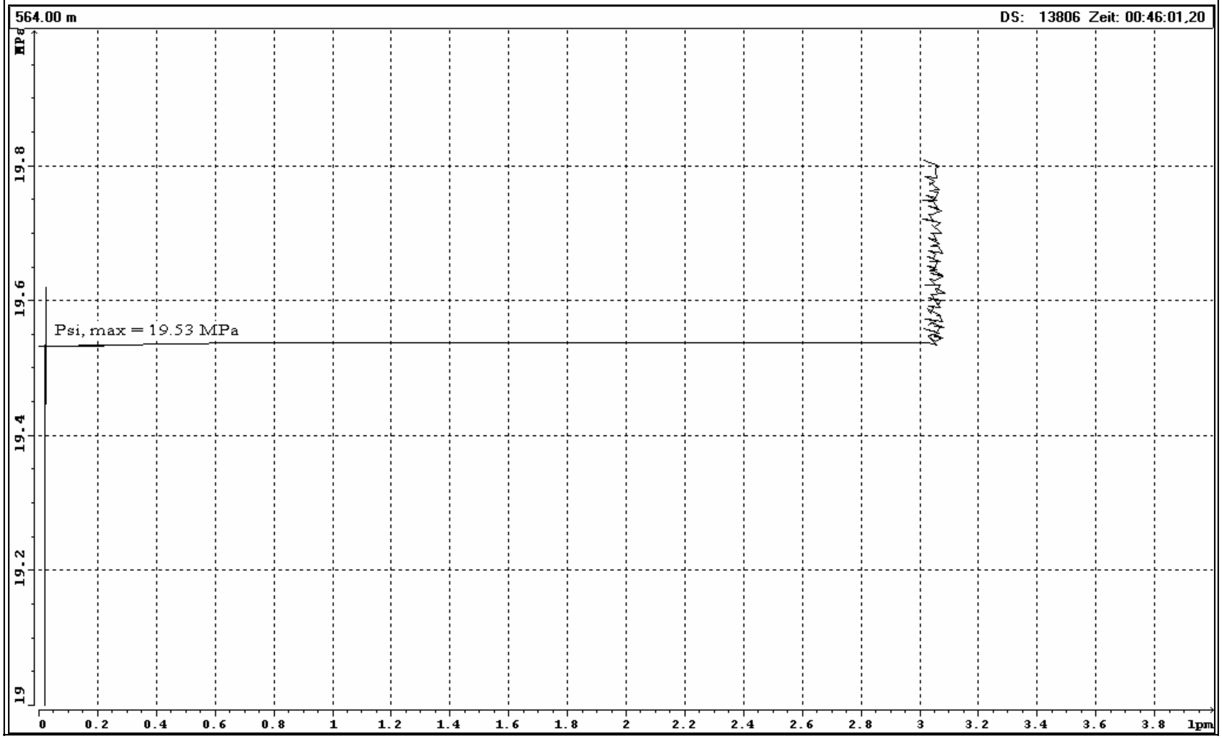
Test at 564.00 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



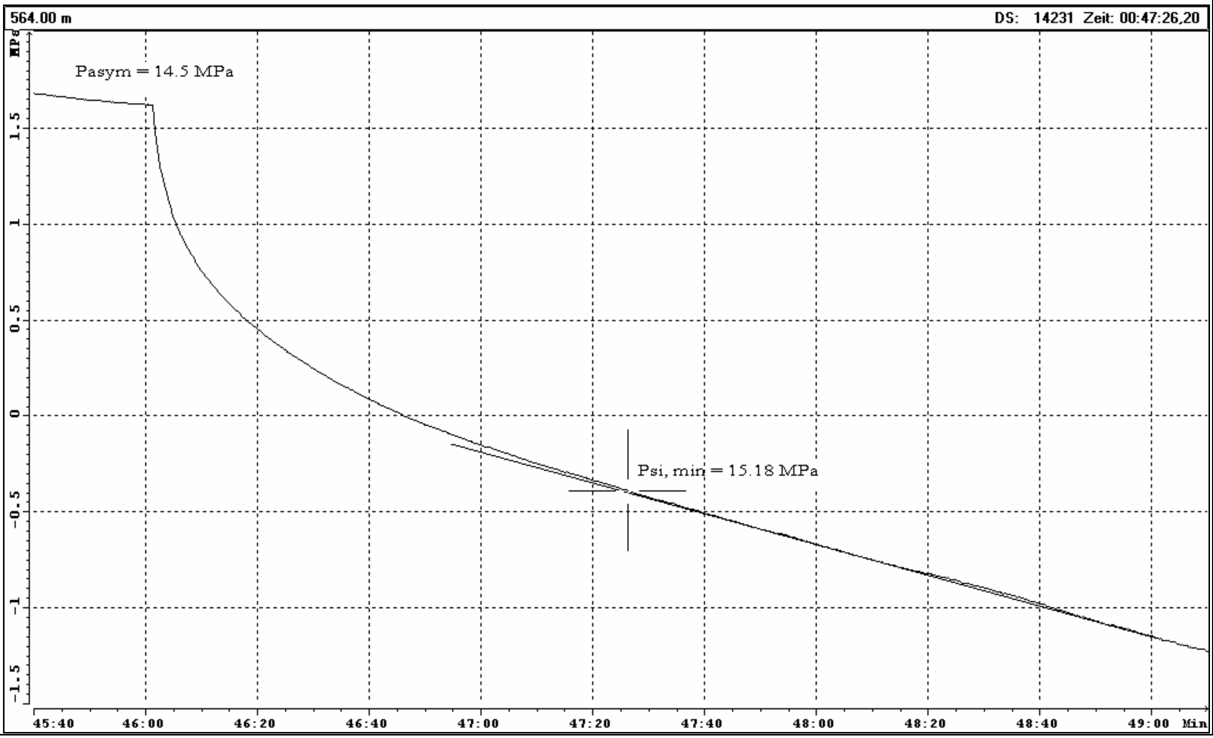
Test at 564.00 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



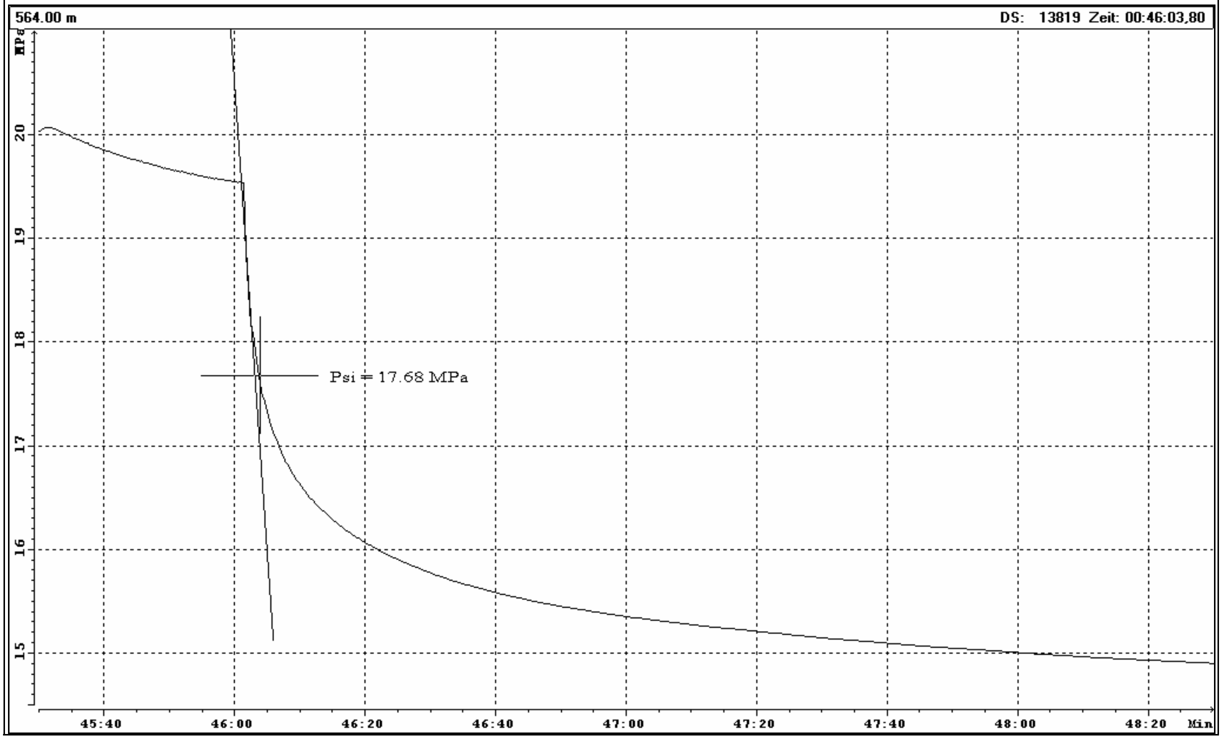
Test at 564.00 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



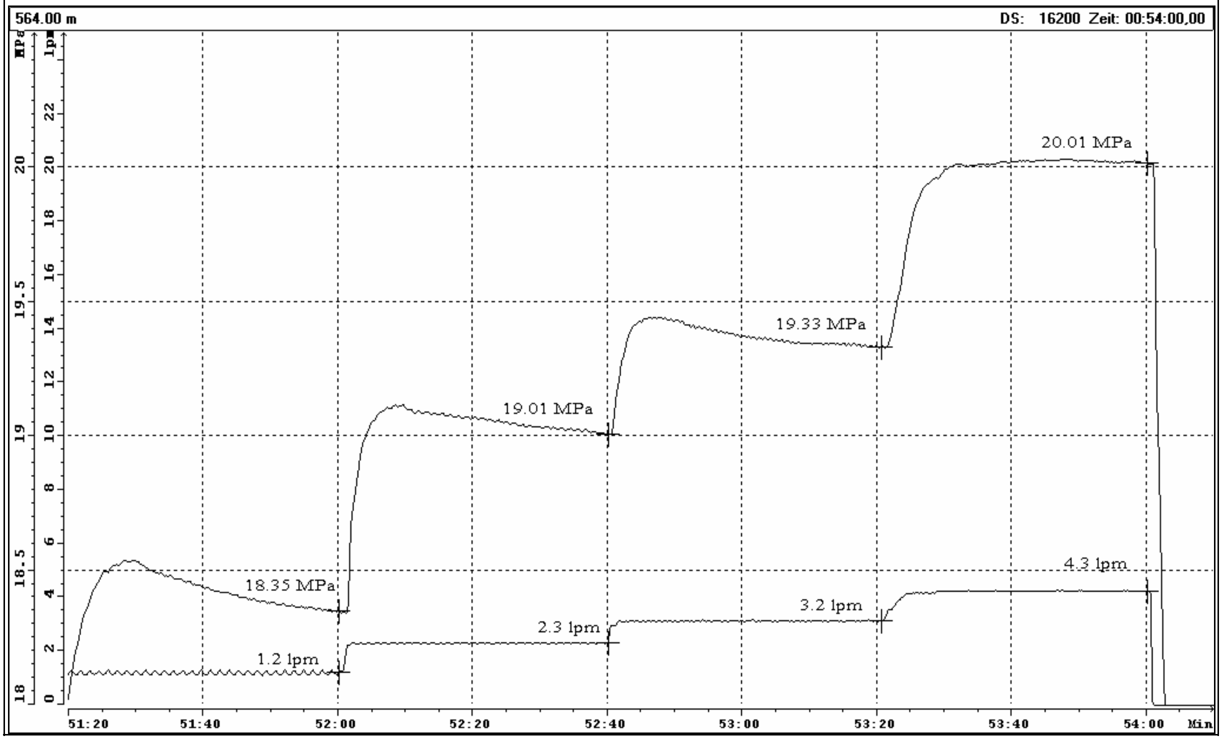
Test at 564.00 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



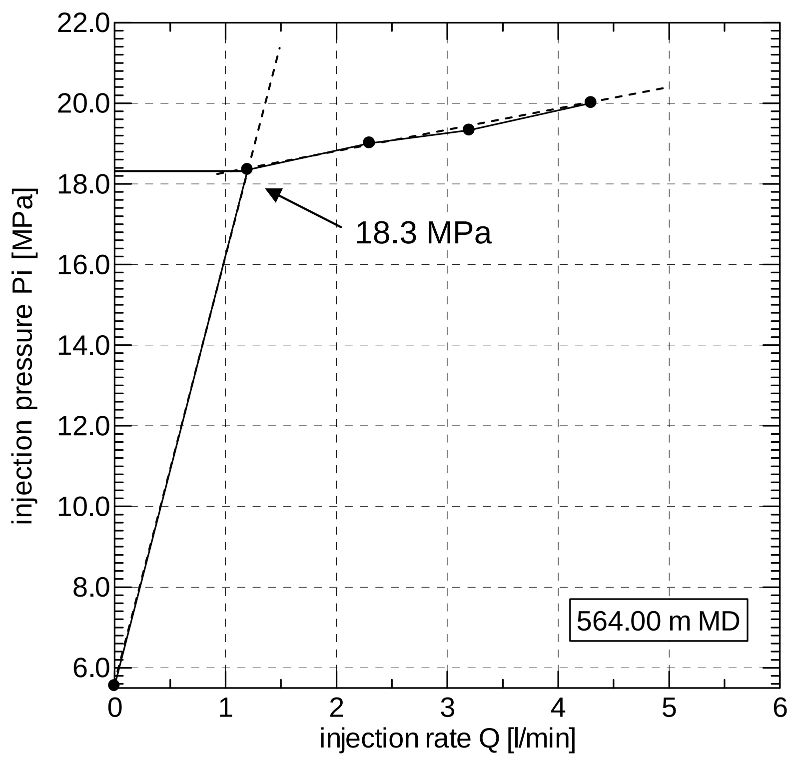
Test at 564.00 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 564.00 m MD: Analysis of Slow - Pump / Step - Rate - Test

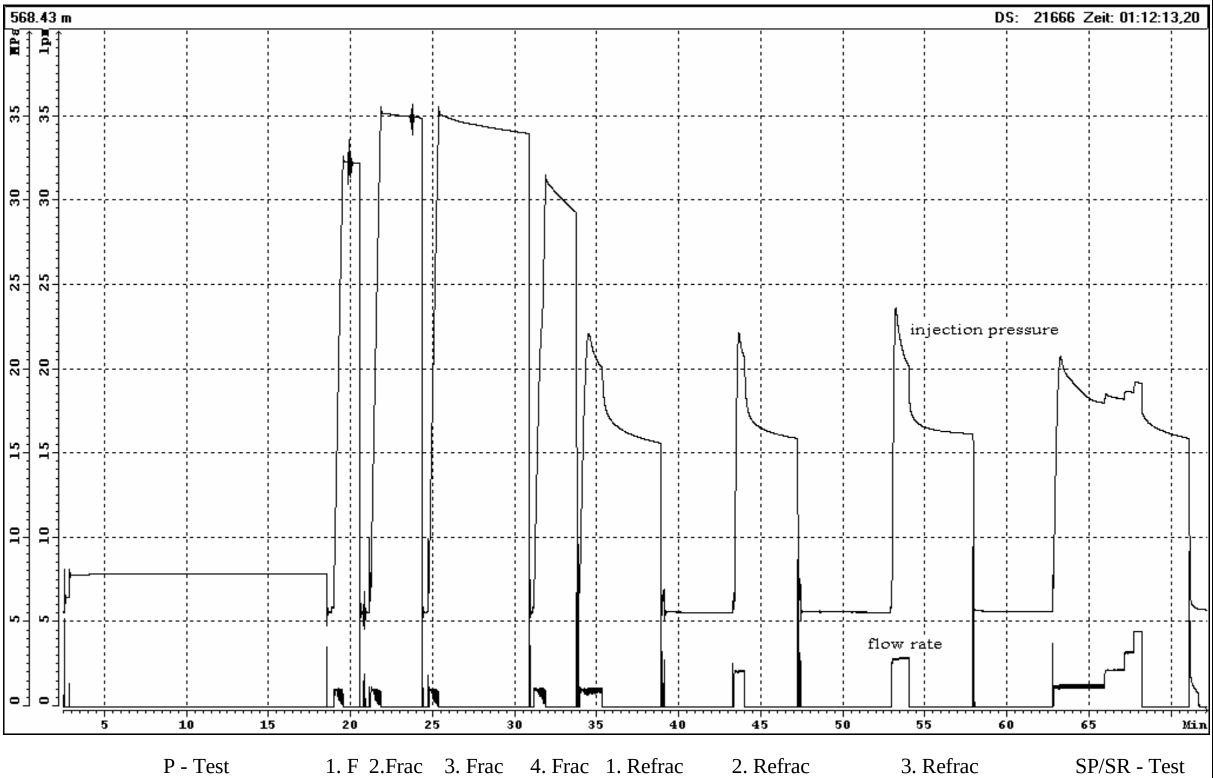


Test at 564.00 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 17 AT 568.43 m MD / 566.26 m TVD

Test at 568.43 m MD: Overview - Plot



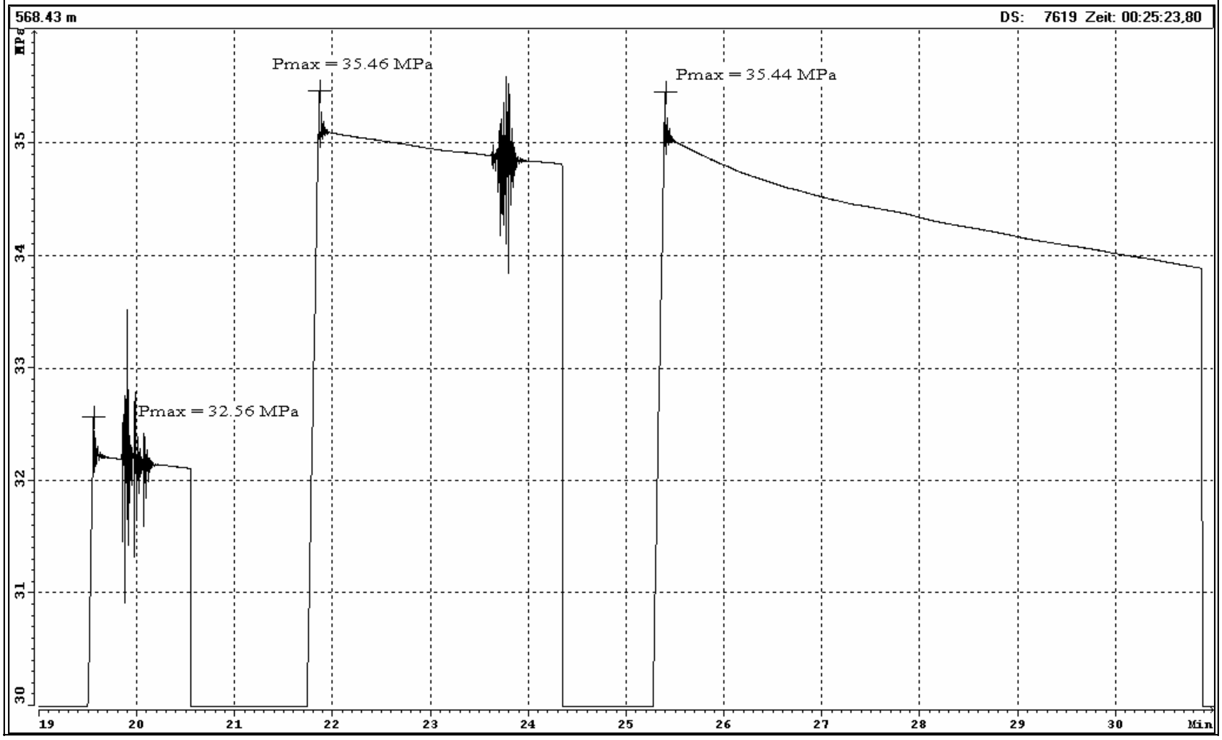
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure increase of 0.05 MPa in 928 sec.		
1. Frac - cycle	Qi (lpm) = 1.0	Vi (l) = 0.5	Vr (l) = 0.1
2. Frac - cycle	Qi (lpm) = 1.0	Vi (l) = 0.5	Vr (l) = 0.1
3. Frac - cycle	Qi (lpm) = 1.0	Vi (l) = 0.5	Vr (l) = 0.3
4. Frac - cycle	Qi (lpm) = 1.0	Vi (l) = 0.6	Vr (l) = 0.6
1. Refrac - cycle	Qi (lpm) = 1.0	Vi (l) = 1.35	Vr (l) = 0.6
2. Refrac - cycle	Qi (lpm) = 2.1	Vi (l) = 1.3	Vr (l) = 0.85
3. Refrac - cycle	Qi (lpm) = 2.8	Vi (l) = 2.95	Vr (l) = 1.7
SP/SR - test	Qi (lpm) = 1.2-4.5	Vi (l) = 10.3	Vr (l) = 3.1

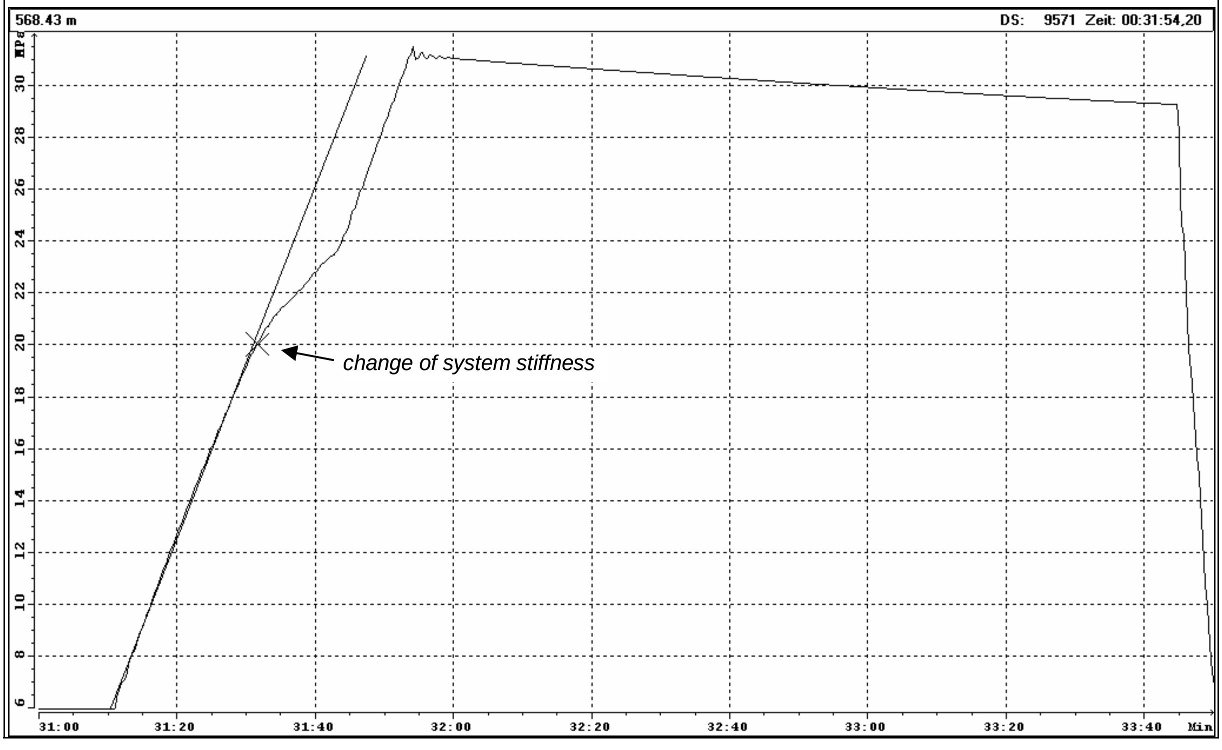
total injected volume (l): 18.0 recovered volume (l): 7.35 or 40.8 %

- Initial test type: HTPF-h
- During the 1. , 2., and 3. frac cycle, the injection was stopped at pressures of 32.6, 35.5, and 35.4 MPa to prevent a damage of the packer elements. Although the test section contains a pre-existing fracture, no breakdown event was observed during the frac-attempts. During the 4. frac-attempt, a change of system-stiffness was observed at about 20 MPa and a pronounced pressure decrease during system shut-in. The subsequent 1. refrac - cycle demonstrates that a fracture was initiated.
- The refrac - pressure was determined from the 1. and 3. refrac - cycle. The analysis of the fracture opening phases shows a decrease of system stiffness dP/dV already at 17.5 and 18.1 MPa, followed by a pressure increase up to 22 and 23.6 MPa.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

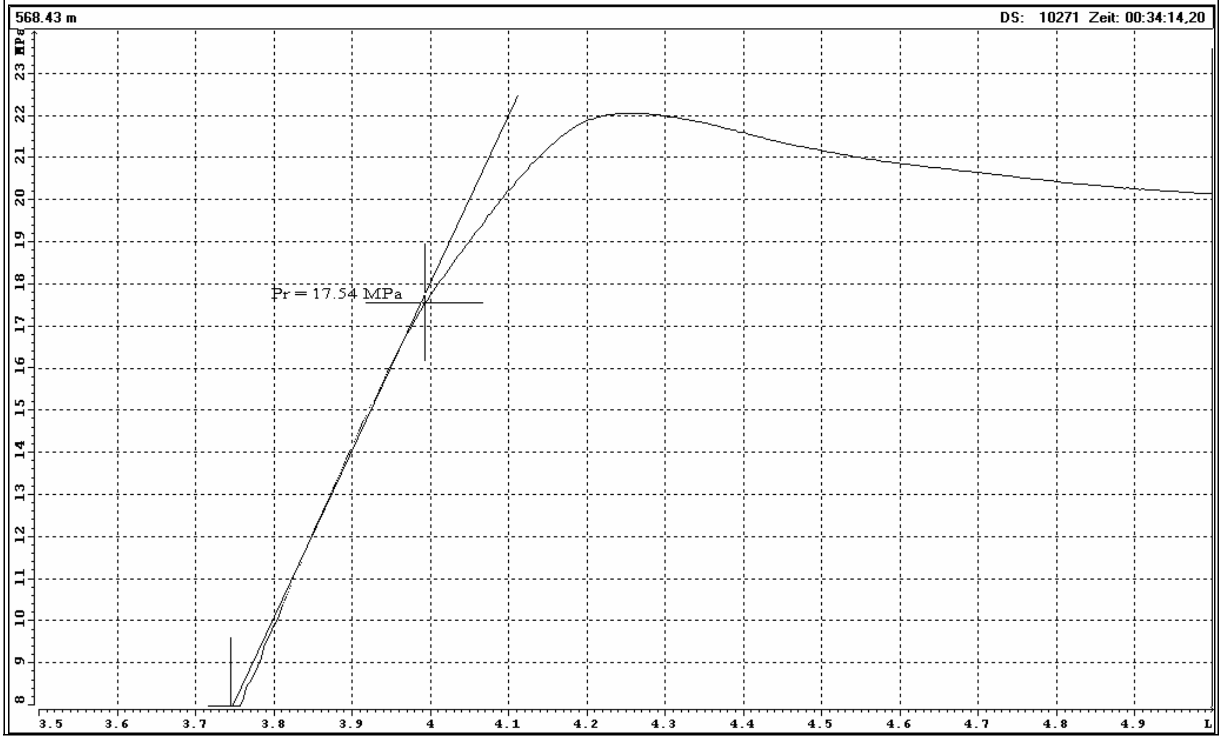
Test at 568.43 m MD: Estimation of P_{max} (1., 2, and 3. Frac - Cycle)



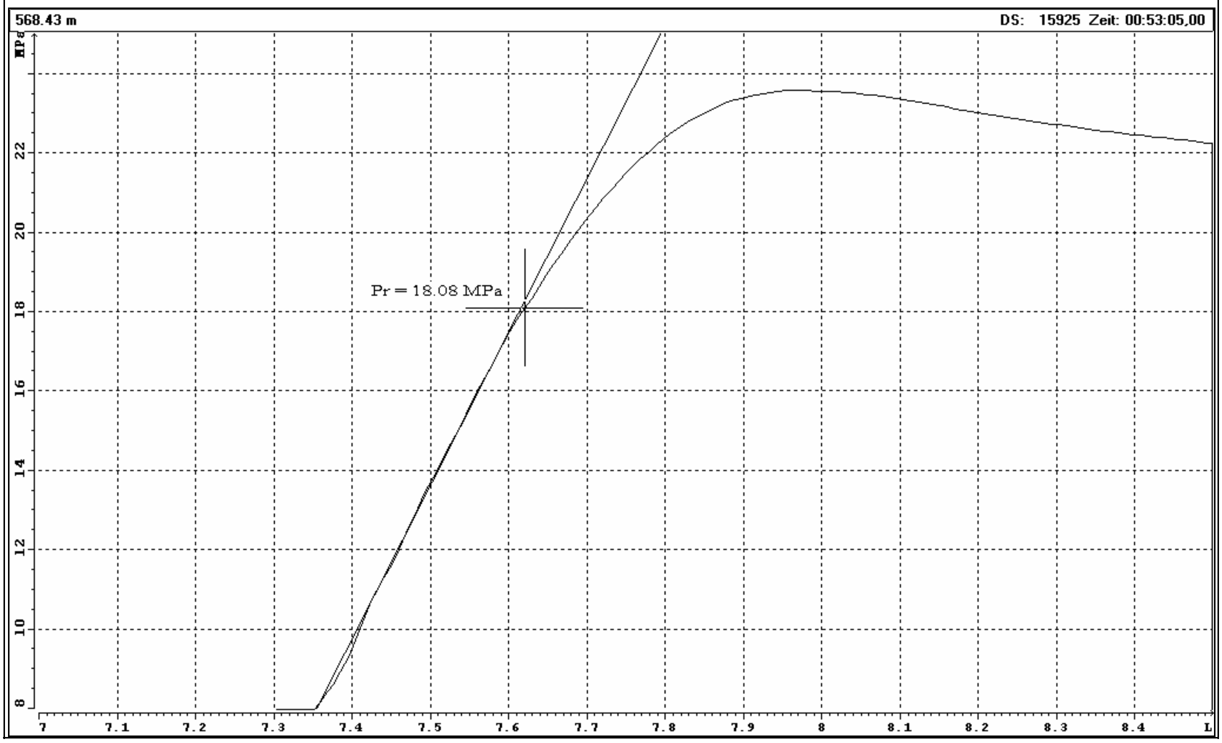
Test at 568.43 m MD: Analysis of 4. Frac - Cycle



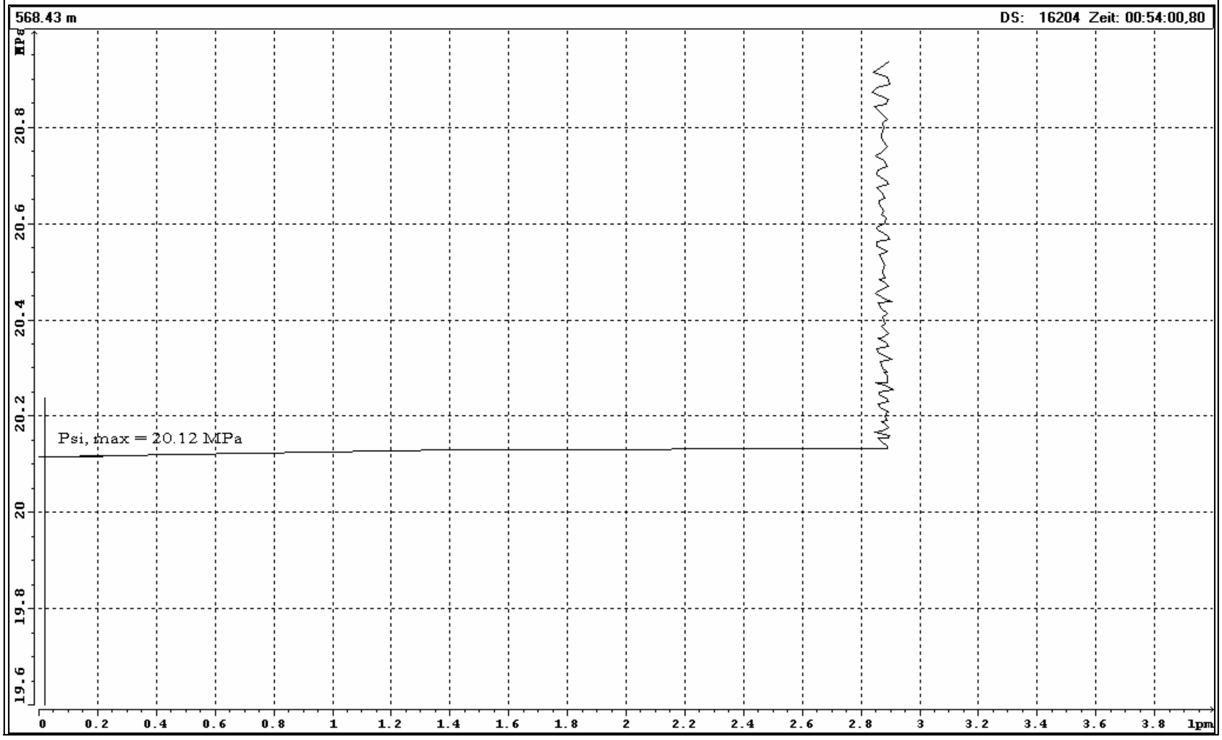
Test at 568.43 m MD: Estimation of P_r (1. Refrac - Cycle)



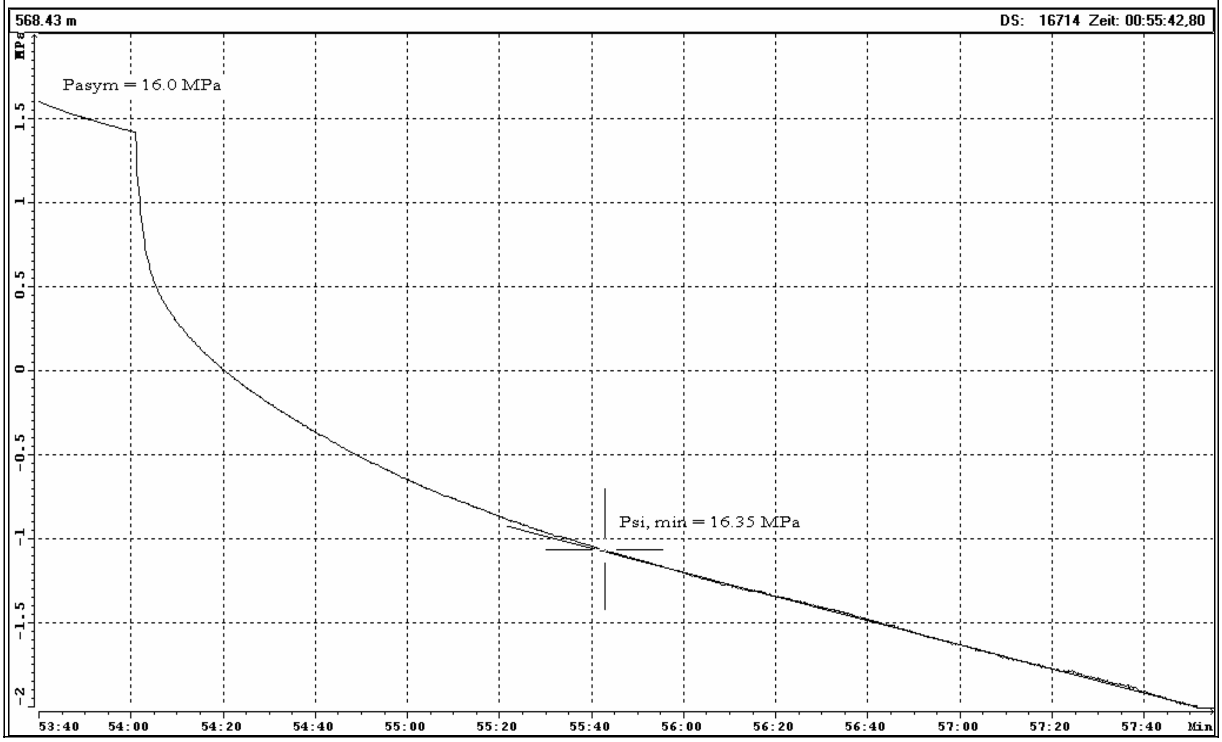
Test at 568.43 m MD: Estimation of P_r (3. Refrac - Cycle)



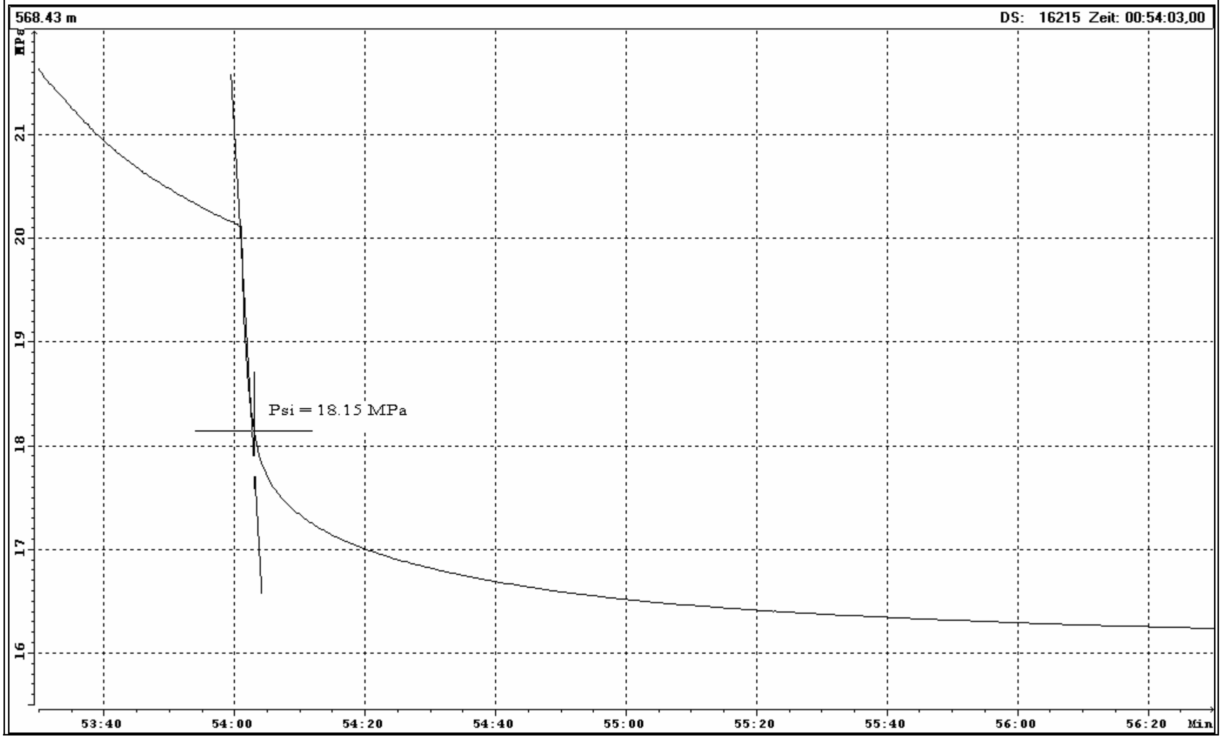
Test at 568.43 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



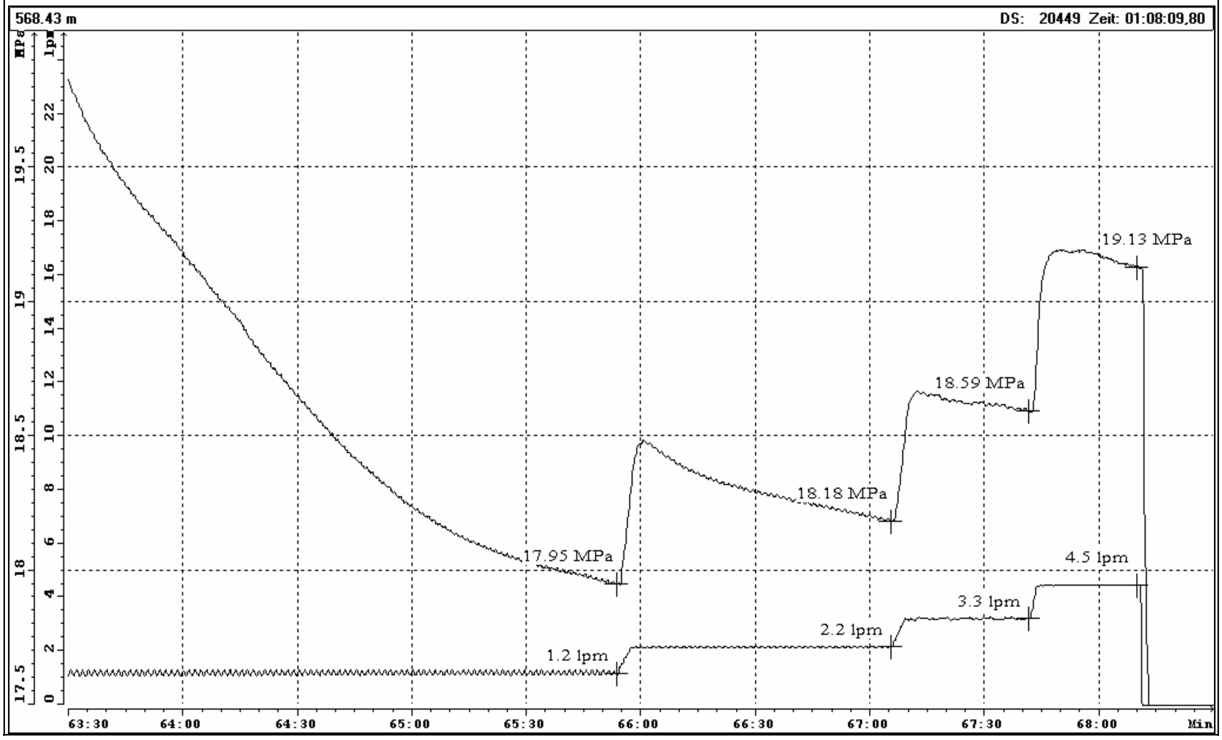
Test at 568.43 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



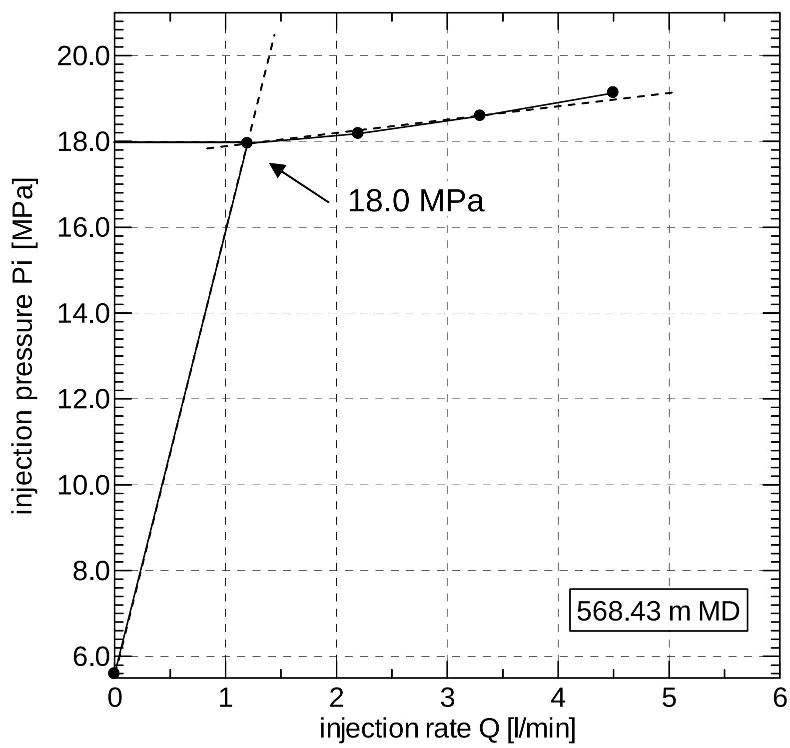
Test at 568.43 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 568.43 m MD: Analysis of Slow - Pump / Step - Rate - Test

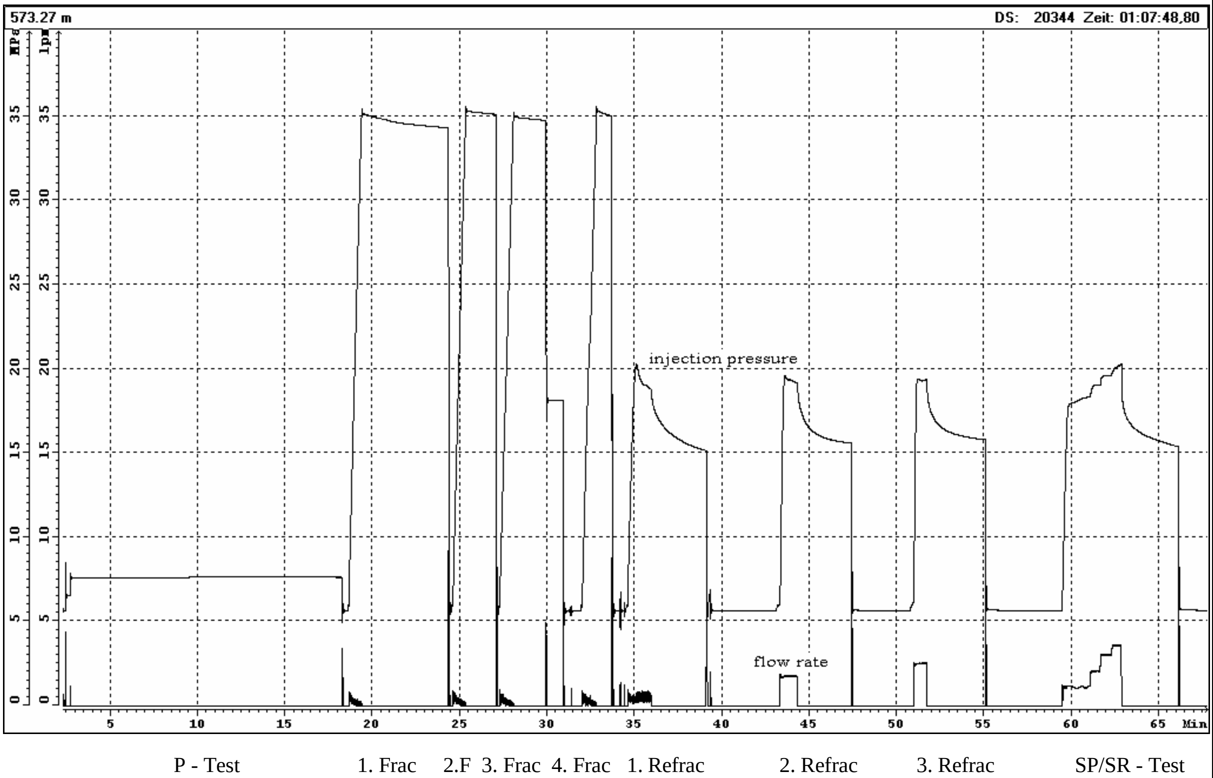


Test at 568.43 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 16 AT 573.27 m MD / 571.07 m TVD

Test at 573.27 m MD: Overview - Plot



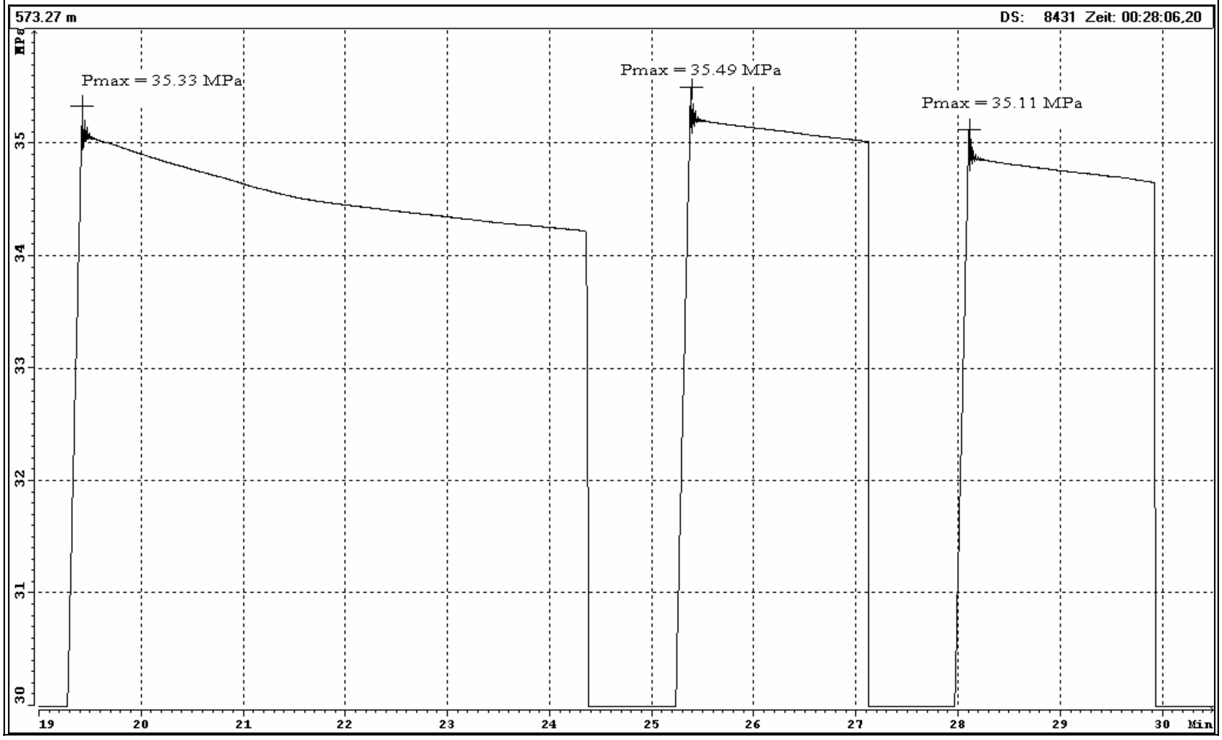
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease of 0.02 MPa in 190 sec., followed by a pressure increase of 0.09 MPa in 442 sec., followed by a decrease of 0.04 MPa in 289 sec.					
1., 2., 3., 4. Frac - cycle	Qi (lpm) =	< 0.7	Vi (l) =	-	Vr (l) =	-
1. Refrac - cycle	Qi (lpm) =	0.7	Vi (l) =	0.7	Vr (l) =	0.3
2. Refrac - cycle	Qi (lpm) =	1.8	Vi (l) =	1.8	Vr (l) =	0.7
3. Refrac - cycle	Qi (lpm) =	2.5	Vi (l) =	1.9	Vr (l) =	1.1
SP/SR - test	Qi (lpm) =	1.2-3.6	Vi (l) =	6.9	Vr (l) =	1.0

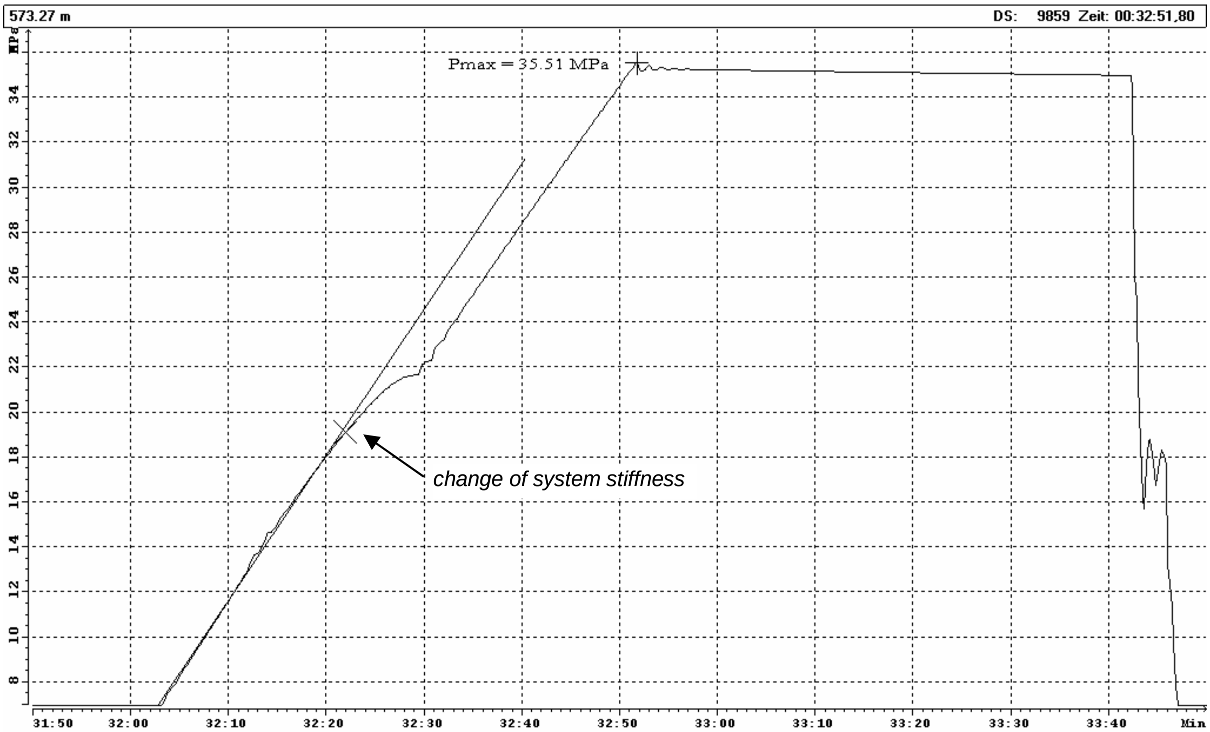
total injected volume (l): 11.3 recovered volume (l): 3.10 or 27.4 %

- Initial test type: HTPF-v
- During the 1. , 2., and 3. frac cycle, the injection was stopped at pressures of 35.3, 35.5, and 35.1 MPa to prevent a damage of the packer elements. Although the test section contains a pre-existing fracture, no breakdown event was observed during the frac-attempts. During the 4. frac-attempt, a change of system-stiffness was observed at about 19 MPa, but no breakdown up to an injection pressure of 35.5 MPa. The subsequent 1. refrac - cycle demonstrates that a fracture was initiated.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV at 18.2 MPa, followed by a pressure increase up to 22.2 MPa. The subsequent refrac - cycles yield lower refrac - pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

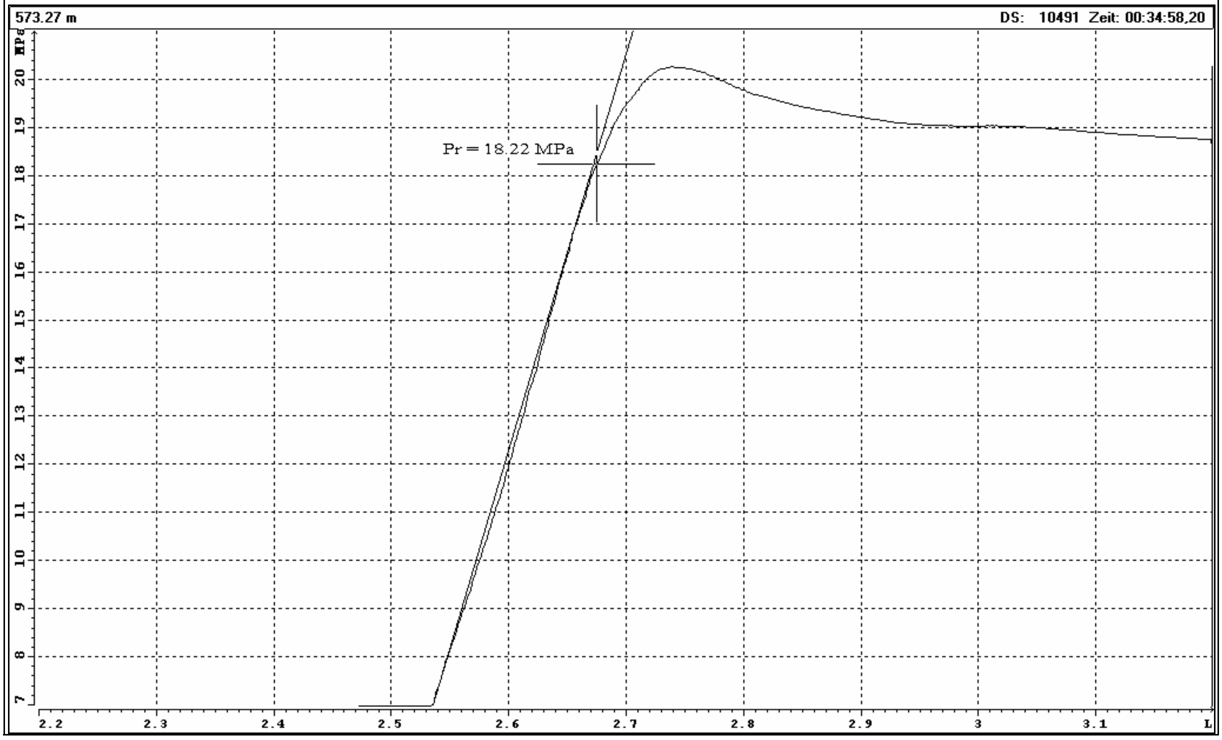
Test at 573.27 m MD: Estimation of P_{max} (1., 2, and 3. Frac - Cycle)



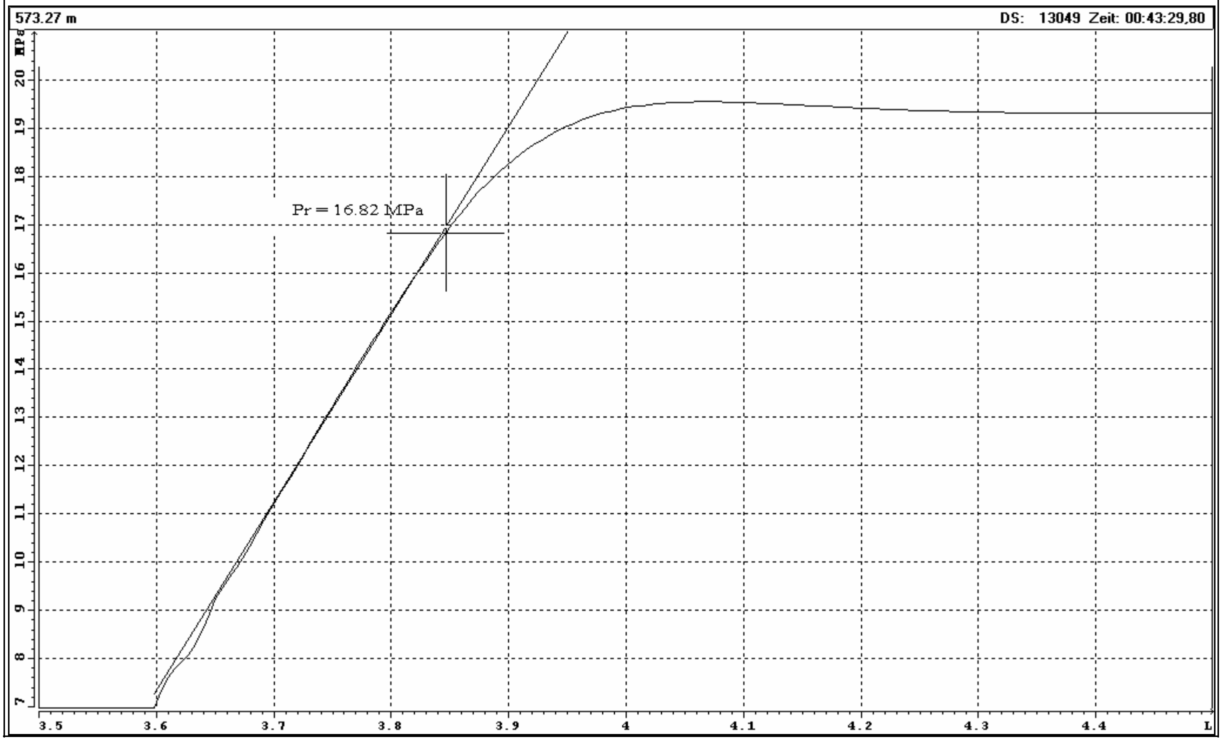
Test at 573.27 m MD: Analysis of 4. Frac - Cycle



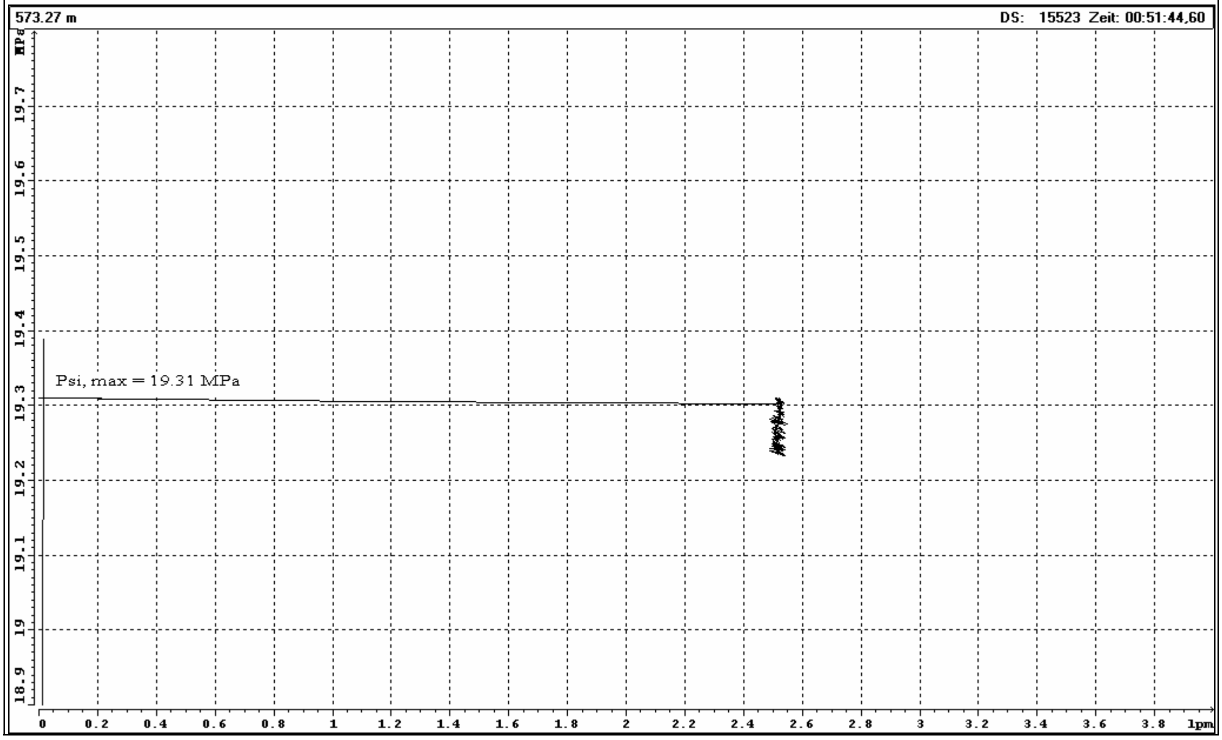
Test at 573.27 m MD: Estimation of P_r (1. Refrac - Cycle)



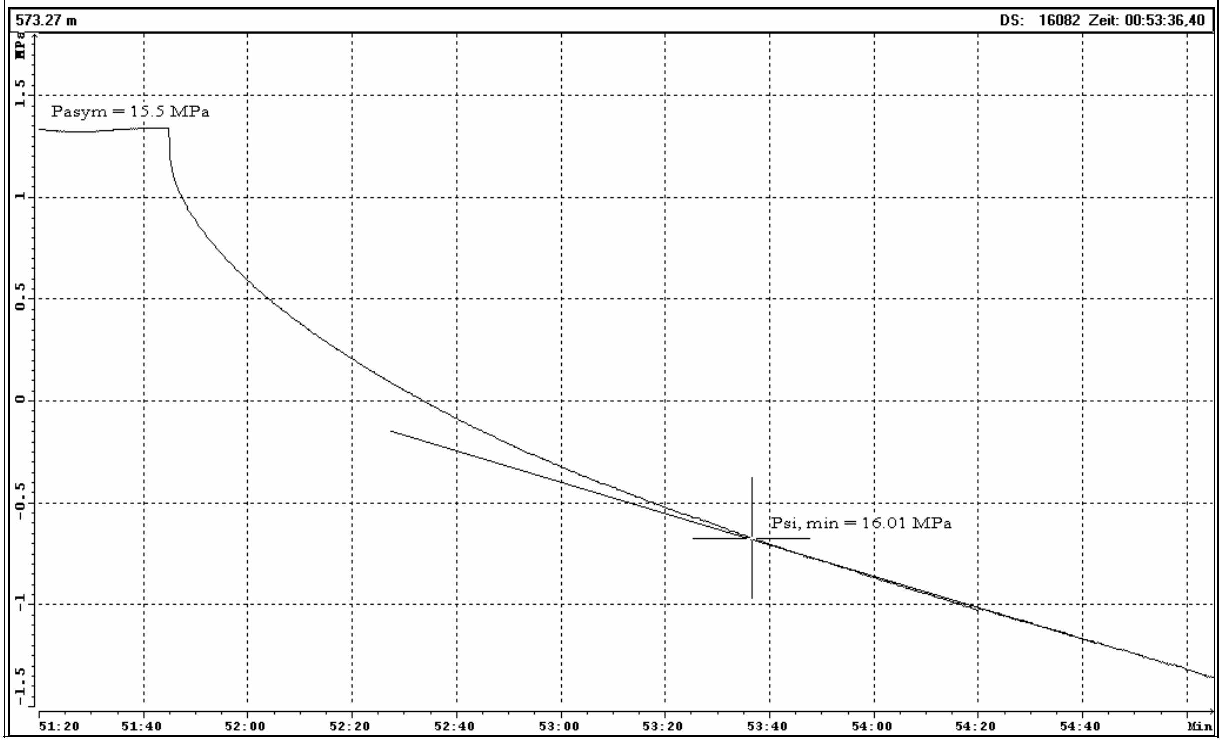
Test at 573.27 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



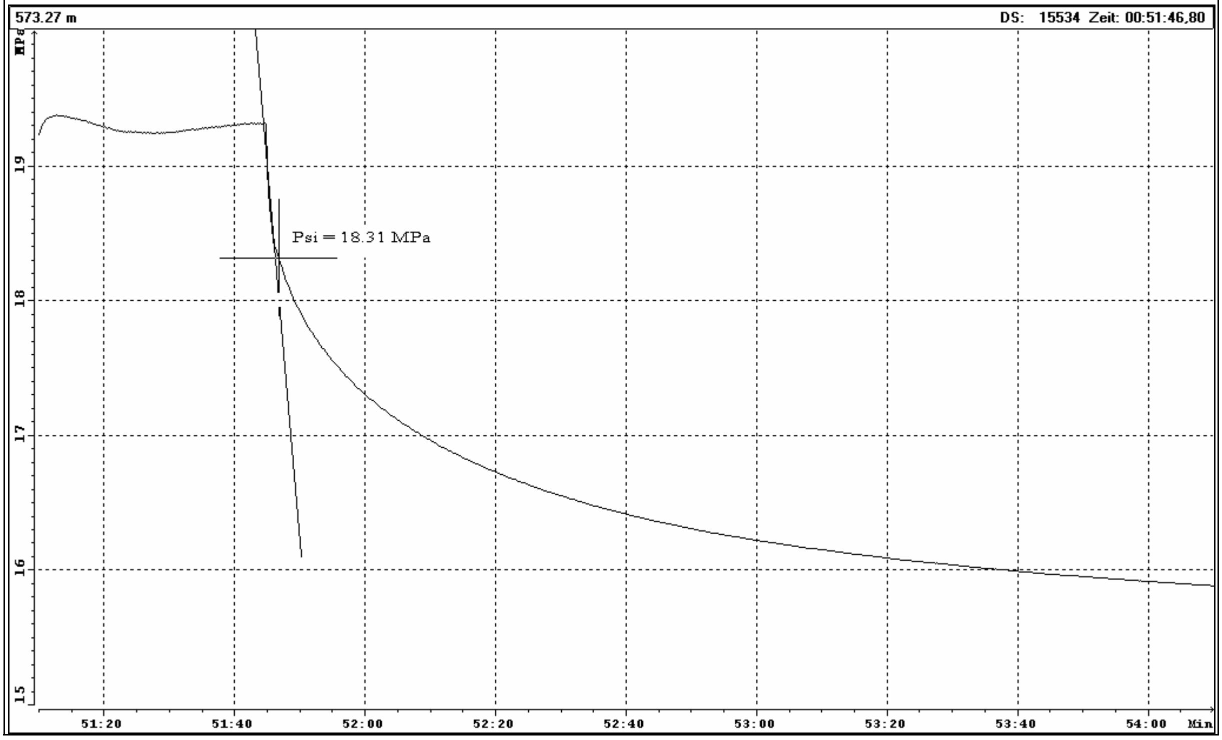
Test at 573.27 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



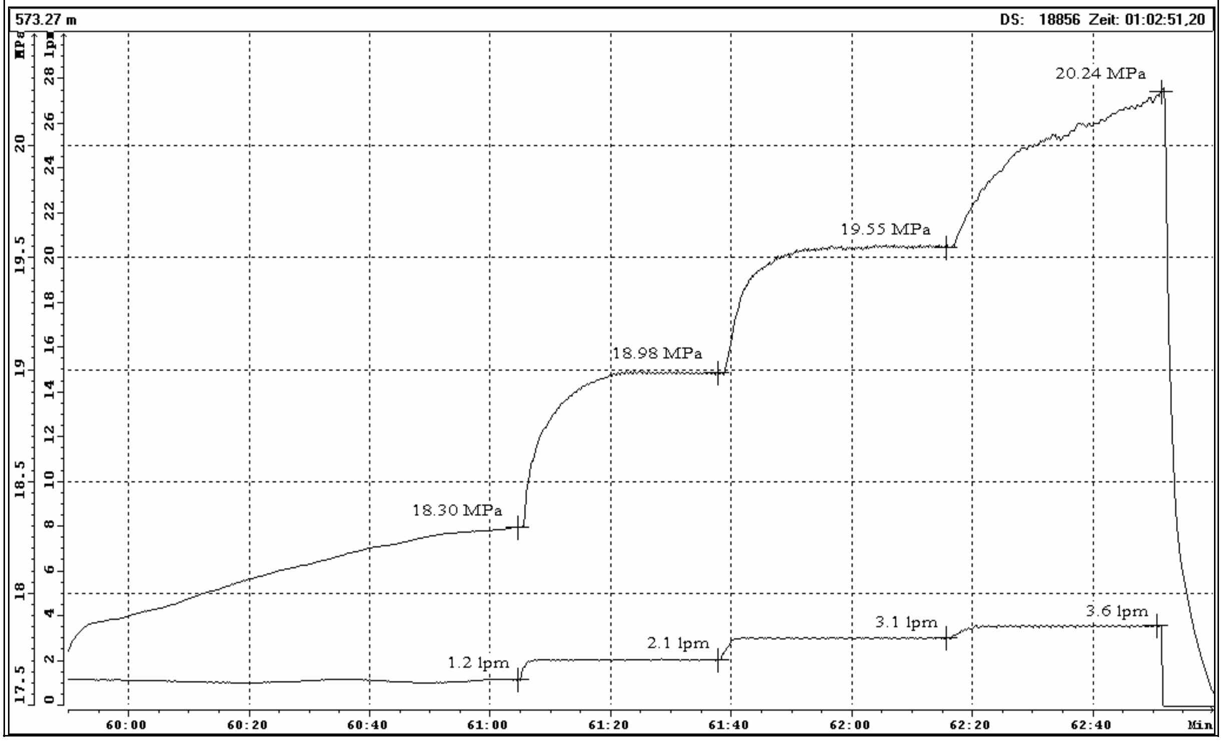
Test at 573.27 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



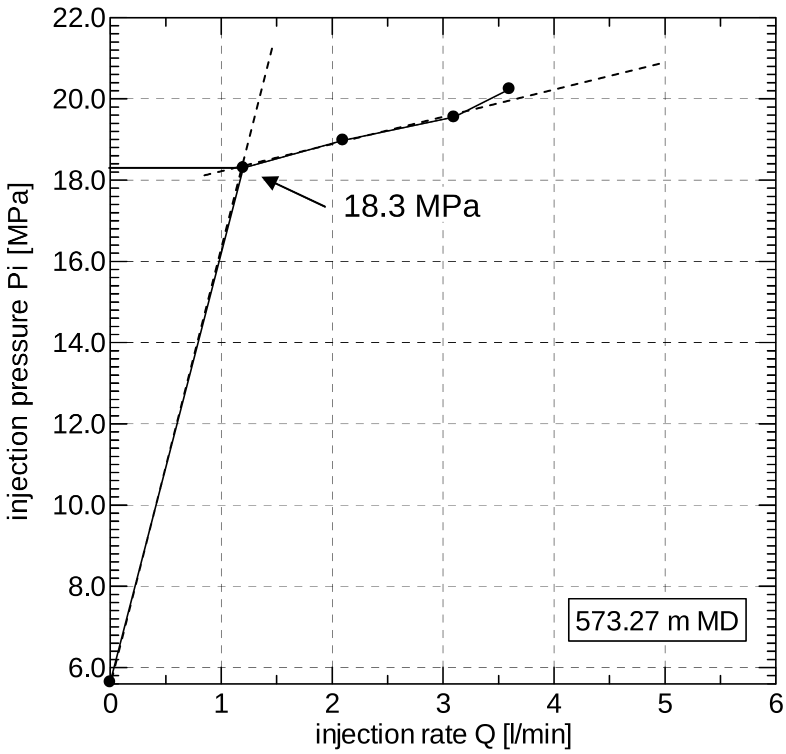
Test at 573.27 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 573.27 m MD: Analysis of Slow - Pump / Step - Rate - Test

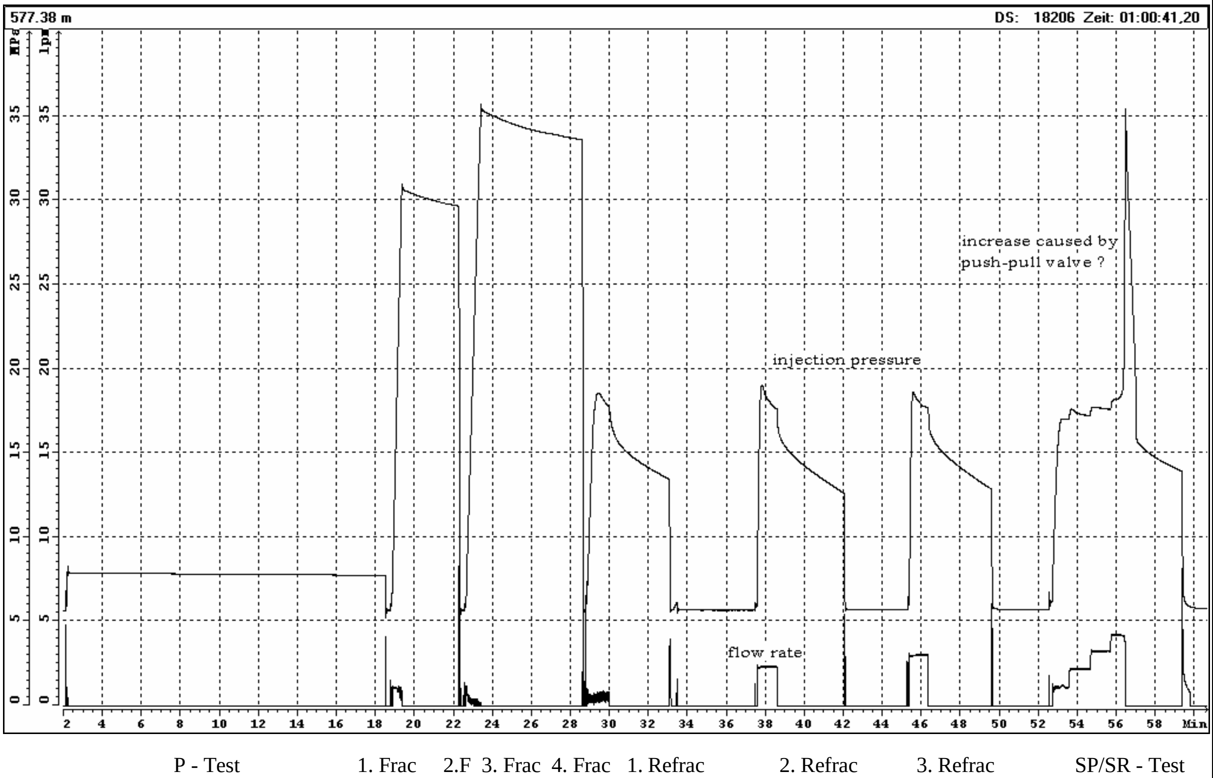


Test at 573.27 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 15 AT 577.38 m MD / 575.15 m TVD

Test at 577.38 m MD: Overview - Plot



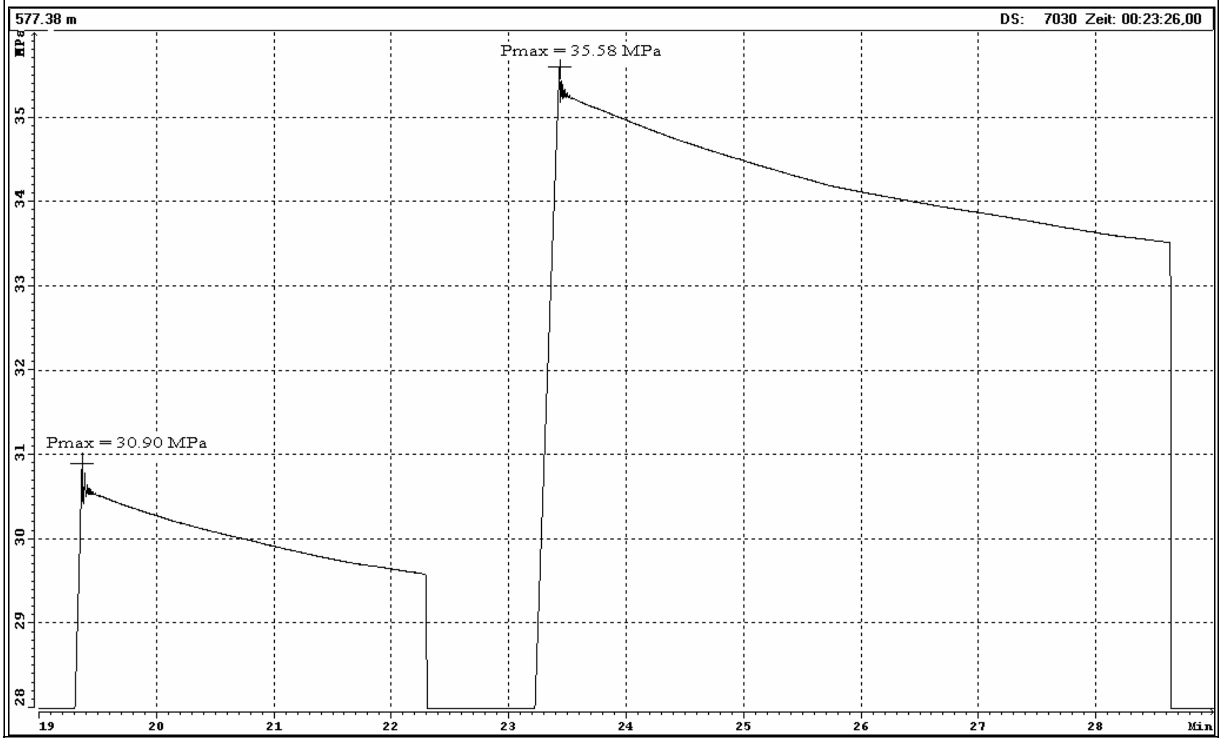
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.16 MPa in 966 sec.		
1. Frac - cycle	Qi (lpm) = 1.0	Vi (l) = 0.5	Vr (l) = 0.4
2. Frac - cycle	Qi (lpm) = < 0.7	Vi (l) = -	Vr (l) = -
1. Refrac - cycle	Qi (lpm) = 0.7	Vi (l) = 0.6	Vr (l) = 0.3
2. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 2.4	Vr (l) = 0.5
3. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 2.9	Vr (l) = 0.7
SP/SR - test	Qi (lpm) = 1.1-4.2	Vi (l) = 9.9	Vr (l) = 2.2

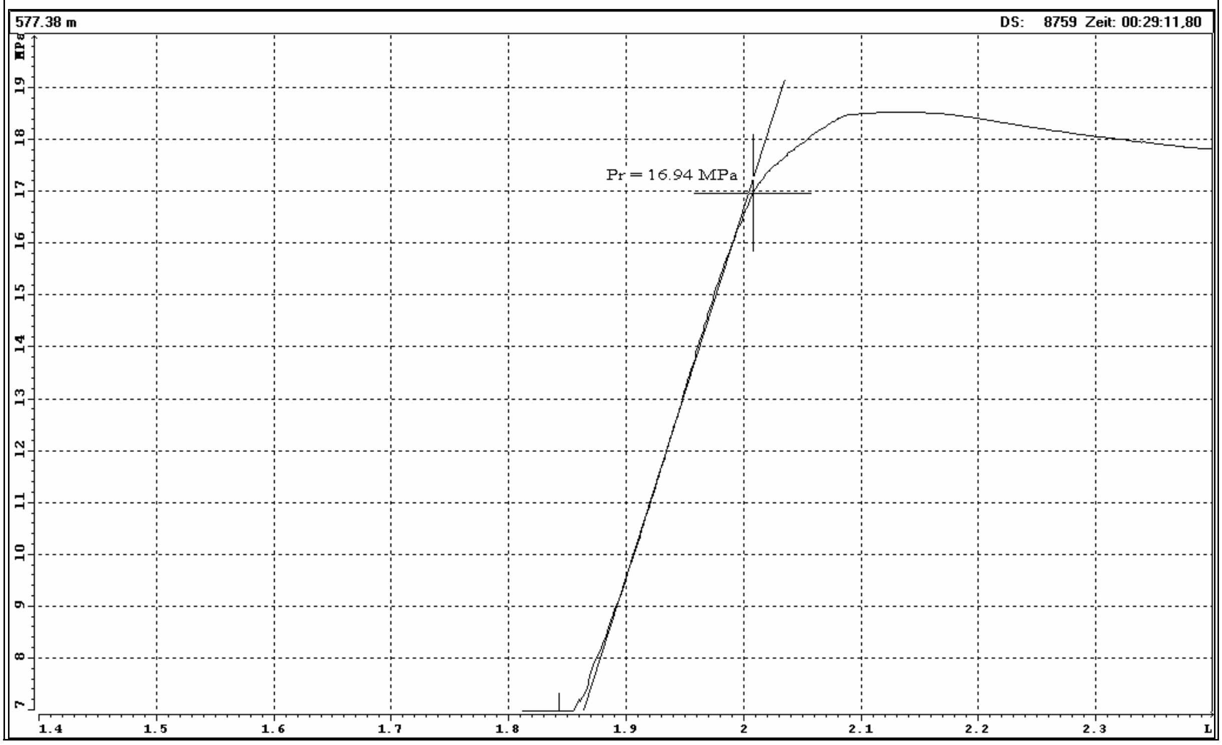
total injected volume (l): 16.3 recovered volume (l): 4.1 or 25.2 %

- Initial test type: HTPF-v
- During the 1. and 2. frac cycle, the injection was stopped at pressures of 30.9 and 35.6 MPa to prevent a damage of the packer elements. Although the test section contains a pre-existing fracture, no breakdown event was observed during the frac-attempts. The subsequent 1. refrac - cycle demonstrates that a fracture was initiated.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the 1. refrac - cycle, the subsequent refrac - cycles yield lower refrac - pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.
- The significant pressure increase observed during the final slow-pump/step-rate test is caused by a movement of the push-pull valve piston.

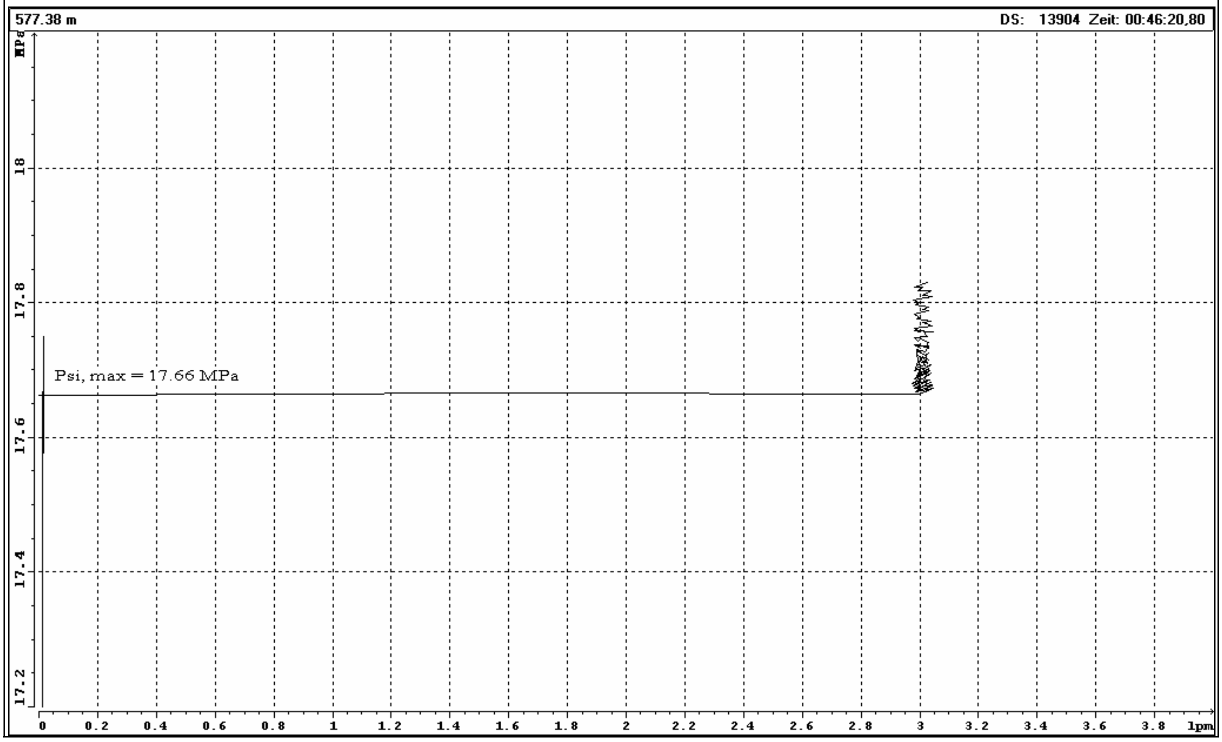
Test at 577.38 m MD: Estimation of P_{max} (1. and 2. Frac - Cycle)



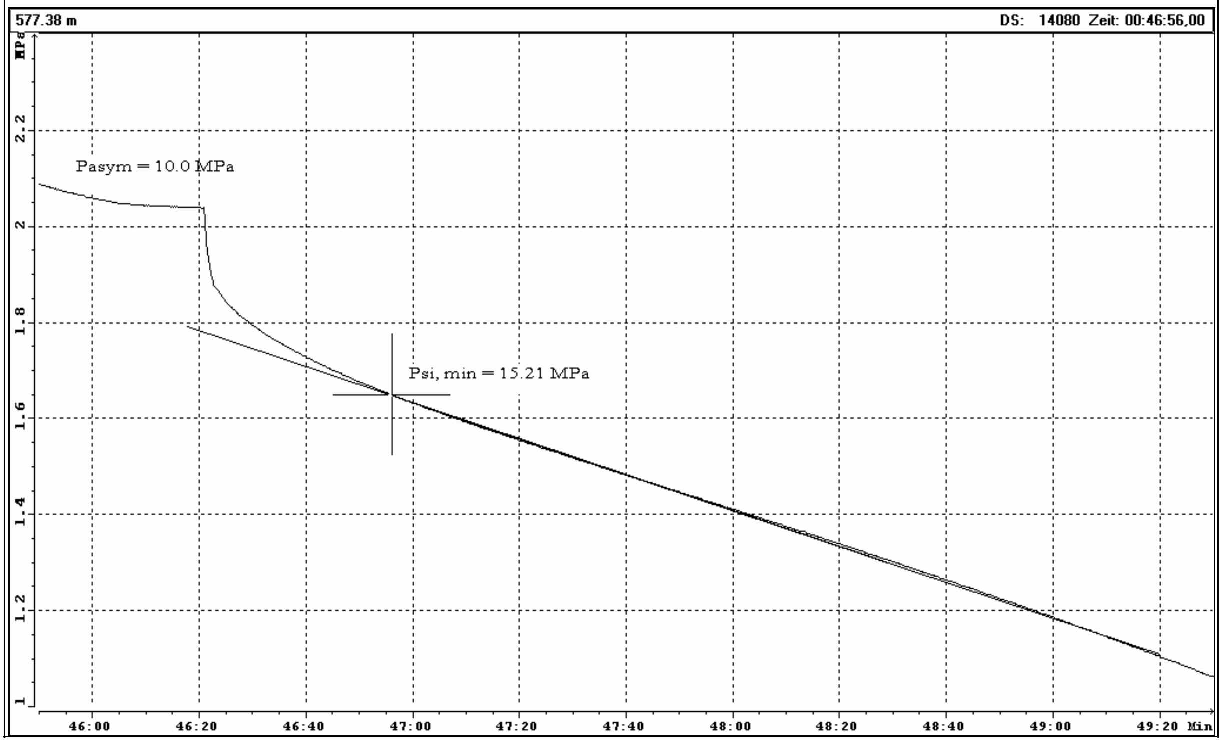
Test at 577.38 m MD: Estimation of P_r (1. Refrac - Cycle)



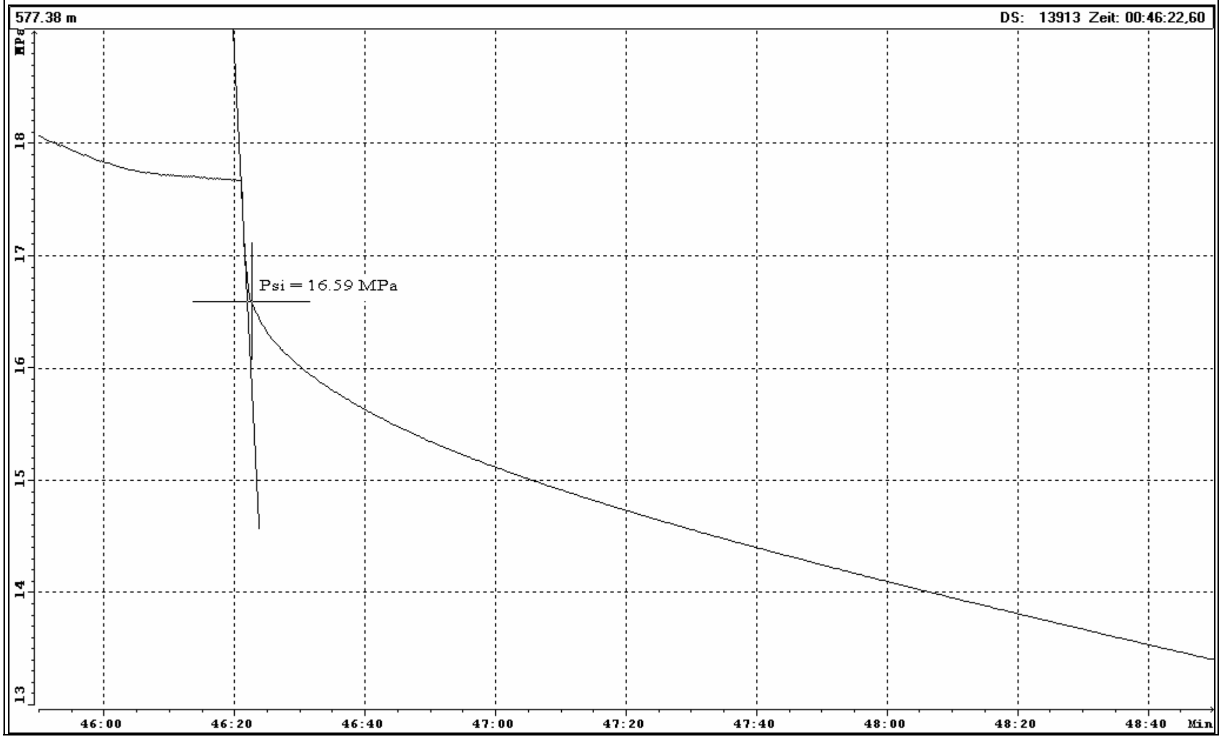
Test at 577.38 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



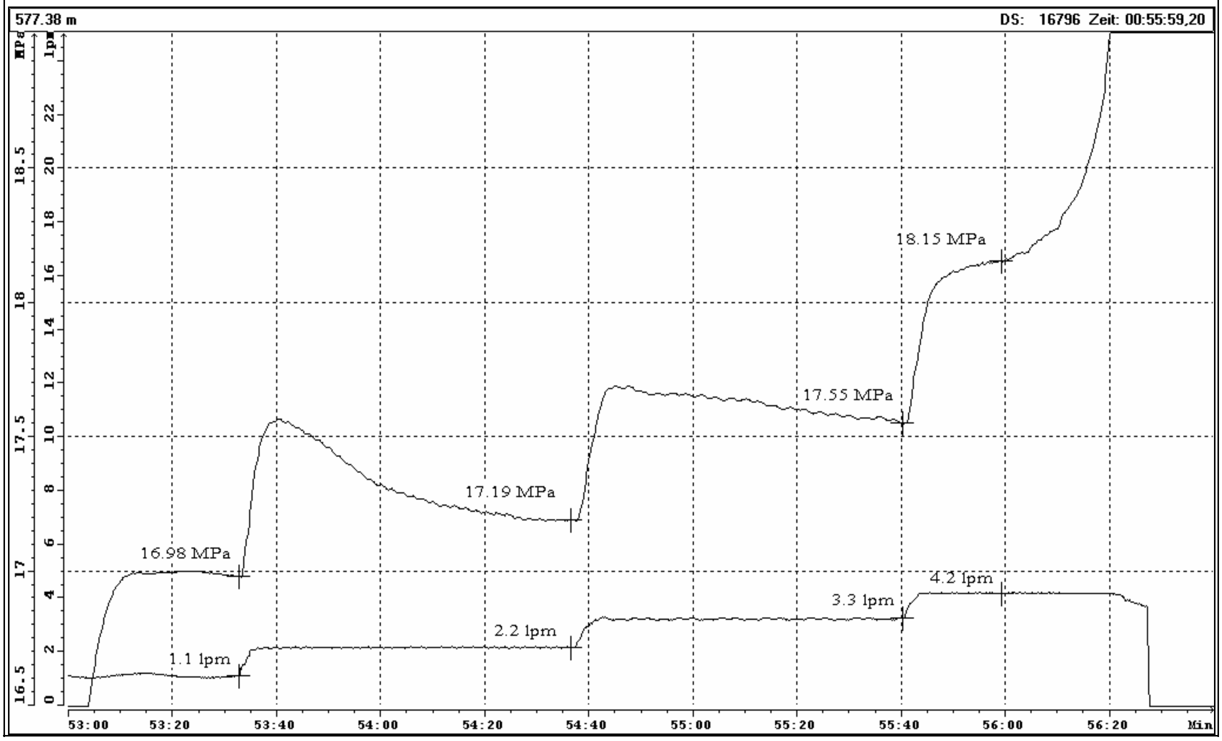
Test at 577.38 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



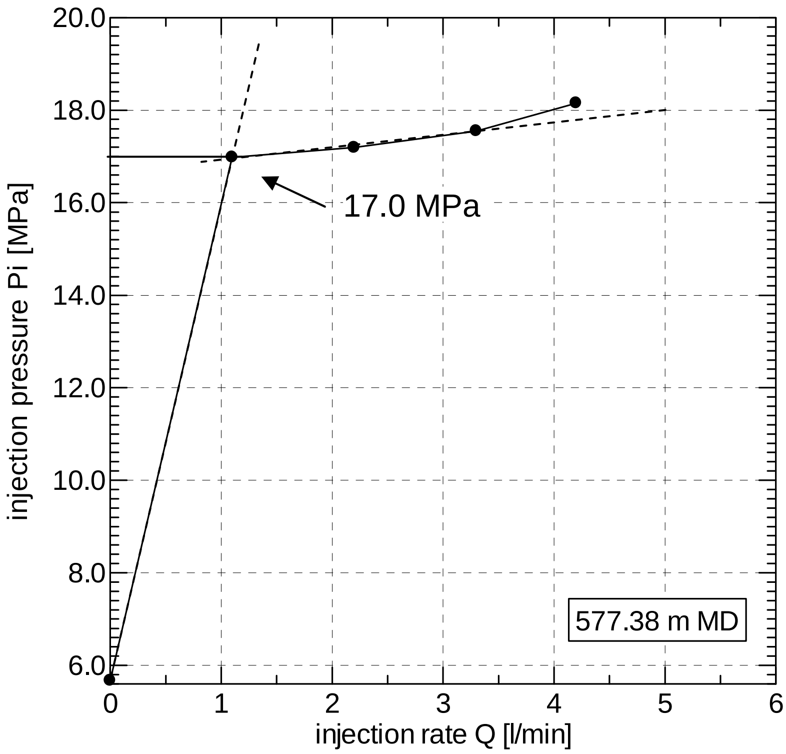
Test at 577.38 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 577.38 m MD: Analysis of Slow - Pump / Step - Rate - Test

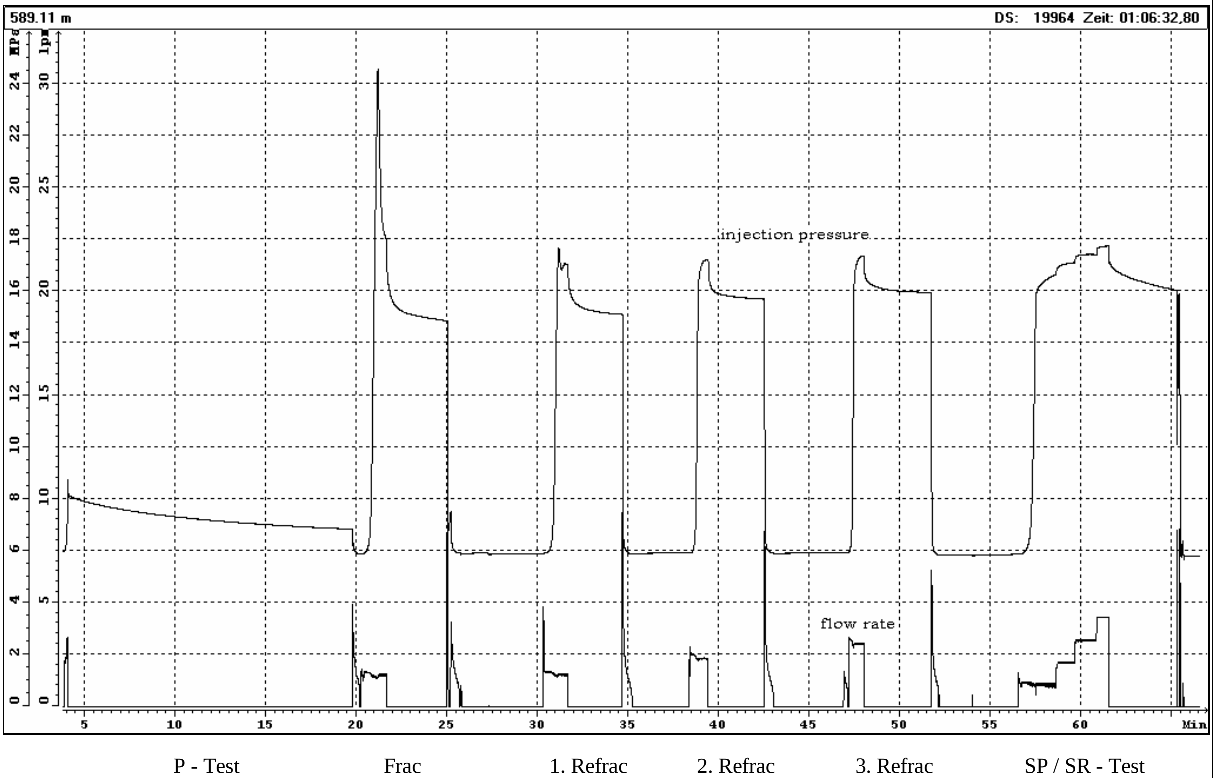


Test at 577.38 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 14 AT 589.11 m MD / 586.80 m TVD

Test at 589.11 m MD: Overview - Plot



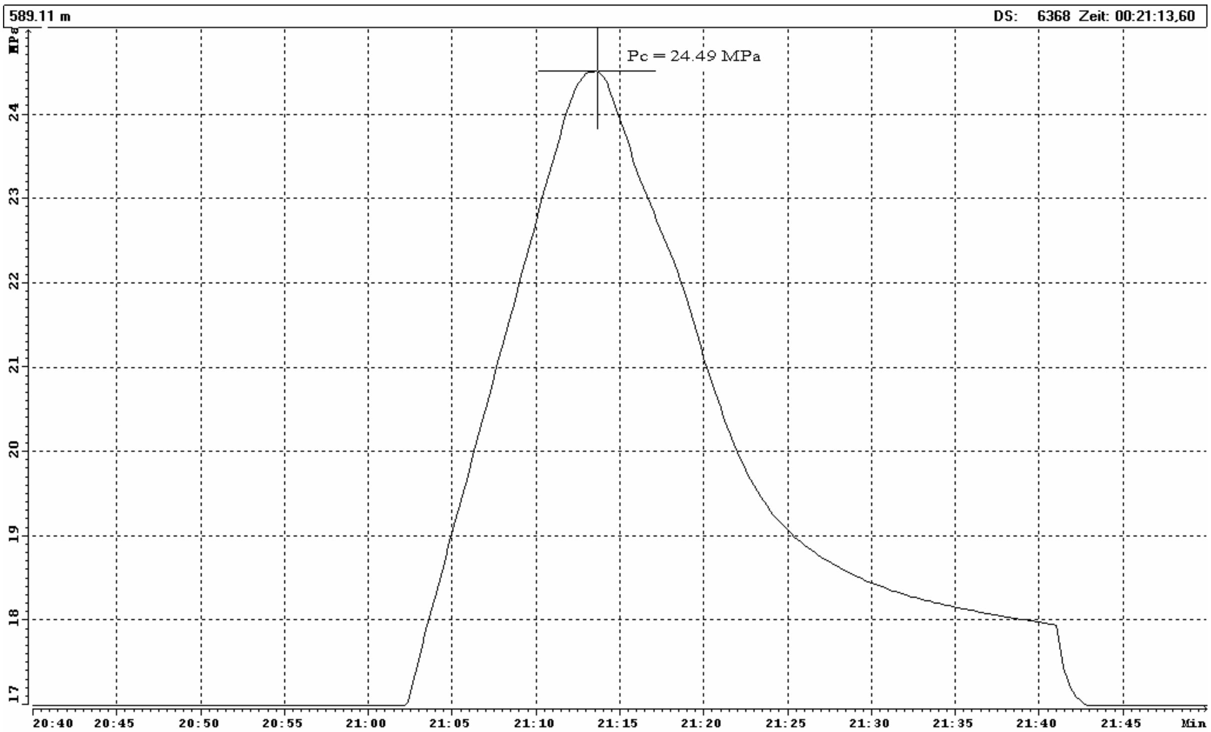
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.27 MPa in 935 sec.		
Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 2.1	Vr (l) = 1.7
1. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 2.2	Vr (l) = 1.5
2. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 2.5	Vr (l) = 1.4
3. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 2.5	Vr (l) = 1.3
SP/SR - test	Qi (lpm) = 1.0-4.3	Vi (l) = 11.1	Vr (l) = 0.75

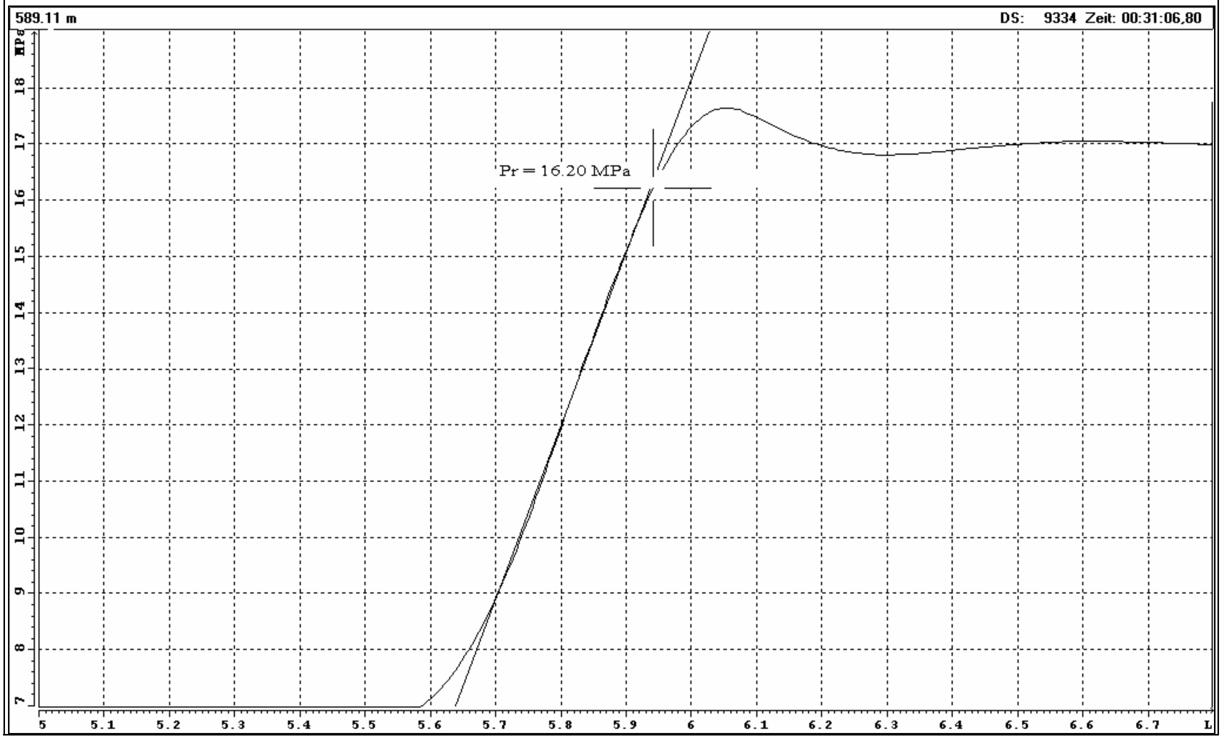
total injected volume (l): 20.4 recovered volume (l): 6.65 or 32.6 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 16.2 MPa, followed by a pressure increase up to 17.6 MPa. The subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct shut-in pressure values, which, however, increased slightly from 16.3 MPa during the 1. refrac - cycle to 16.7 MPa during the 3. refrac - cycle. Therefore, the shut - in pressure of the 1. refrac - cycle was used for the stress analysis.

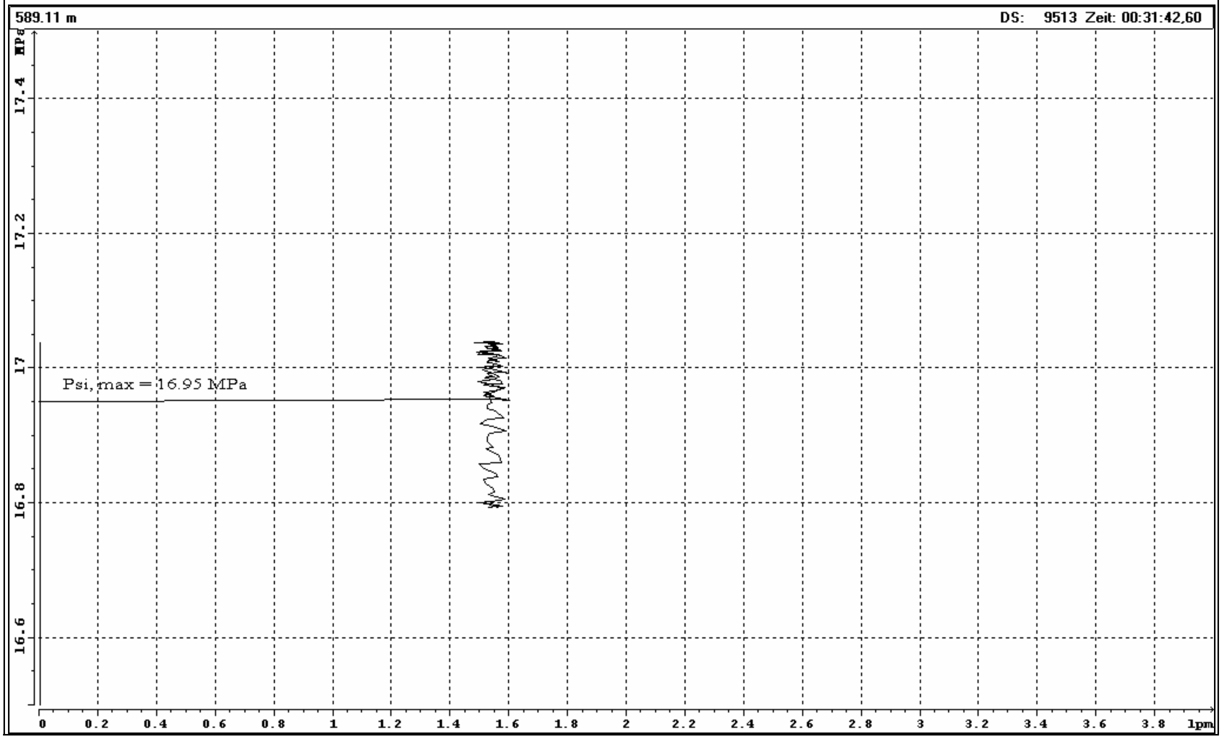
Test at 589.11 m MD: Estimation of P_c (Frac - Cycle)



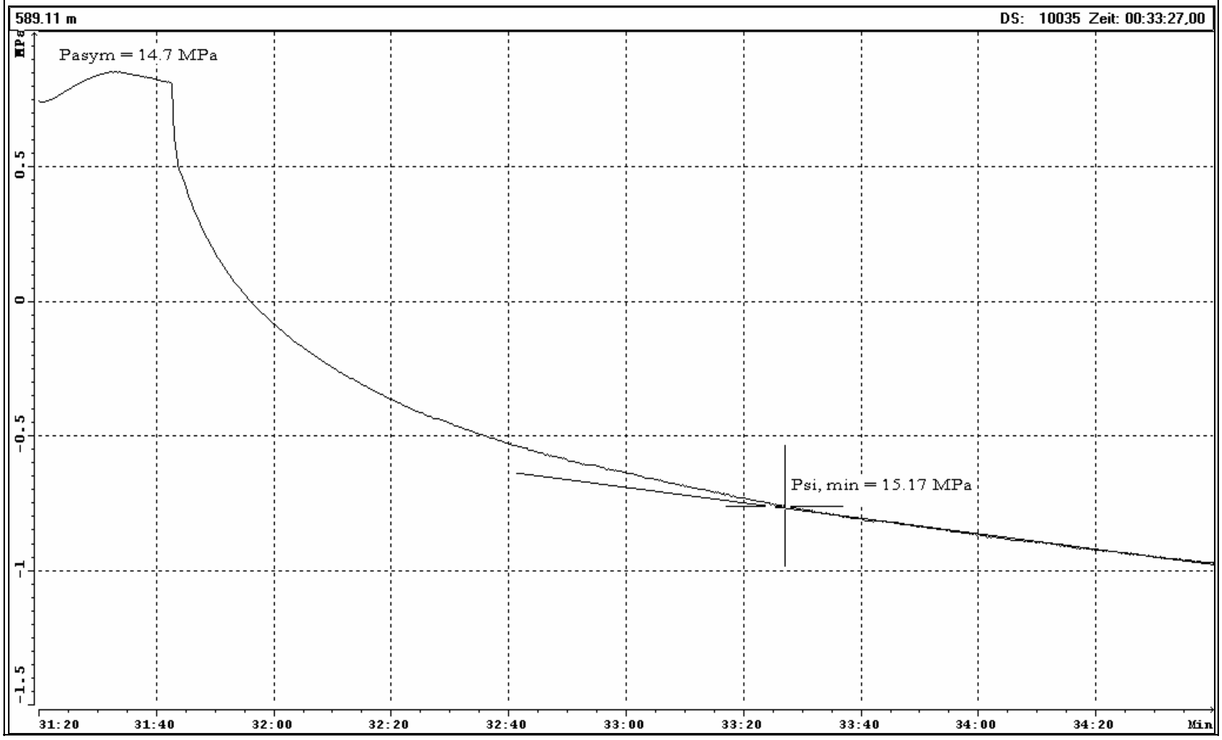
Test at 589.11 m MD: Estimation of P_r (1. Refrac - Cycle)



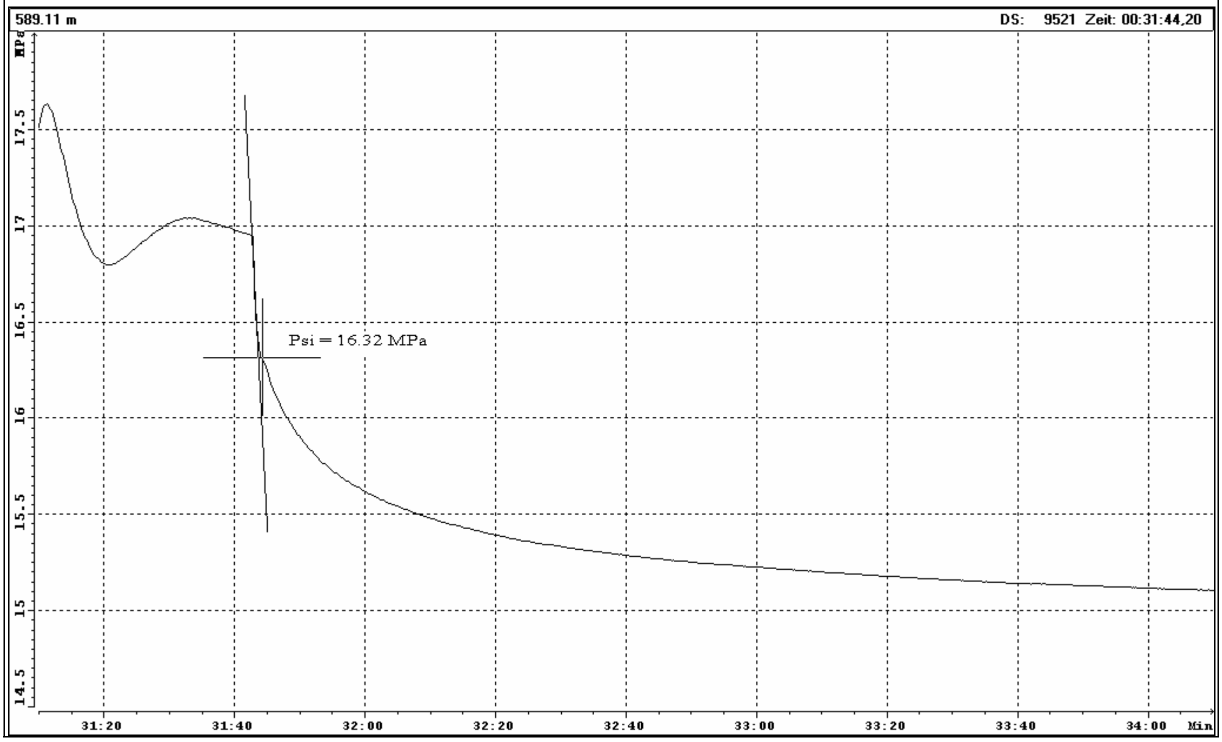
Test at 589.11 m MD: Estimation of $P_{si,\ max}$ (1. Refrac - Cycle)



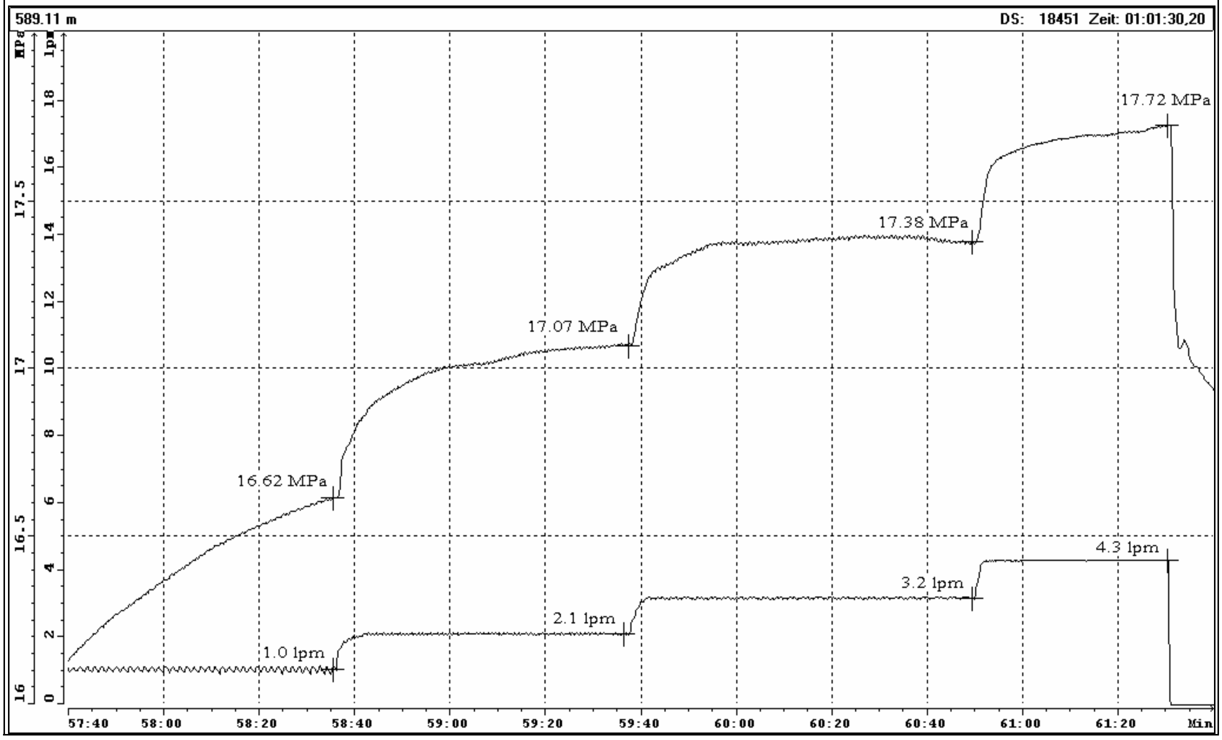
Test at 589.11 m MD: Estimation of $P_{si,\ min}$ (1. Refrac - Cycle)



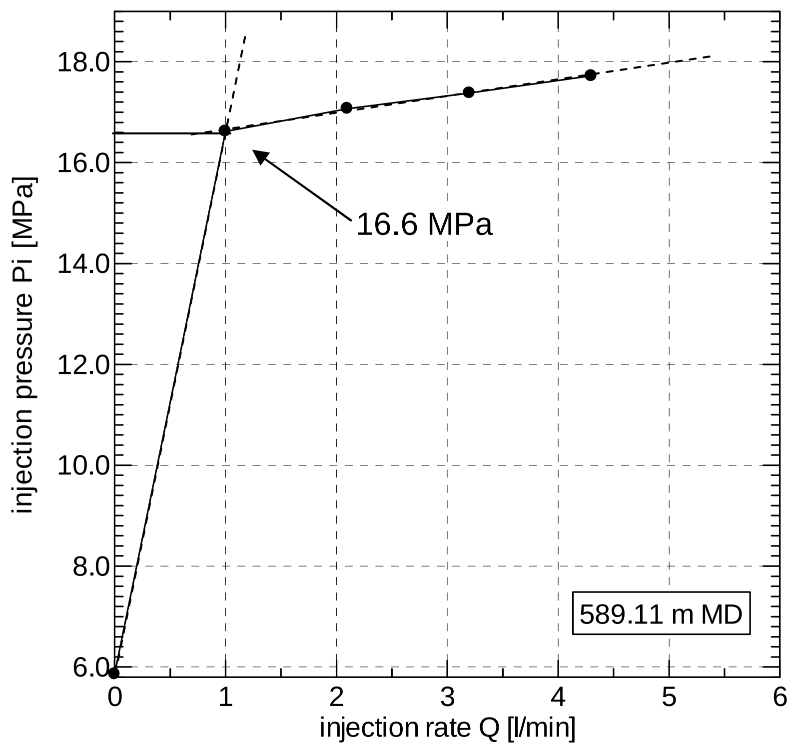
Test at 589.11 m MD: Estimation of P_{si} (1. Refrac - Cycle)



Test at 589.11 m MD: Analysis of Slow - Pump / Step - Rate - Test

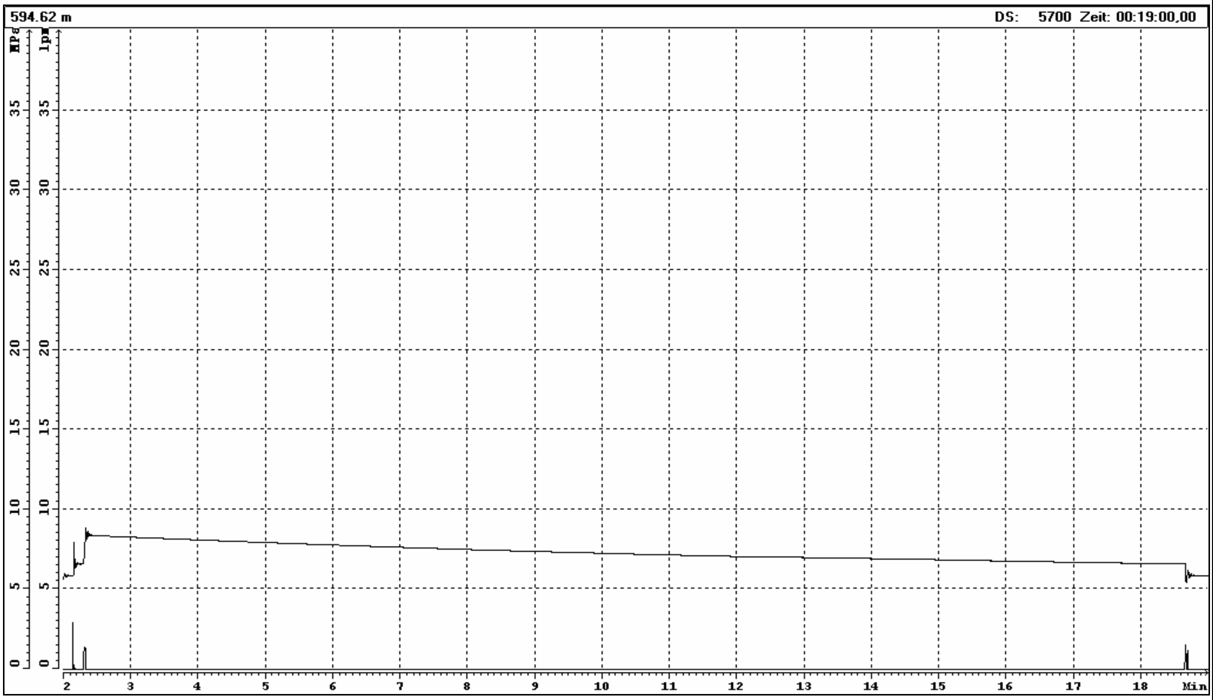


Test at 589.11 m MD: Examination of P_{si} (Step - Rate - Test)



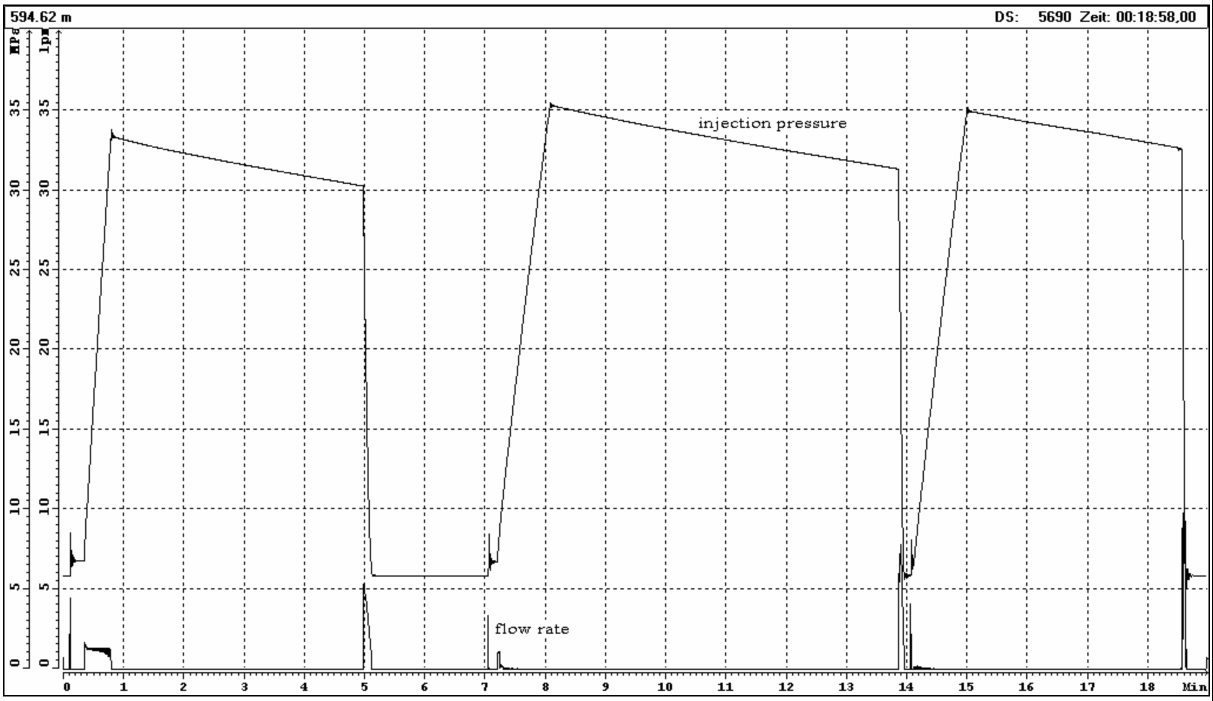
TEST NO. 13 AT 594.62 m MD / 592.27 m TVD

Test at 594.62 m MD: Overview - Plot (Part I)



P - Test

Test at 594.62 m MD: Overview - Plot (Part II)



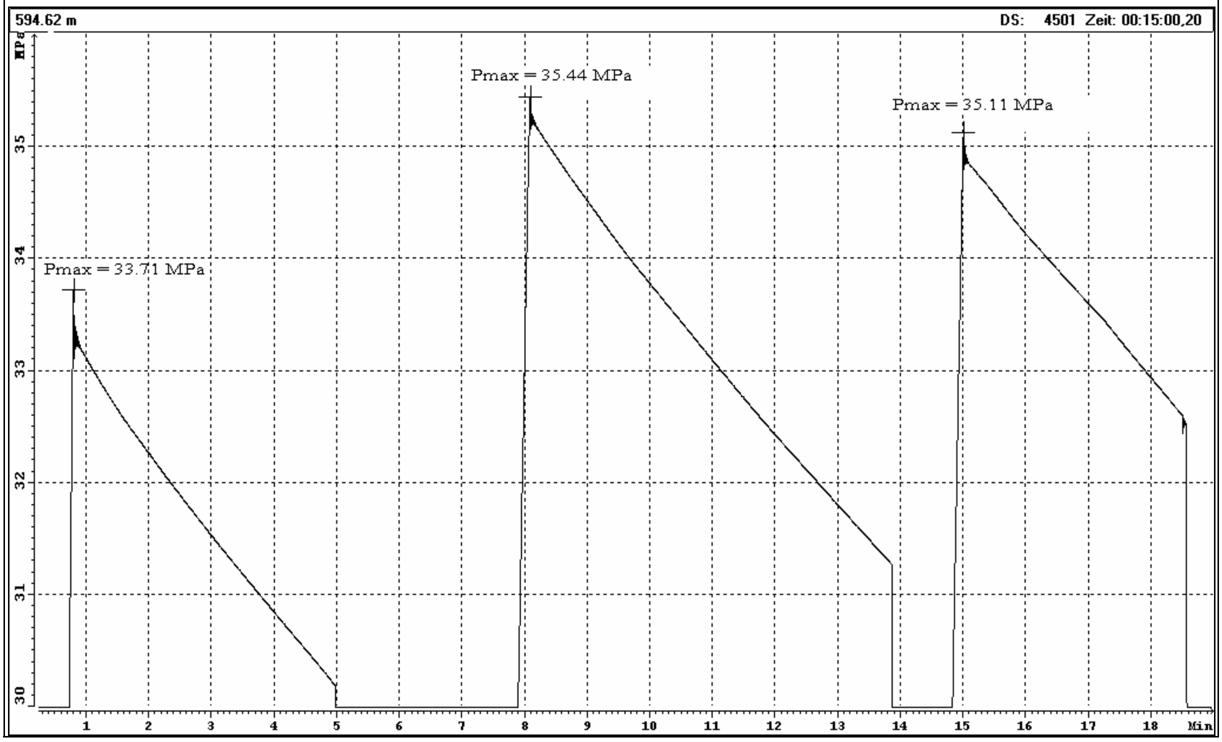
1. Frac 2. Frac 3. Frac

TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.76 MPa in 969 sec.				
1. Frac - cycle	Qi (lpm) = 1.0	Vi (l) =	0.6	Vr (l) =	0.5
2. Frac - cycle	Qi (lpm) < 0.7	Vi (l) =		Vr (l) =	0.5
3. Frac - cycle	Qi (lpm) < 0.7	Vi (l) =		Vr (l) =	0.4

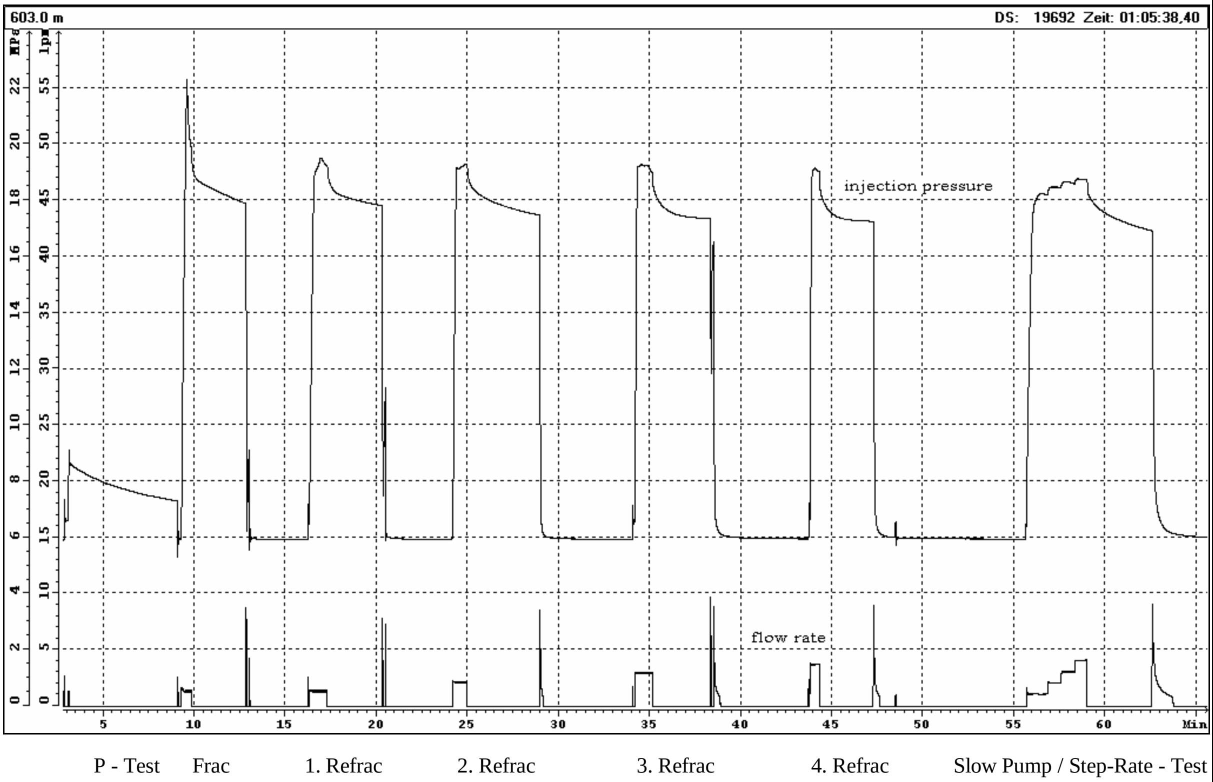
- Initial test type: HTPF-v
- The data acquisition system was re-started after the pressure-pulse test. Therefore, the test was recorded in two files.
- During the 1., 2. and 3. frac cycle, the injection was stopped at pressures of 33.7, 35.4 and 35.1 MPa, respectively. Although the test - section contains a pre-existing fracture, no breakdown event was observed during the frac -attempts. Therefore, the test was abandoned to prevent a damage of the packer elements.

Test at 594.62 m MD: Estimation of P_{max} (1. , 2., and 3. Frac - Cycle)



TEST NO. 12 AT 603.0 m MD / 600.58 m TVD

Test at 603.0 m MD : Overview - Plot



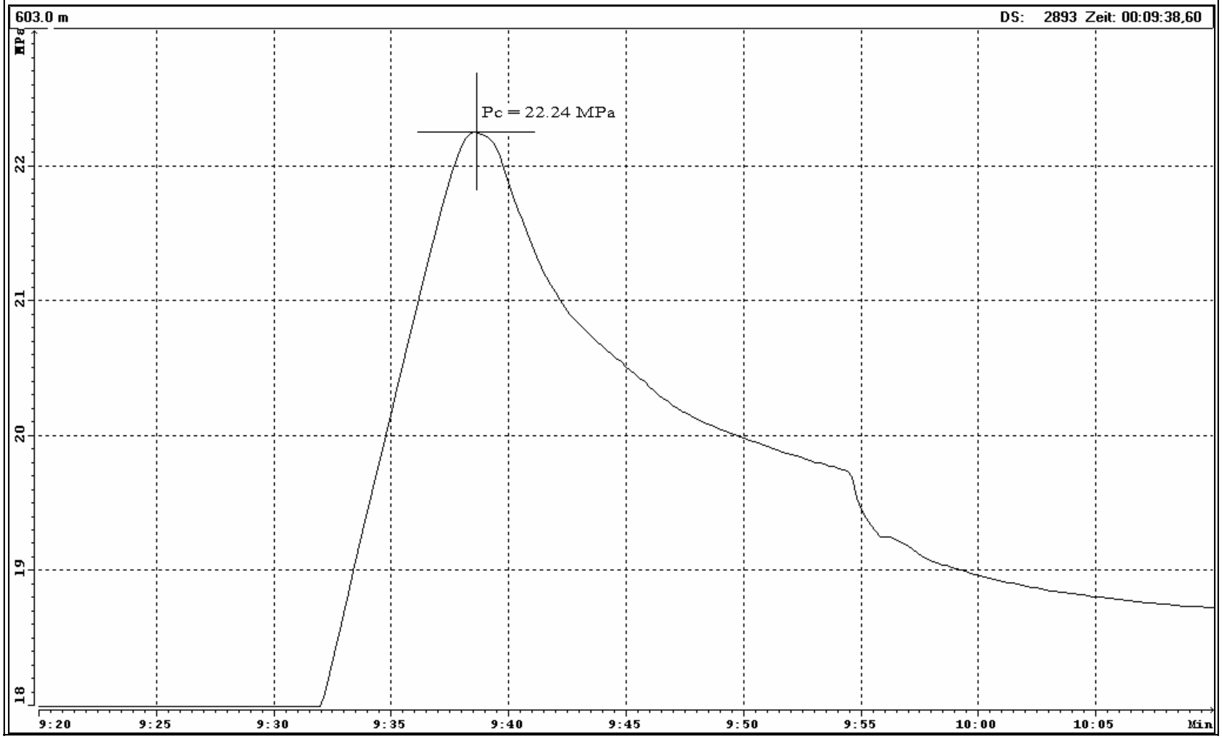
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 1.29 MPa in 349 sec.		
Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 0.8	Vr (l) = 0.6
1. Refrac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.35	Vr (l) = 0.9
2. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 1.7	Vr (l) = 1.3
3. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 2.9	Vr (l) = 2.2
4. Refrac - cycle	Qi (lpm) = 3.7	Vi (l) = 2.0	Vr (l) = 1.8
SP/SR - test	Qi (lpm) = 1.1-4.1	Vi (l) = 7.9	Vr (l) = 5.0

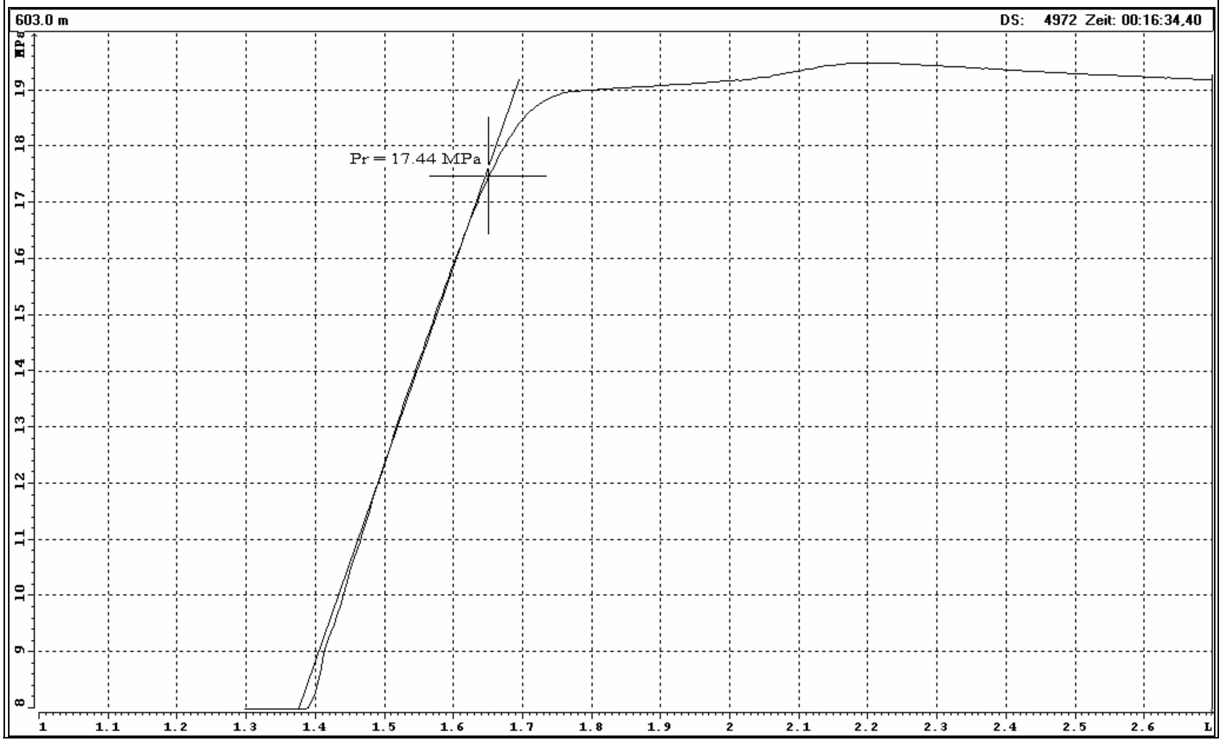
total injected volume (l): 16.65 recovered volume (l): 11.8 or 70.9 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4 refrac - cycle was used.

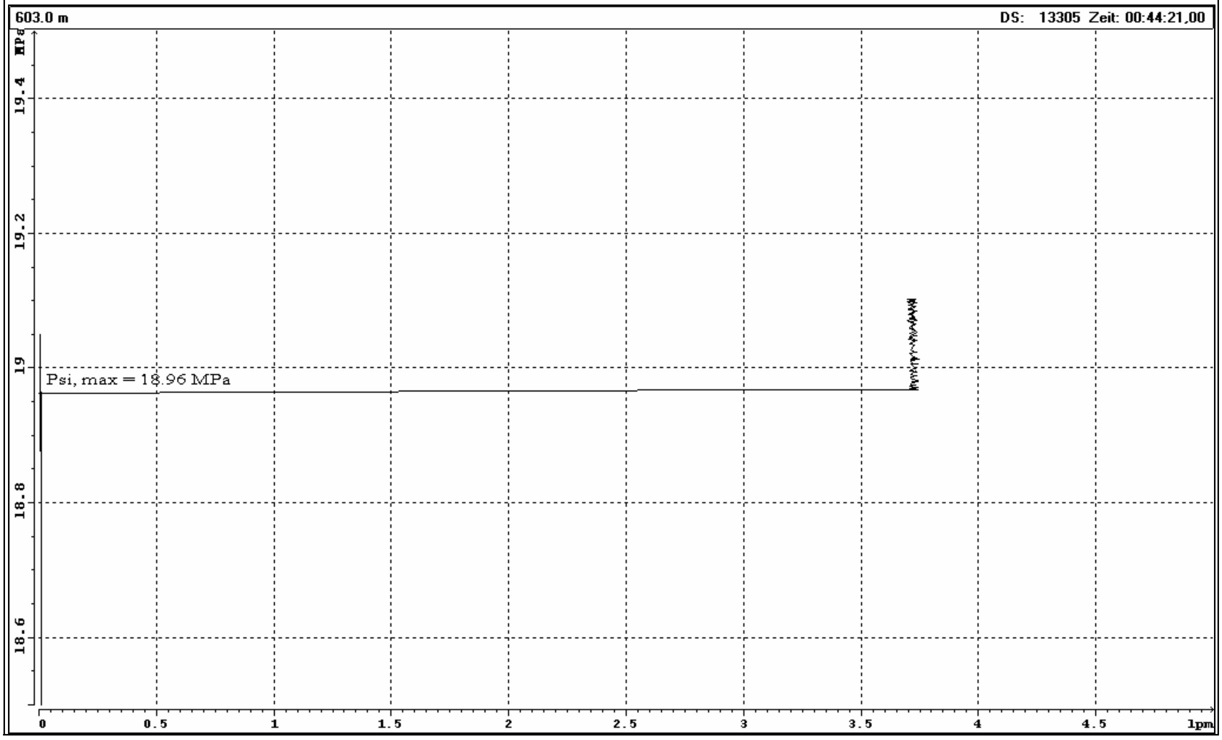
Test at 603.0 m MD: Estimation of P_c (Frac - Cycle)



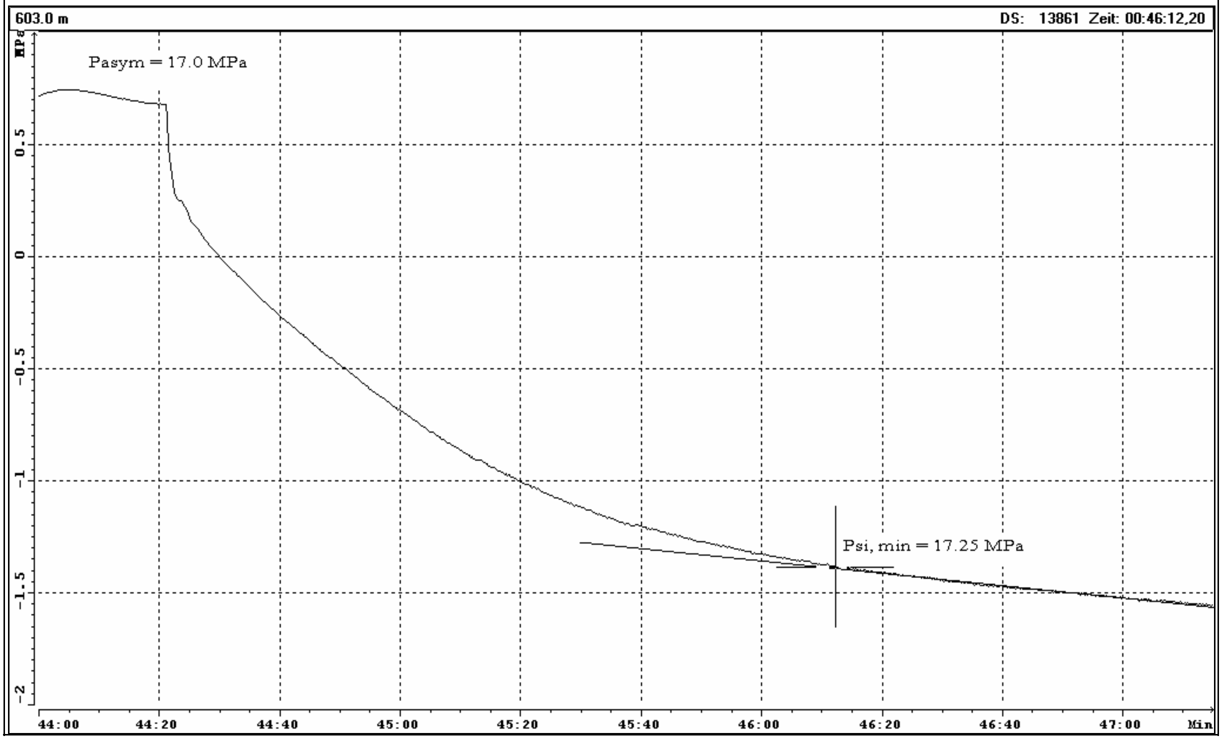
Test at 603.0 m MD: Estimation of P_r (1. Refrac - Cycle)



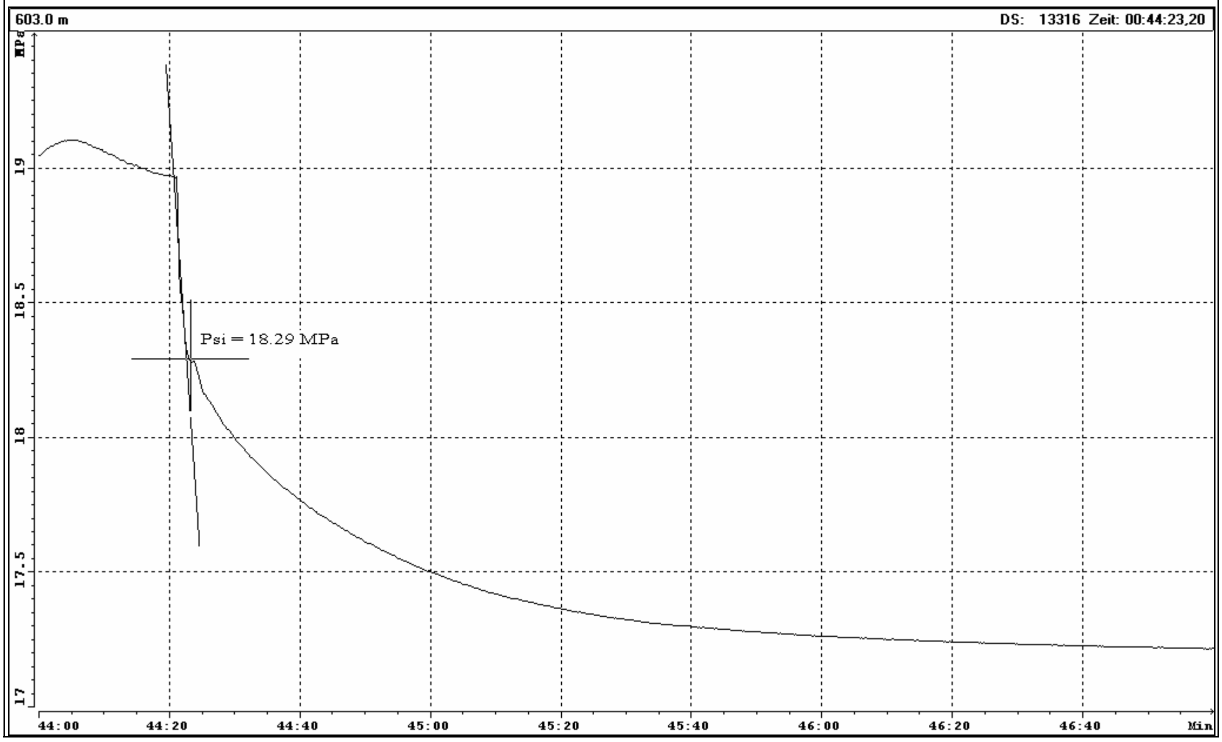
Test at 603.0 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



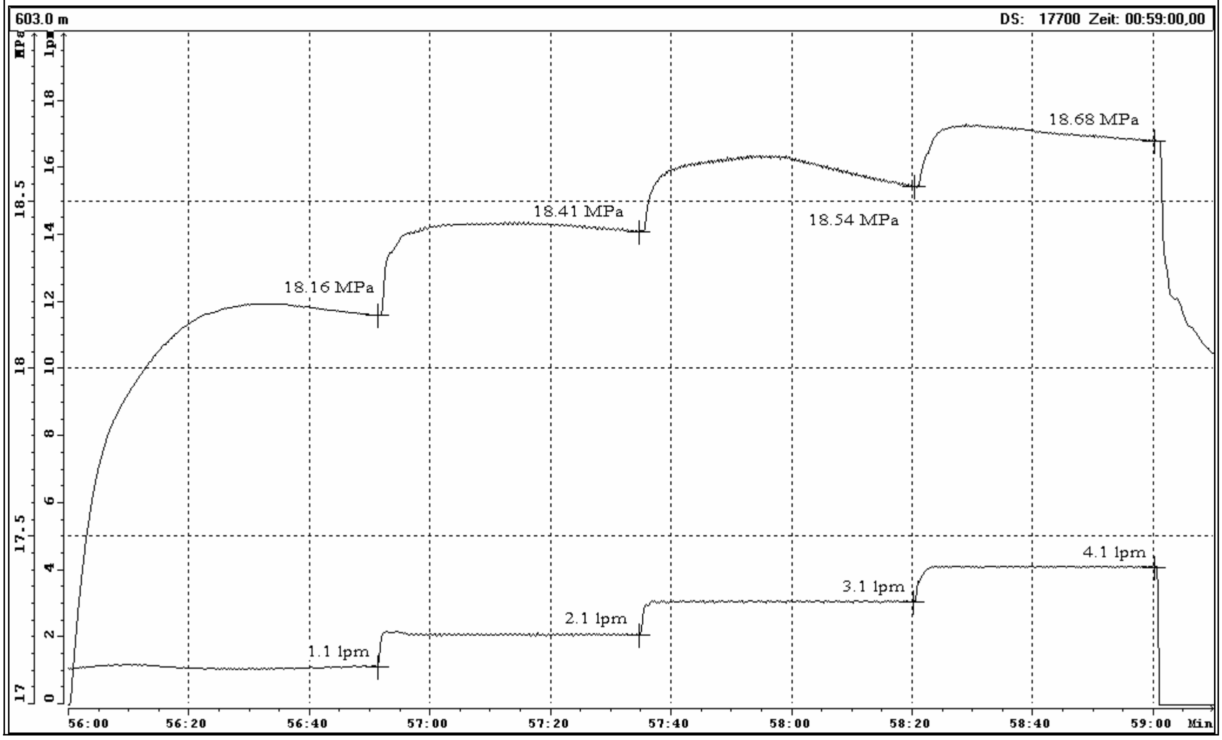
Test at 603.0 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



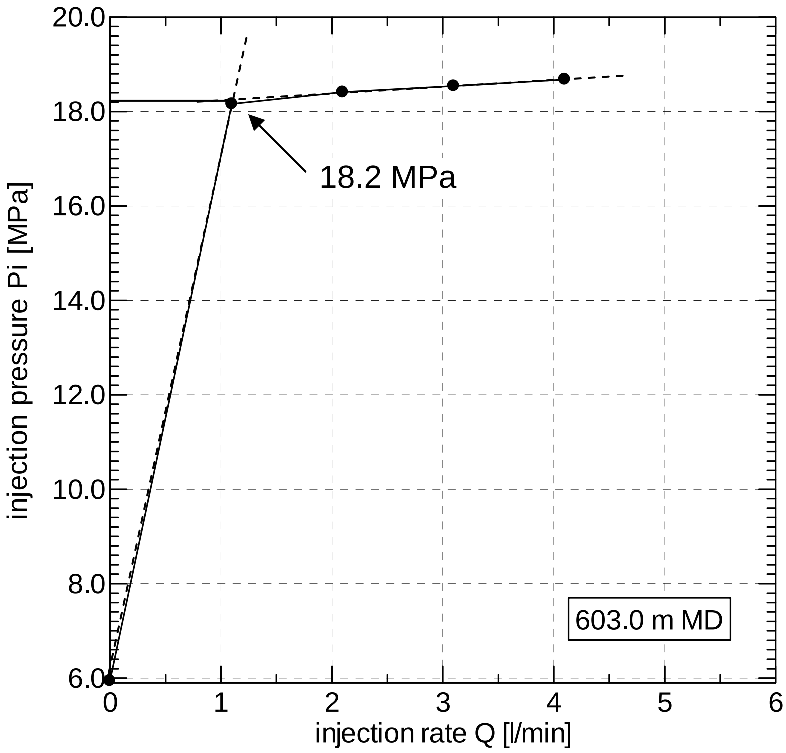
Test at 603.0 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 603.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

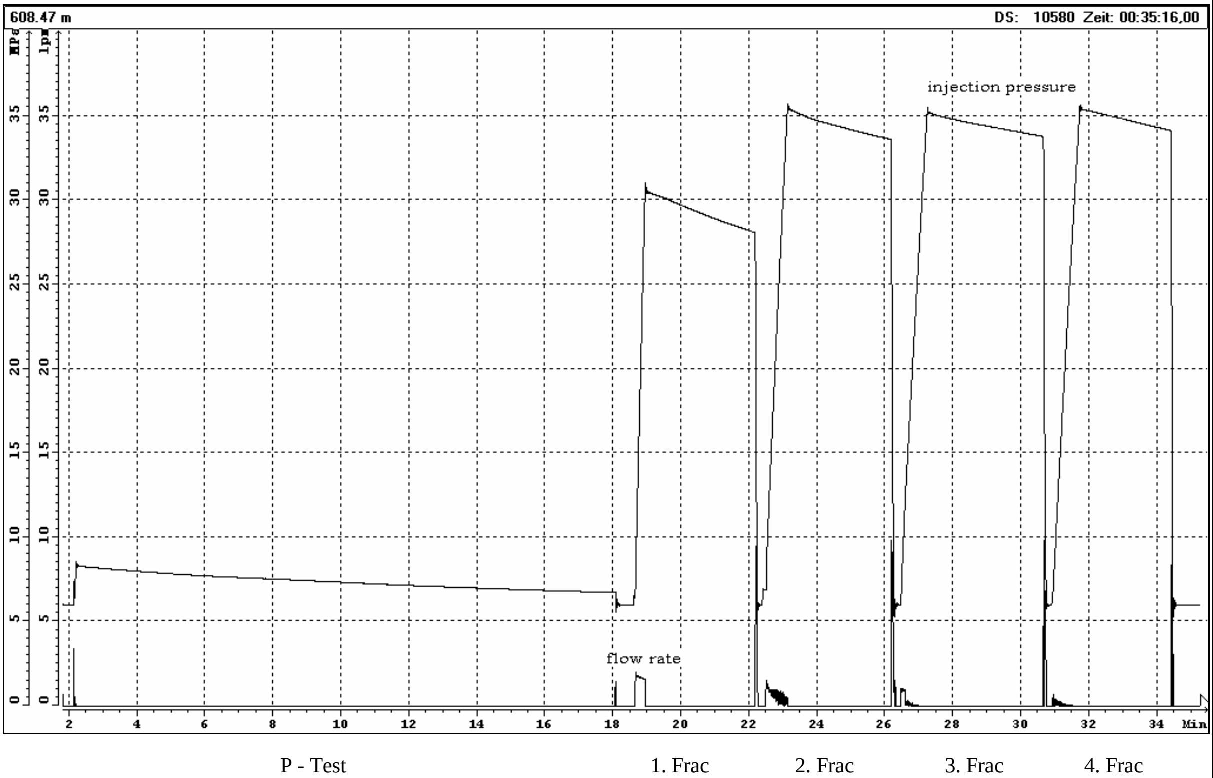


Test at 603.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 11 AT 608.47 m MD / 606.01 m TVD

Test at 608.47 m MD: Overview - Plot

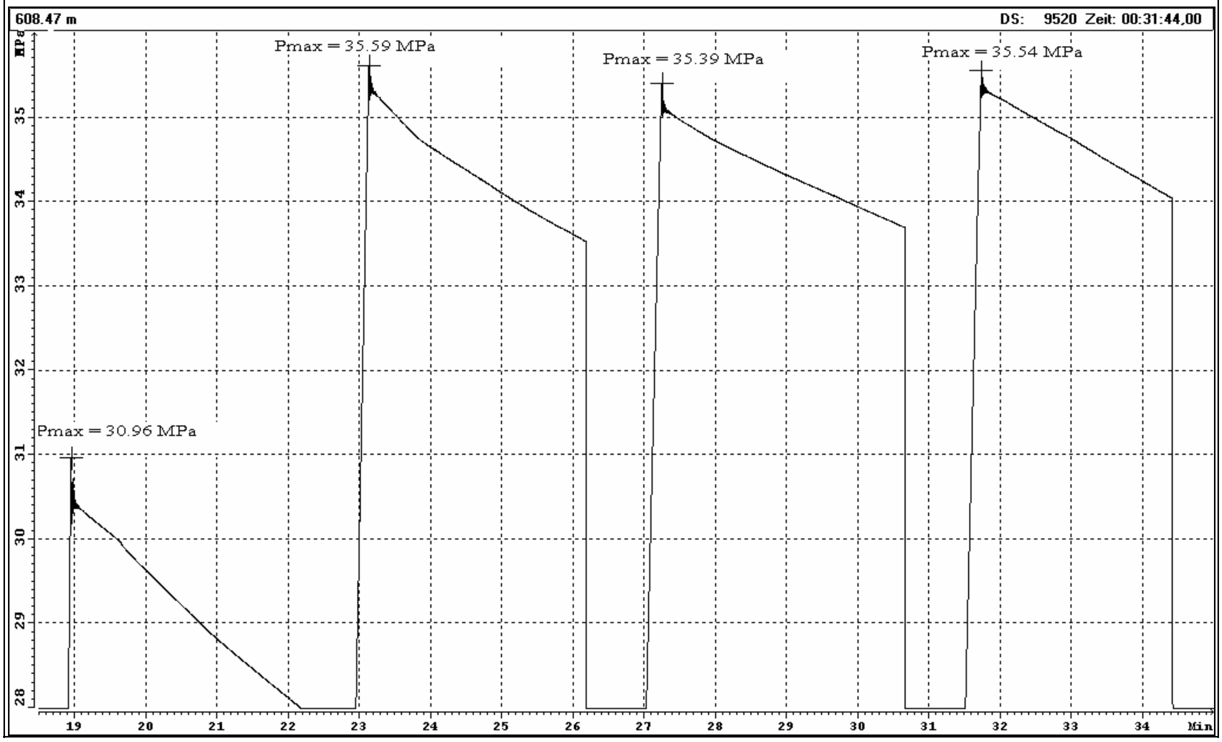


TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.55 MPa in 945 sec.		
1. Frac - cycle	Qi (lpm) = 1.7	Vi (l) = 0.5	Vr (l) = 0.4
2. Frac - cycle	Qi (lpm) = 0.7	Vi (l) = 0.5	Vr (l) = 0.5
3. Frac - cycle	Qi (lpm) < 0.7	Vi (l) =	Vr (l) = 0.5
4. Frac - cycle	Qi (lpm) < 0.7	Vi (l) =	Vr (l) = 0.2

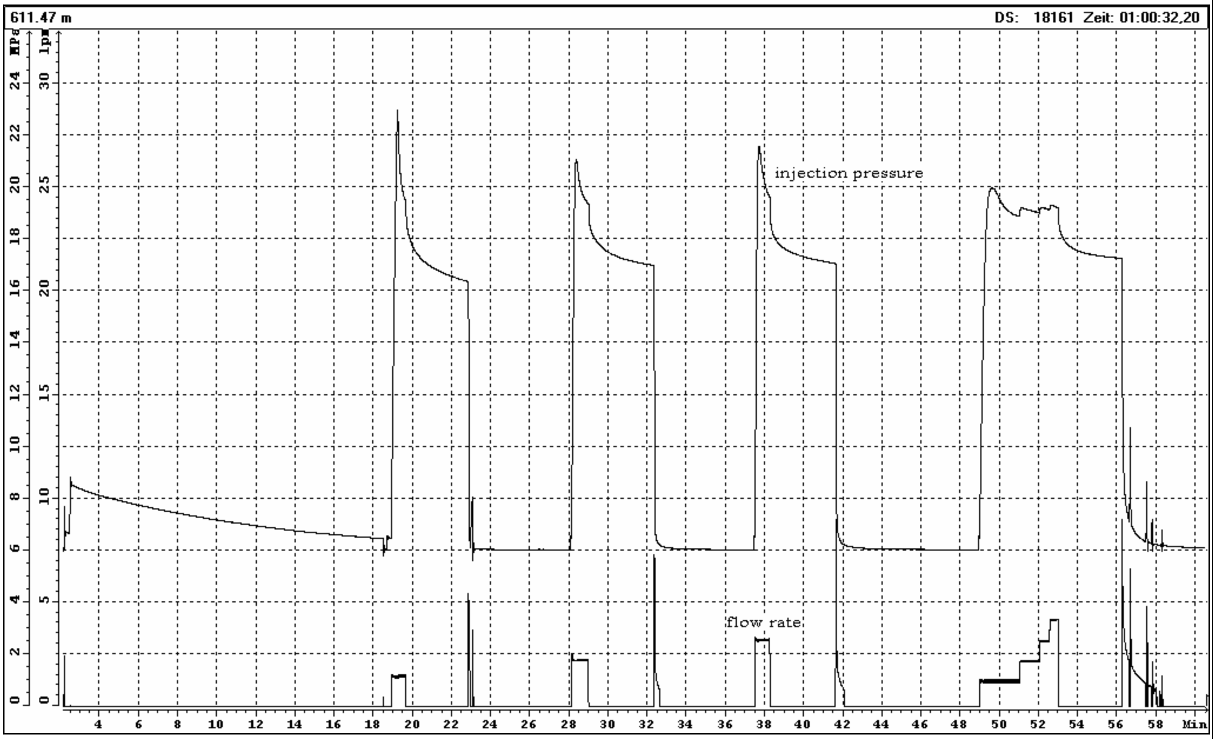
- Initial test type: HTPF-h
- During the 1., 2., 3., and 4. frac cycle, the injection was stopped at pressures of 31.0, 35.6, 35.4 and 35.5 MPa, respectively. Although the test - section contains a pre-existing fracture, no breakdown event was observed during the frac -attempts. Therefore, the test was abandoned to prevent a damage of the packer elements.

Test at 608.47 m MD: Estimation of P_{max} (1. , 2., 3. and 4. Frac - Cycle)



TEST NO. 10 AT 611.47 m MD / 608.98 m TVD

Test at 611.47 m MD : Overview - Plot



P - Test   Frac (1. Refrac)   2. Refrac   3. Refrac   SP/SR - Test

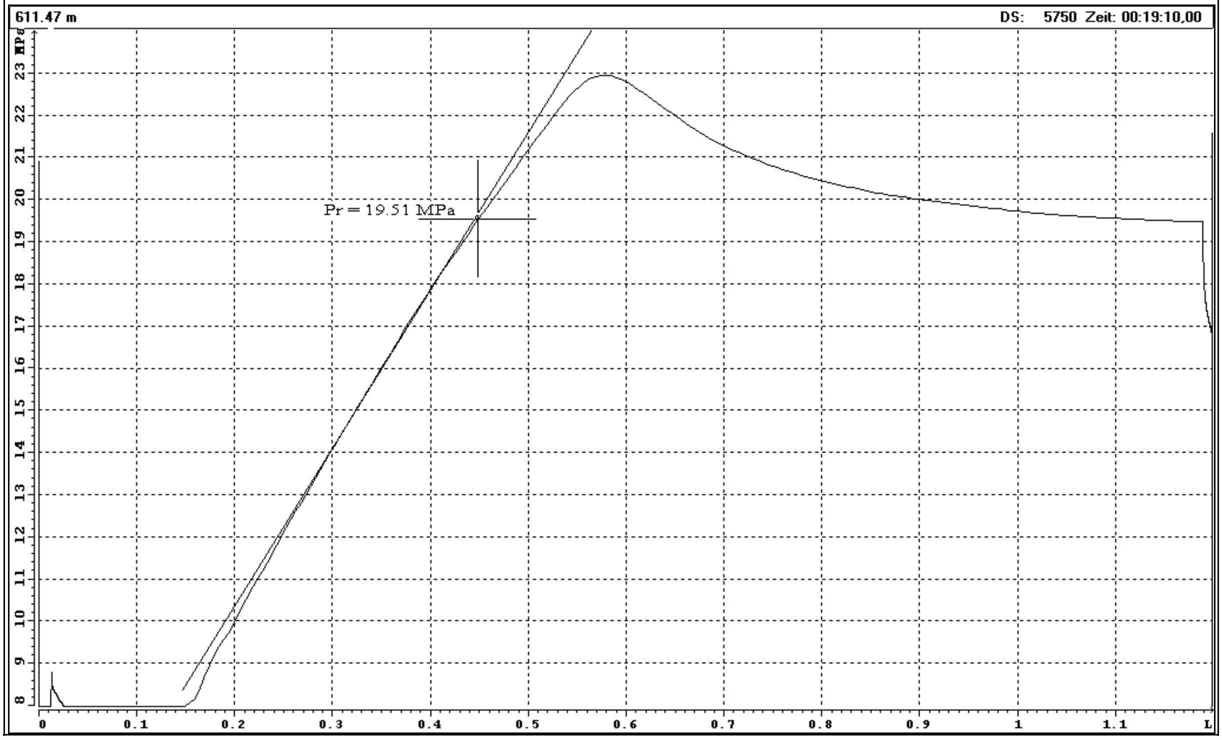
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 2.06 MPa in 951 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.4	Vi (l) = 1.1	Vr (l) = 0.7
2. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 1.95	Vr (l) = 1.6
3. Refrac - cycle	Qi (lpm) = 3.2	Vi (l) = 2.4	Vr (l) = 2.25
SP/SR - test	Qi (lpm) = 1.2-4.2	Vi (l) = 8.2	Vr (l) = 5.5

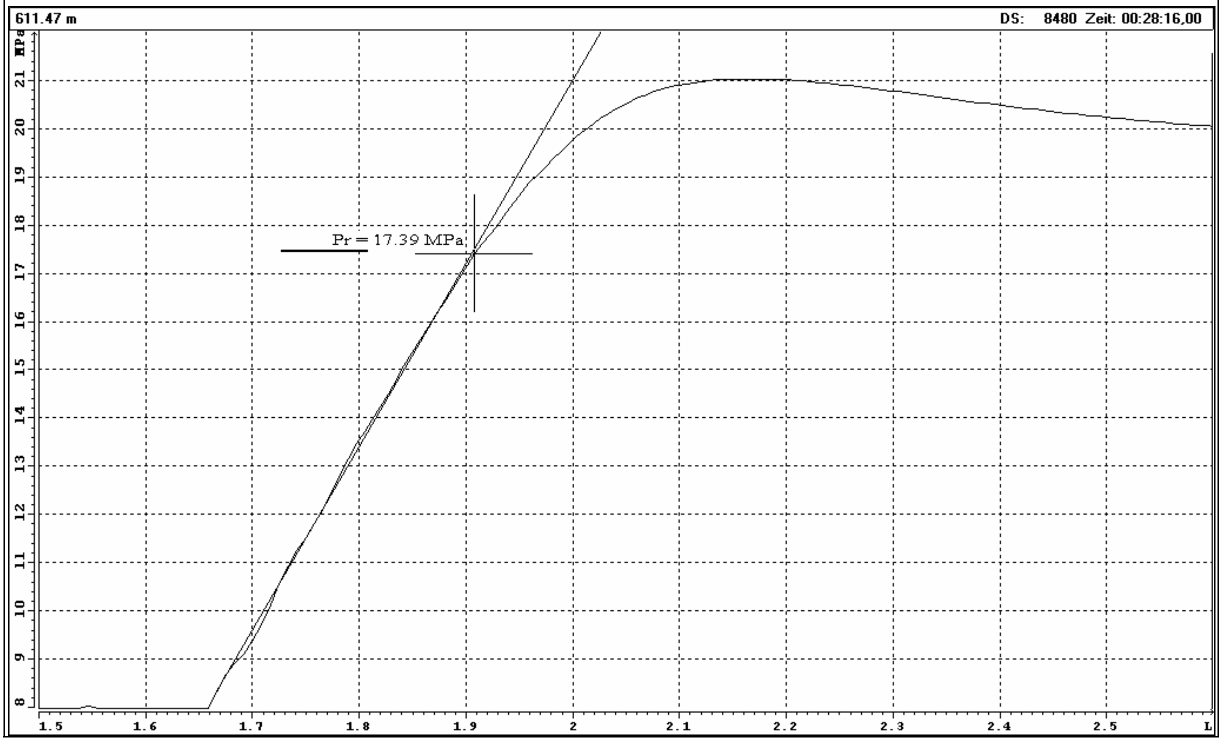
total injected volume (l): 13.65   recovered volume (l): 10.05 or 73.6 %

- Initial test type: HTPF-v
- The pressure pulse test as well as the frac - cycle indicate the stimulation of a pre - existing fracture (no distinct breakdown event)
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 19.5 MPa, followed by a pressure increase up to 22.9 MPa. In comparison to the first cycle, the subsequent re-frac - cycles yield slightly lower fracture re-opening pressure values.
- The shut-in phases yield consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

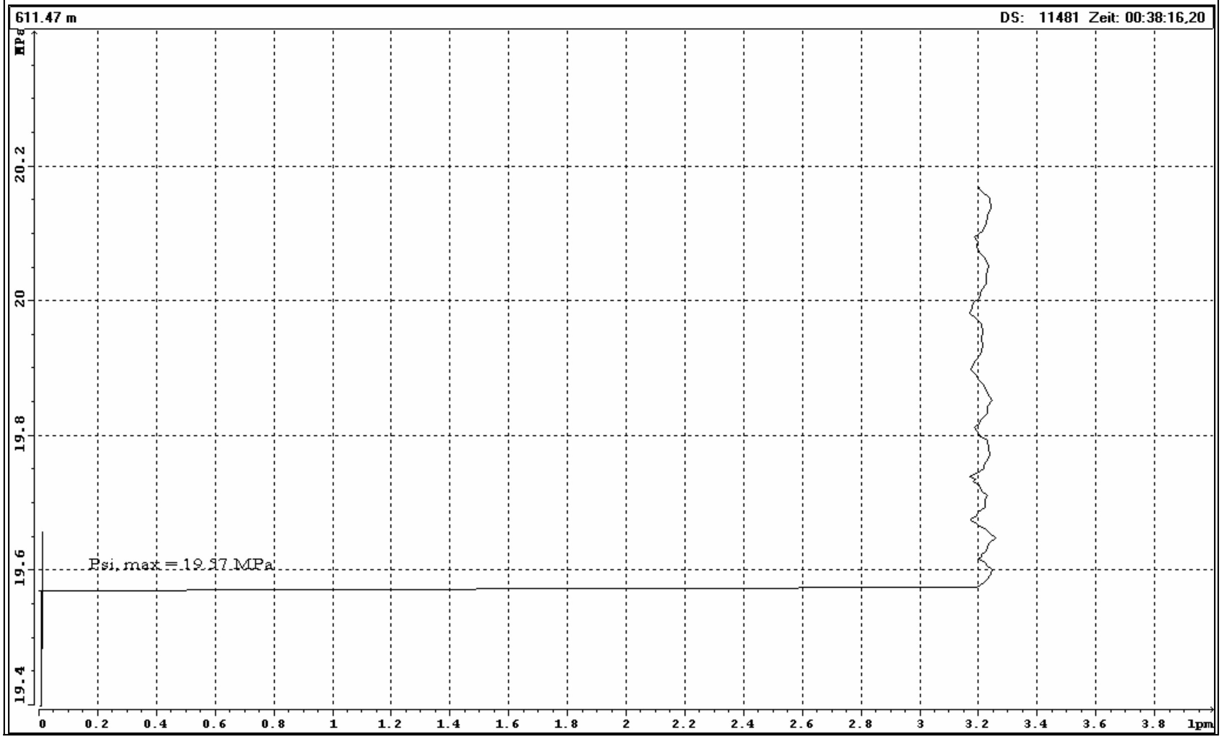
Test at 611.47 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



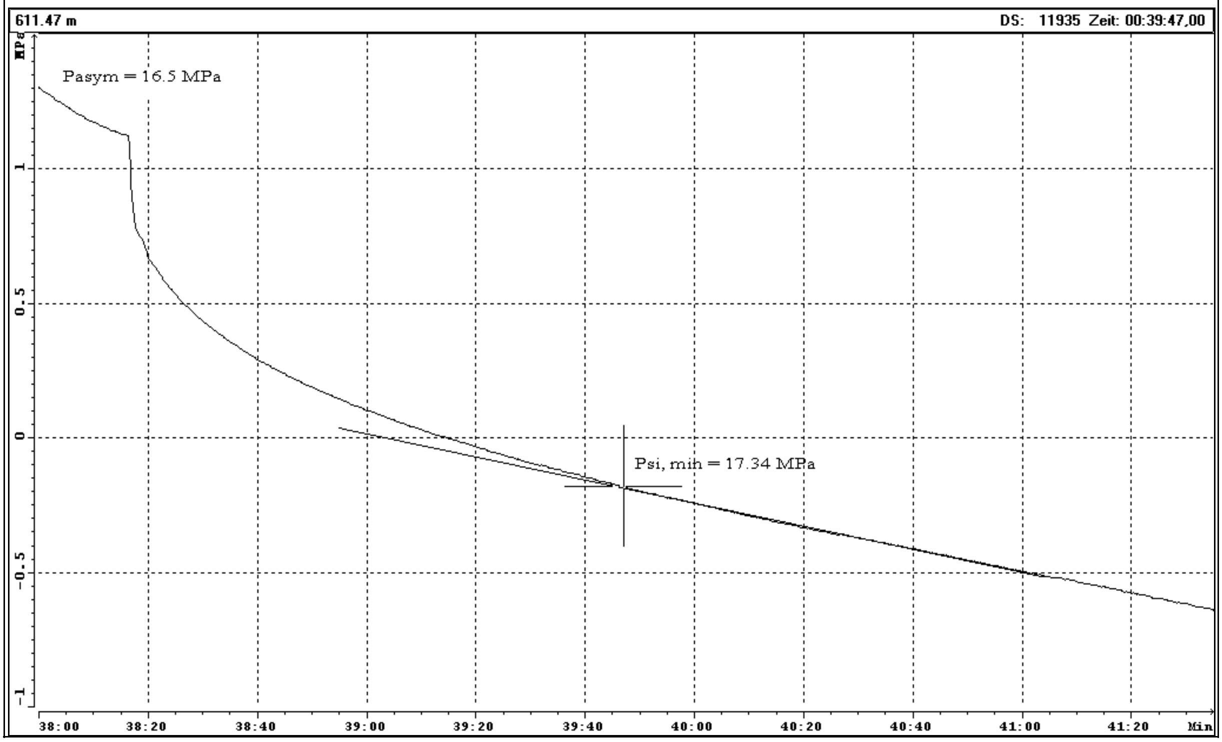
Test at 611.47 m MD: Estimation of P_r (2. Refrac) - Cycle, for comparison)



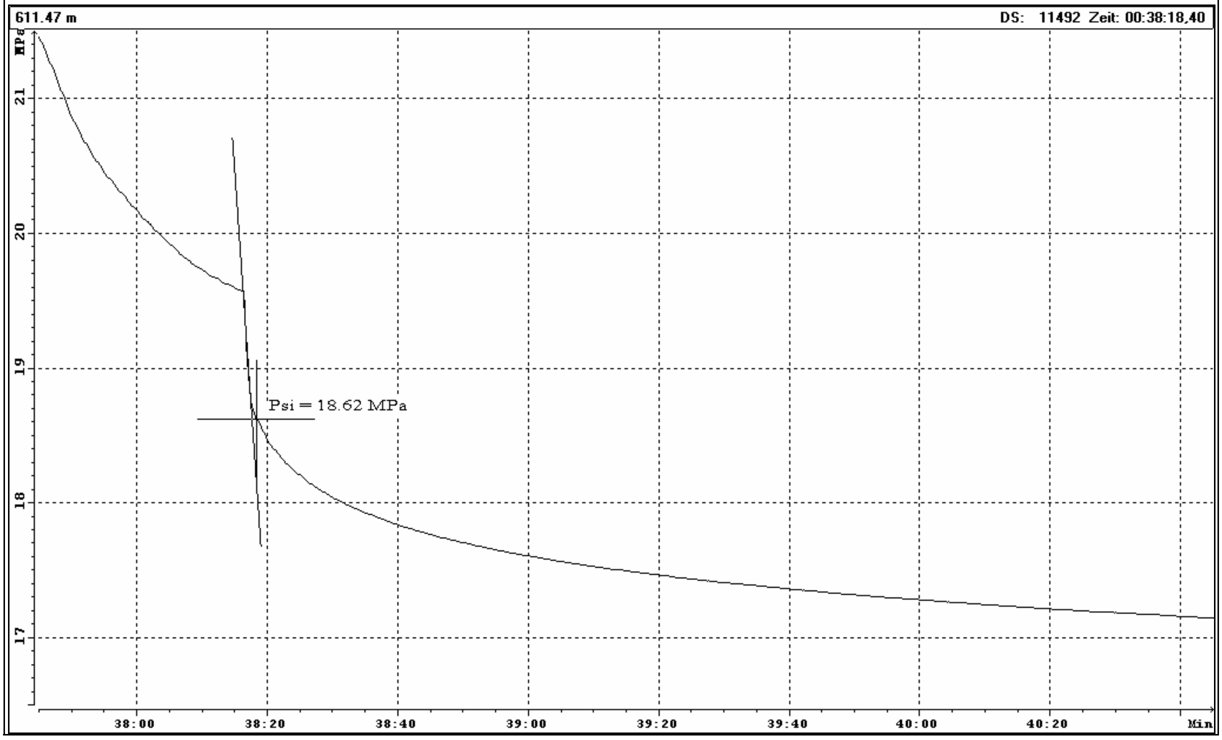
Test at 611.47 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



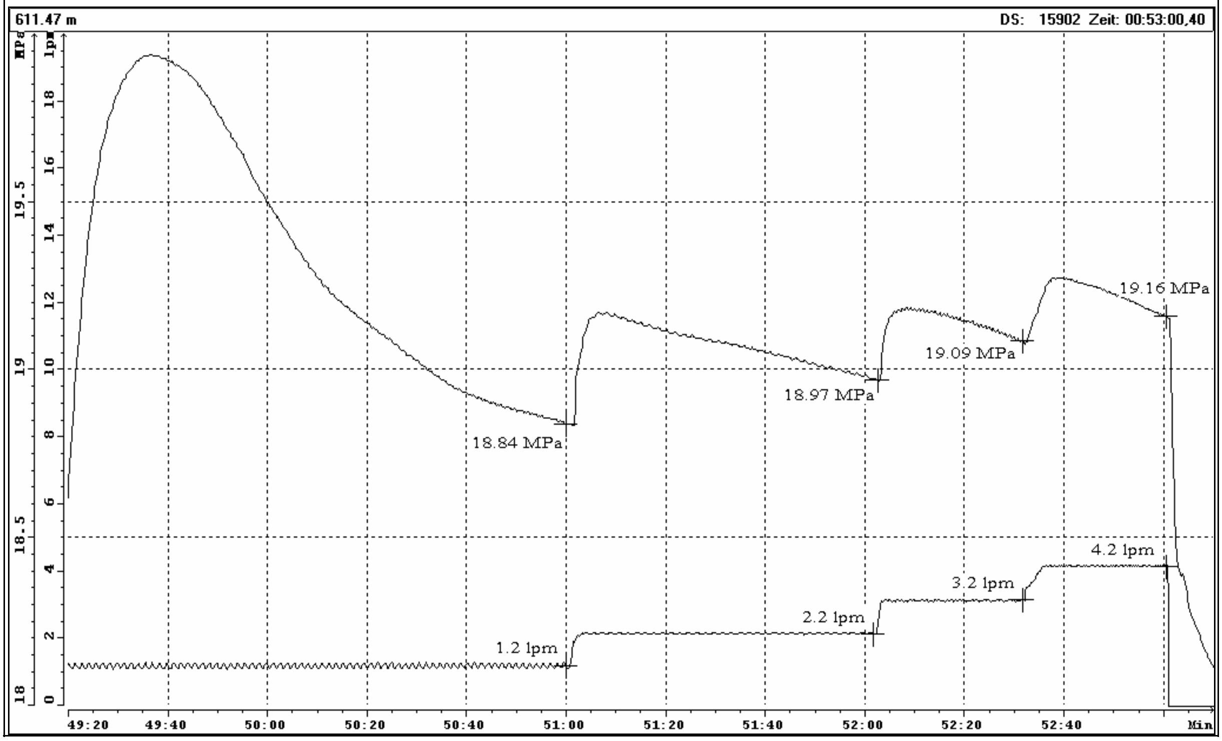
Test at 611.47 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



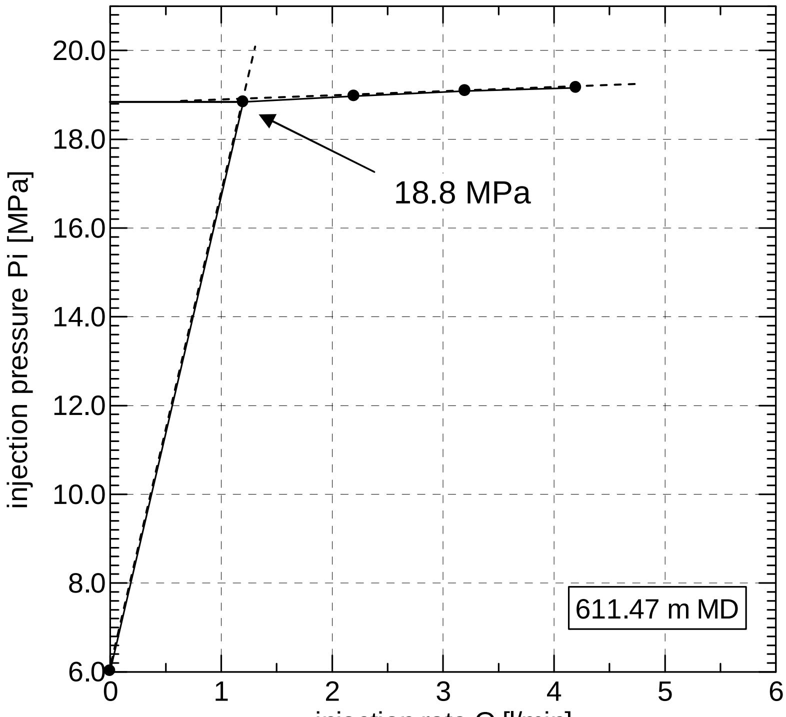
Test at 611.47 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 611.47 m MD: Analysis of Slow - Pump / Step - Rate - Test

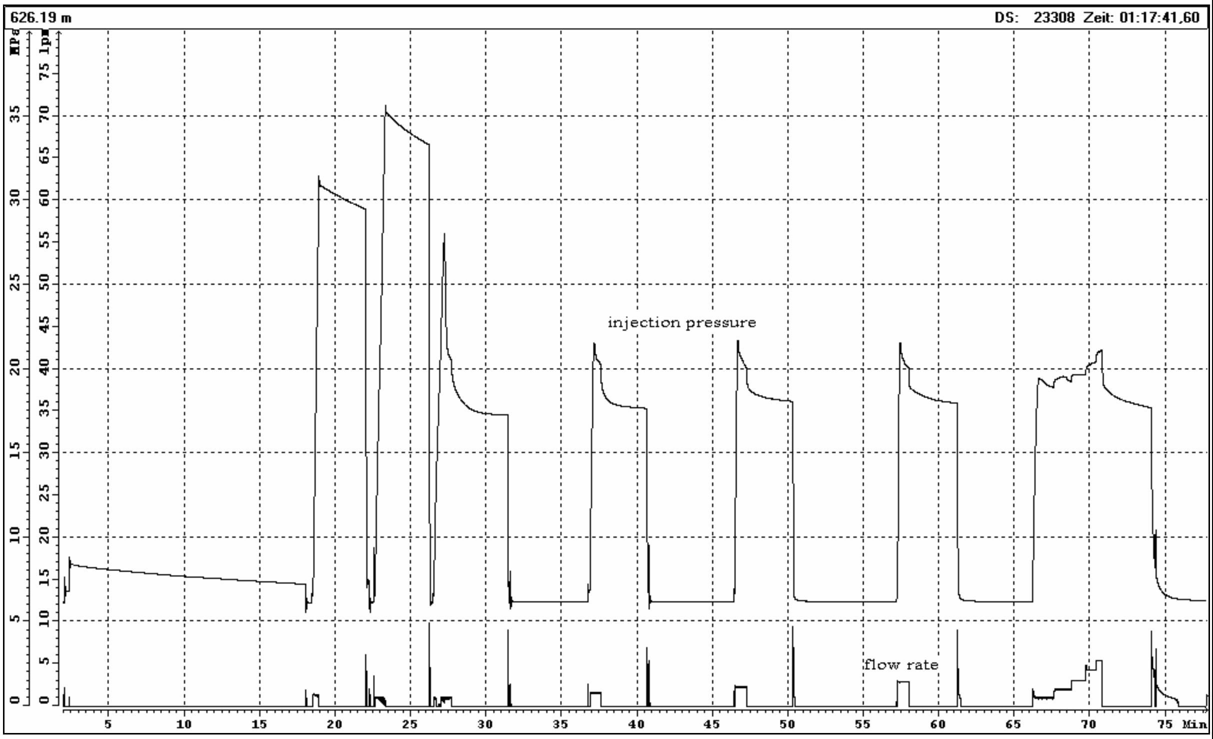


Test at 611.47 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 9 AT 626.19 m MD / 623.59 m TVD

Test at 626.19 m MD: Overview - Plot



P - Test 1.Frac 2. Frac 3. Frac 1. Refrac 2. Refrac 3. Refrac SP/SR - Test

<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

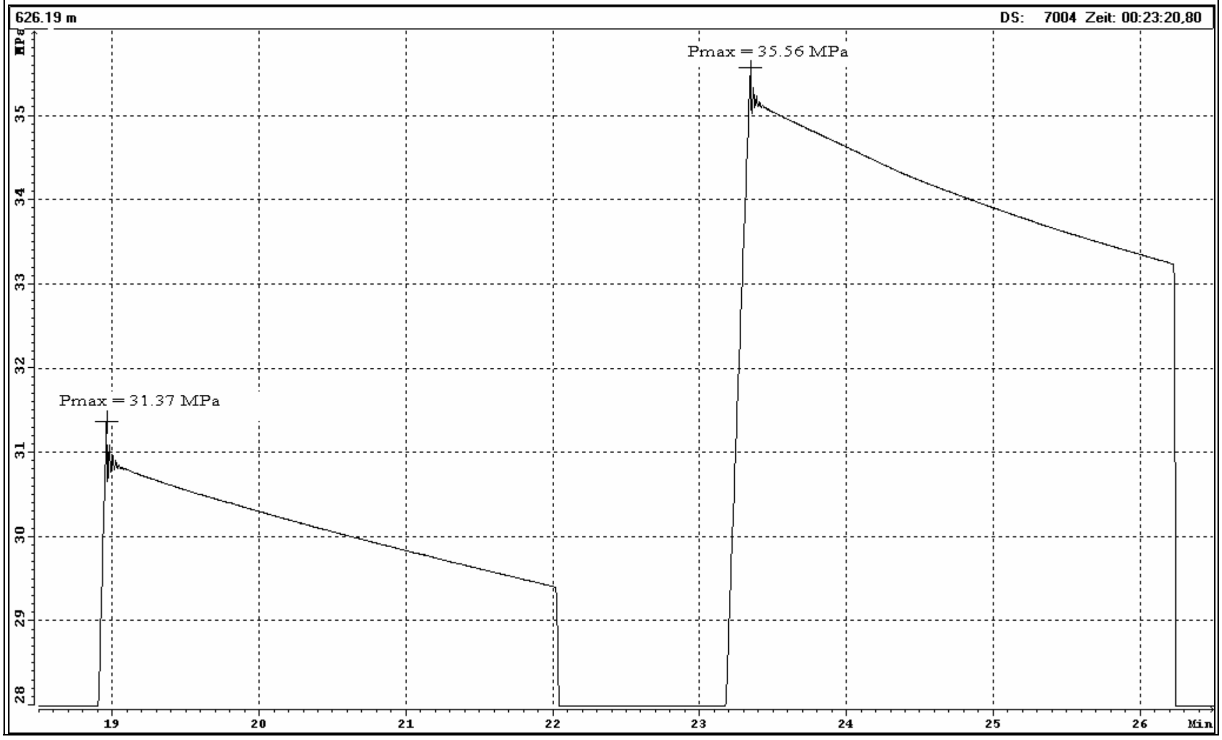
P - Test : pressure decrease: 1.16 MPa in 930 sec.

1. Frac - cycle	Qi (lpm) = 1.3	Vi (l) = 0.5	Vr (l) = 0.5
2. Frac - cycle	Qi (lpm) = 1.0	Vi (l) = 0.6	Vr (l) = 0.6
3. Frac - cycle	Qi (lpm) = 1.1	Vi (l) = 0.8	Vr (l) = 0.8
1. Refrac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.1	Vr (l) = 1.0
2. Refrac - cycle	Qi (lpm) = 2.3	Vi (l) = 1.8	Vr (l) = 1.6
3. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 2.1	Vr (l) = 1.7
SP/SR - test	Qi (lpm) = 1.0-5.4	Vi (l) = 11.9	Vr (l) = 6.0

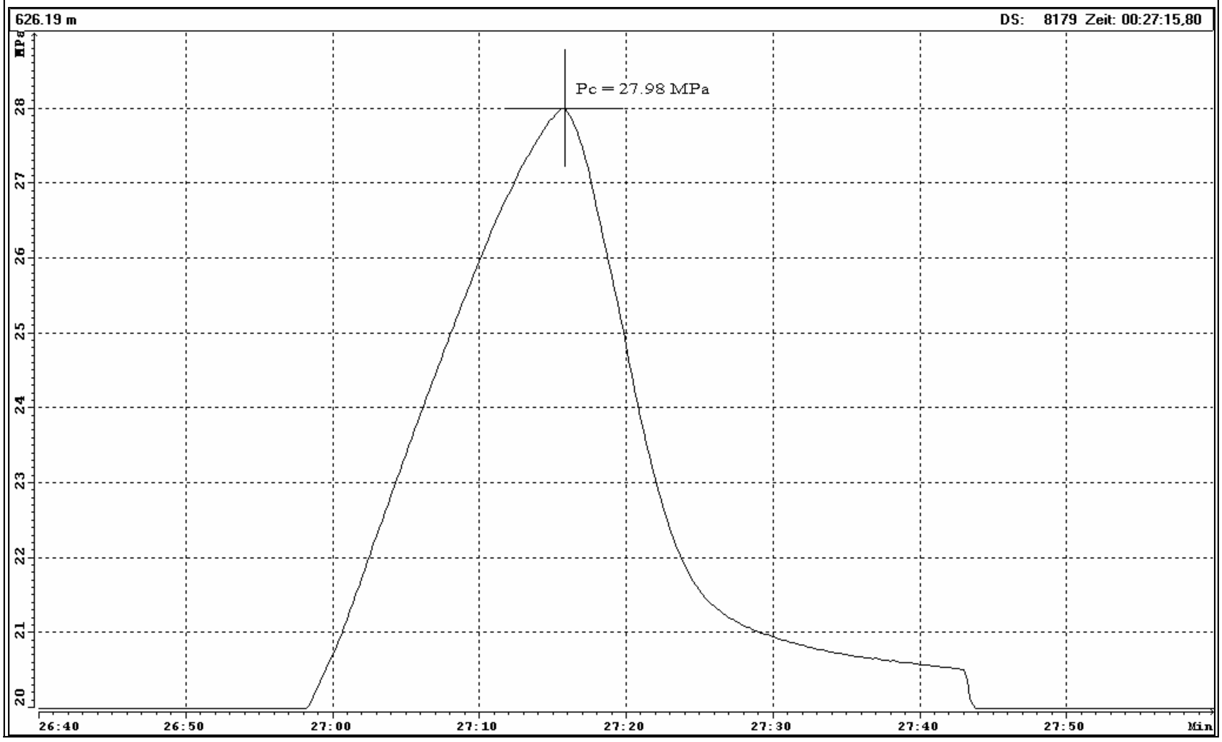
total injected volume (l): 18.8 recovered volume (l): 12.2 or 64.9 %

- Initial test type: HF
- During the 1. and 2. frac cycle, the injection was stopped at pressures of 31.4 and 35.6 MPa to prevent a damage of the packer elements. No breakdown event was observed during the frac - attempts. However, the subsequent 3. frac - cycle demonstrates the initiation of a fracture with a distinct breakdown event at 28 MPa.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

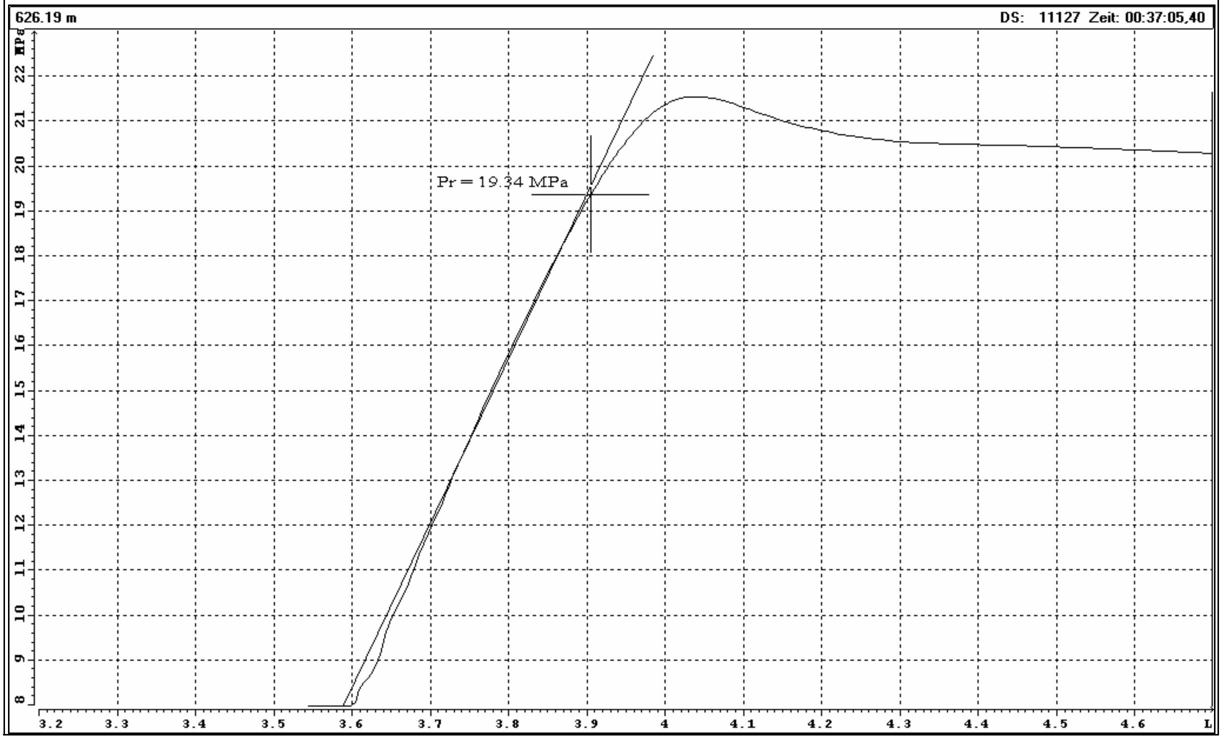
Test at 626.19 m MD: Estimation of P_{max} (1. and 2. Frac - Cycle)



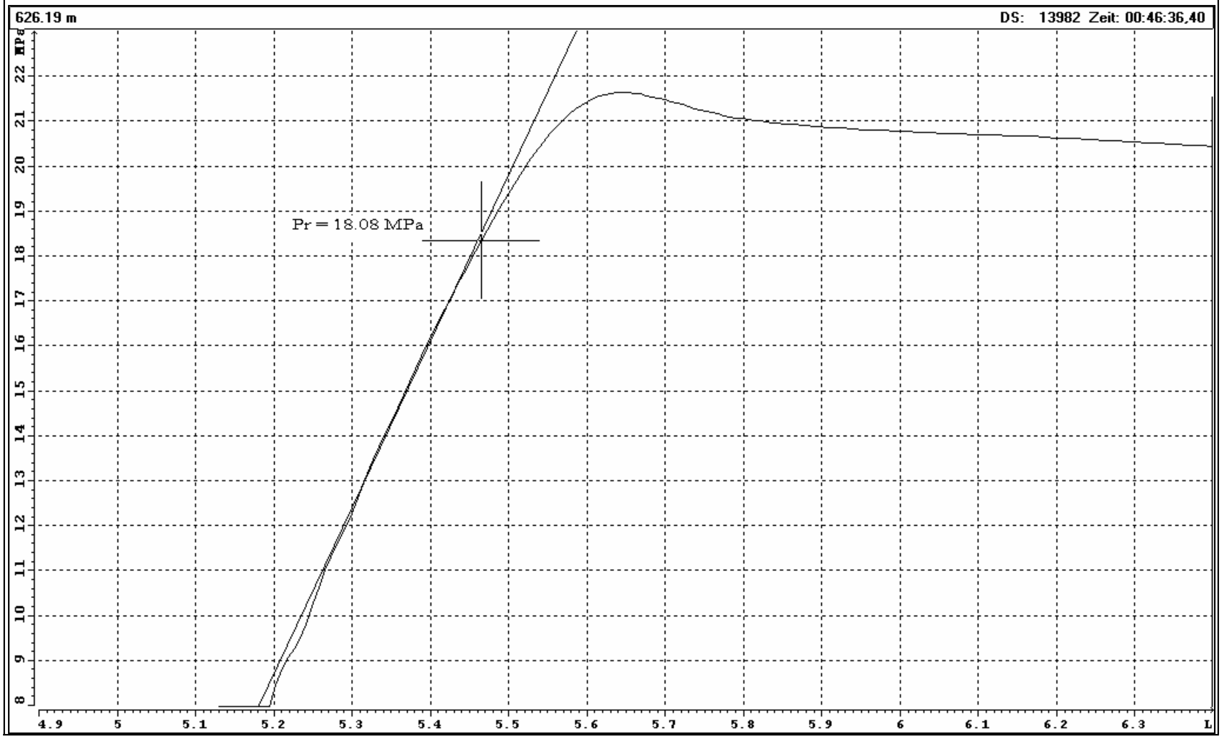
Test at 626.19 m MD: Estimation of P_c (3. Frac - Cycle)



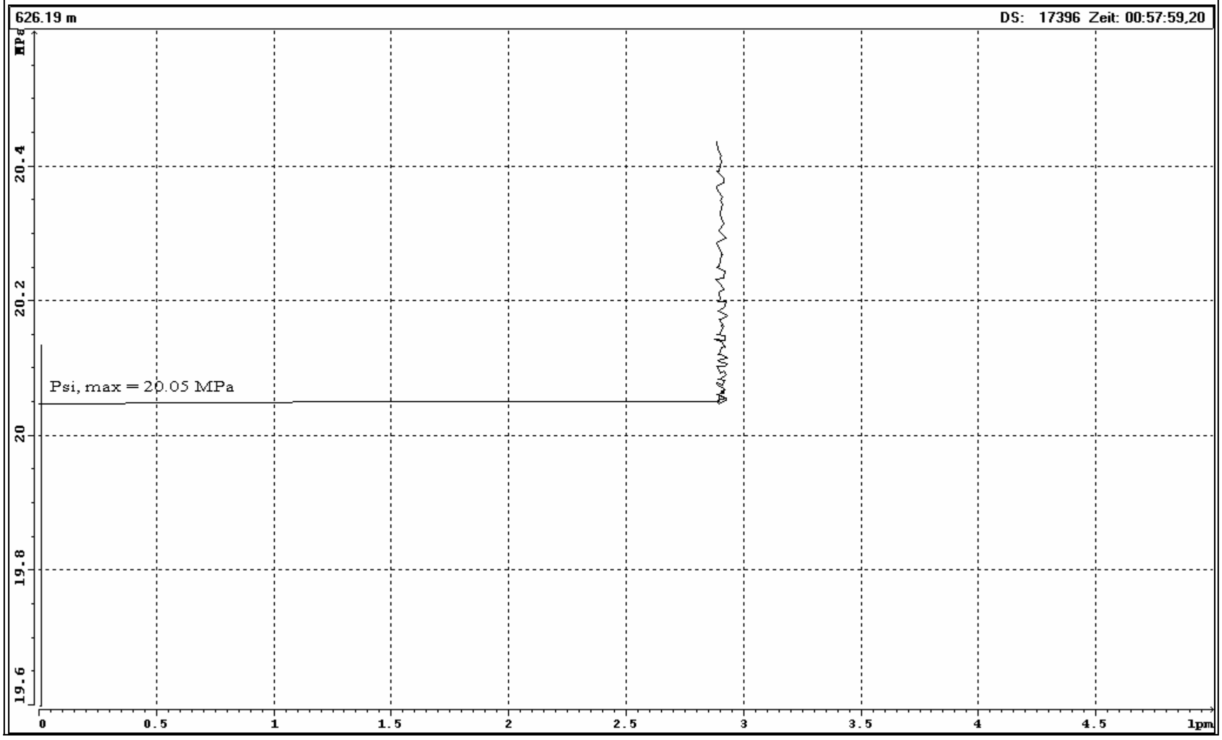
Test at 626.19 m MD: Estimation of P_r (1. Refrac - Cycle)



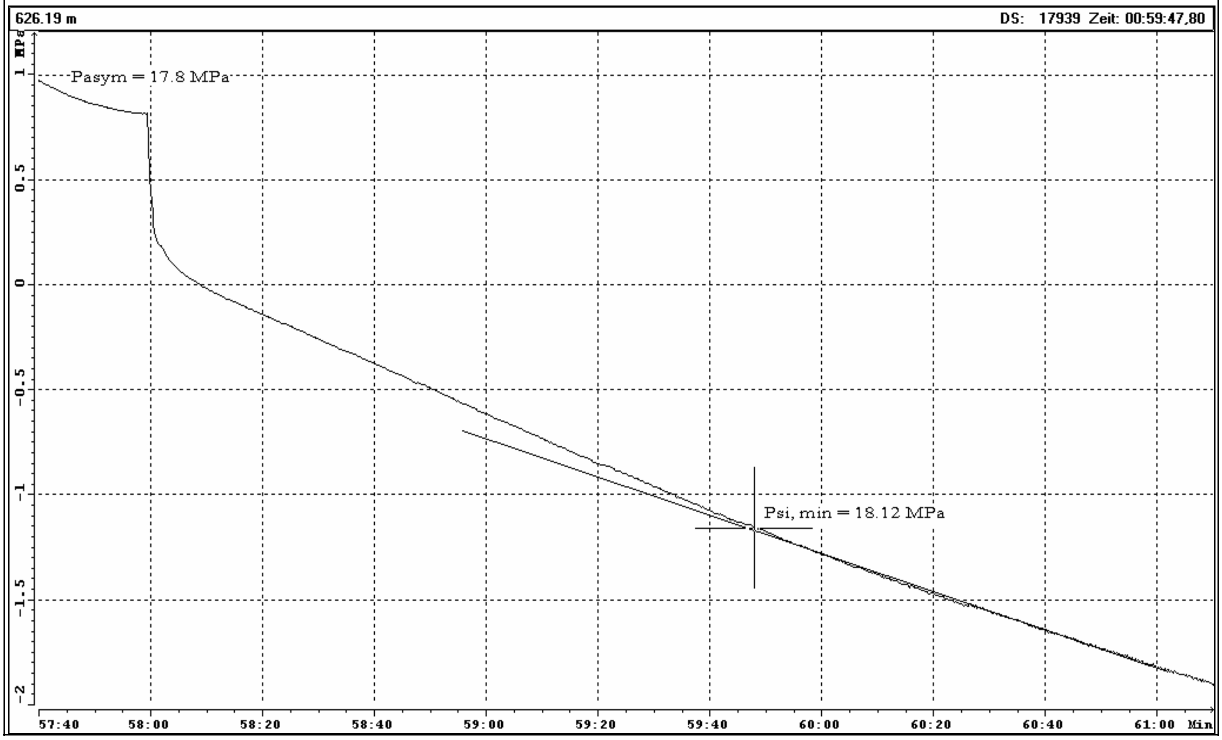
Test at 626.19 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



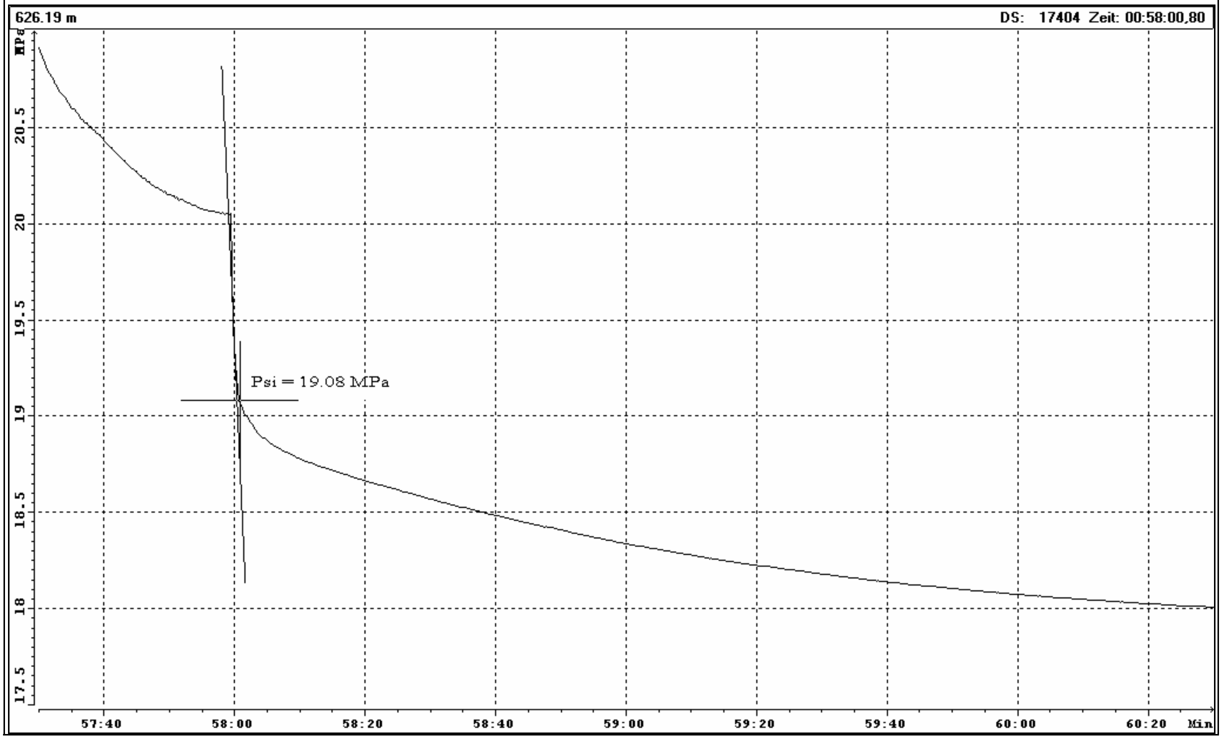
Test at 626.19 m MD: Estimation of $P_{si,\,max}$ (3. Refrac - Cycle)



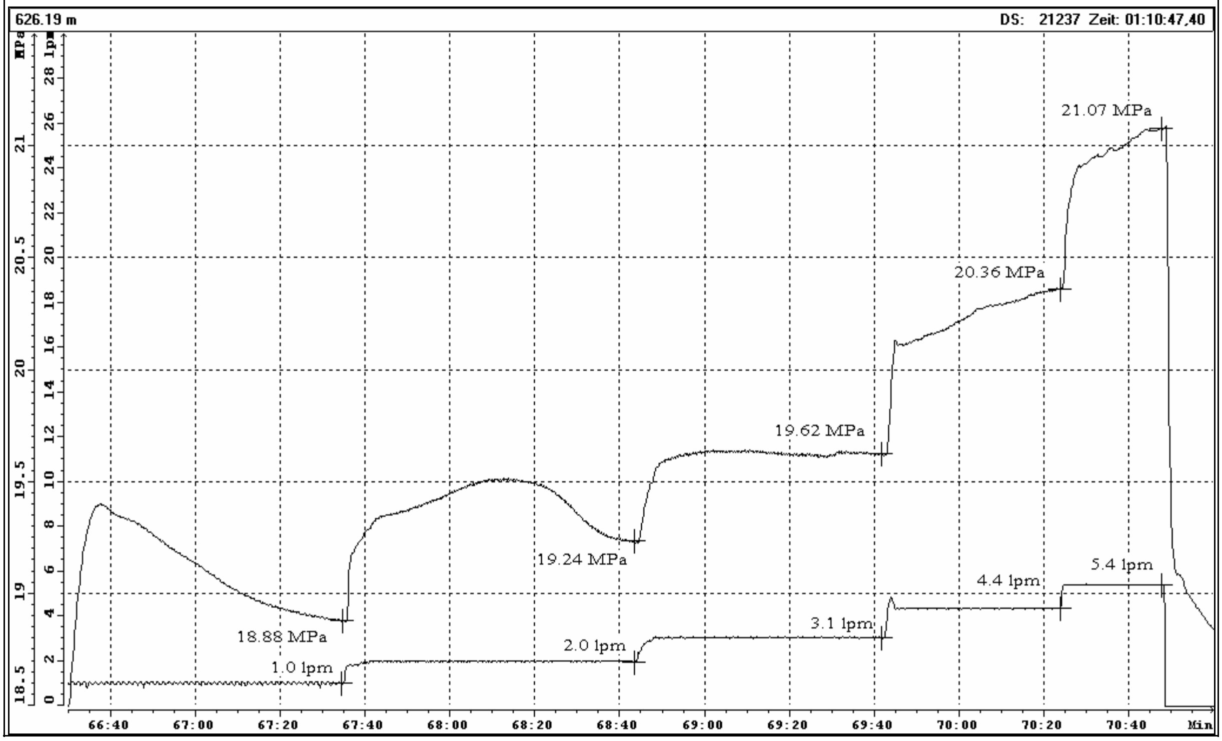
Test at 626.19 m MD: Estimation of $P_{si,\,min}$ (3. Refrac - Cycle)



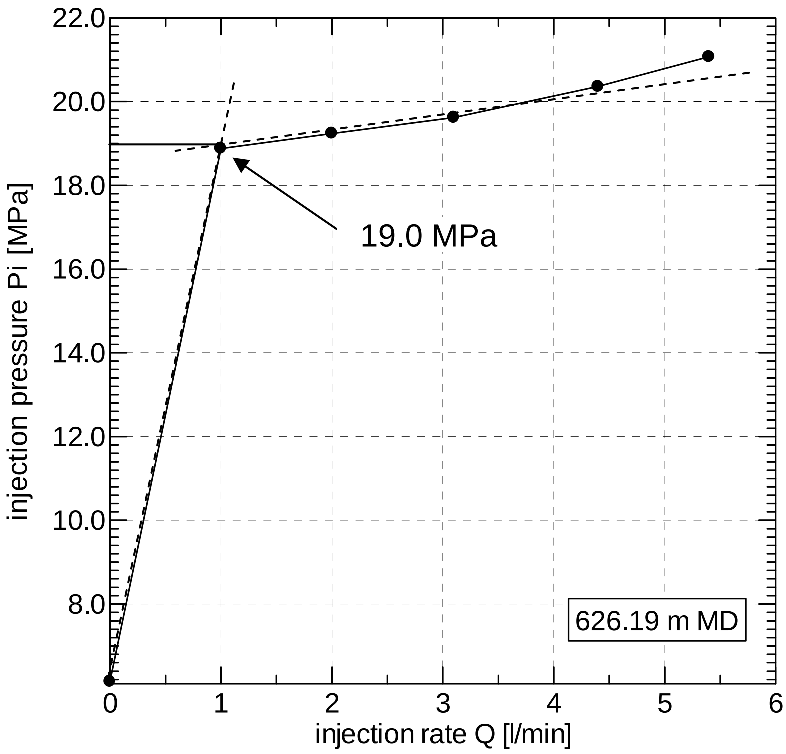
Test at 626.19 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 626.19 m MD: Analysis of Slow - Pump / Step - Rate - Test

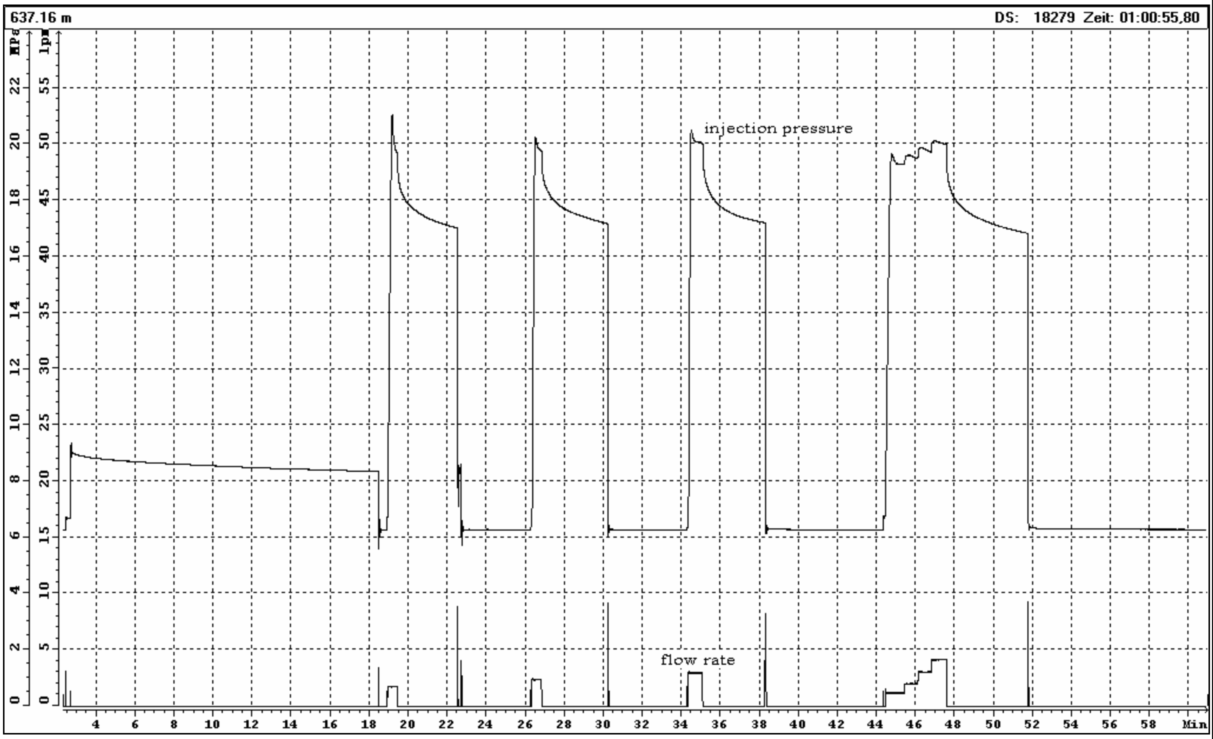


Test at 626.19 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 8 AT 637.16 m MD / 634.48 m TVD

Test at 637.16 m MD : Overview - Plot



P - Test Frac (1. Refrac) 2. Refrac 3. Refrac Slow-Pump/Step-Rate - Test

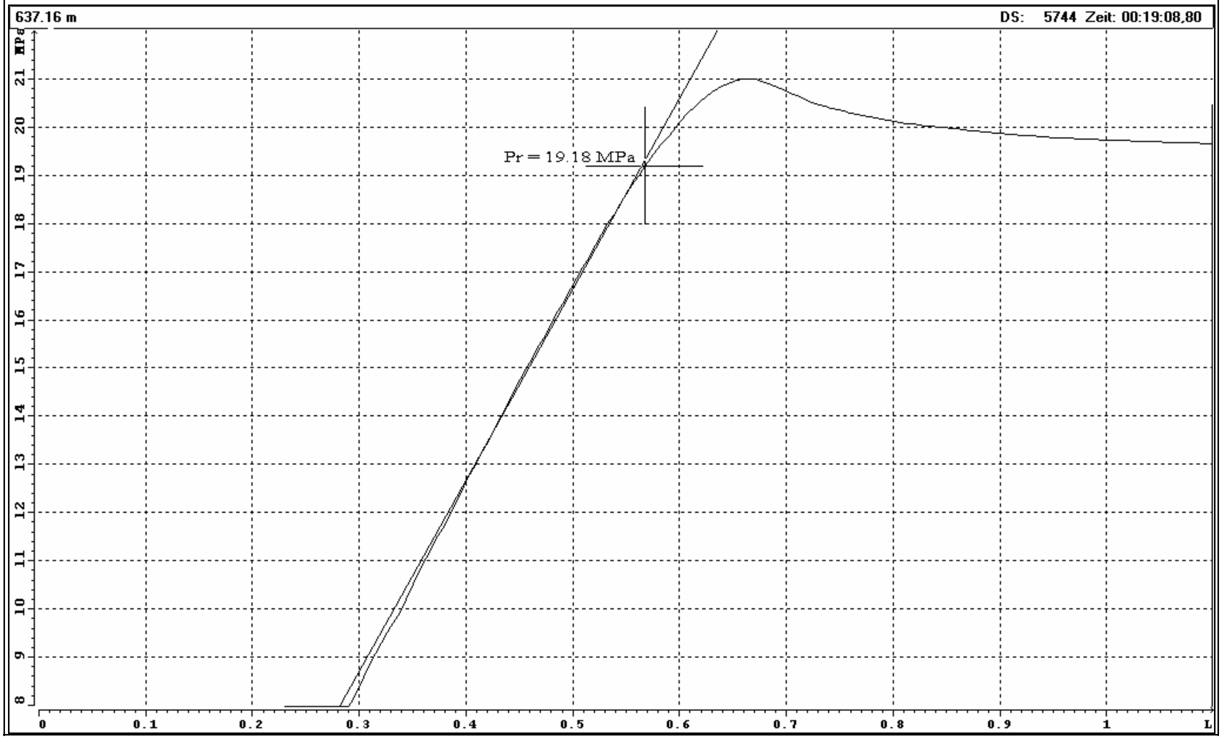
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.64 MPa in 939 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.7	Vi (l) = 0.9	Vr (l) = 0.4
2. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 1.2	Vr (l) = 0.5
3. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 2.2	Vr (l) = 0.85
SP/SR - test	Qi (lpm) = 1.1-4.2	Vi (l) = 8.0	Vr (l) = 1.8

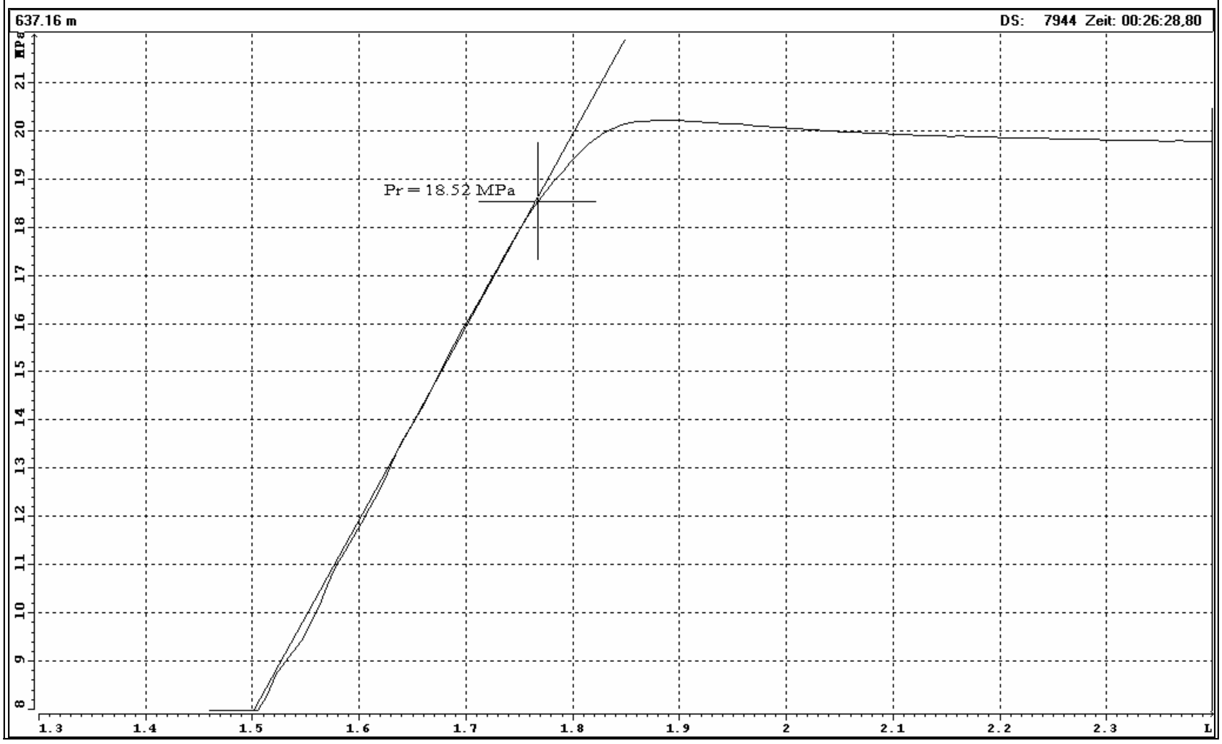
total injected volume (l): 12.3 recovered volume (l): 3.55 or 28.9 %

- Initial test type: HTPF-v
- The frac - cycle is characterized by the stimulation of a pre-existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

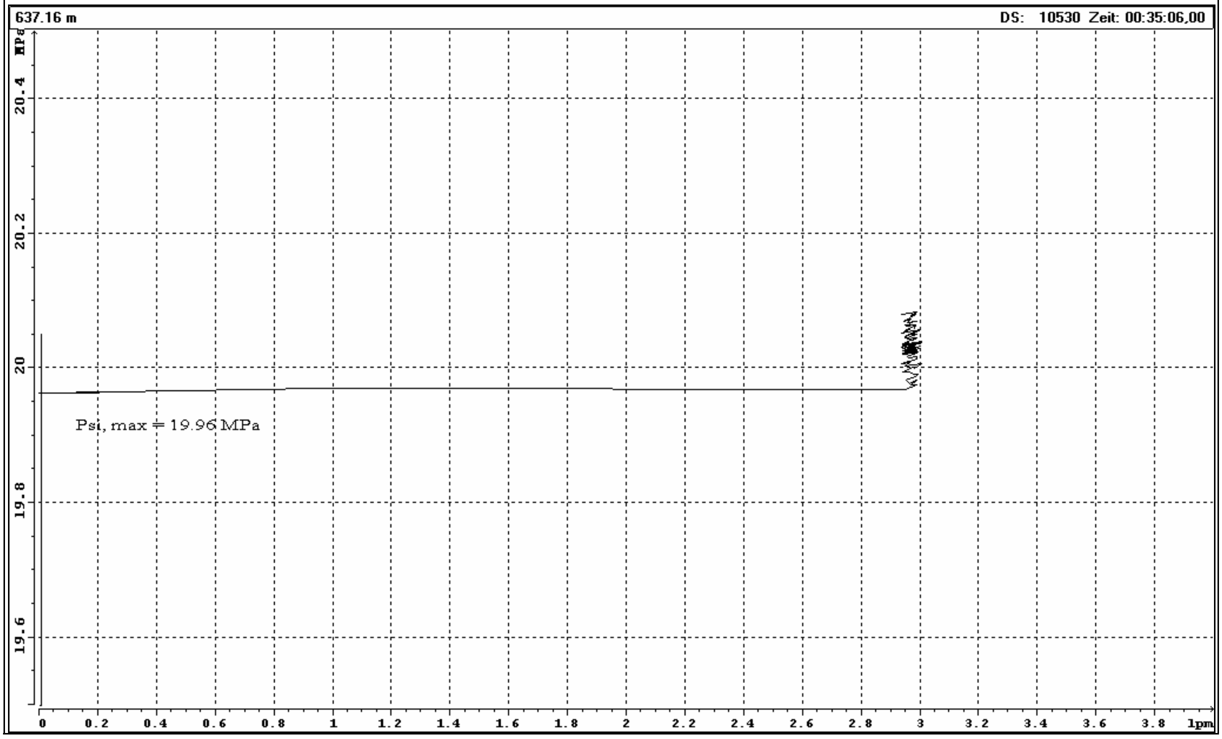
Test at 637.16 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



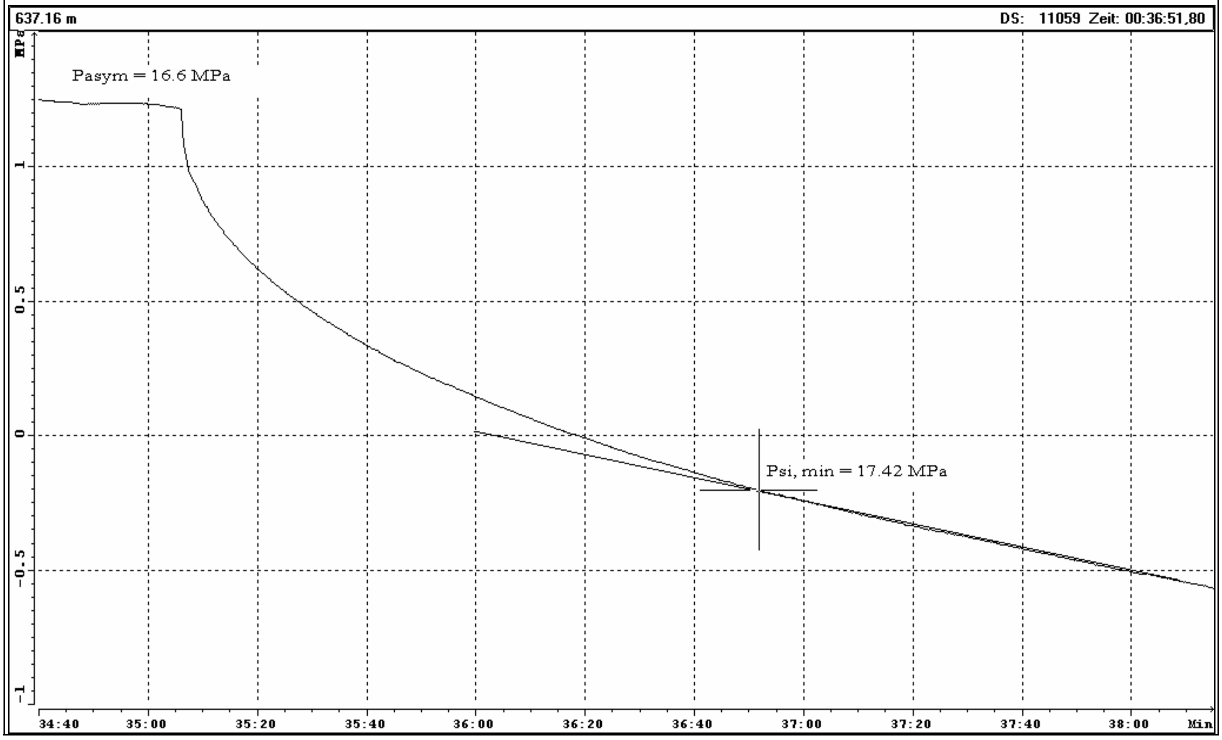
Test at 637.16 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



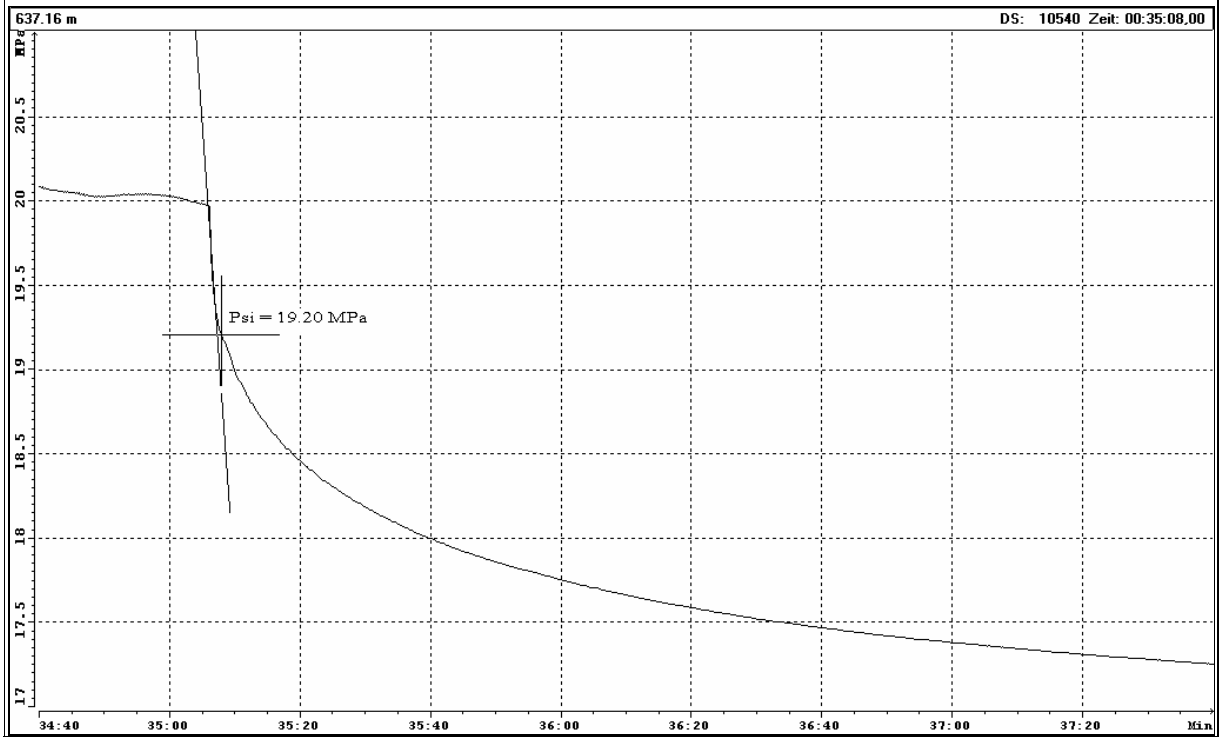
Test at 637.16 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



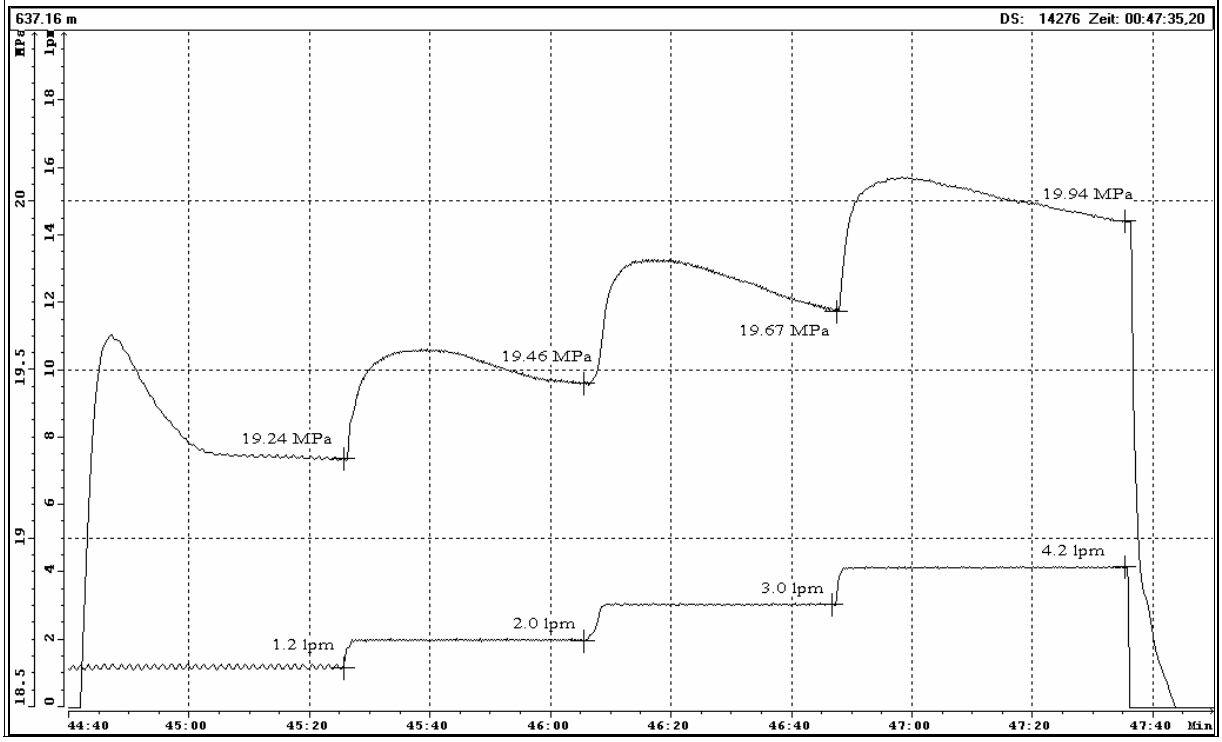
Test at 637.16 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



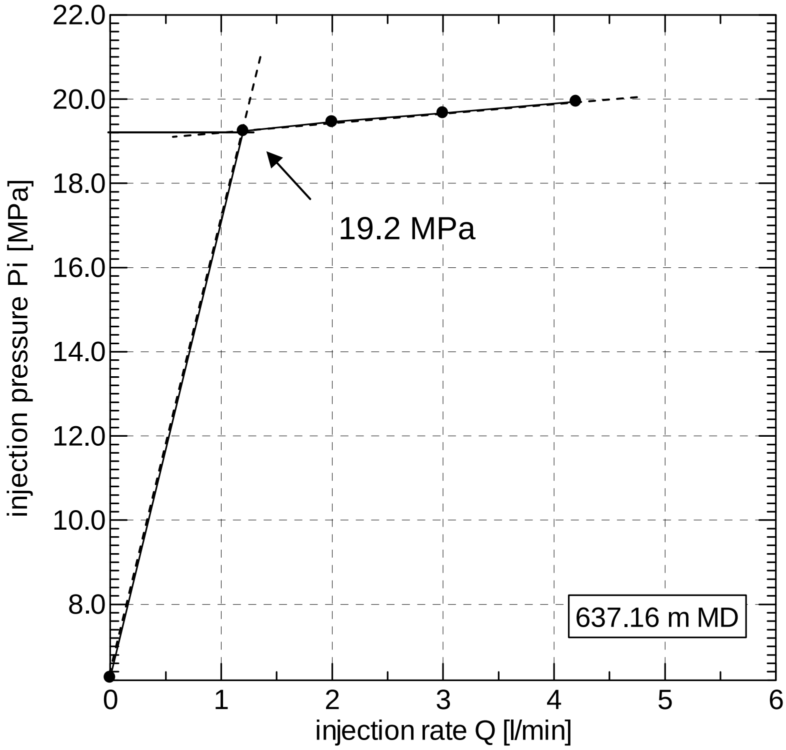
Test at 637.16 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 637.16 m MD: Analysis of Slow - Pump / Step - Rate - Test

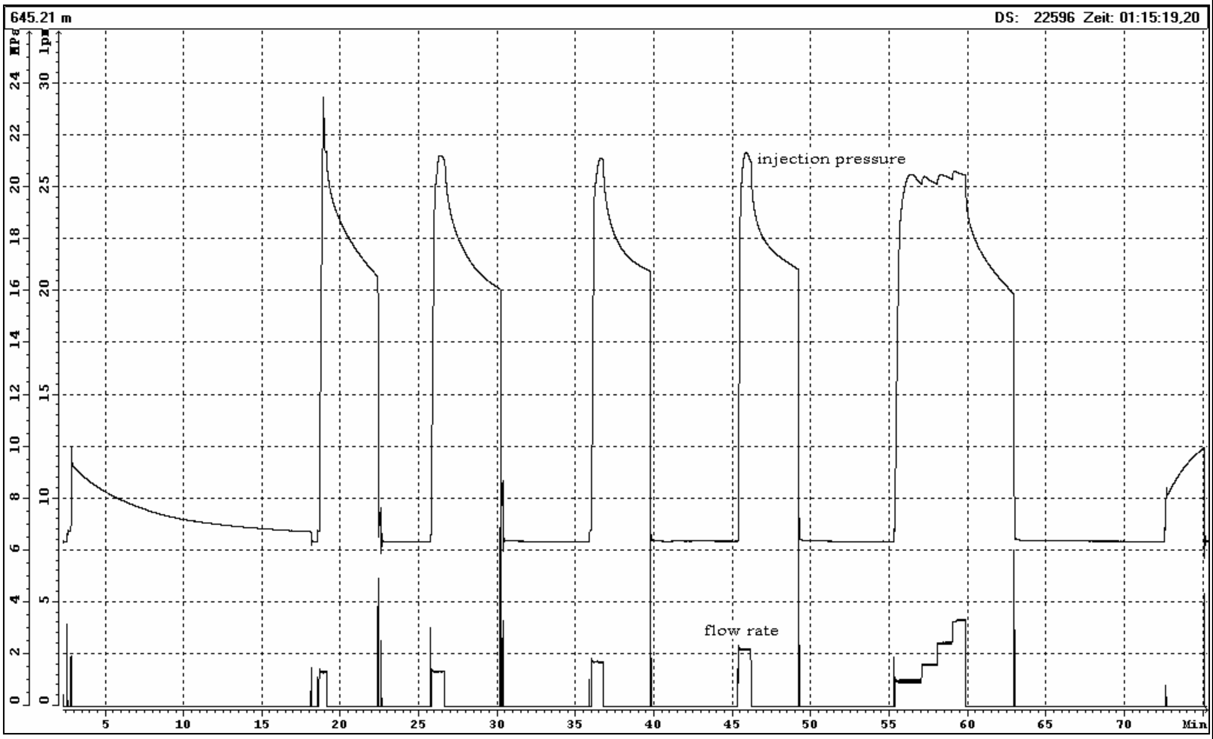


Test at 637.16 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 7 AT 645.21 m MD / 642.47 m TVD

Test at 645.21 m MD: Overview - Plot



1. P - Test Frac 1. Refrac 2. Refrac 3. Refrac SP / SR - Test 2. P-Test

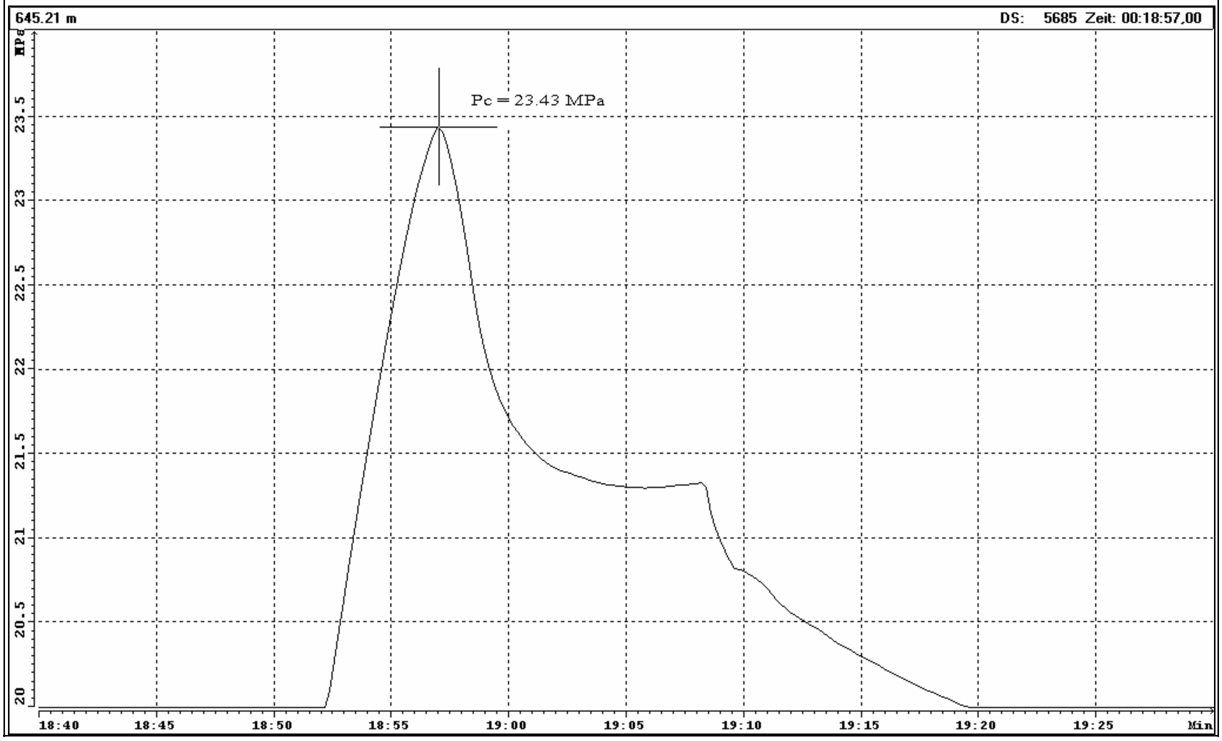
TEST SUMMARY / ANALYSIS / REMARKS

1. P - Test :	pressure decrease: 1.27 MPa in 935 sec.			
2. P - Test :	pressure increase due to the back-flow from the stimulated fracture			
Frac - cycle	Qi (lpm) = 1.7	Vi (l) = 0.8	Vr (l) = 0.4	
1. Refrac - cycle	Qi (lpm) = 1.7	Vi (l) = 1.5	Vr (l) = 0.8	
2. Refrac - cycle	Qi (lpm) = 2.1	Vi (l) = 1.6	Vr (l) = 1.1	
3. Refrac - cycle	Qi (lpm) = 2.7	Vi (l) = 2.3	Vr (l) = 1.3	
SP/SR - test	Qi (lpm) = 1.2-4.1	Vi (l) = 10.4	Vr (l) = 1.8	

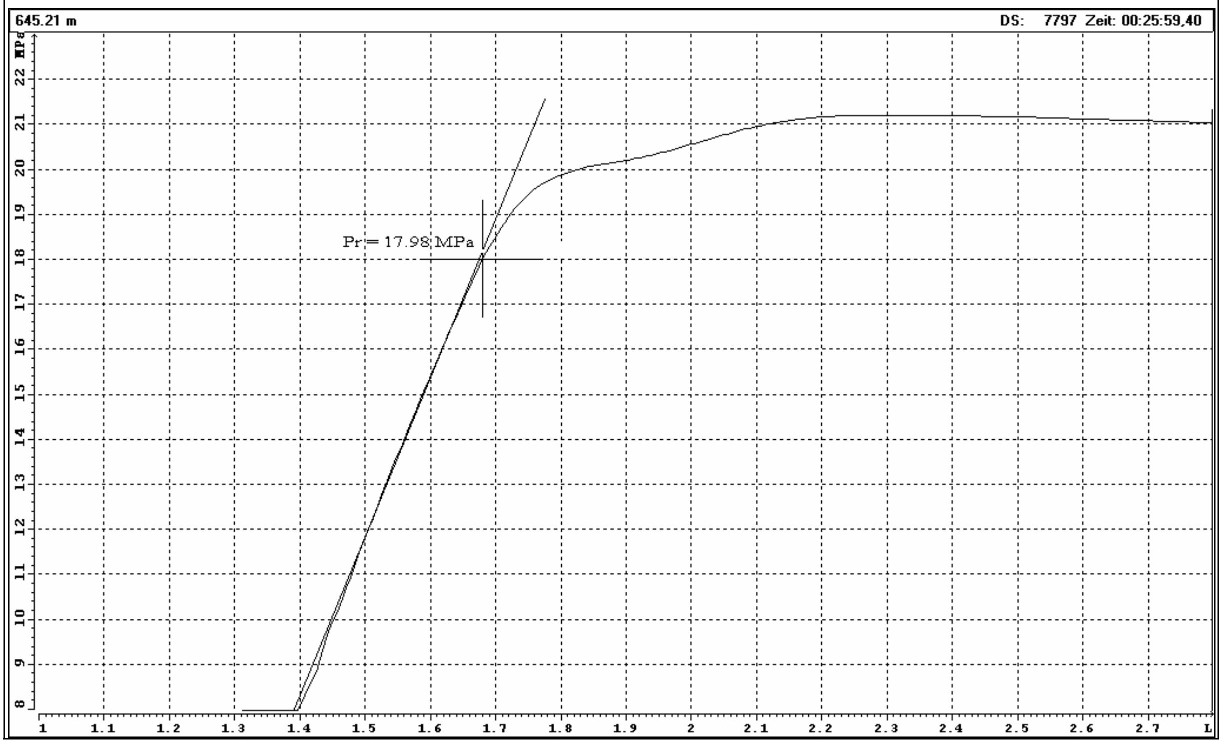
total injected volume (l): 16.6 recovered volume (l): 5.4 or 32.5 %

- Initial test type: HTPF-h
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture (weak breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV at 18 MPa, followed by a pressure increase up to 21.2 MPa. The subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

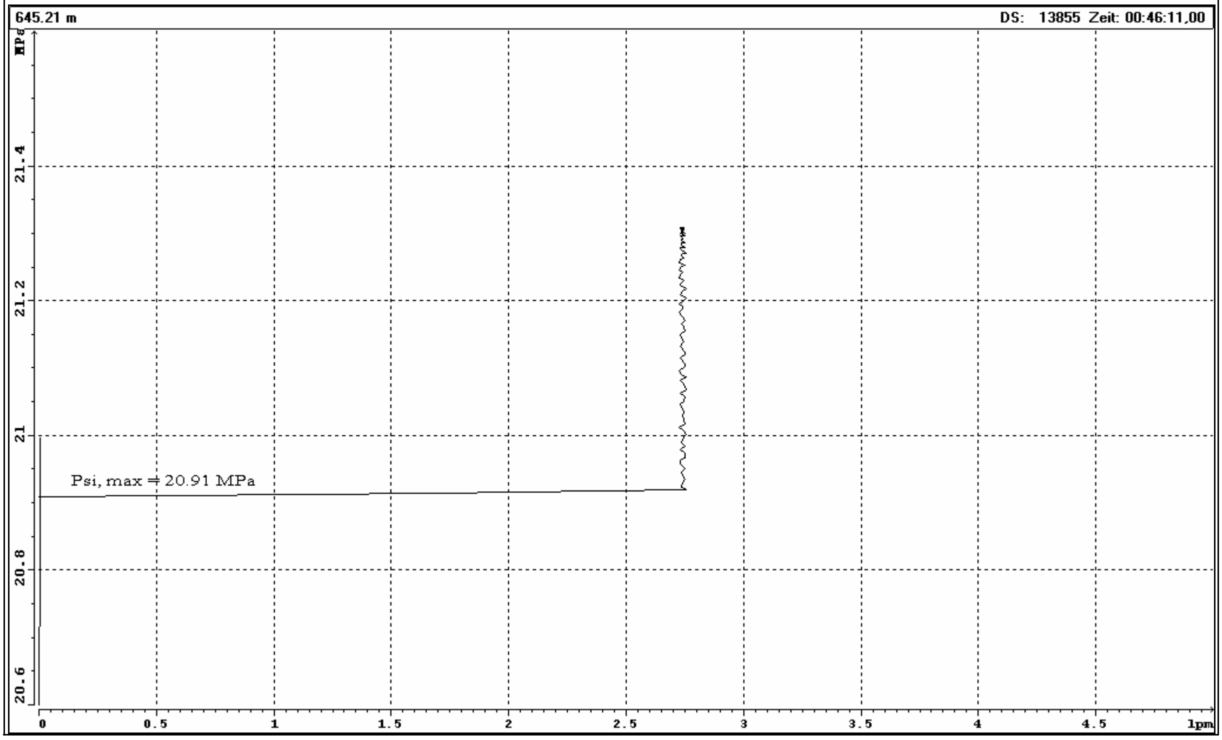
Test at 645.21 m MD: Estimation of P_c (Frac - Cycle)



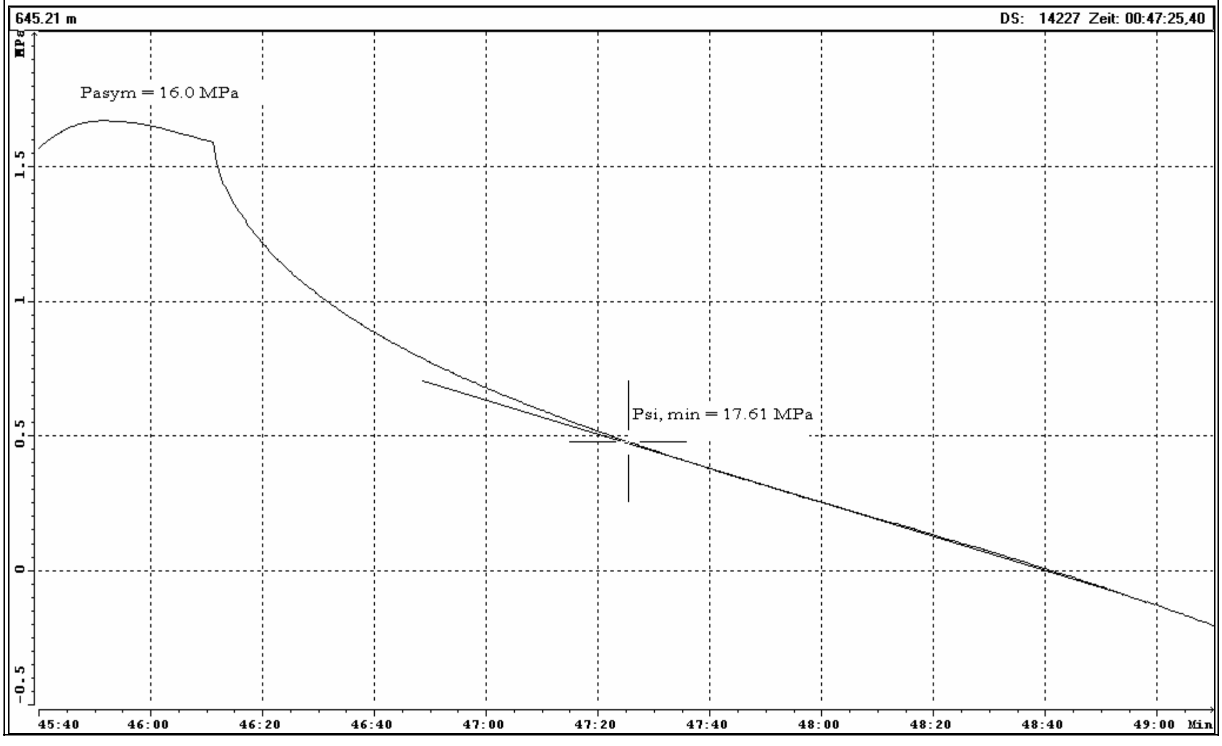
Test at 645.21 m MD: Estimation of P_r (1. Refrac - Cycle)



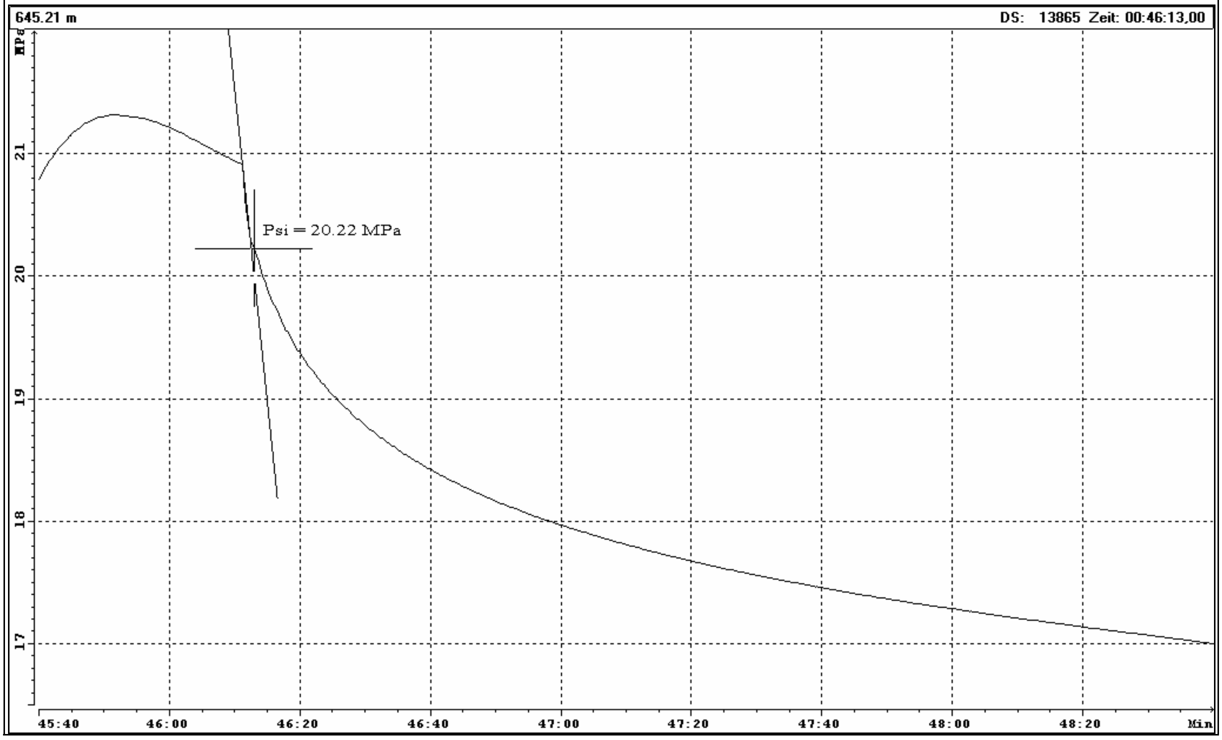
Test at 645.21 m MD: Estimation of $P_{si,\,max}$ (3. Refrac - Cycle)



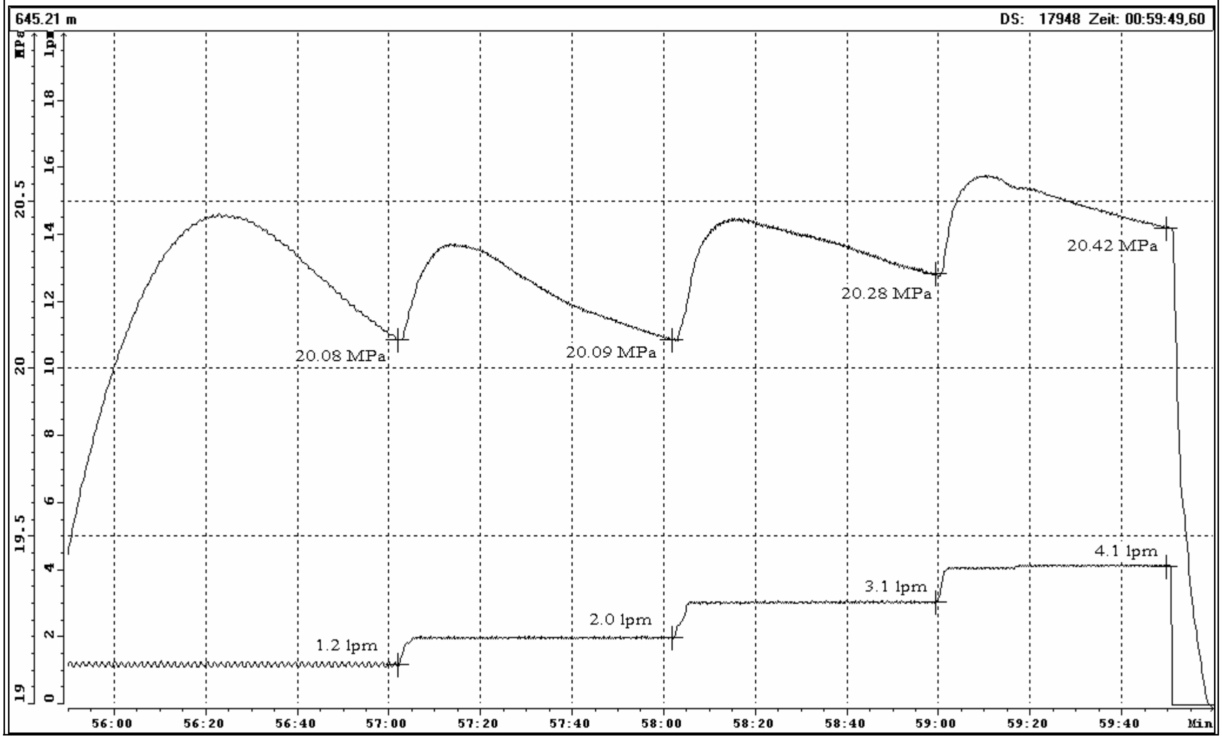
Test at 645.21 m MD: Estimation of $P_{si,\,min}$ (3. Refrac - Cycle)



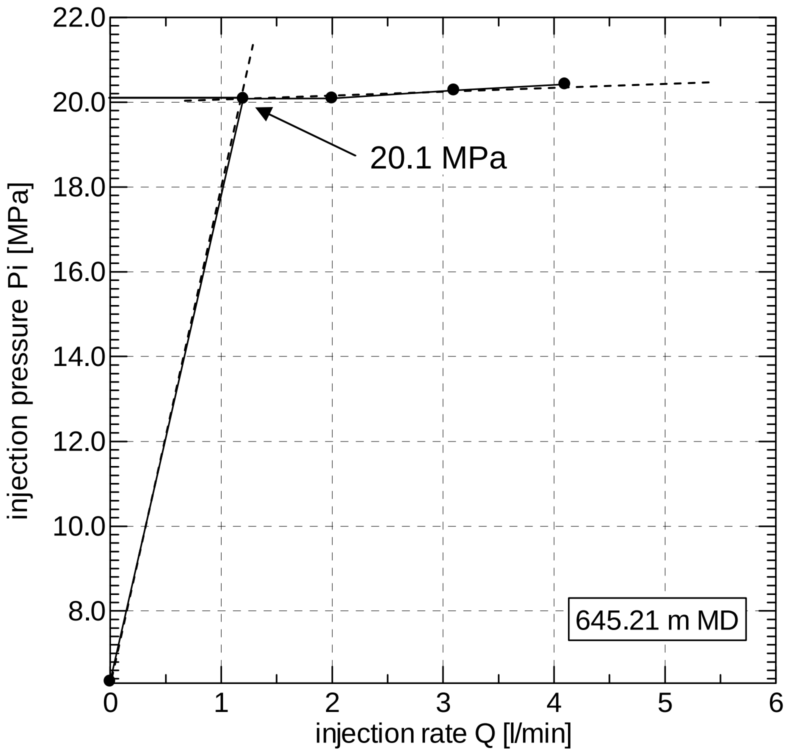
Test at 645.21 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 645.21 m MD: Analysis of Slow - Pump / Step - Rate - Test

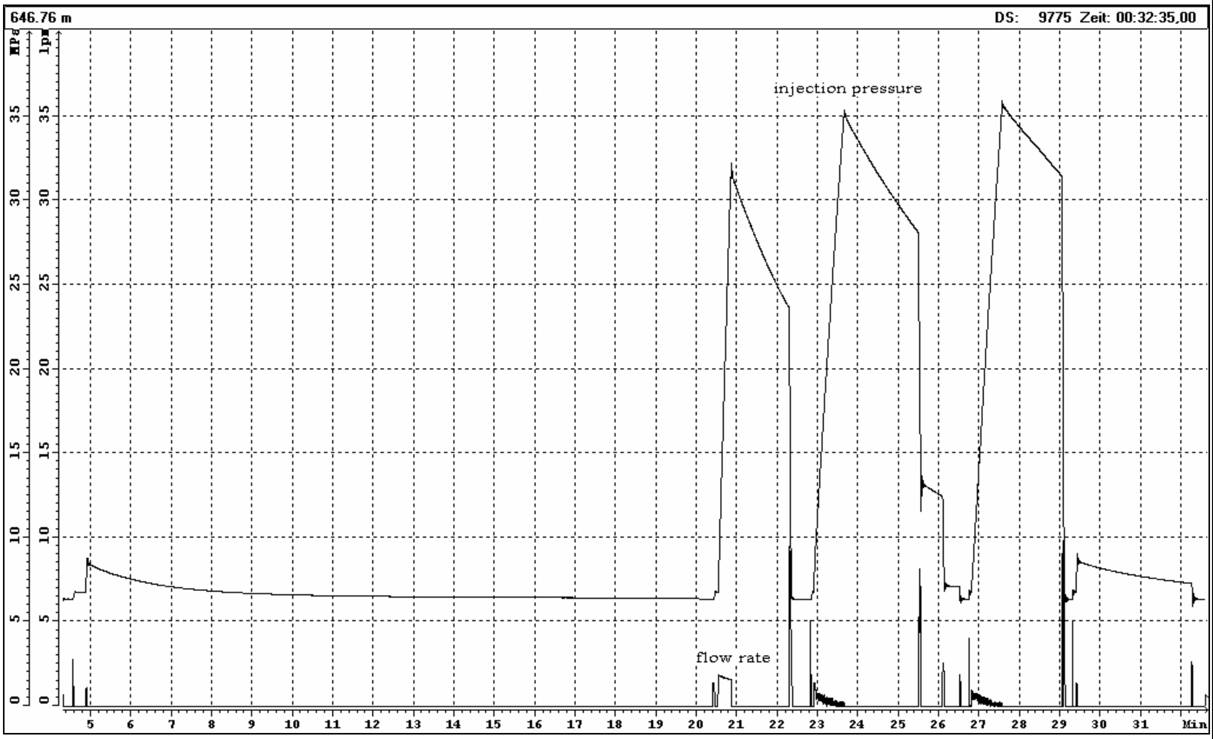


Test at 645.21 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 6 AT 646.76 m MD / 644.0 m TVD

Test at 646.76 m MD: Overview - Plot



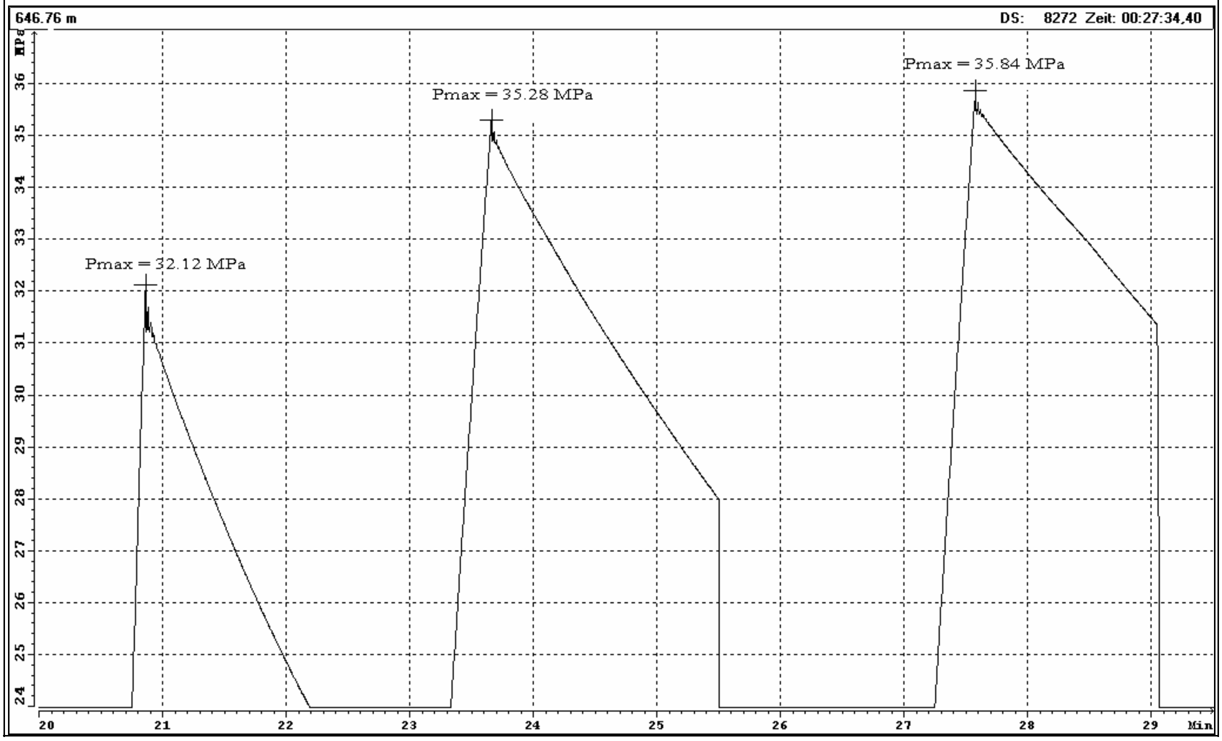
1. P - Test 1. Frac 2. Frac 3. Frac 2. P - Test

<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

1. P - Test :	pressure decrease: 1.97 MPa in 901 sec.				
2. P - Test :	pressure decrease: 1.20 MPa in 162 sec.				
1. Frac - cycle	Qi (lpm) = 1.7	Vi (l) =	0.6	Vr (l) =	0.4
2. Frac - cycle	Qi (lpm) < 0.7	Vi (l) =		Vr (l) =	0.3
3. Frac - cycle	Qi (lpm) < 0.7	Vi (l) =		Vr (l) =	0.5

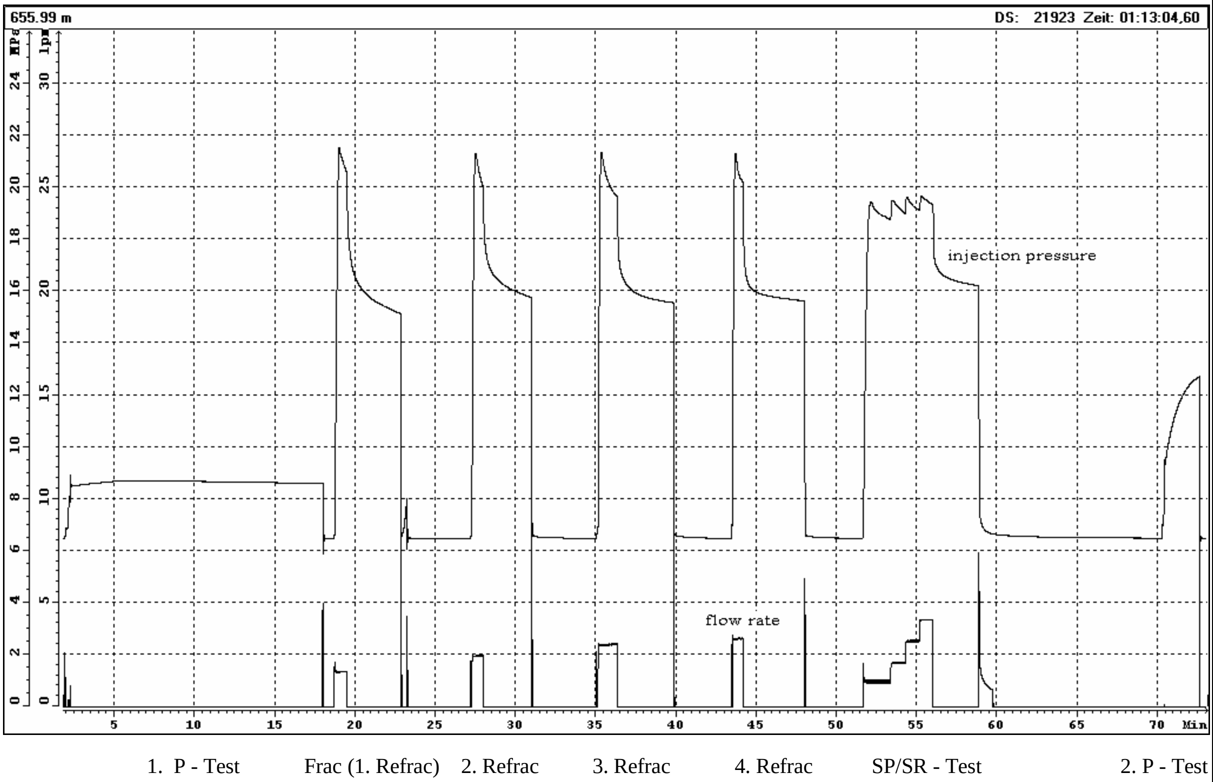
- Initial test type: HTPF-v
- During the 1., 2., and 4. frac cycle, the injection was stopped at pressures of 32.1, 35.3 and 35.8 MPa, respectively. Although the test - section contains a pre-existing fracture, no breakdown event was observed during the frac -attempts. Therefore, the test was abandoned to prevent a damage of the packer elements.

Test at 646.76 m MD: Estimation of P_{max} (1. , 2., and 3. Frac - Cycle)



TEST NO. 5 AT 655.99 m MD / 653.16 m TVD

Test at 655.99 m MD : Overview - Plot



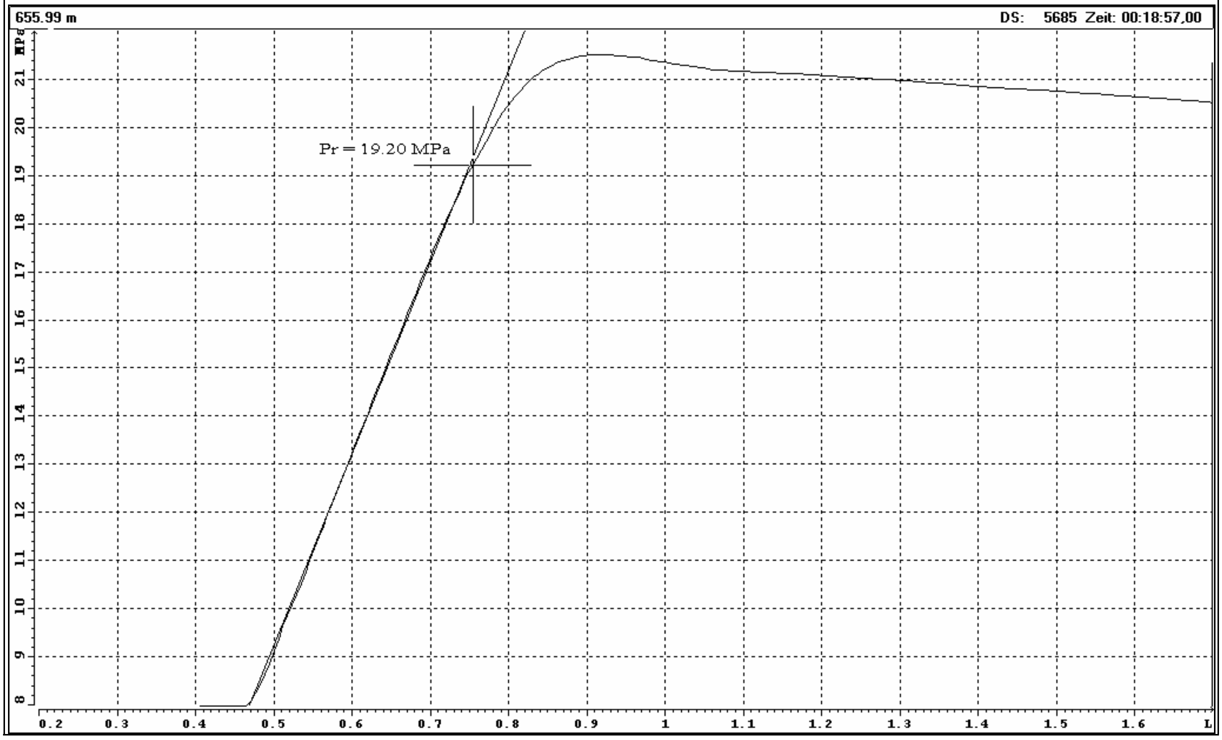
TEST SUMMARY / ANALYSIS / REMARKS

1. P - Test :	pressure increase of 0.19 MPa in 231 sec., followed by a pressure decrease of 0.10 MPa in 703 sec.		
2. P - Test :	pressure increase due to the back-flow from the stimulated fracture		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.7	Vi (l) = 1.4	Vr (l) = 0.55
2. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 1.9	Vr (l) = 1.1
3. Refrac - cycle	Qi (lpm) = 3.0	Vi (l) = 3.7	Vr (l) = 1.5
4. Refrac - cycle	Qi (lpm) = 3.3	Vi (l) = 2.2	Vr (l) = 1.5
SP/SR - test	Qi (lpm) = 1.2-4.2	Vi (l) = 10.3	Vr (l) = 5.1

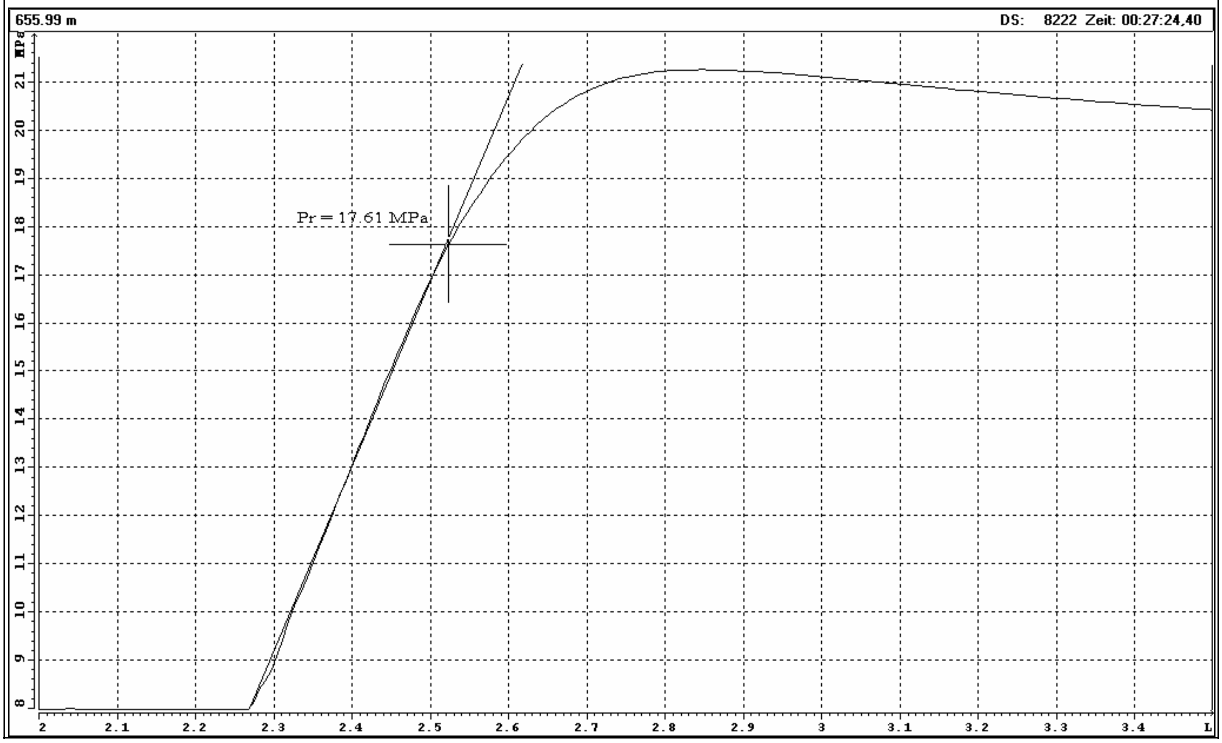
total injected volume (l): 19.5 recovered volume (l): 9.75 or 50.0 %

- Initial test type: HTPF-v
- The frac - cycle is characterized by the stimulation of a pre-existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

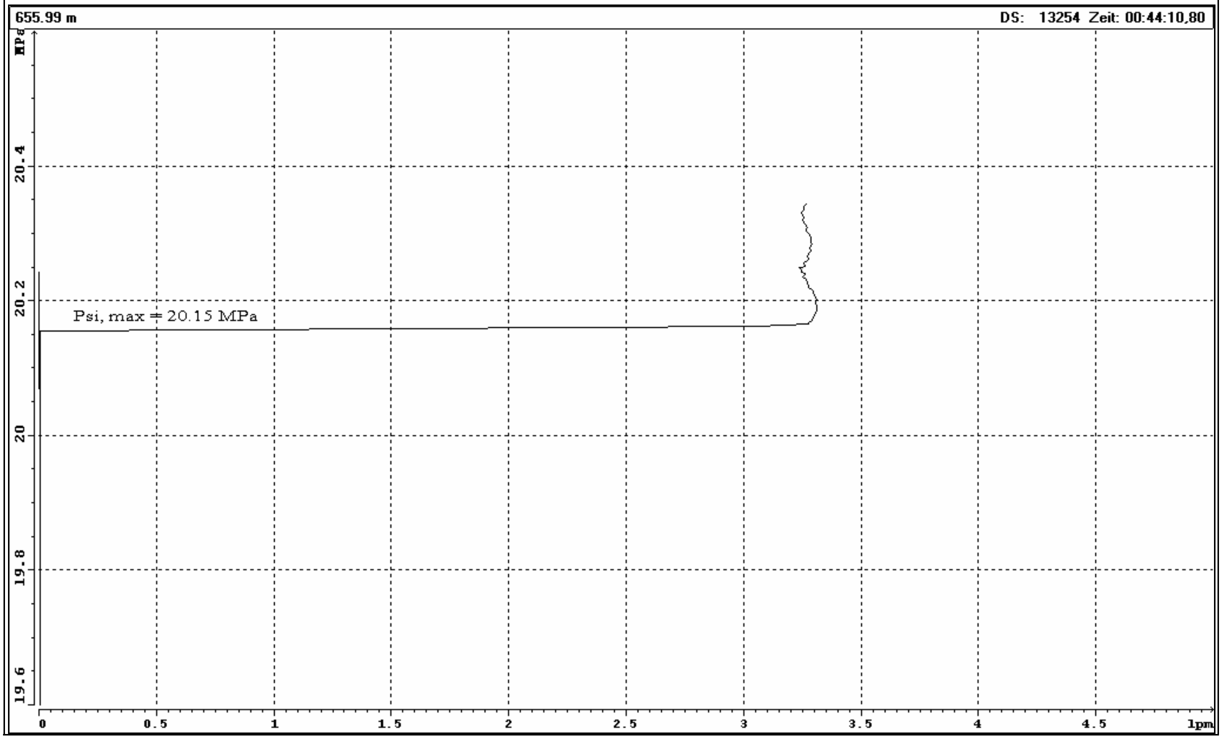
Test at 655.99 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



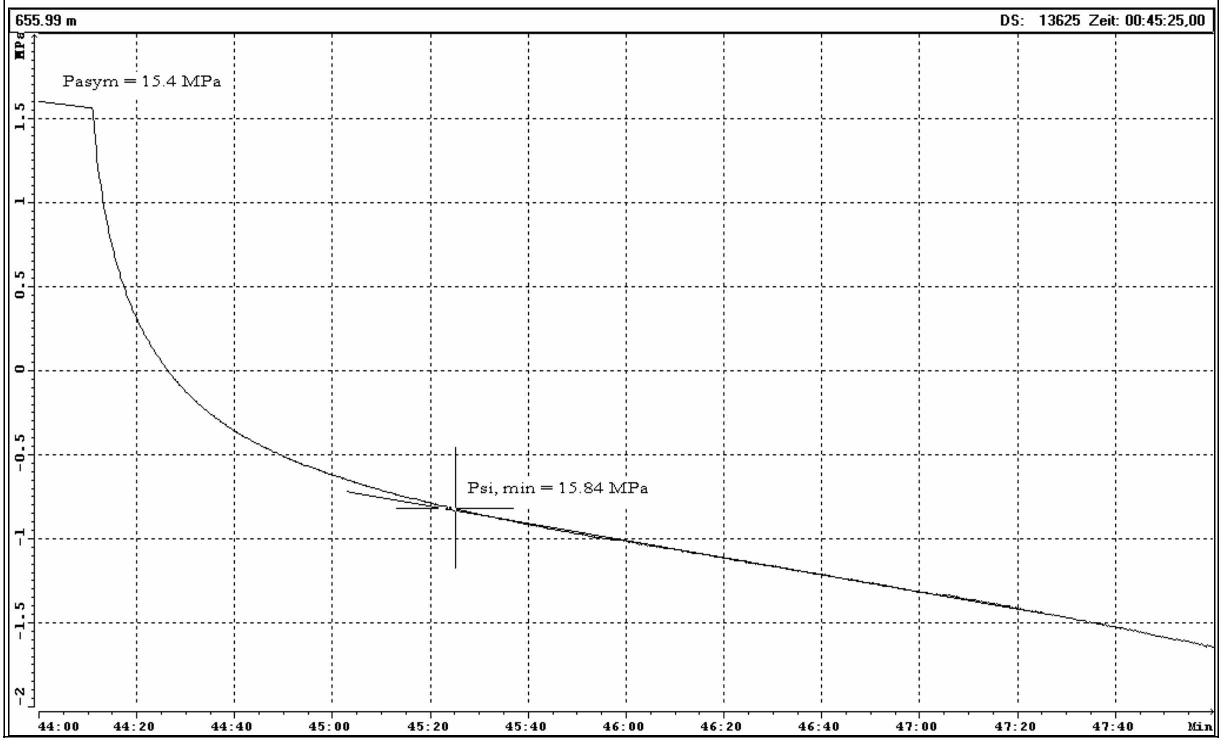
Test at 655.99 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



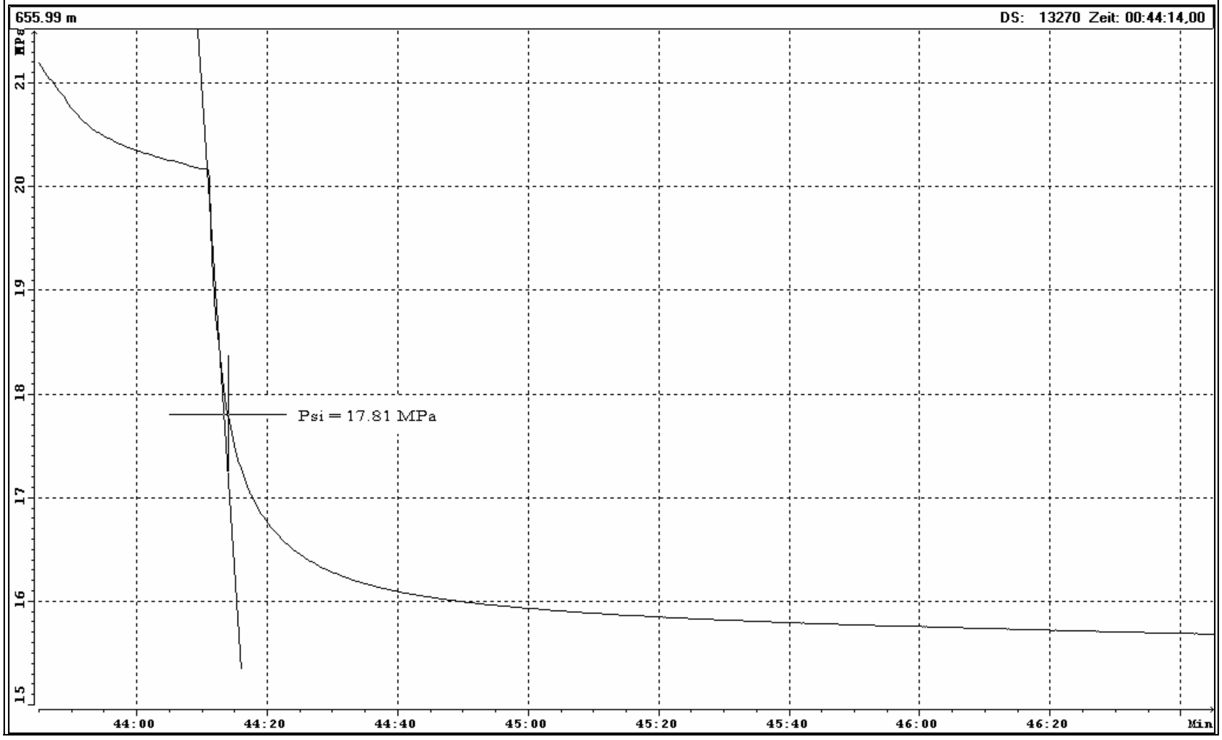
Test at 655.99 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



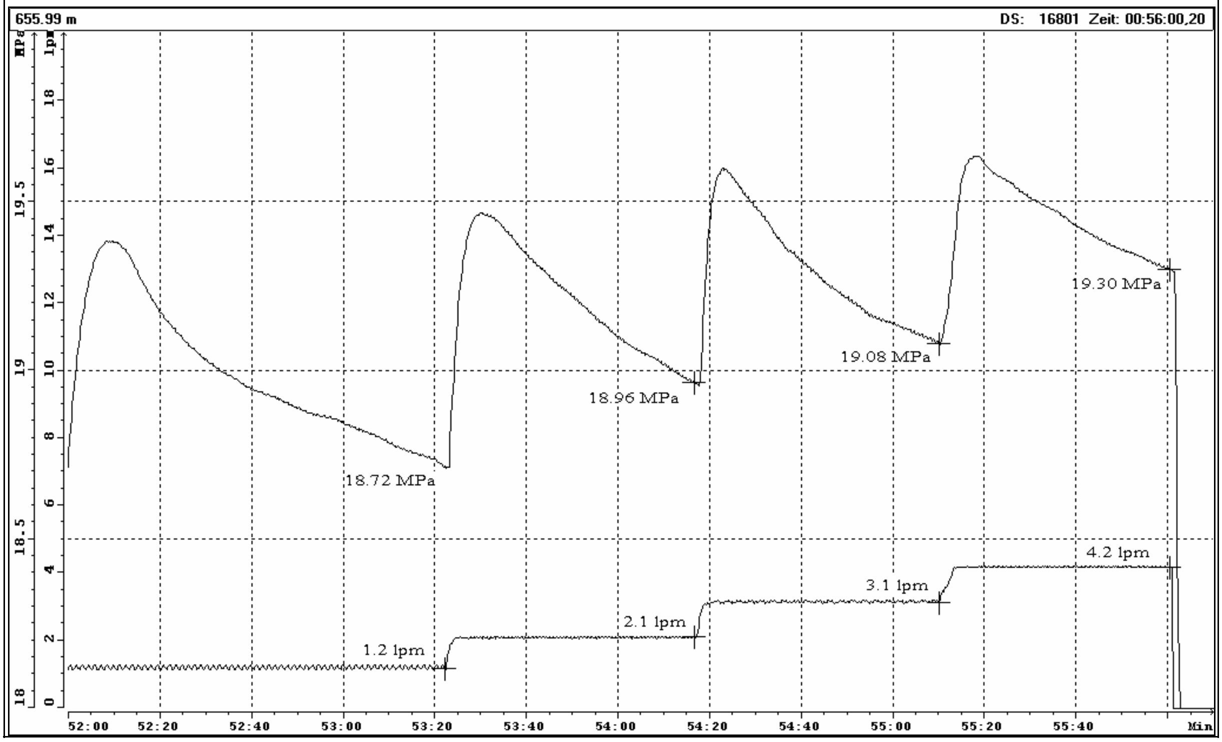
Test at 655.99 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



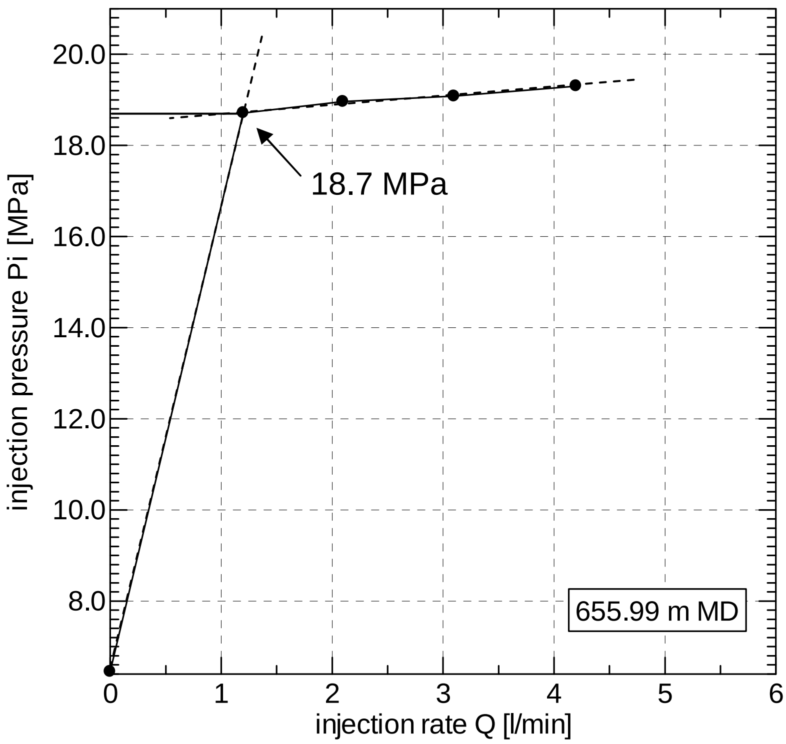
Test at 655.99 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 655.99 m MD: Analysis of Slow - Pump / Step - Rate - Test

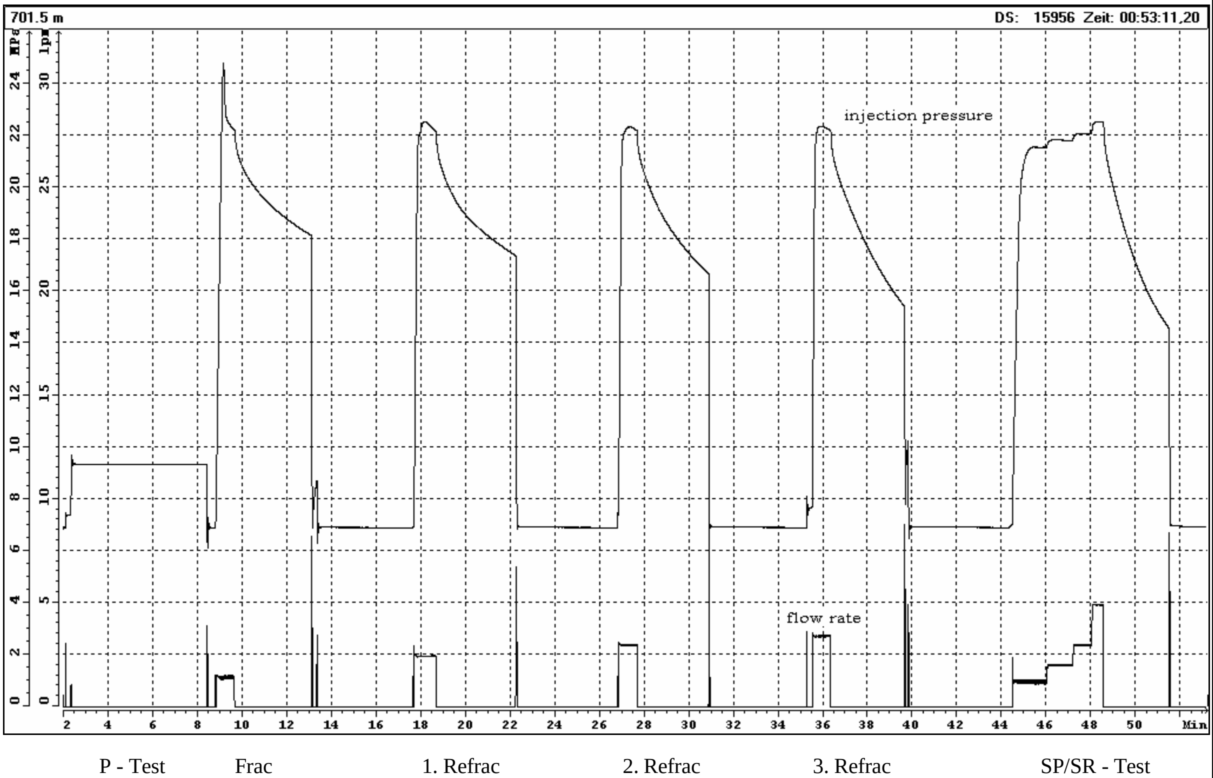


Test at 655.99 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 4 AT 701.5 m MD / 698.30 m TVD

Test at 701.5 m MD : Overview - Plot



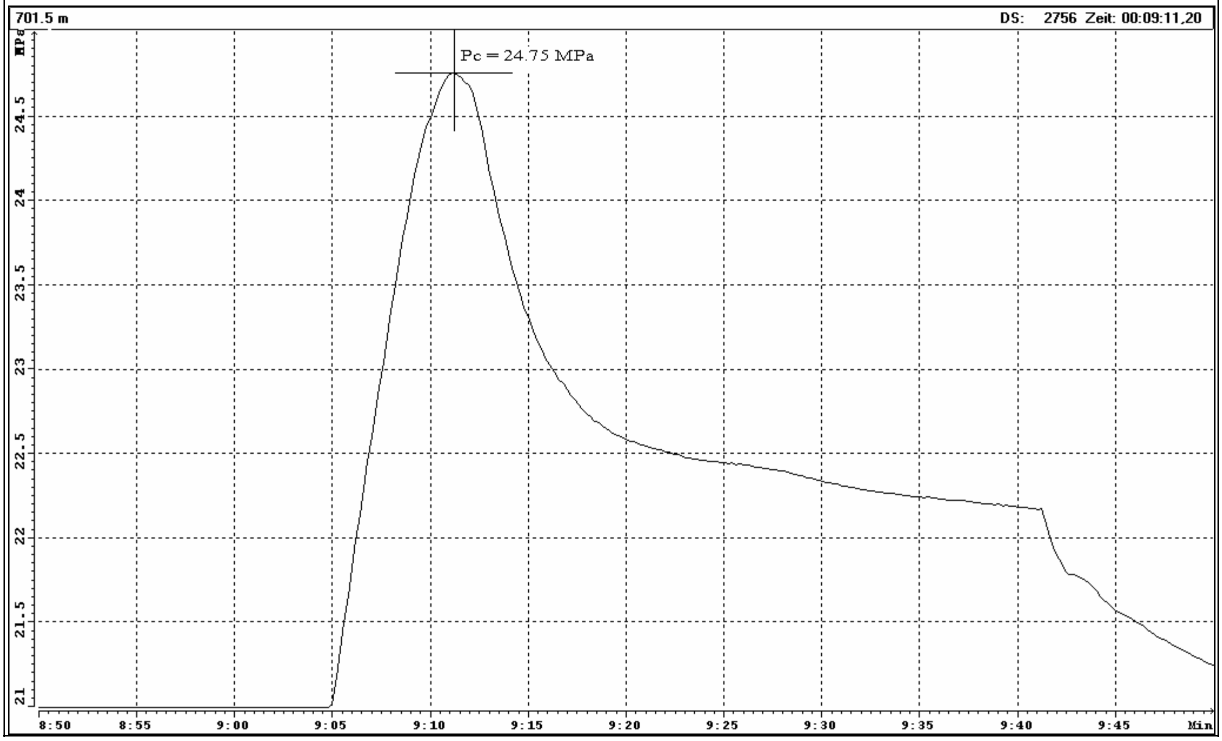
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.03 MPa in 357 sec.		
Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.2	Vr (l) = 0.35
1. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 2.4	Vr (l) = 0.6
2. Refrac - cycle	Qi (lpm) = 2.9	Vi (l) = 2.4	Vr (l) = 0.6
3. Refrac - cycle	Qi (lpm) = 3.4	Vi (l) = 2.8	Vr (l) = 0.65
SP/SR - test	Qi (lpm) = 1.2-4.9	Vi (l) = 9.3	Vr (l) = 1.1

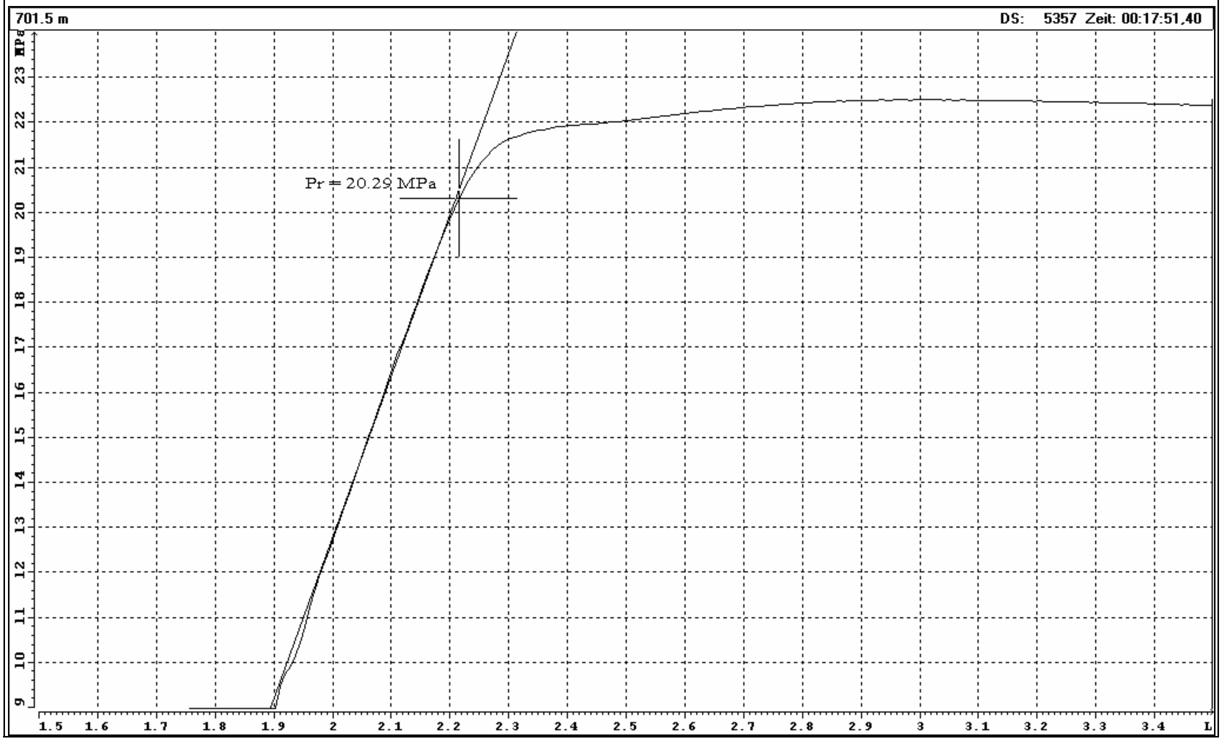
total injected volume (l): 18.1 recovered volume (l): 3.3 or 18.2 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture (weak breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV at 20.3 MPa, followed by a pressure increase up to 22.5 MPa. The subsequent refrac - cycles yield lower fracture re-opening pressure values.
- Although the pressure fall-off during the shut-in phases increases, the analysis yield consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

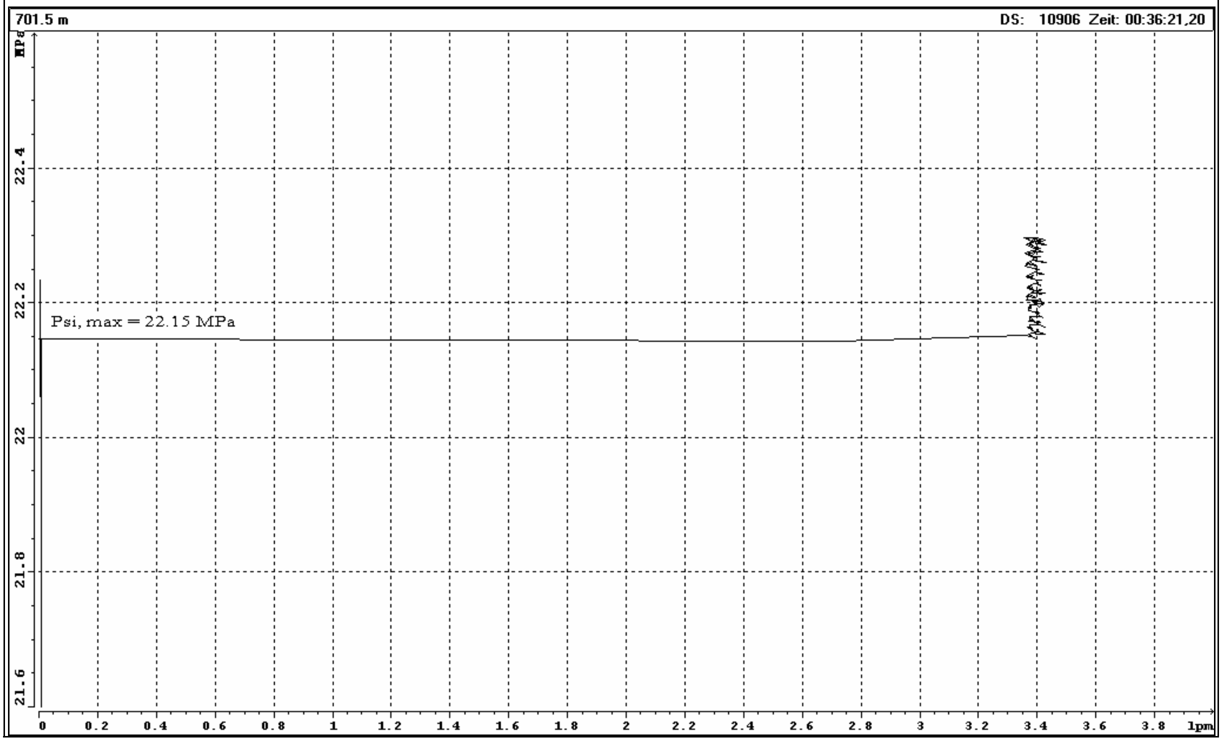
Test at 701.5 m MD: Estimation of P_c (Frac - Cycle)



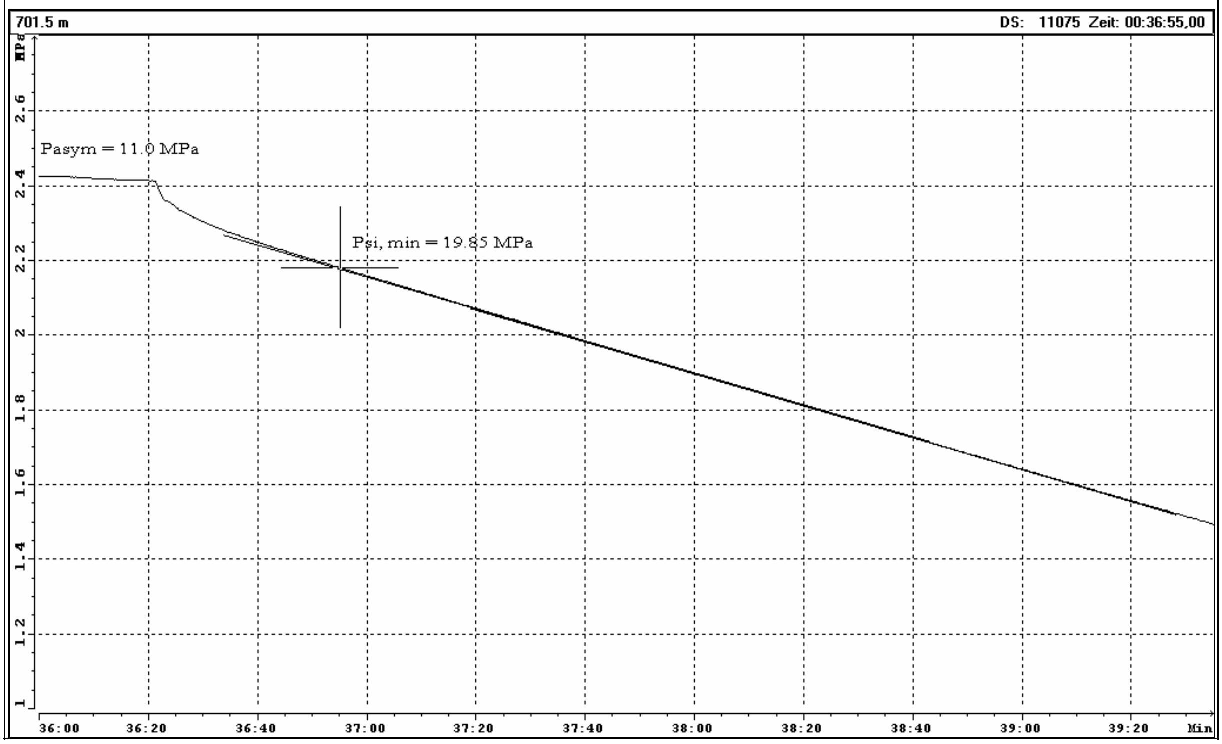
Test at 701.5 m MD: Estimation of P_r (1. Refrac - Cycle)



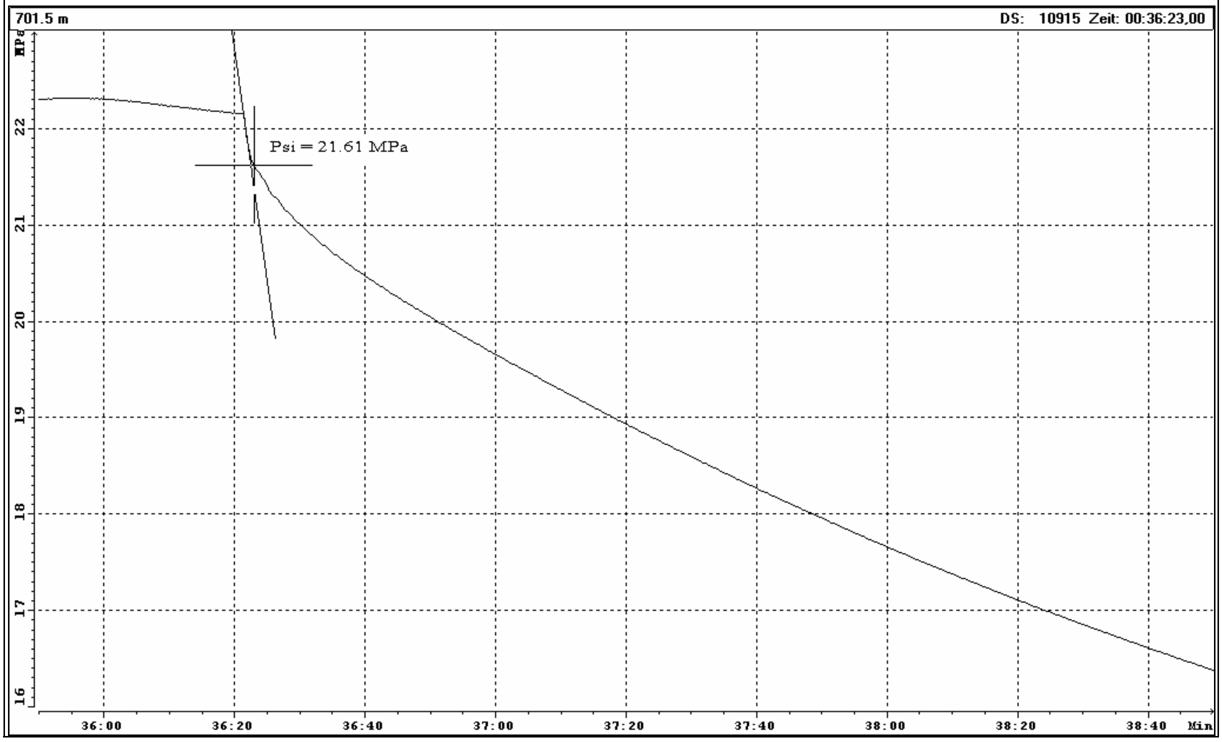
Test at 701.5 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



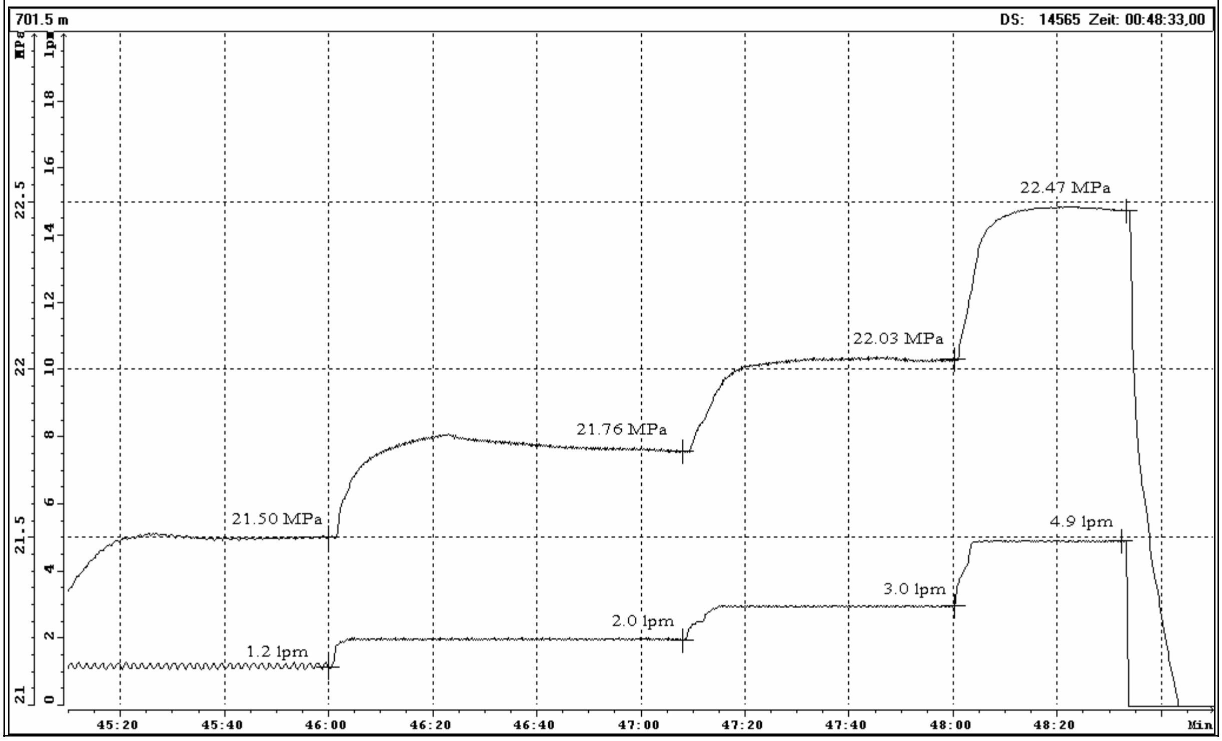
Test at 701.5 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



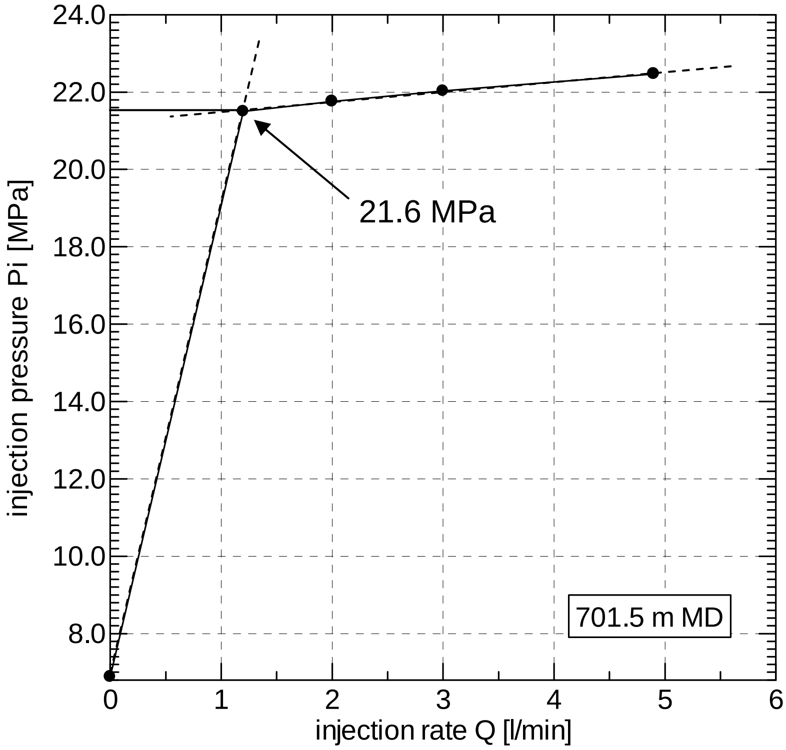
Test at 701.5 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 701.5 m MD: Analysis of Slow - Pump / Step - Rate - Test

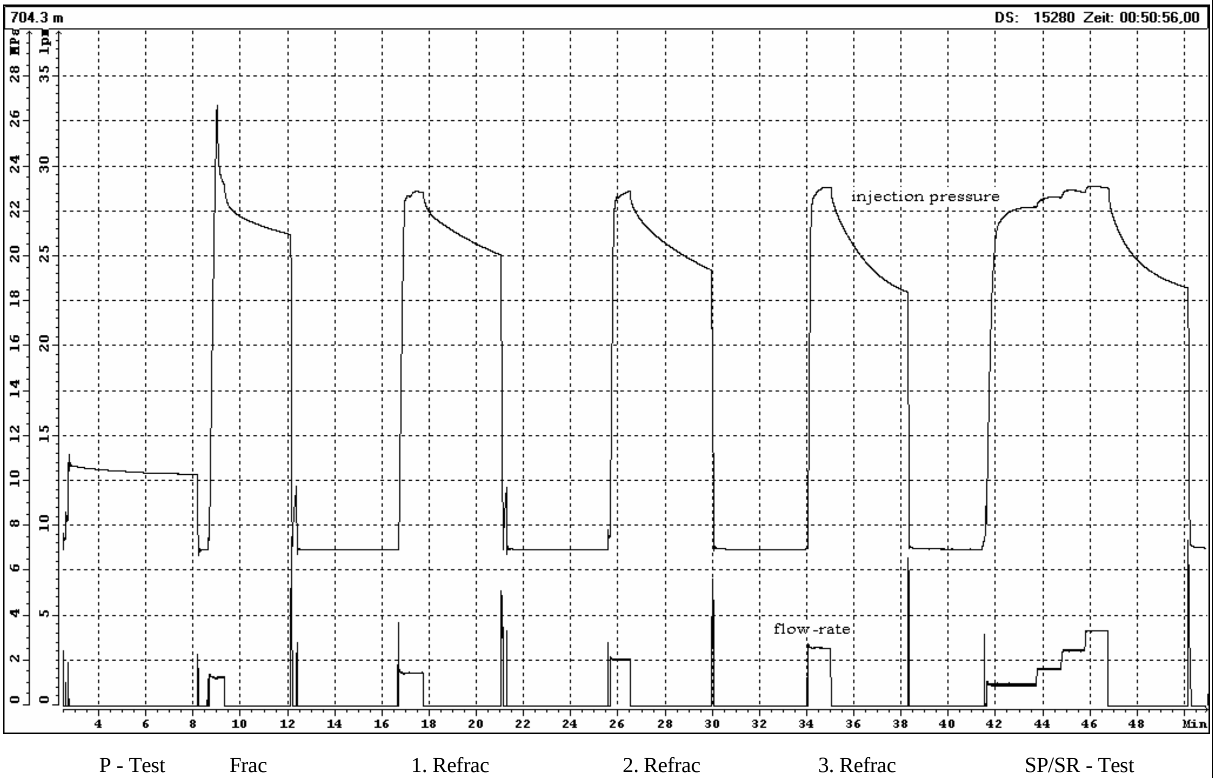


Test at 701.5 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 3 AT 704.3 m MD / 701.08 m TVD

Test at 704.3 m MD : Overview - Plot



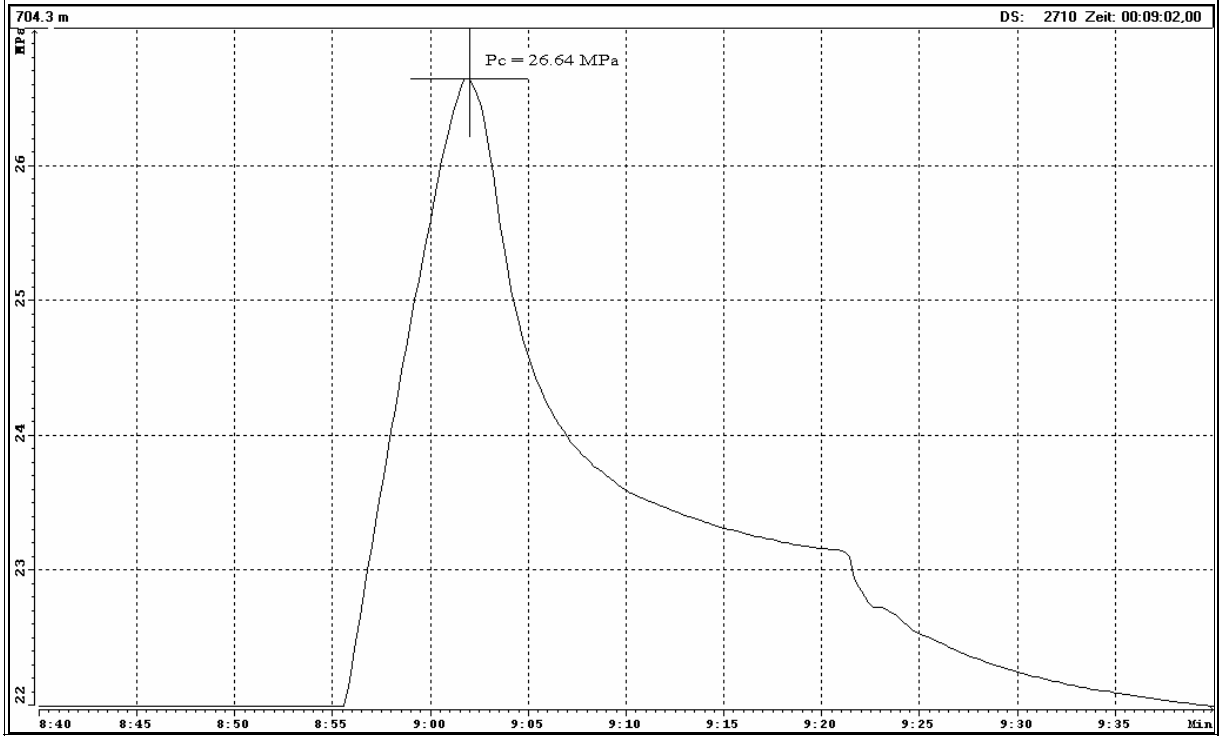
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.38 MPa in 319 sec.		
Frac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.05	Vr (l) = 0.7
1. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 1.9	Vr (l) = 0.85
2. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 2.2	Vr (l) = 0.9
3. Refrac - cycle	Qi (lpm) = 3.2	Vi (l) = 3.1	Vr (l) = 1.2
SP/SR - test	Qi (lpm) = 1.1-4.2	Vi (l) = 11.8	Vr (l) = 1.7

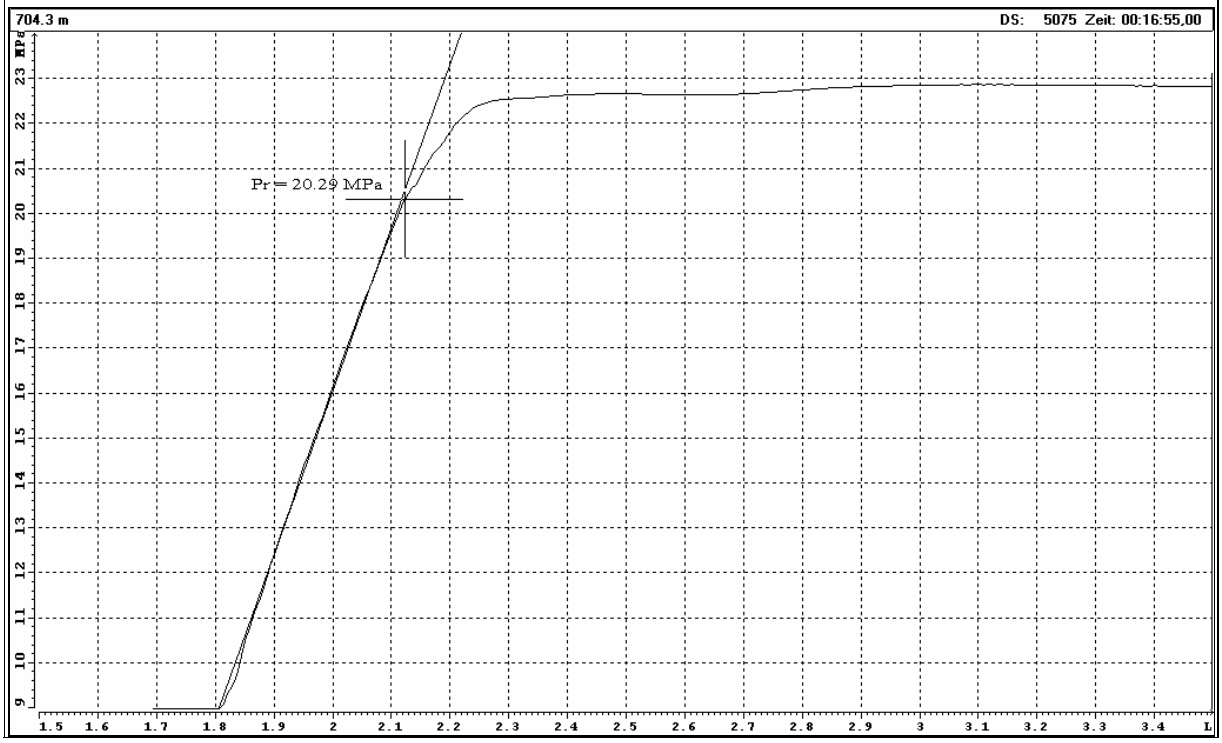
total injected volume (l): 20.05 recovered volume (l): 5.35 or 26.7 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV at 20.3 MPa, followed by a pressure increase up to 22.6 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield slightly lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

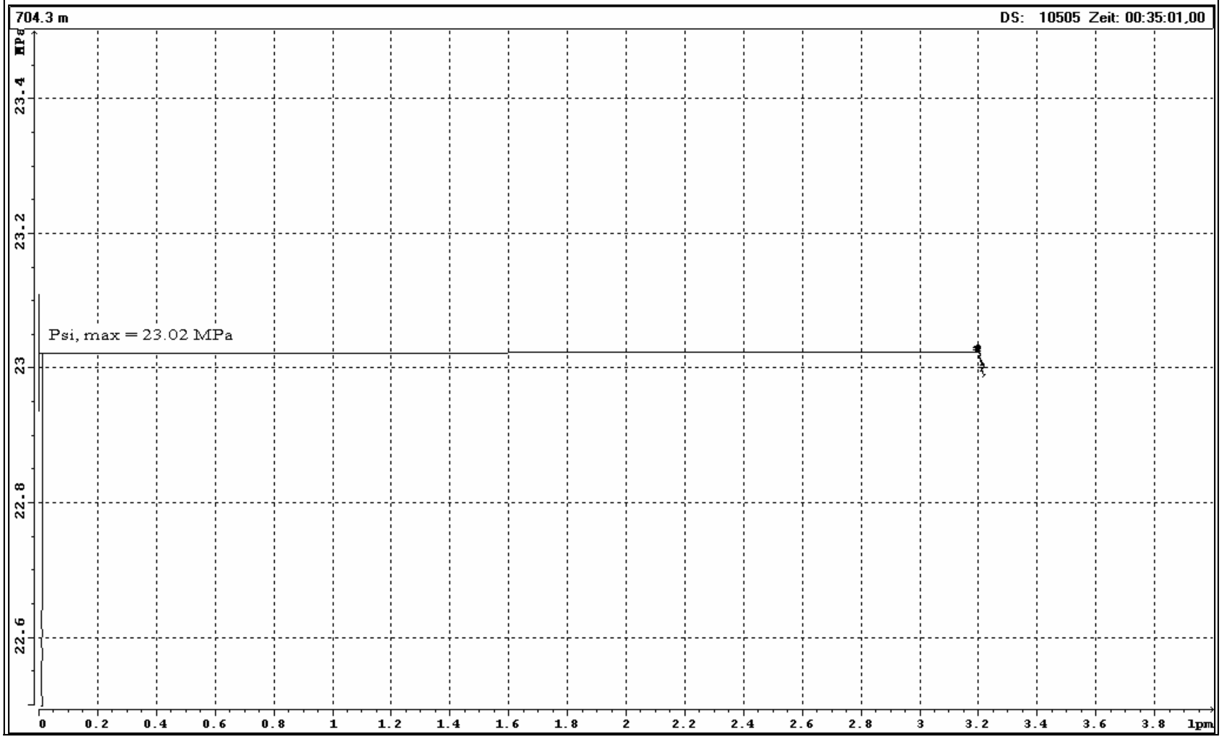
Test at 704.3 m MD: Estimation of P_c (Frac - Cycle)



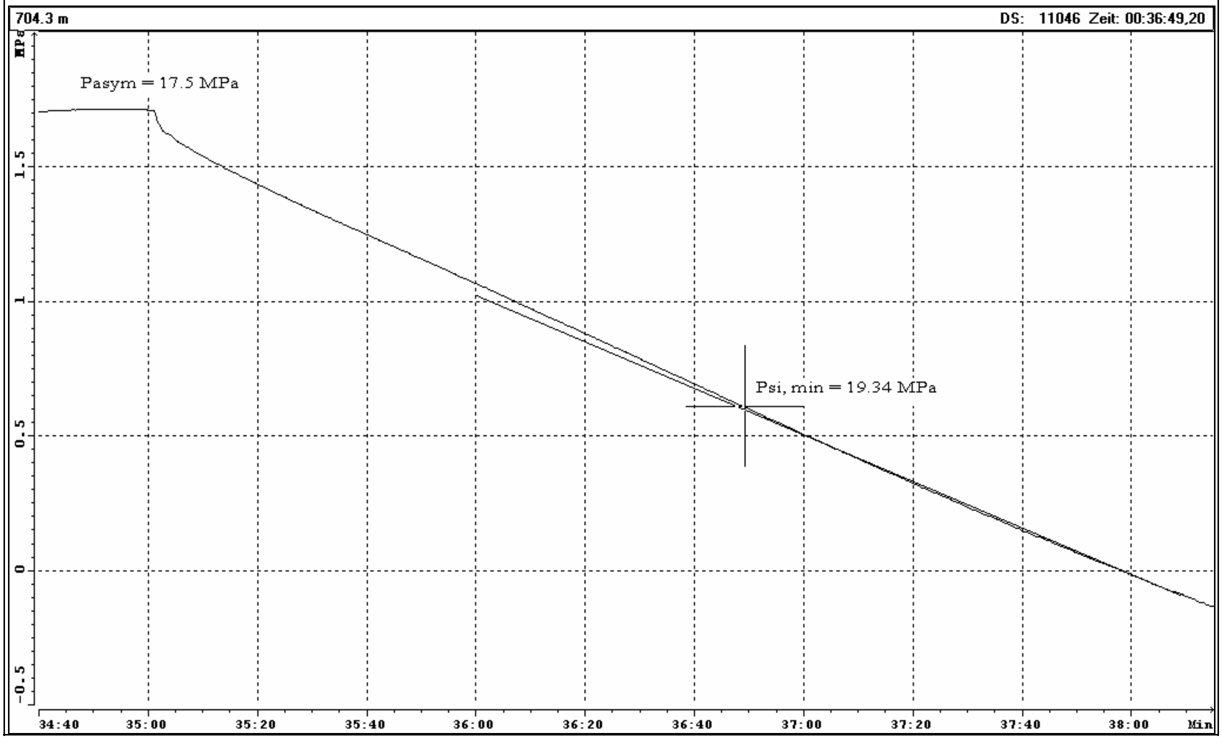
Test at 704.3 m MD: Estimation of P_r (1. Refrac - Cycle)



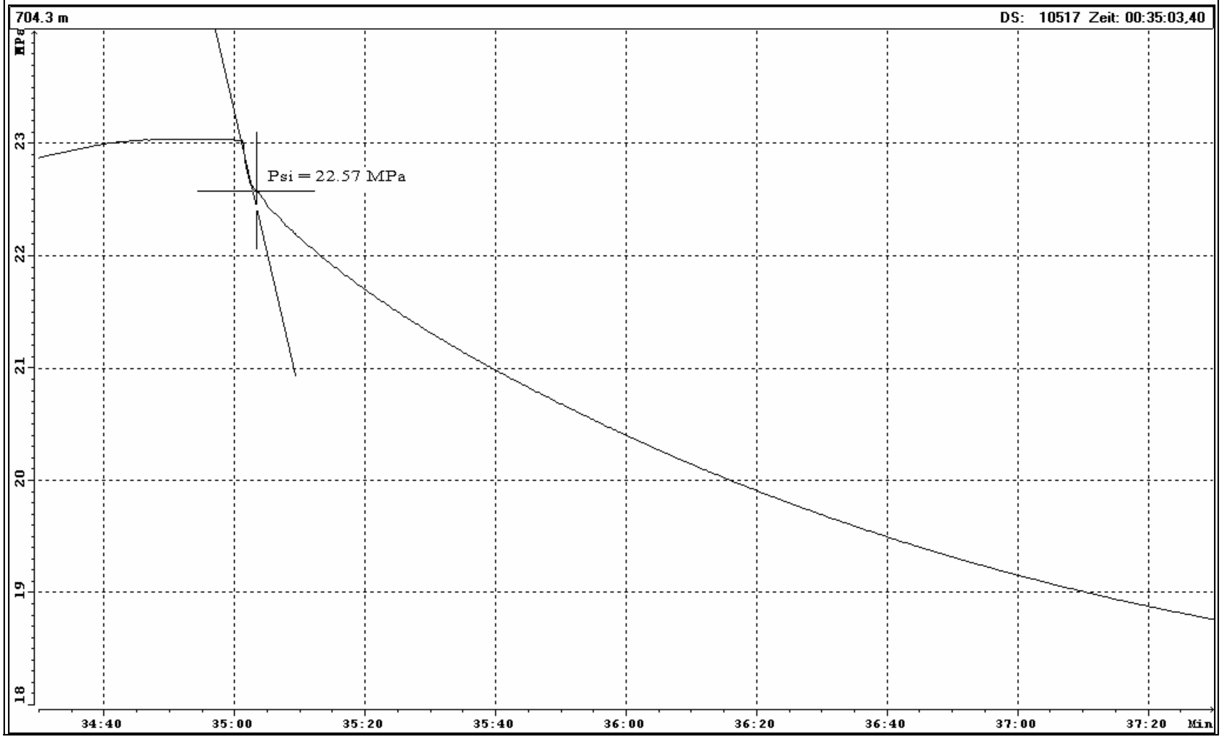
Test at 704.3 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



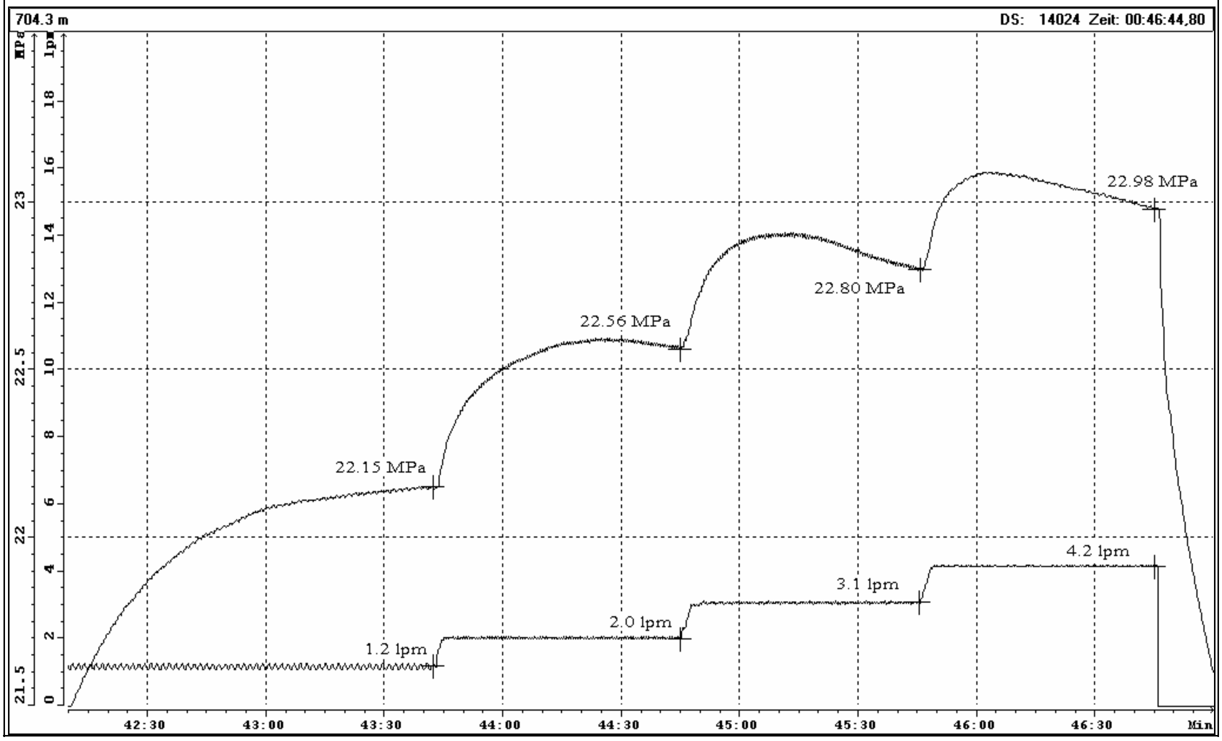
Test at 704.3 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



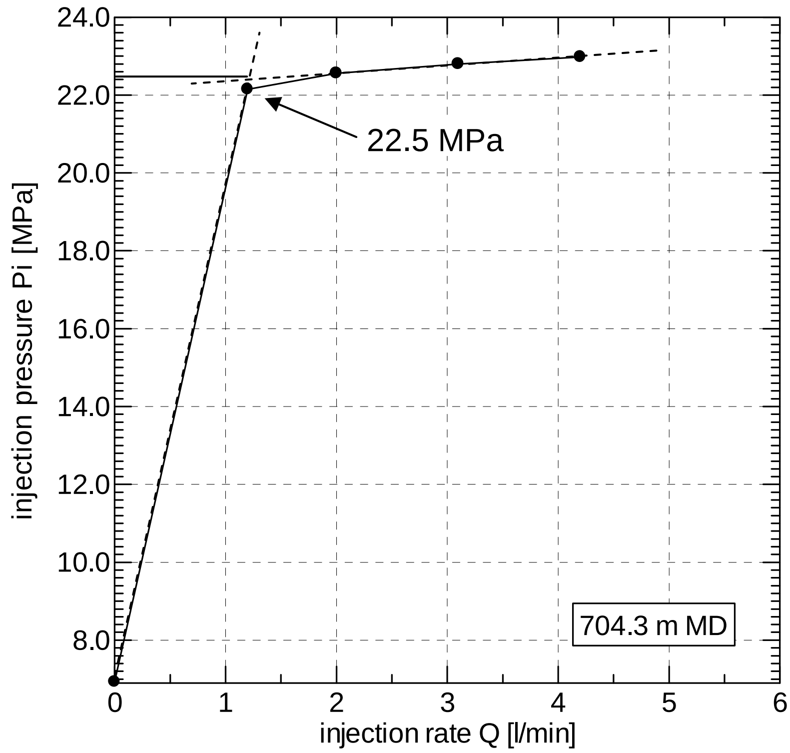
Test at 704.3 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 704.3 m MD: Analysis of Slow - Pump / Step - Rate - Test

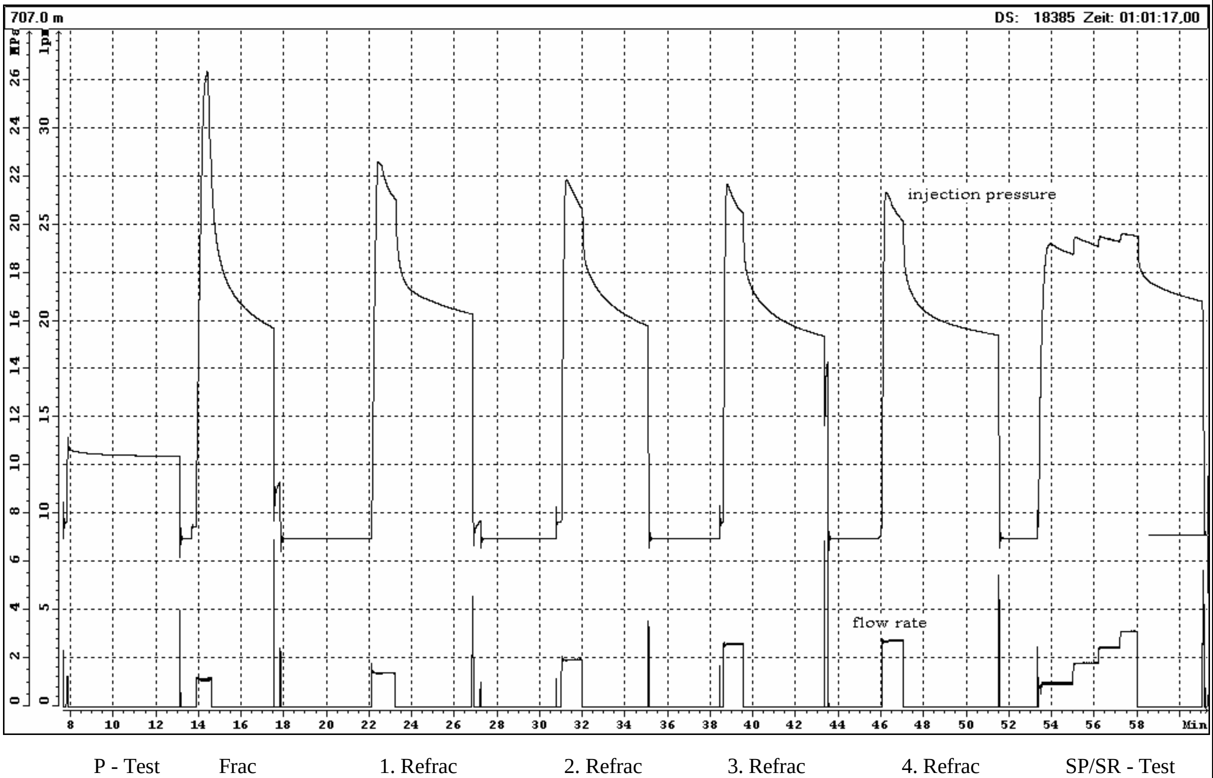


Test at 704.3 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 2 AT 707.0 m MD / 703.75 m TVD

Test at 707.0 m MD : Overview - Plot



TEST SUMMARY / ANALYSIS / REMARKS

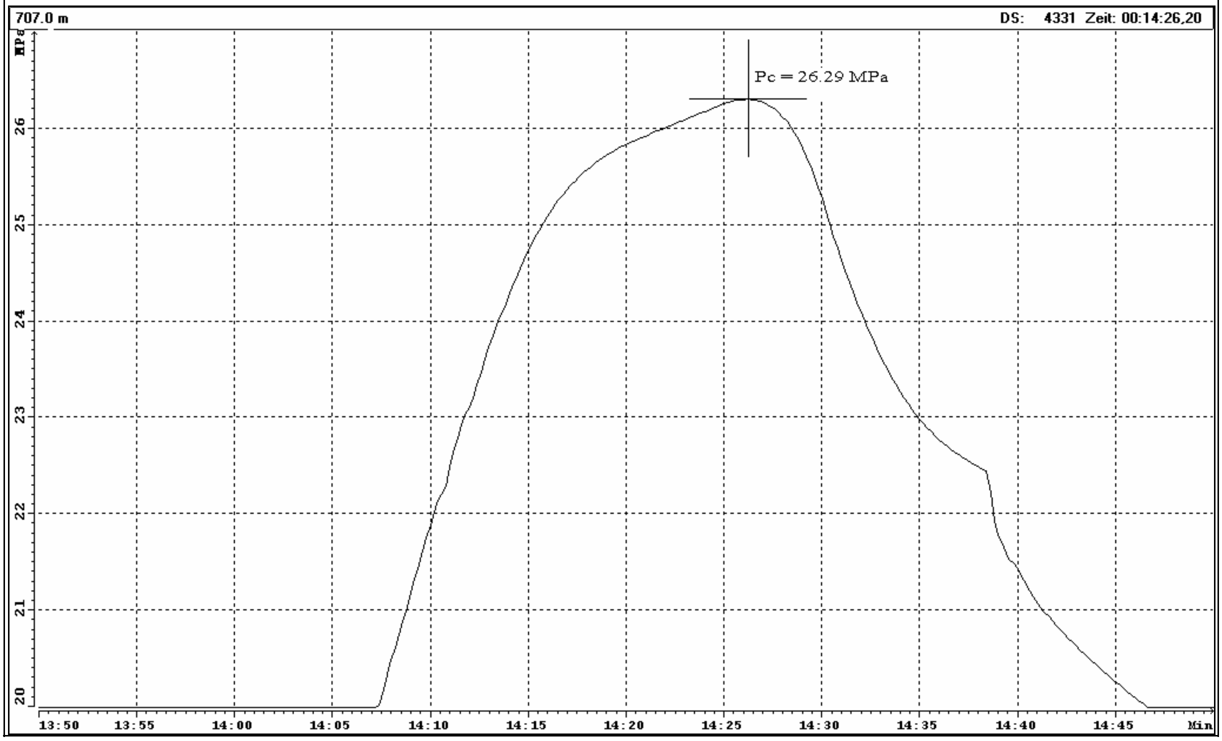
P - Test : pressure decrease of 0.24 MPa in 223 sec., followed by a minor increase of 0.01 MPa in 82 sec.

Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.0	Vr (l) = 0.25
1. Refrac - cycle	Qi (lpm) = 1.7	Vi (l) = 2.0	Vr (l) = 0.25
2. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 2.4	Vr (l) = 0.3
3. Refrac - cycle	Qi (lpm) = 3.2	Vi (l) = 3.1	Vr (l) = 0.3
4. Refrac - cycle	Qi (lpm) = 3.4	Vi (l) = 3.4	Vr (l) = 0.35
SP/SR - test	Qi (lpm) = 1.2-3.9	Vi (l) = 11.0	Vr (l) = 1.0

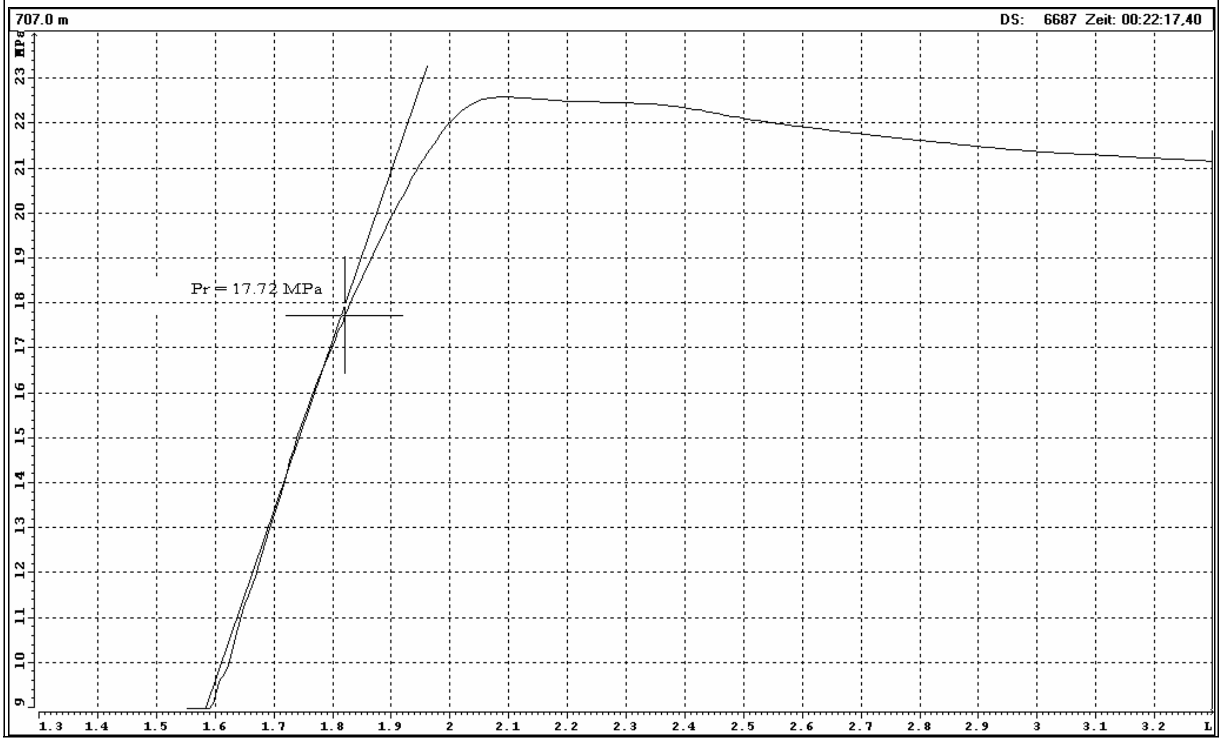
total injected volume (l): 22.9 recovered volume (l): 2.45 or 10.7 %

- Initial test type: HF
- The frac - cycle is characterized by the initiation of a fracture with a weak breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV at 17.7 MPa, followed by a pressure increase up to 22.6 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

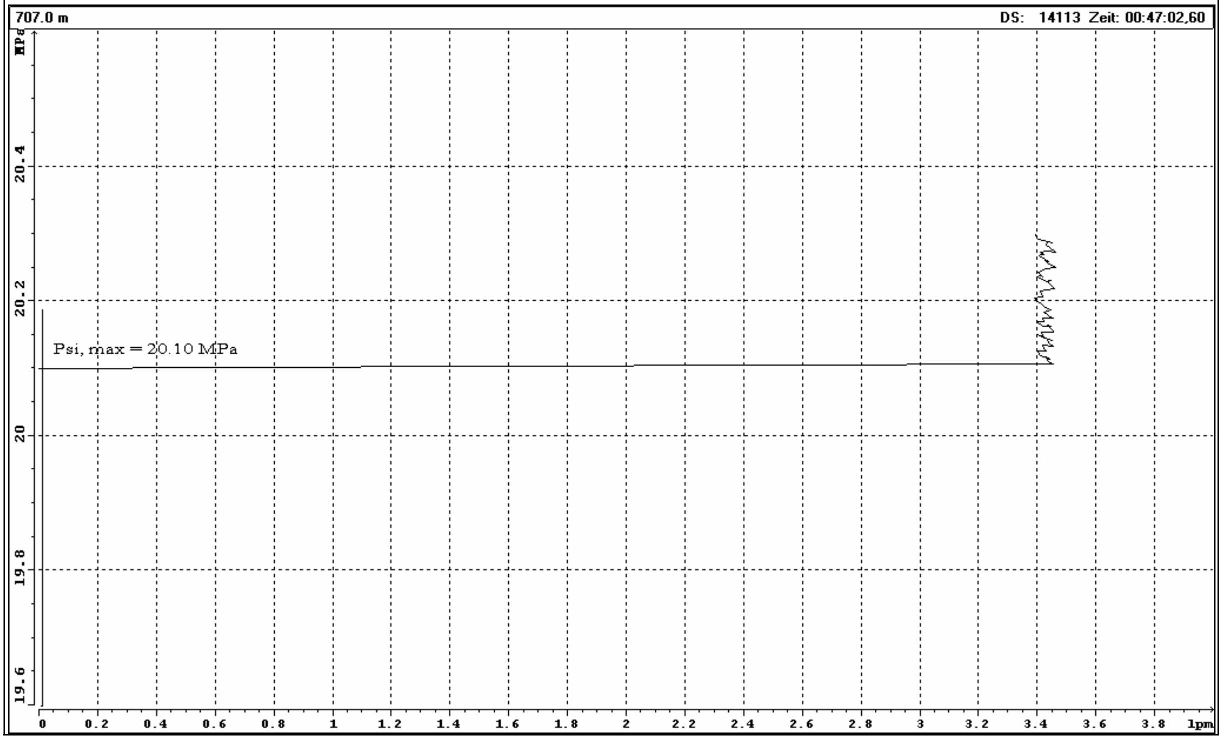
Test at 707.0 m MD: Estimation of P_c (Frac - Cycle)



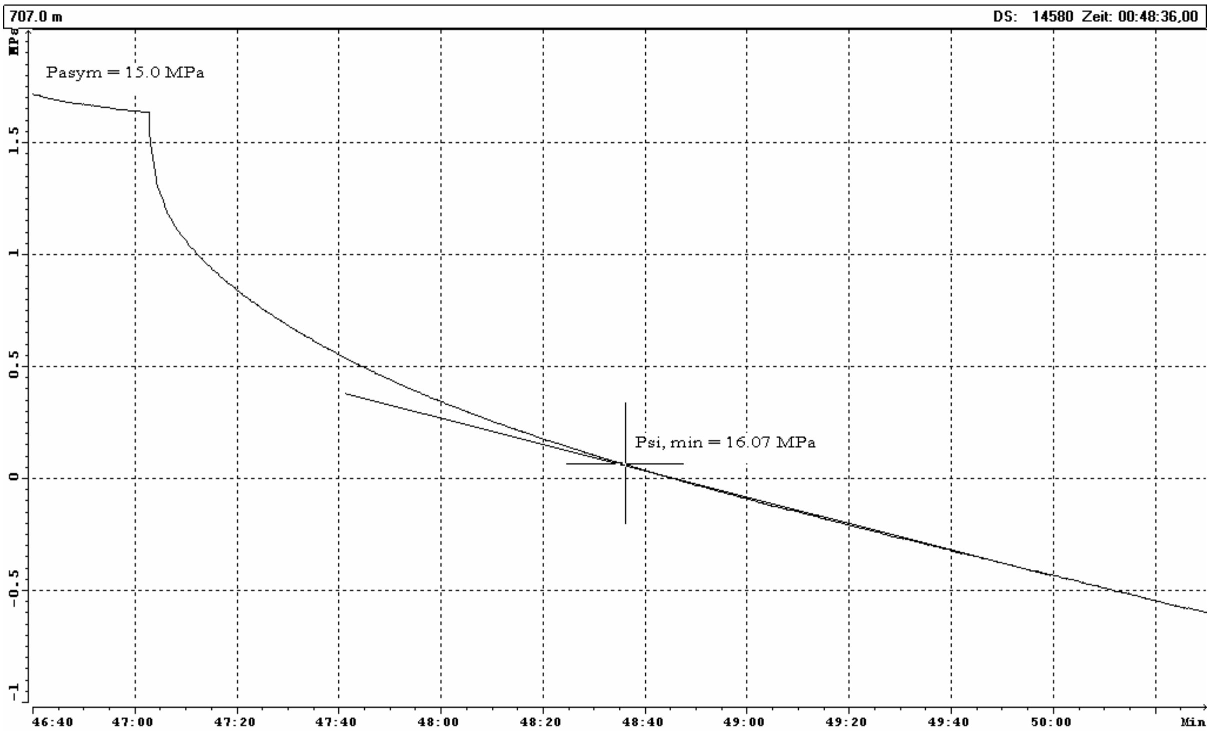
Test at 707.0 m MD: Estimation of P_r (1. Refrac - Cycle)



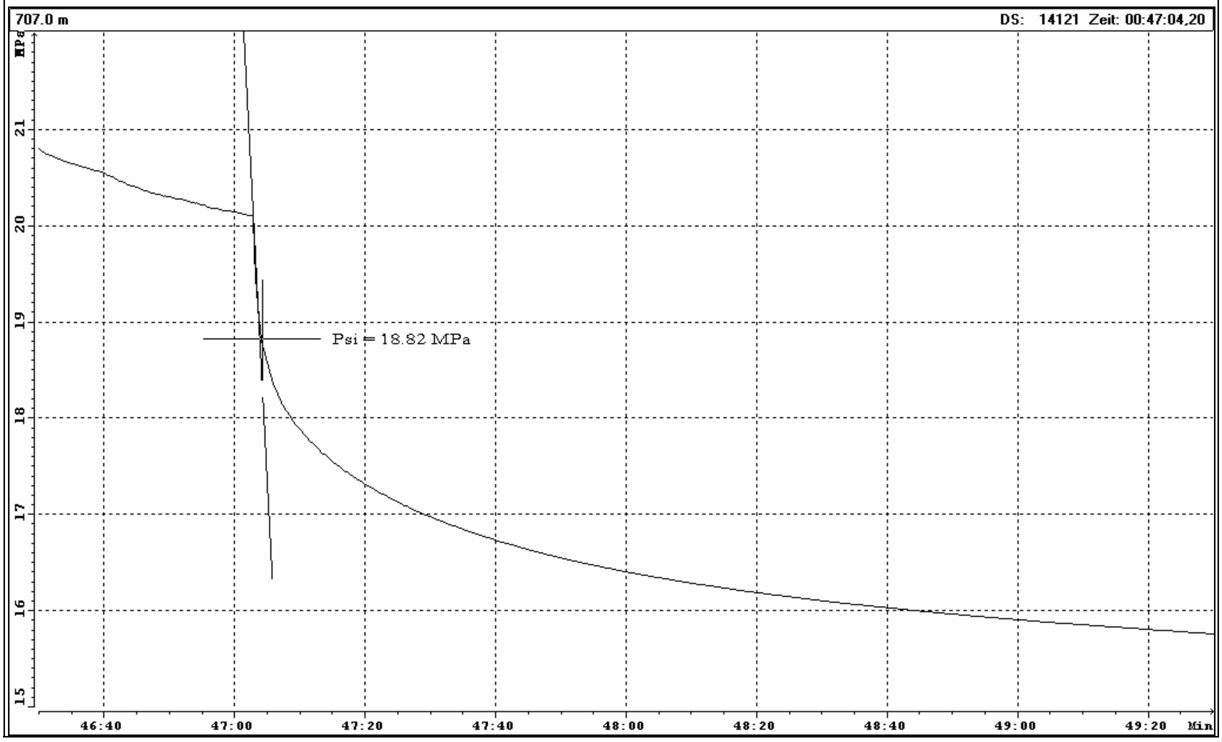
Test at 707.0 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



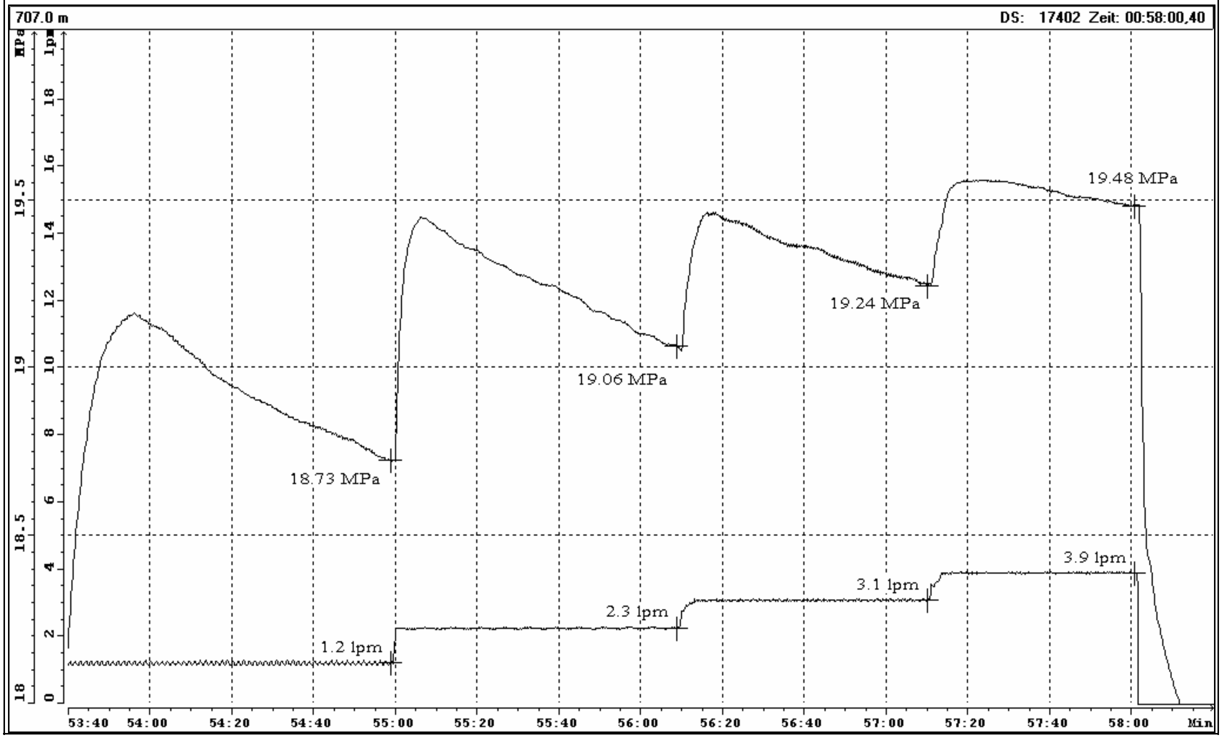
Test at 707.0 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



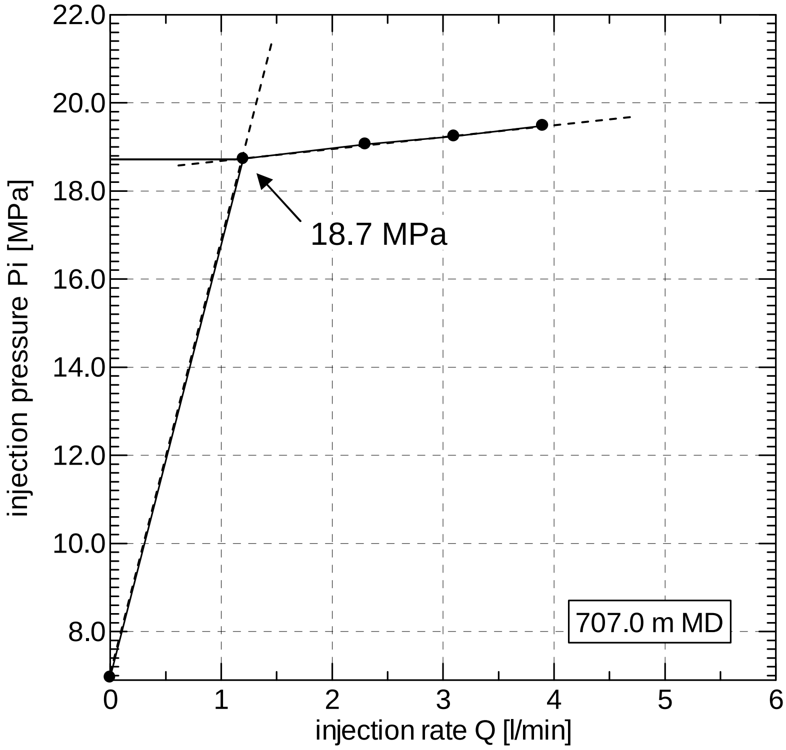
Test at 707.0 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 707.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

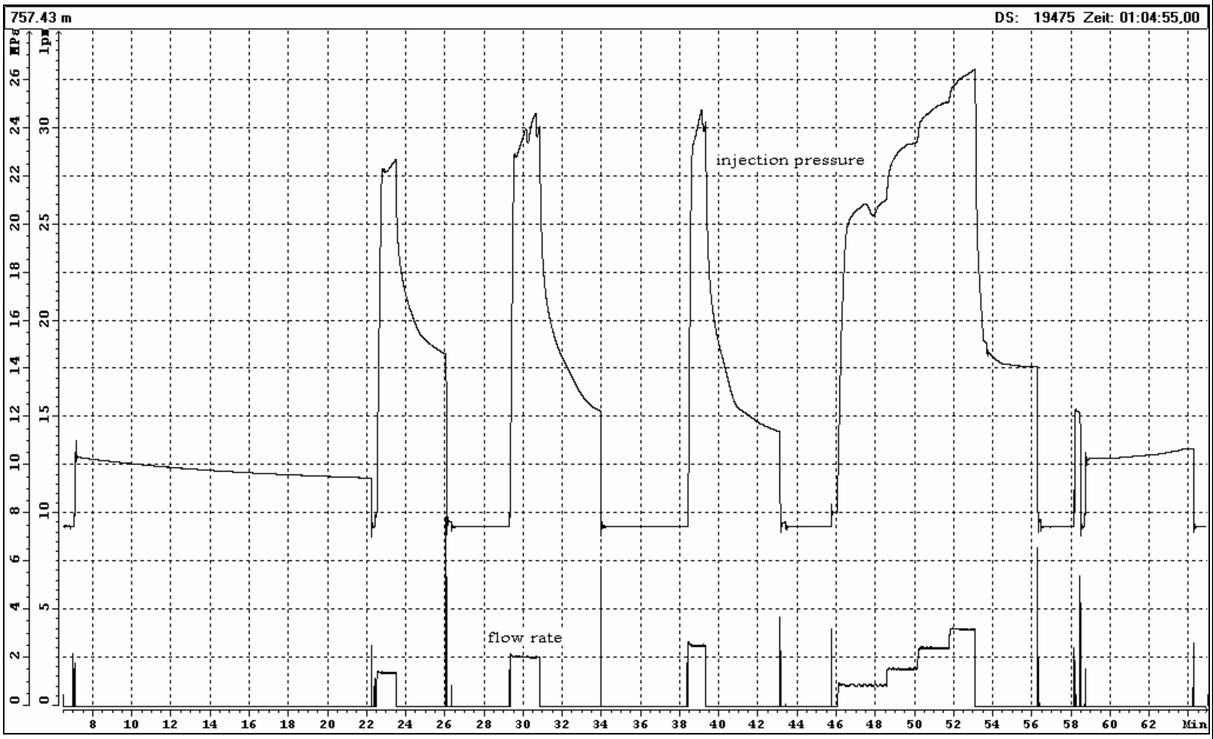


Test at 707.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 1 AT 757.43 m MD / 753.75 m TVD

Test at 757.43 m MD : Overview - Plot



1. P - Test | Frac (1. Refrac) | 2. Refrac | 3. Refrac | SP/SR - Test | 2. P - Test

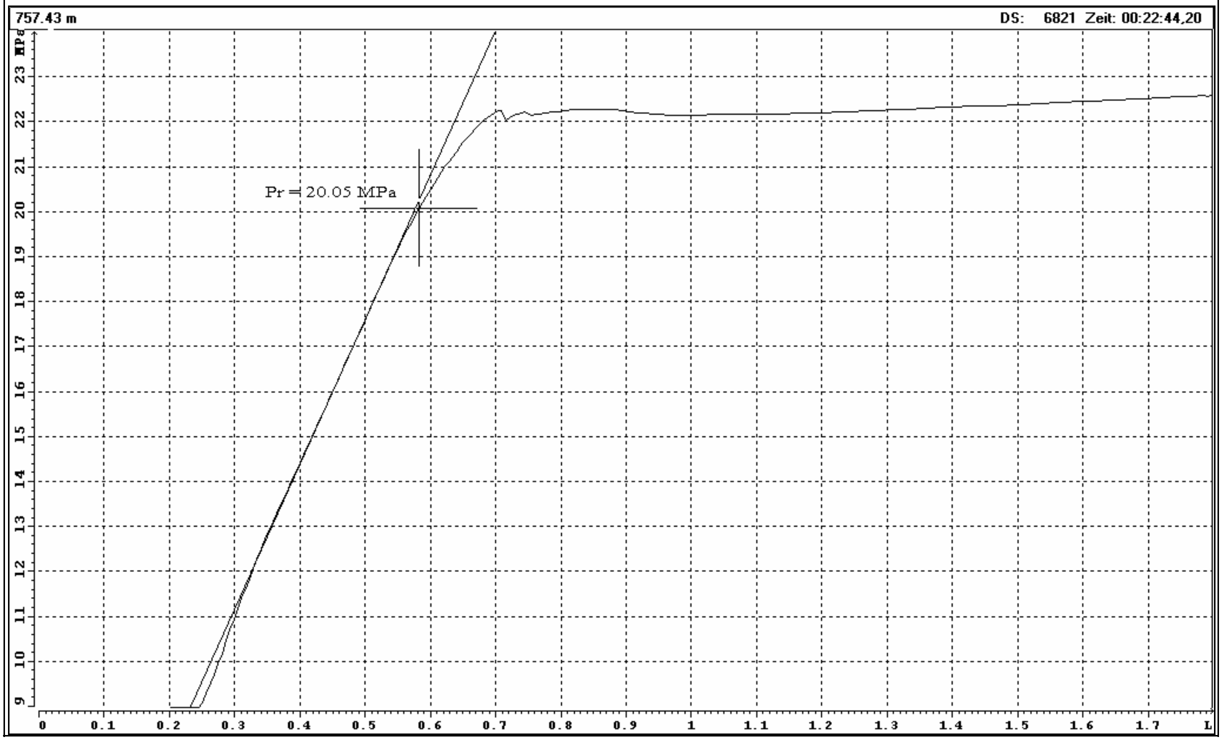
TEST SUMMARY / ANALYSIS / REMARKS

1. P - Test :	pressure increase of 0.19 MPa in 231 sec., followed by a pressure decrease of 0.10 MPa in 703 sec.		
2. P - Test :	pressure increase due to the back-flow from the stimulated fracture		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.7	Vi (l) = 1.75	Vr (l) = 0.15
2. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 3.9	Vr (l) = 0.2
3. Refrac - cycle	Qi (lpm) = 3.2	Vi (l) = 2.8	Vr (l) = 0.1
SP/SR - test	Qi (lpm) = 1.1-4.0	Vi (l) = 16.0	Vr (l) = 0.25

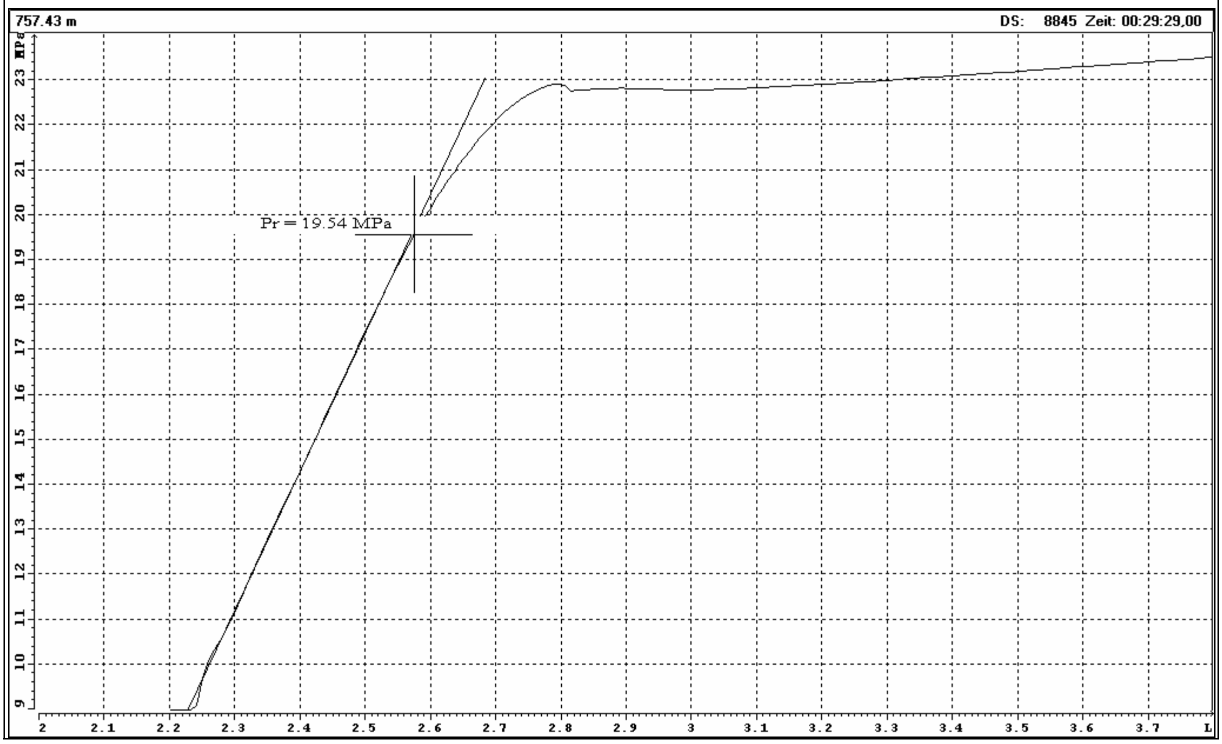
total injected volume (l): 24.5 recovered volume (l): 0.7 or 2.9 %

- Initial test type: HTPF-v
- The frac - cycle is characterized by the stimulation of a pre-existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield slightly lower fracture re-opening pressure values.
- Although the shut-in phases are less distinct (step-wise pressure fall-off), the analysis yield consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.
- The final slow-pump / step-rate tests demonstrates a pronounced increase of the injection pressure with injection flow-rate.

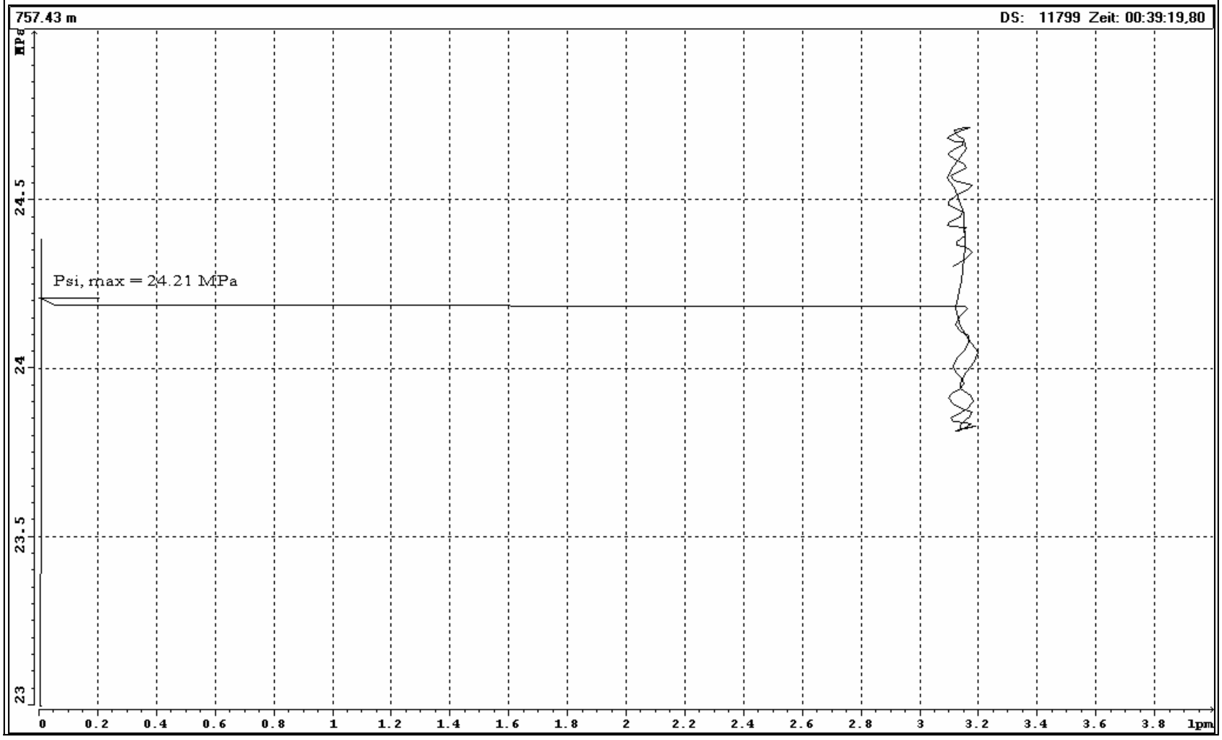
Test at 757.43 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



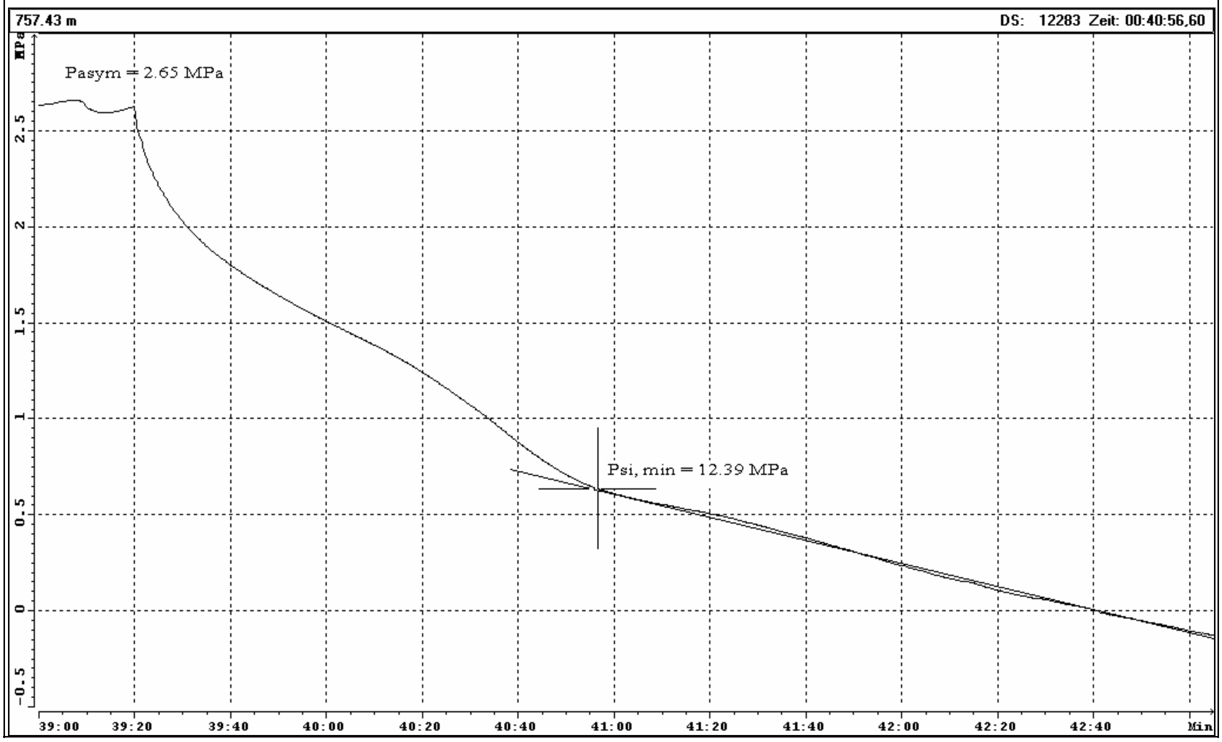
Test at 757.43 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



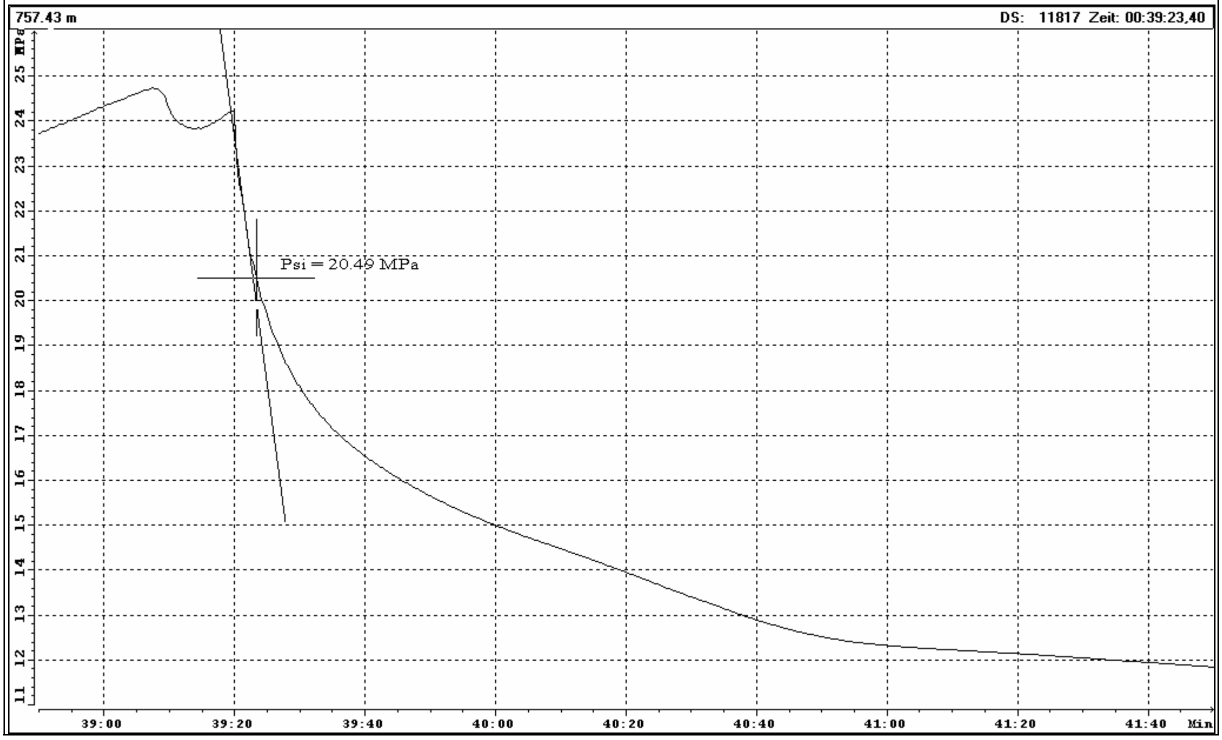
Test at 757.43 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



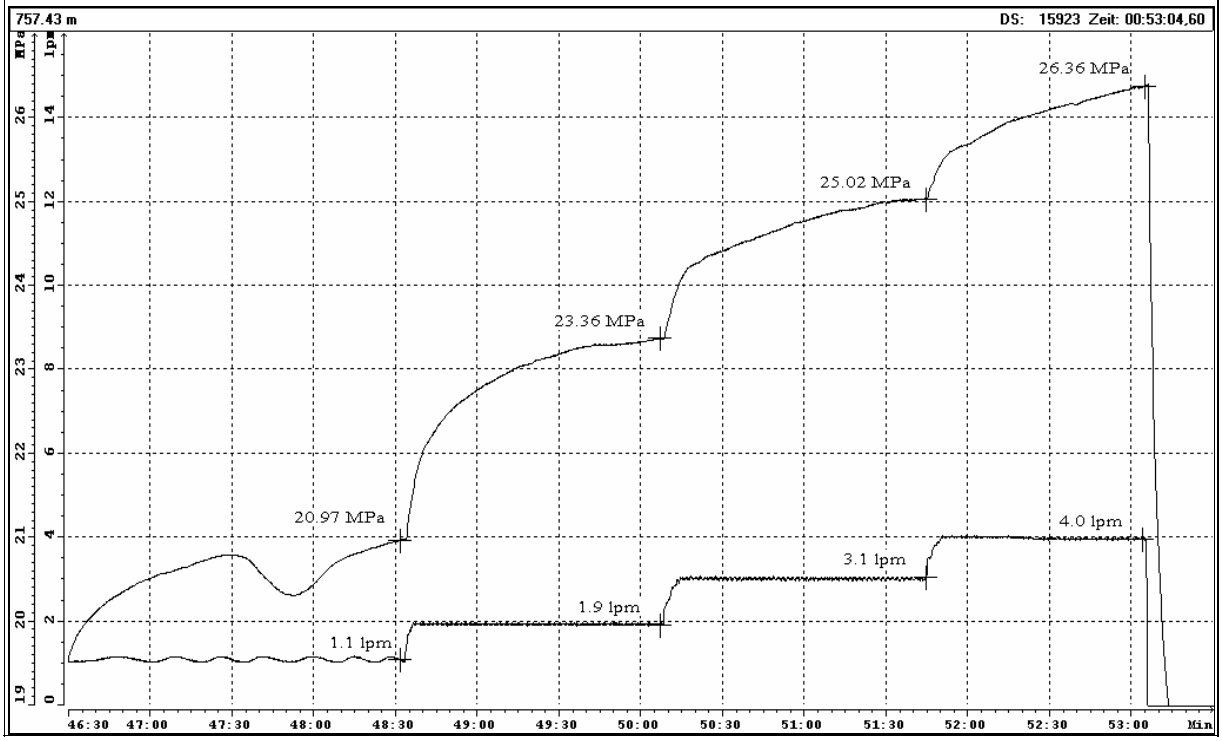
Test at 757.43 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



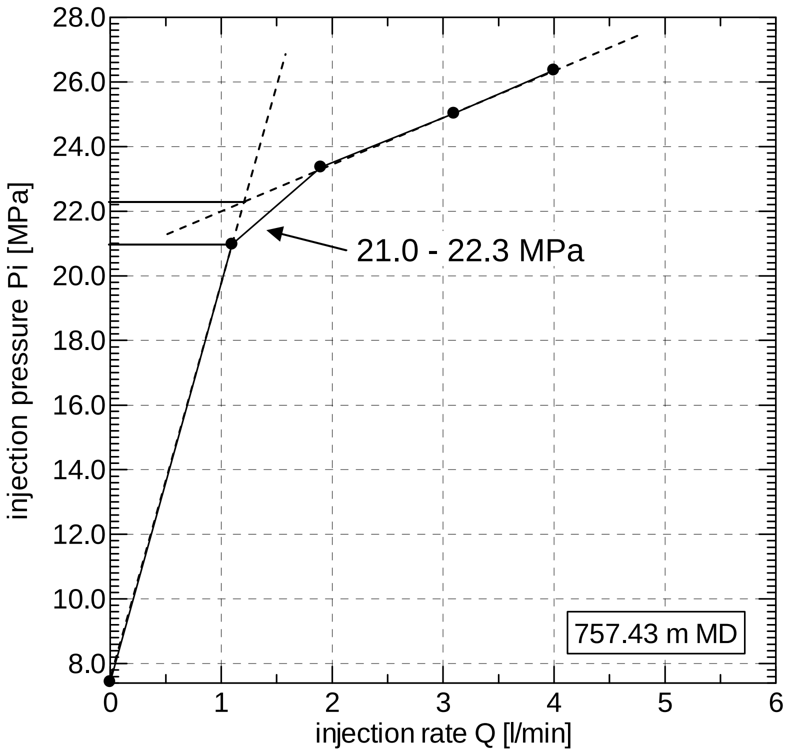
Test at 757.43 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 757.43 m MD: Analysis of Slow - Pump / Step - Rate - Test



Test at 757.43 m MD: Examination of P_{si} (Step - Rate - Test)



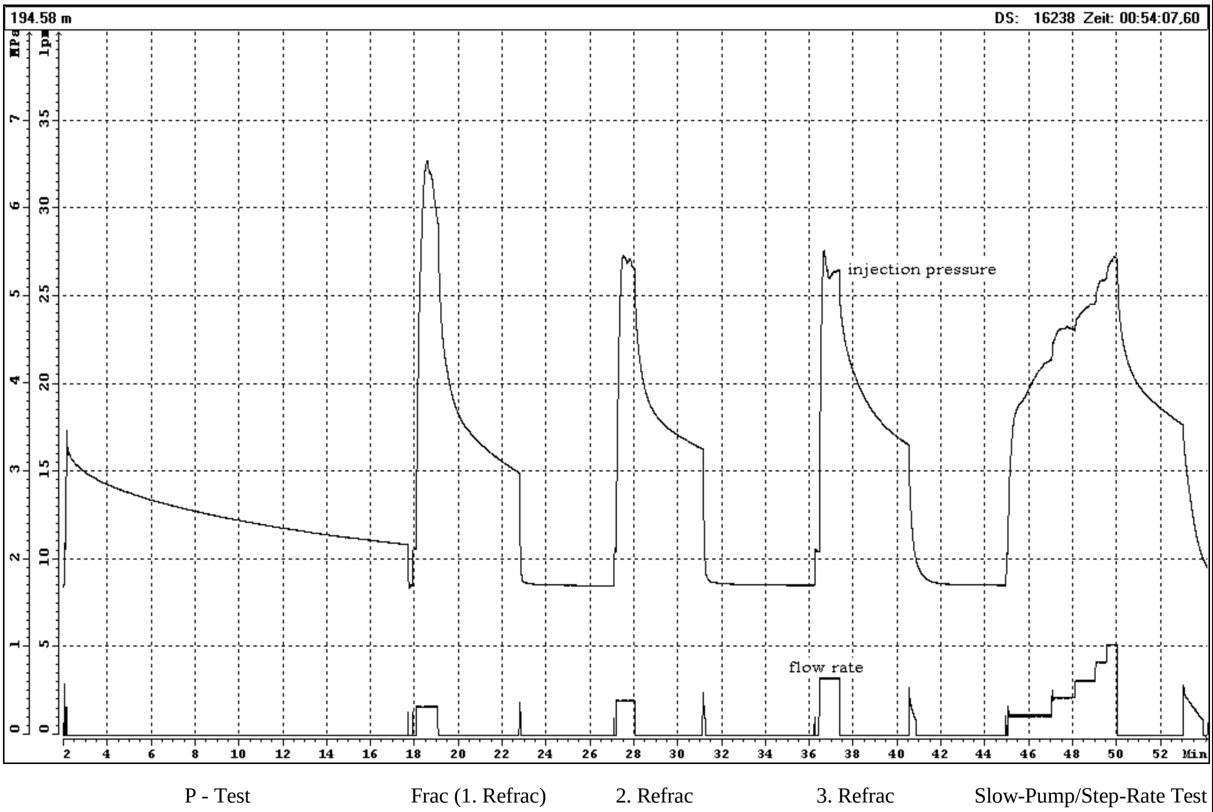
Appendix B4

Records from in-situ Hydrofrac / Hydraulic Injection Tests together with Evaluation of Characteristic Pressure Data

Borehole No. KFM04A

TEST NO. 11 AT 194.58 m MD / 171.43 m TVD

Test at 194.58 m MD : Overview - Plot



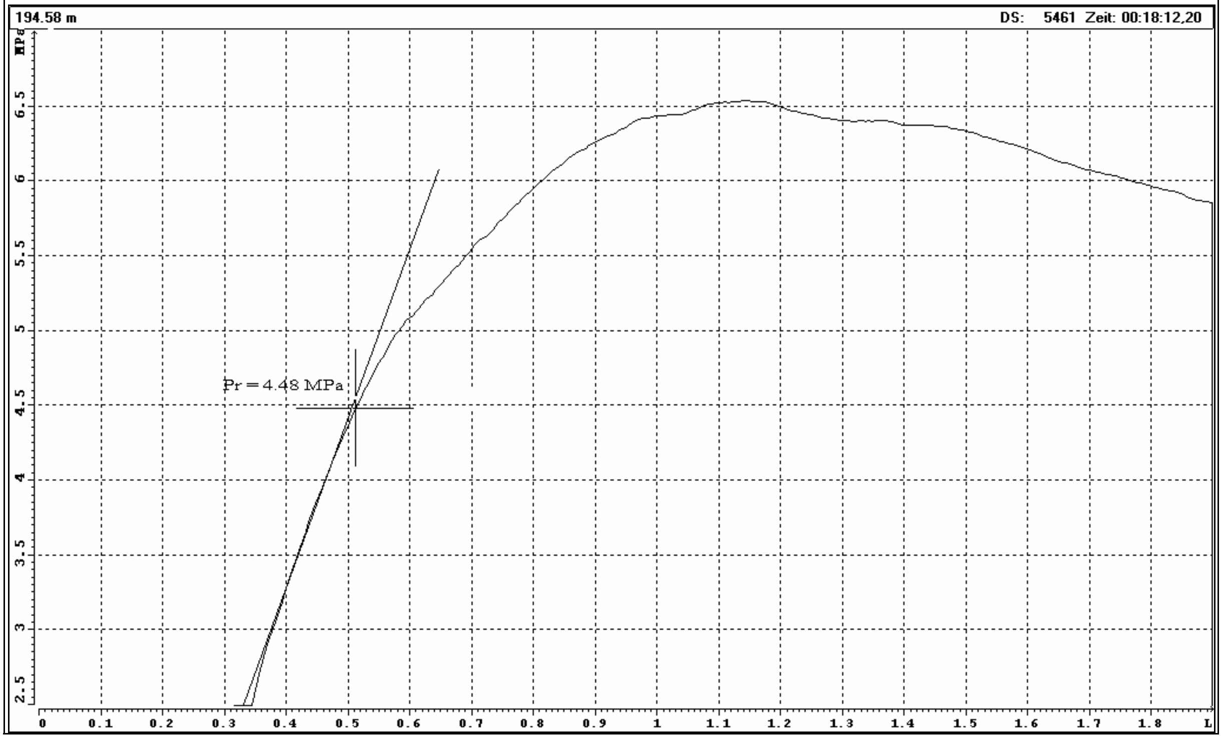
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 1.04 MPa in 925 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.6	Vi (l) = 1.6	Vr (l) = 0.3
2. Refrac - cycle	Qi (lpm) = 2.0	Vi (l) = 1.7	Vr (l) = 0.6
3. Refrac - cycle	Qi (lpm) = 3.2	Vi (l) = 3.0	Vr (l) = 1.1
SP/SR - test	Qi (lpm) = 1.1-5.1	Vi (l) = 12.1	Vr (l) = 2.8

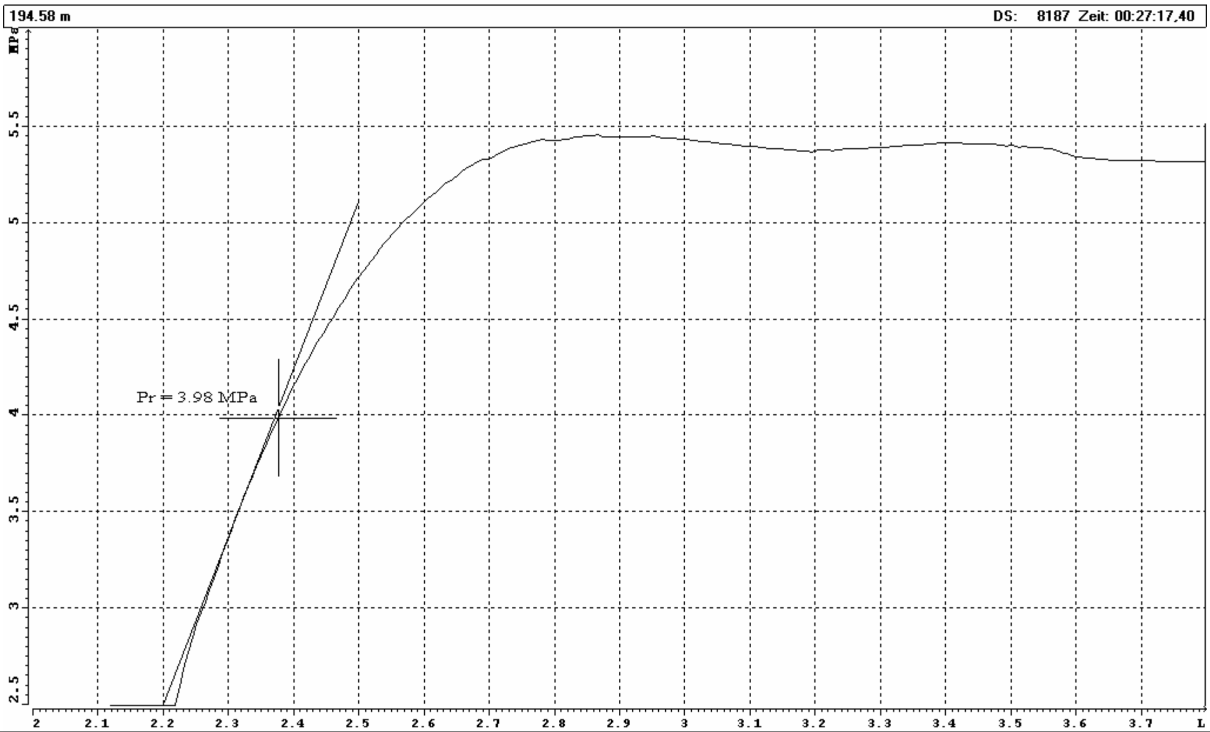
total injected volume (l): 18.4 recovered volume (l): 4.8 or 26.1 %

- Initial test type: HTPF-h
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no distinct breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 4.5 MPa, followed by a pressure increase up to 6.5 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

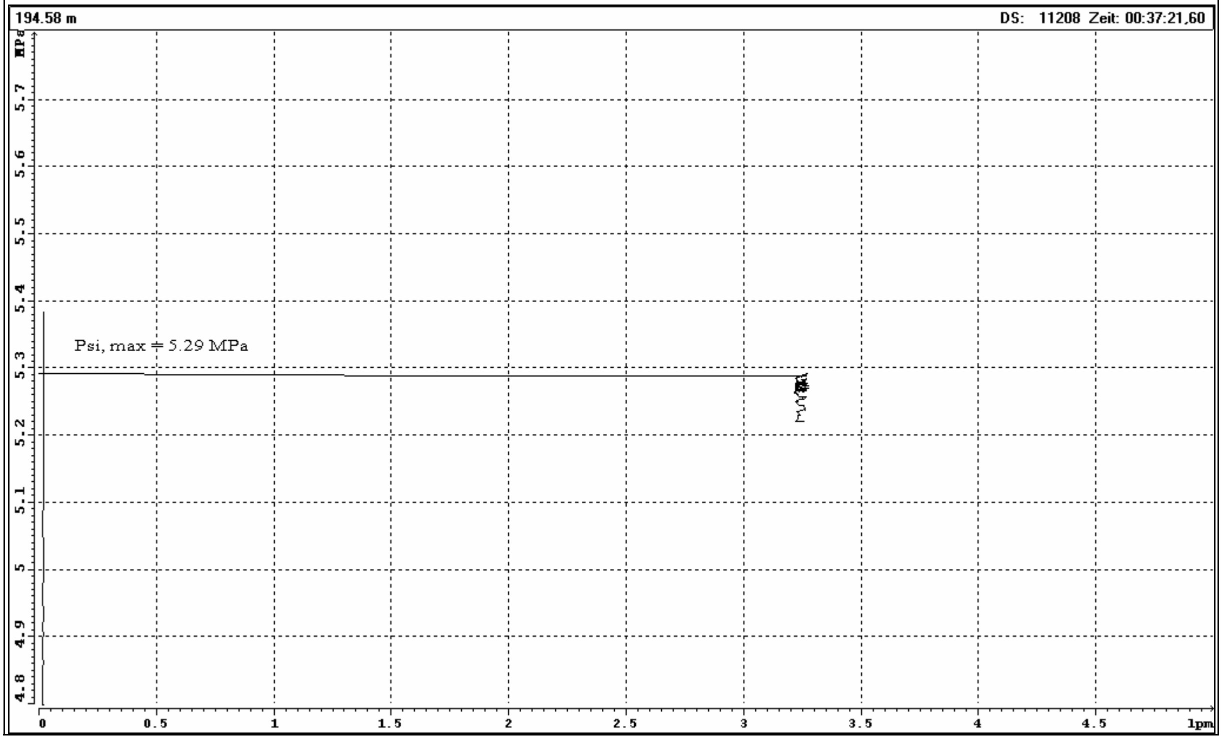
Test at 194.58 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



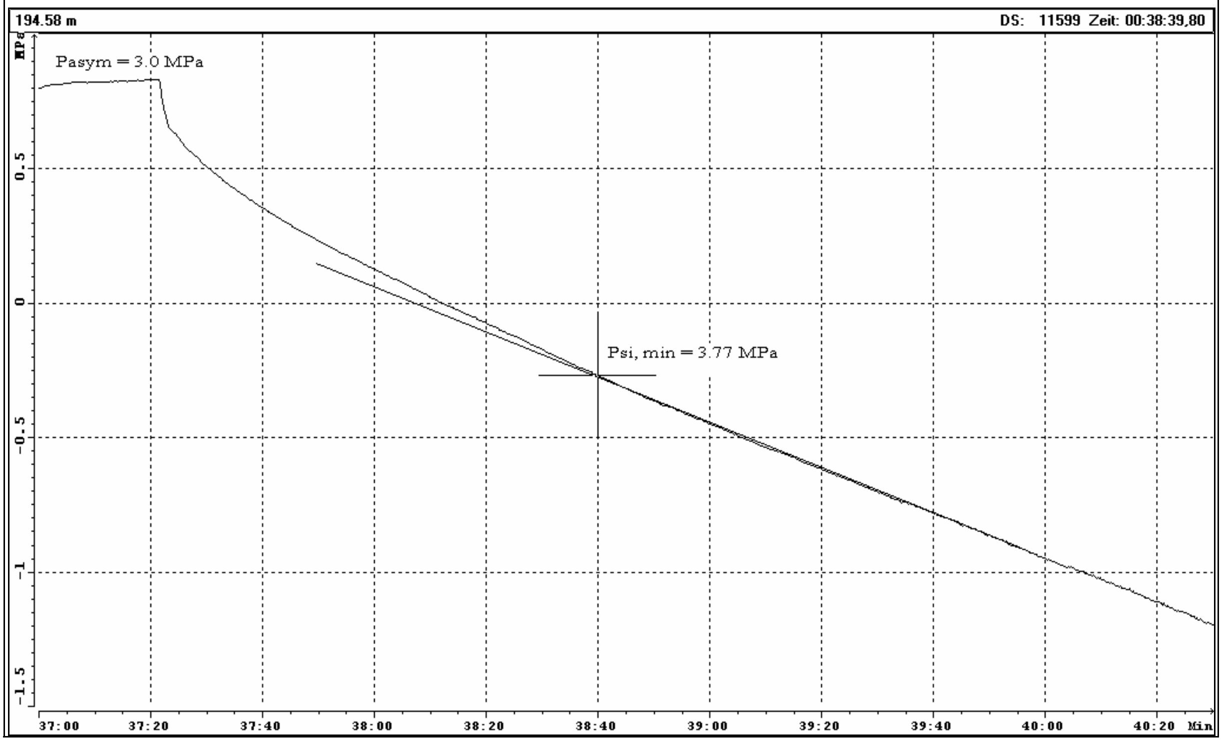
Test at 194.58 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



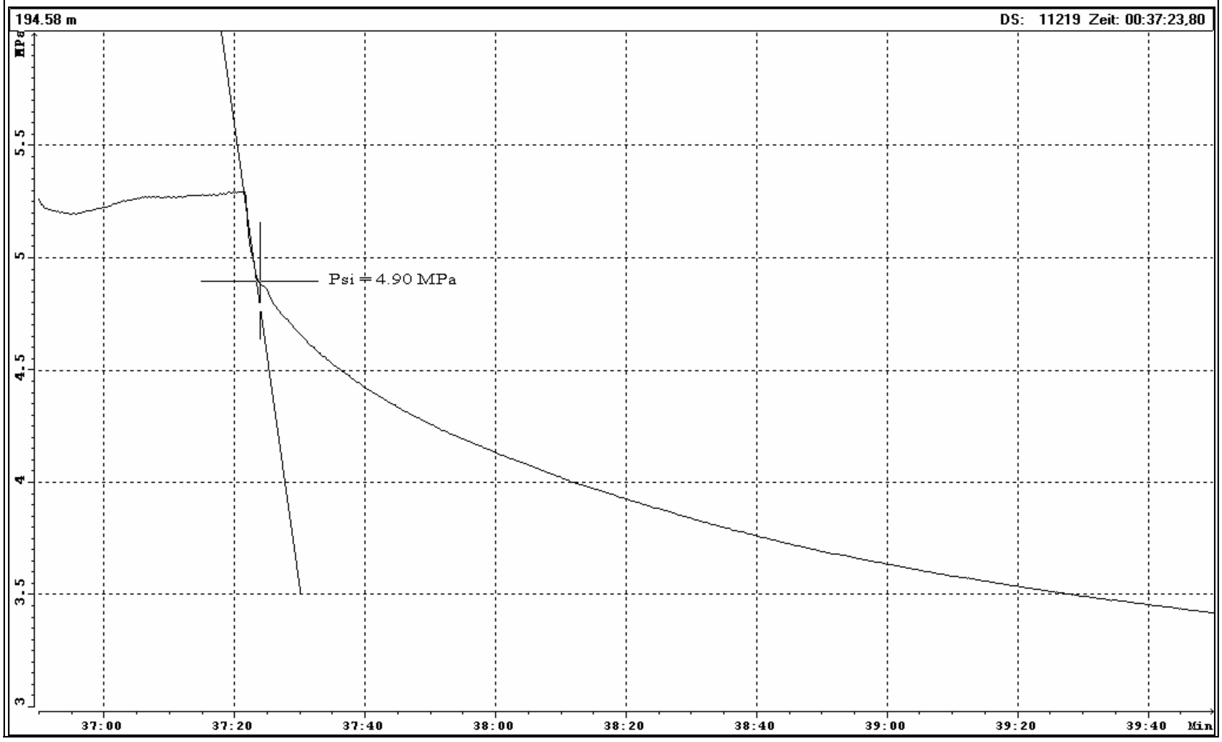
Test at 194.58 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



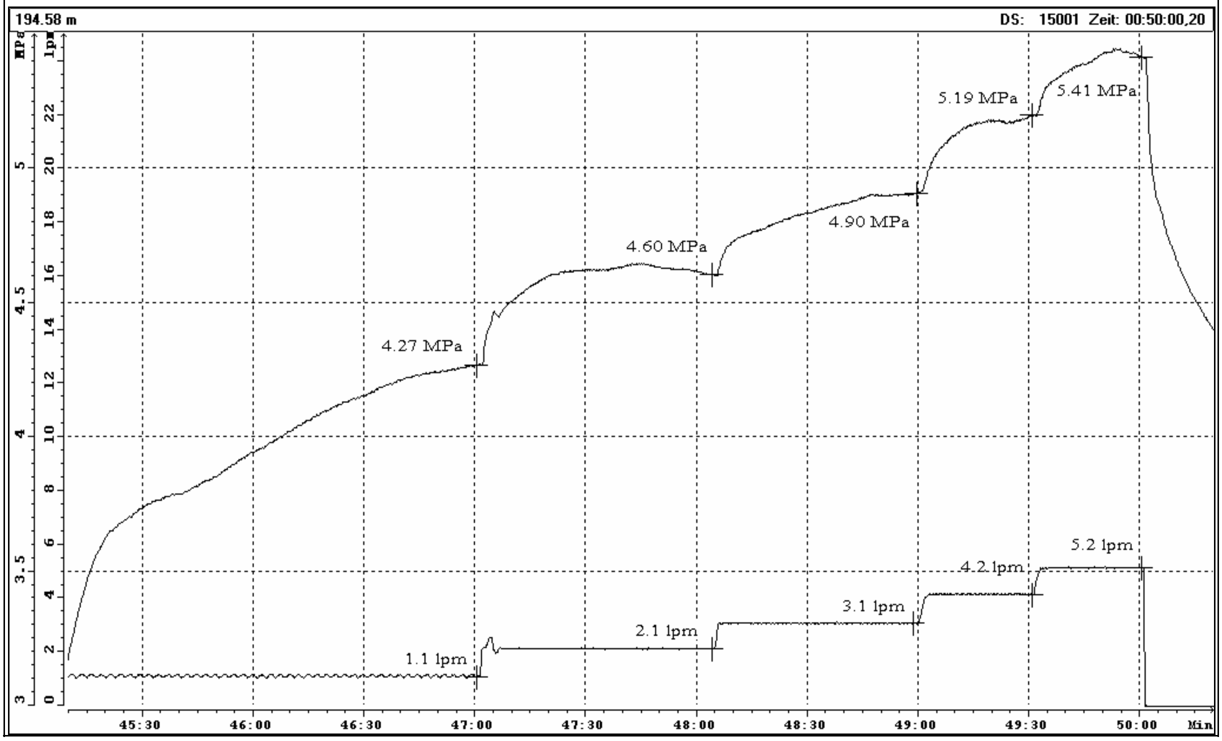
Test at 194.58 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



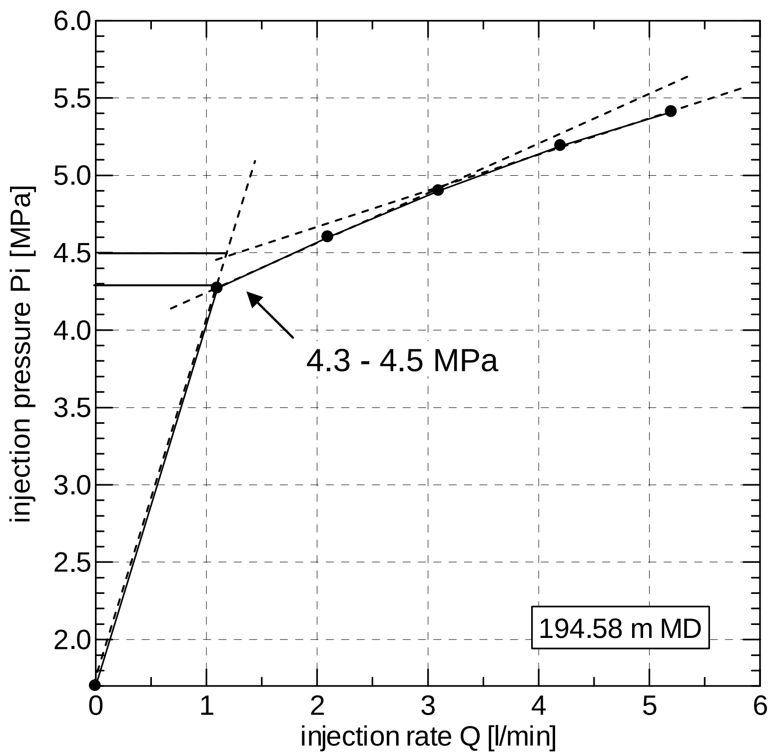
Test at 194.58 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 194.58 m MD: Analysis of Slow - Pump / Step - Rate - Test

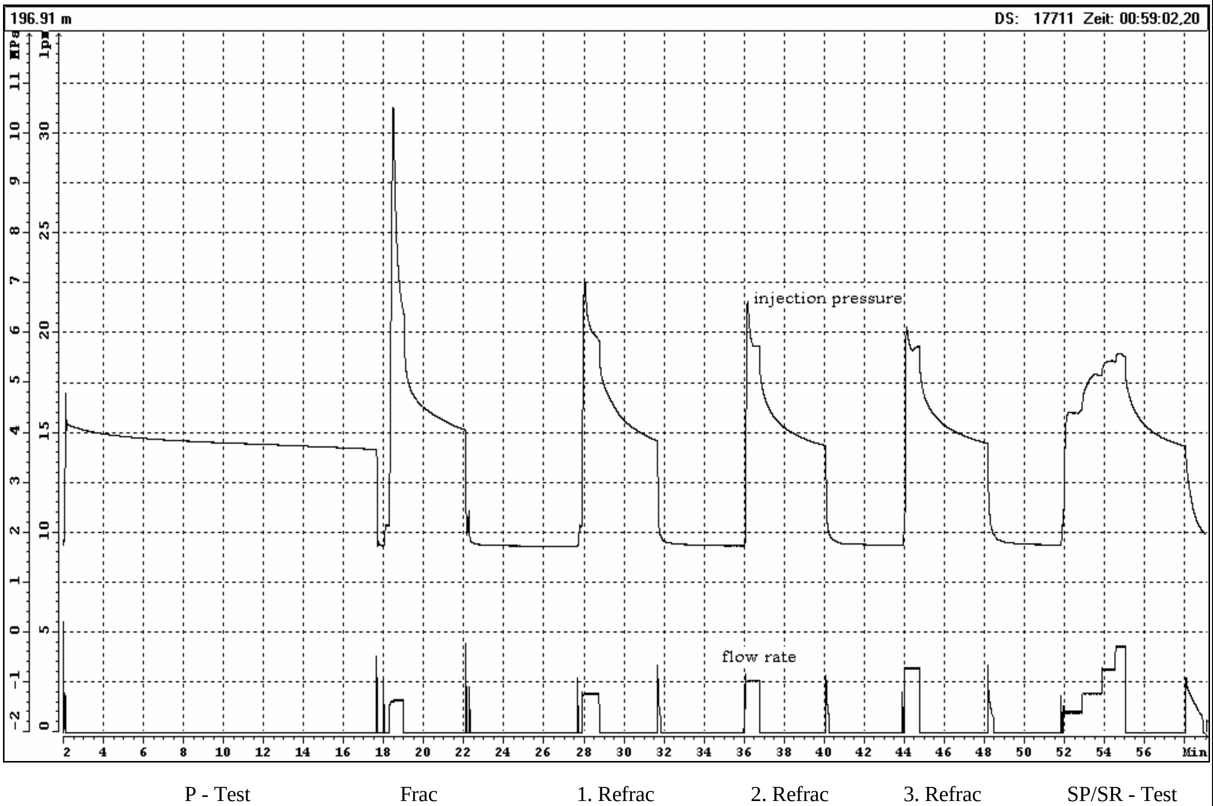


Test at 194.58 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 10 AT 196.91 m MD / 173.47 m TVD

Test at 196.91 m MD: Overview - Plot



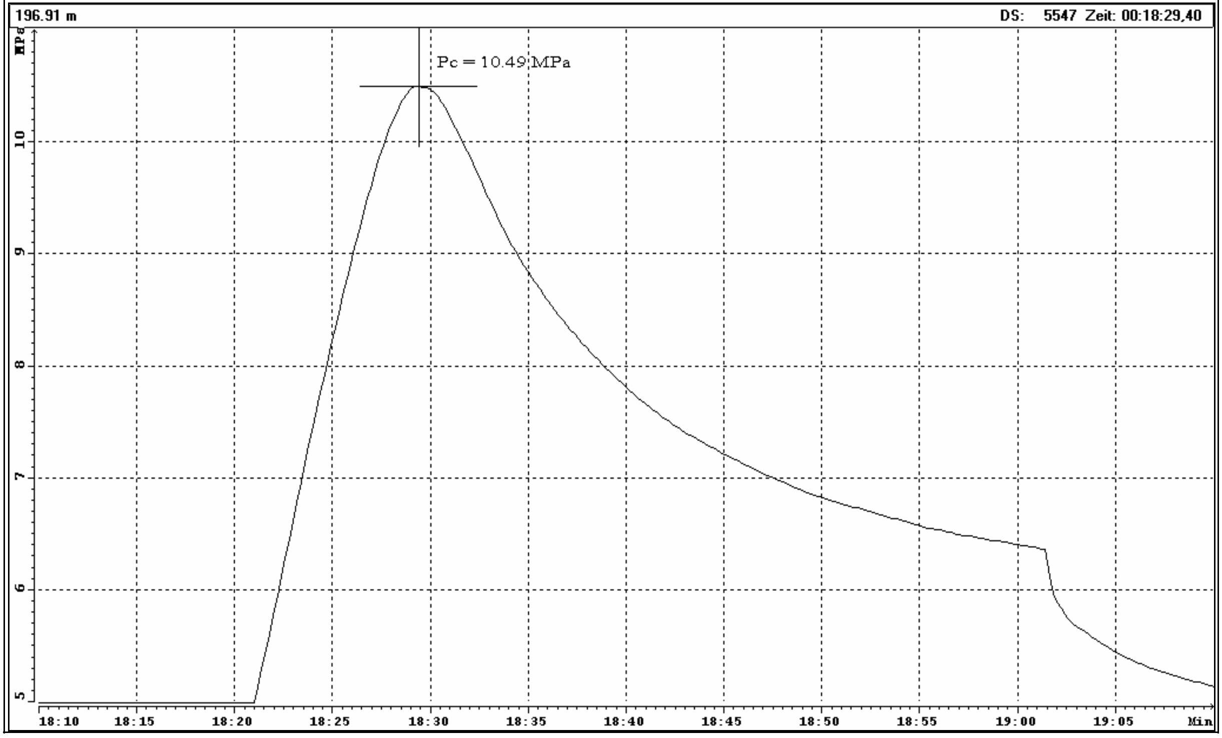
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.50 MPa in 925 sec.		
Frac - cycle	Qi (lpm) = 1.6	Vi (l) = 1.3	Vr (l) = 0.5
1. Refrac - cycle	Qi (lpm) = 2.0	Vi (l) = 1.8	Vr (l) = 0.8
2. Refrac - cycle	Qi (lpm) = 2.6	Vi (l) = 2.0	Vr (l) = 1.1
3. Refrac - cycle	Qi (lpm) = 3.2	Vi (l) = 2.4	Vr (l) = 1.5
SP/SR - test	Qi (lpm) = 1.0-4.3	Vi (l) = 7.2	Vr (l) = 3.1

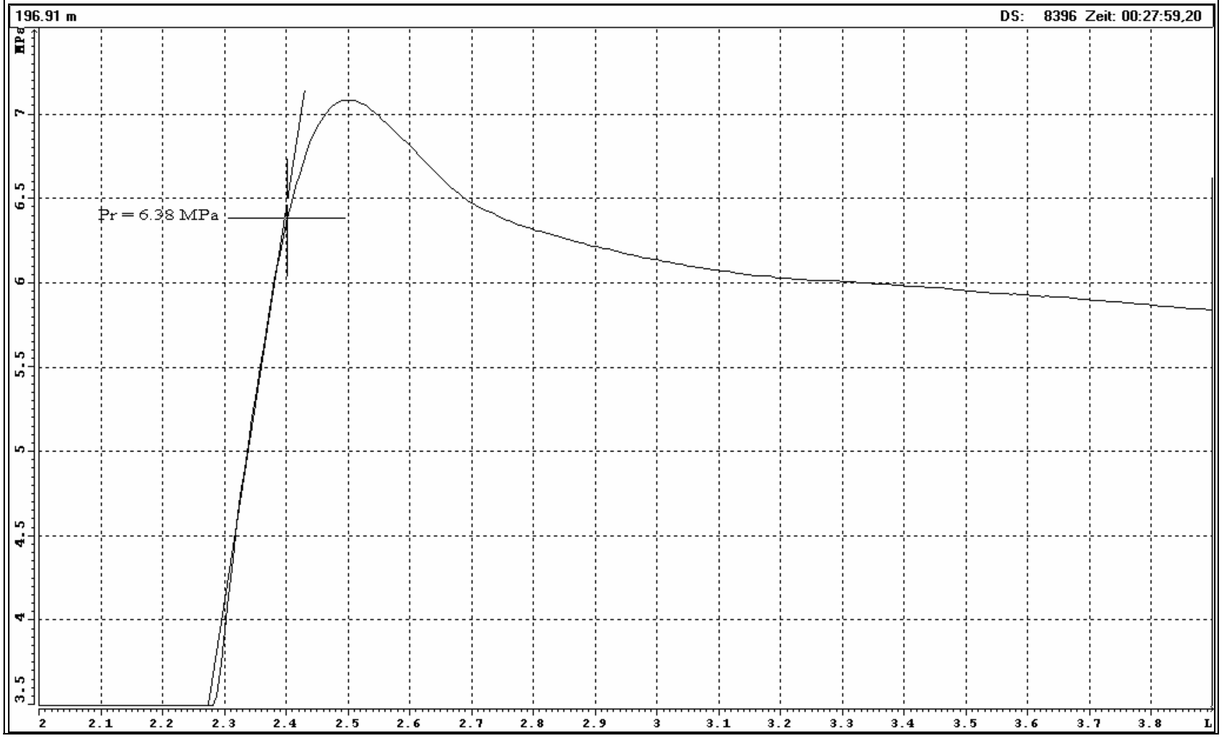
total injected volume (l): 14.7 recovered volume (l): 7.0 or 47.6 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

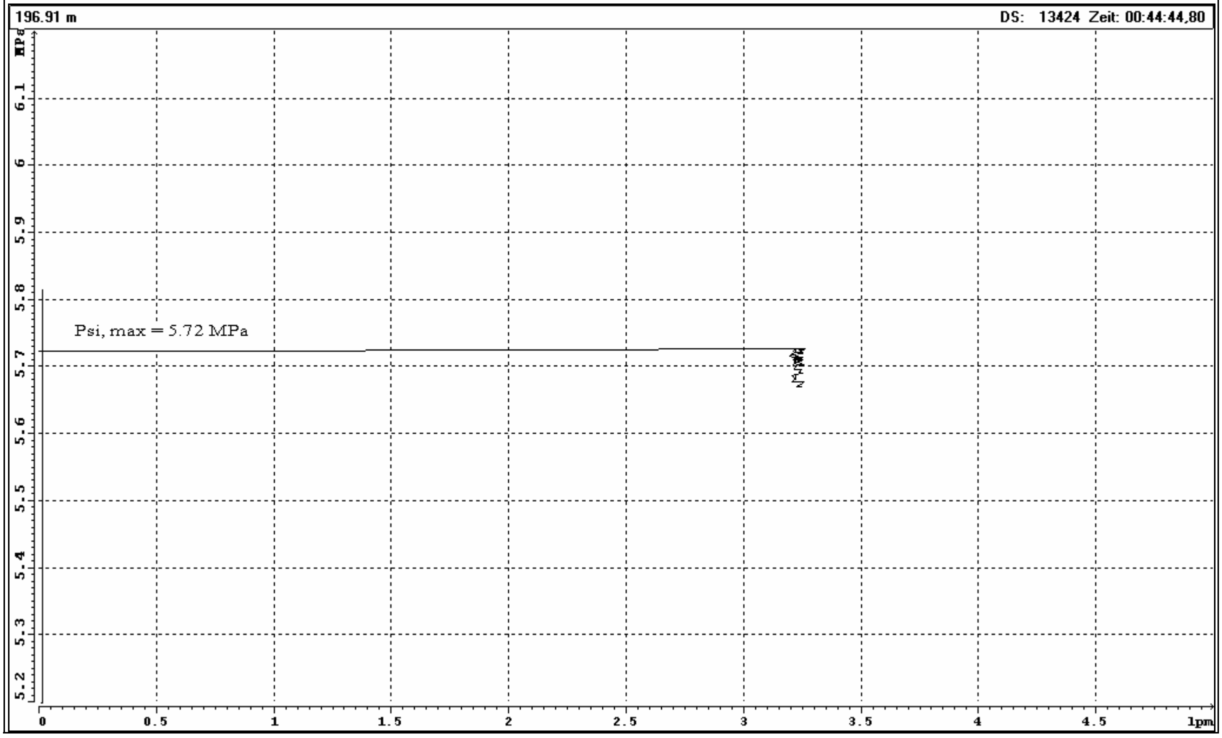
Test at 196.91 m MD: Estimation of P_c (Frac - Cycle)



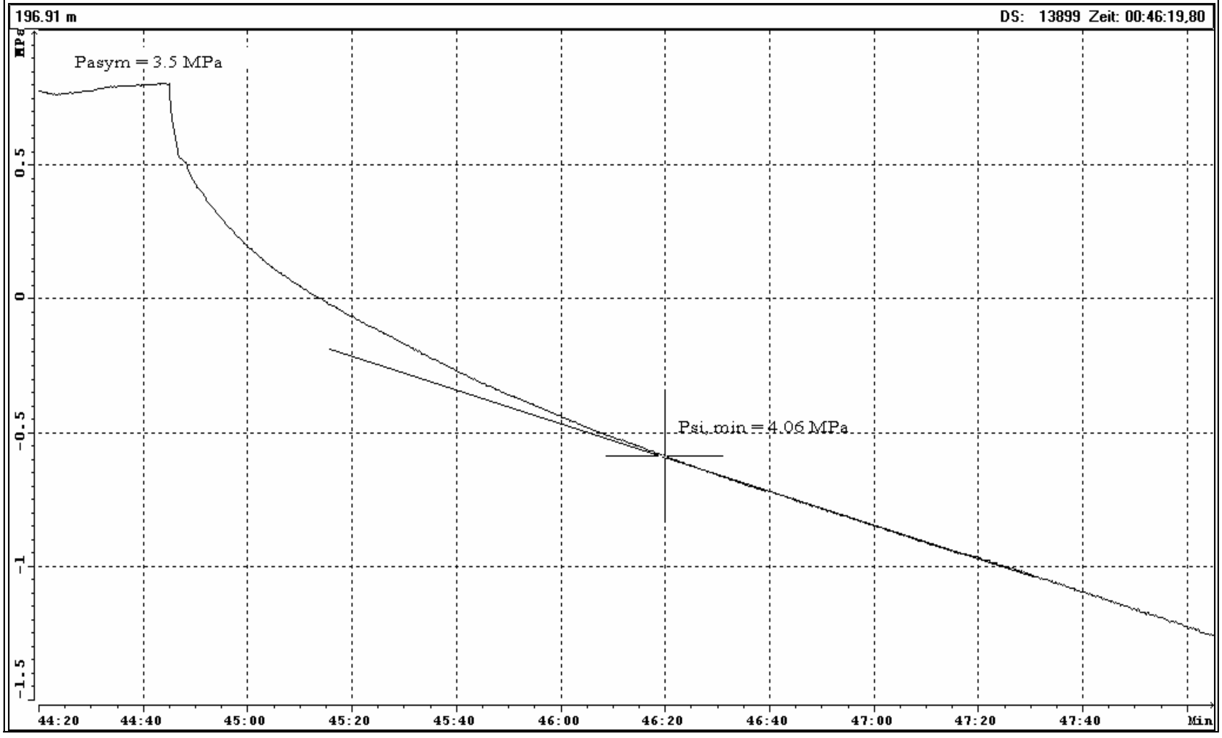
Test at 196.91 m MD: Estimation of P_r (1. Refrac - Cycle)



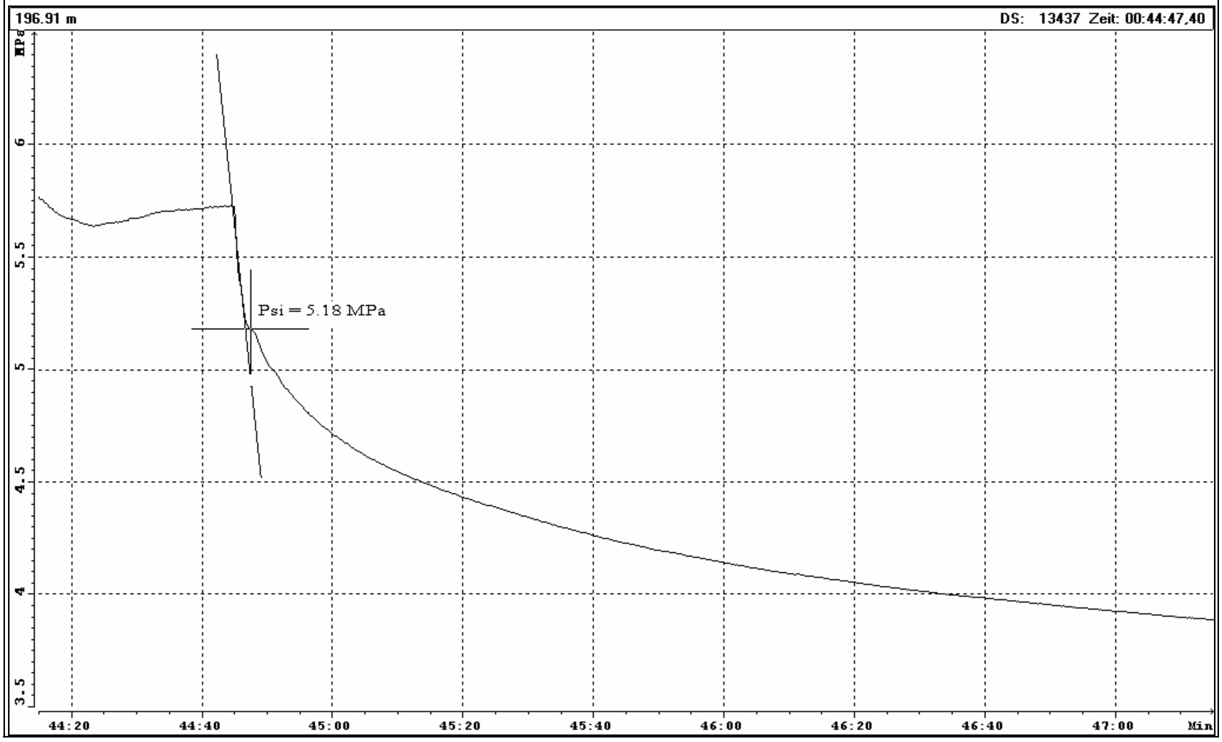
Test at 196.91 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



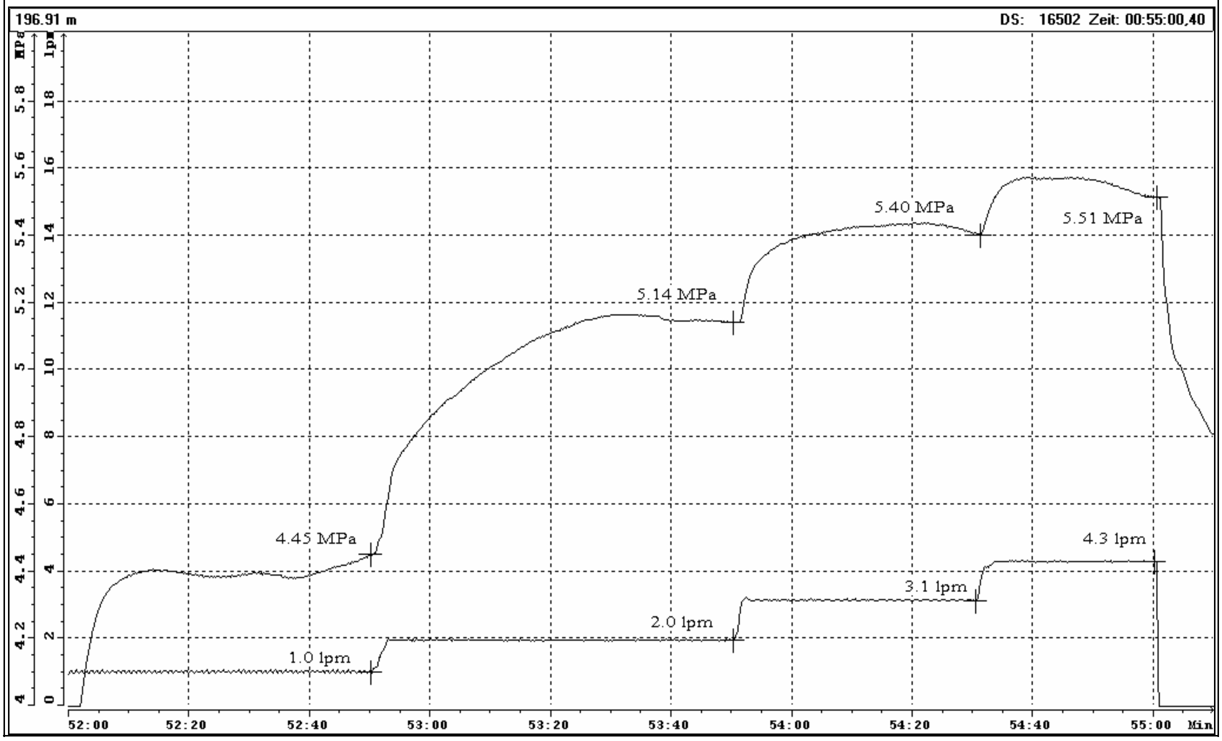
Test at 196.91 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



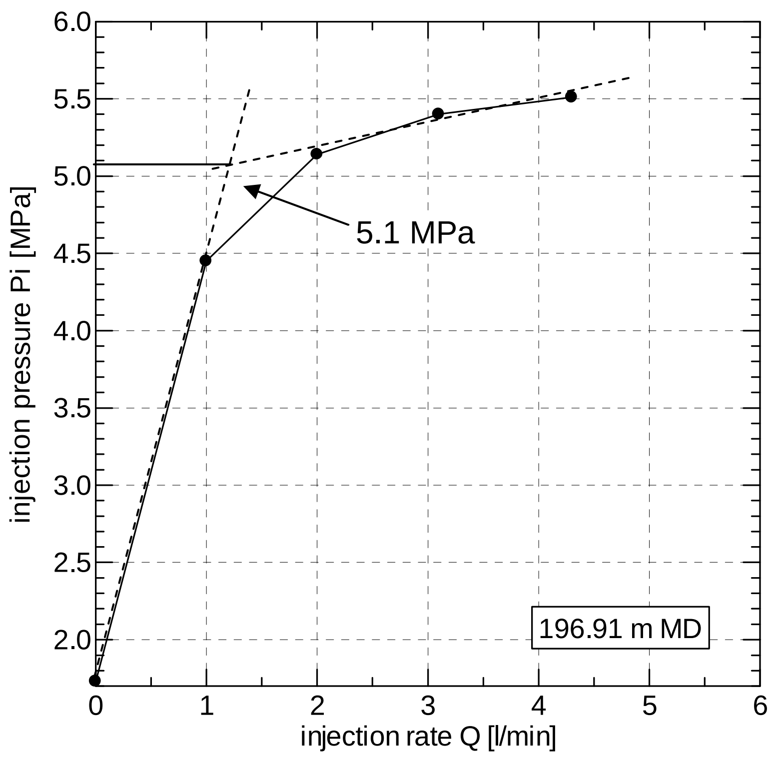
Test at 196.91 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 196.91 m MD: Analysis of Slow - Pump / Step - Rate - Test

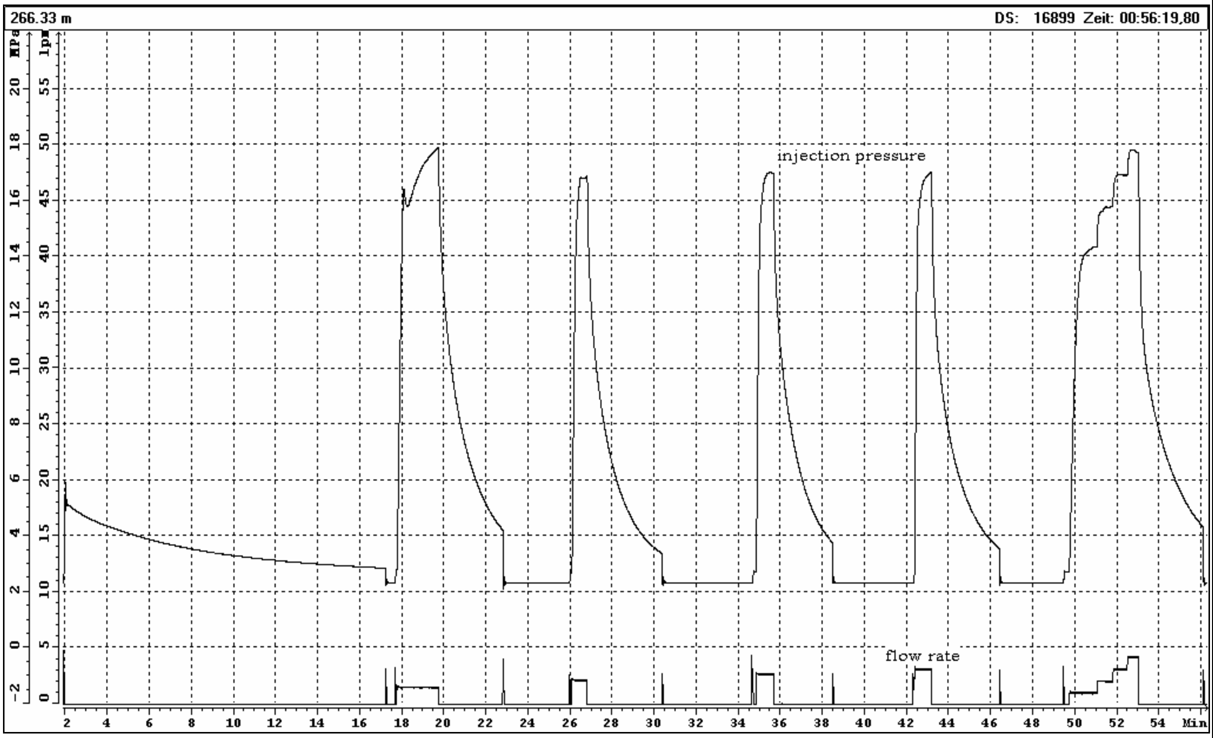


Test at 196.91 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 9 AT 266.33 m MD / 233.61 m TVD

Test at 266.33 m MD: Overview - Plot



P - Test | Frac (1. Refrac) | 2. Refrac | 3. Refrac | 4. Refrac | SP/SR - Test

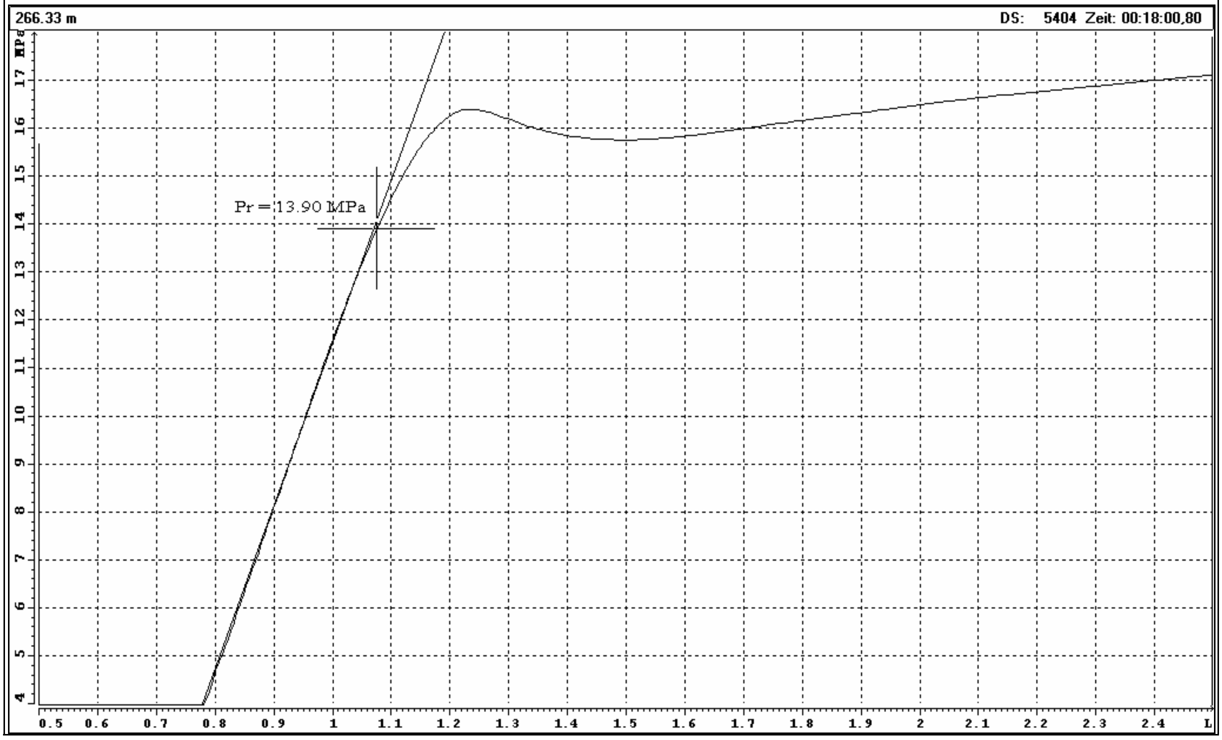
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 2.25 MPa in 904 sec.					
Frac (1. Refrac) - cycle	Qi (lpm) =	1.6	Vi (l) =	3.2	Vr (l) =	0.2
2. Refrac - cycle	Qi (lpm) =	2.1	Vi (l) =	1.7	Vr (l) =	0.2
3. Refrac - cycle	Qi (lpm) =	2.7	Vi (l) =	2.4	Vr (l) =	0.2
4. Refrac - cycle	Qi (lpm) =	3.1	Vi (l) =	2.7	Vr (l) =	0.2
SP/SR - test	Qi (lpm) =	1.1-4.2	Vi (l) =	7.5	Vr (l) =	0.2

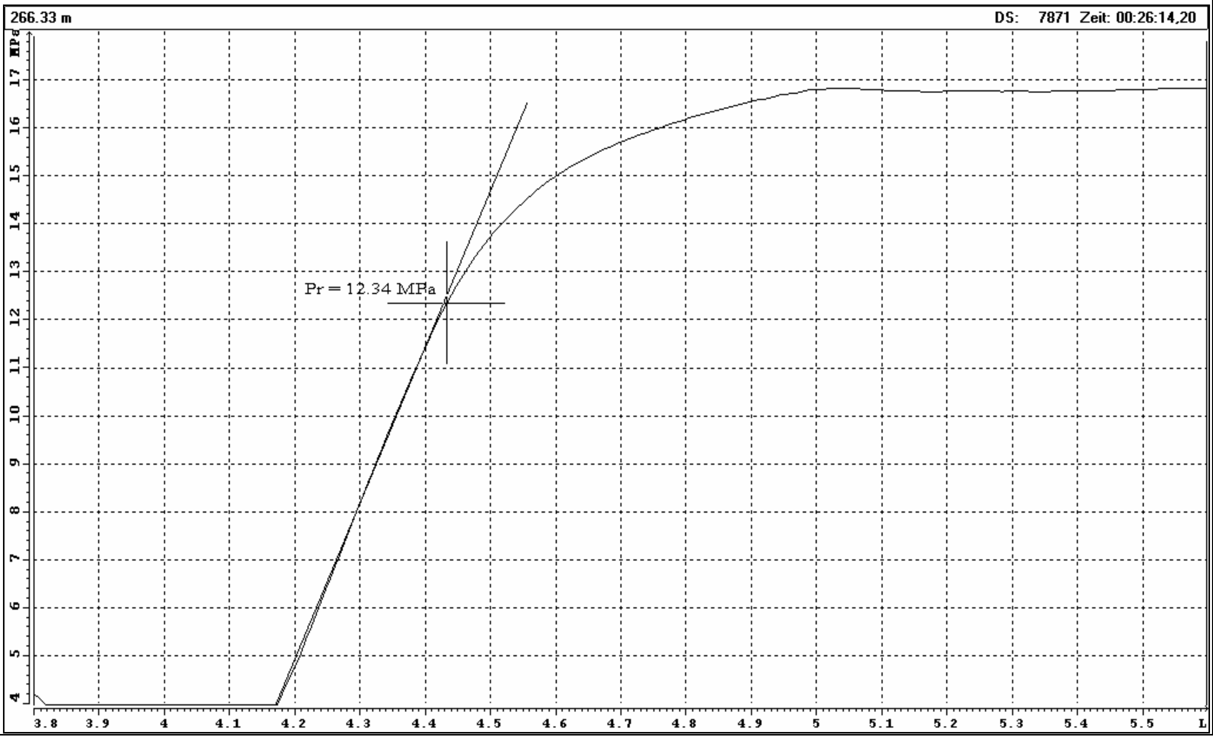
total injected volume (l): 17.5 recovered volume (l): 1.0 or 5.7 %

- Initial test type: HTPF-v
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 13.9 MPa, followed by a pressure increase up to 16.4 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- Although the shut-in phases are less distinct, the analysis yield consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

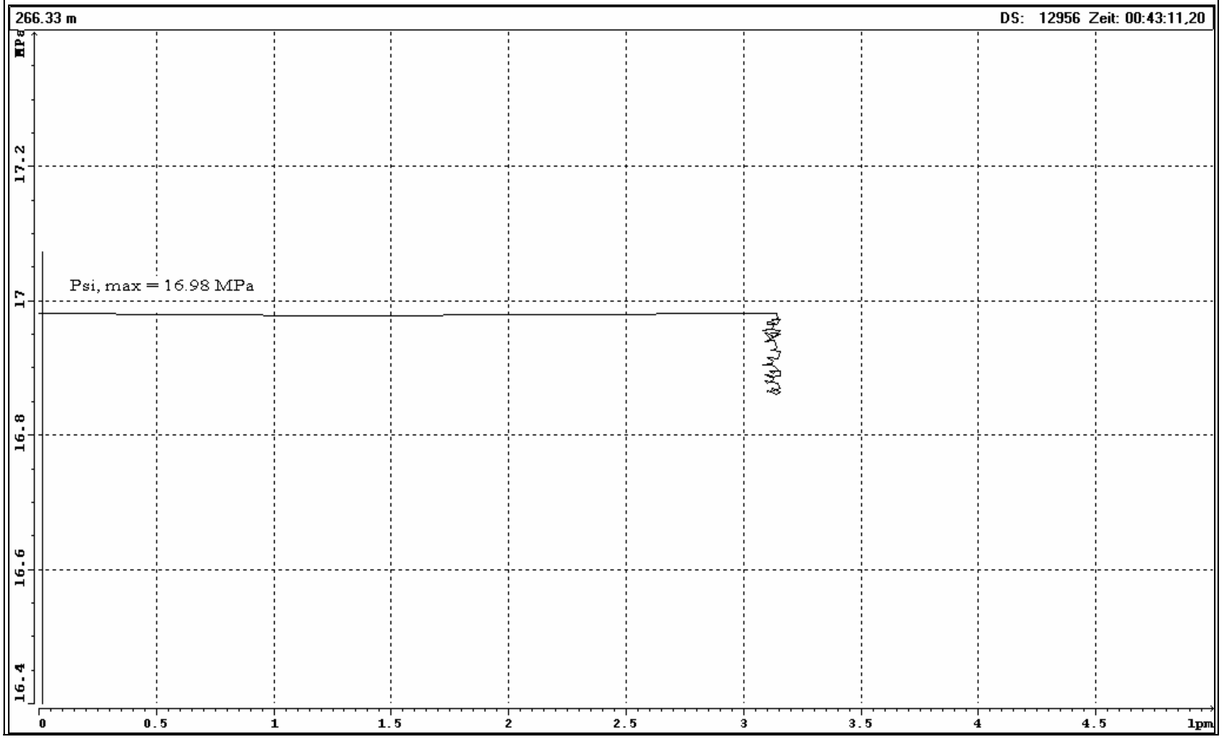
Test at 266.33 m MD: Estimation of P_r (1. Refrac - Cycle)



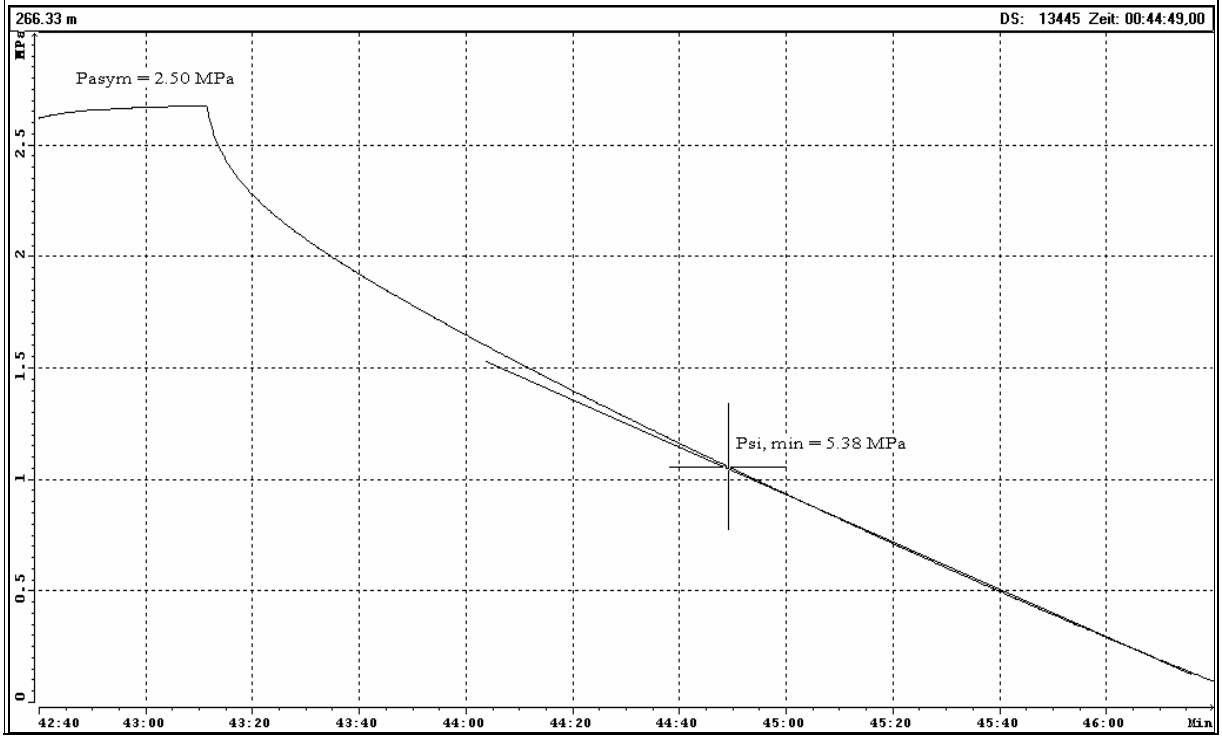
Test at 266.33 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



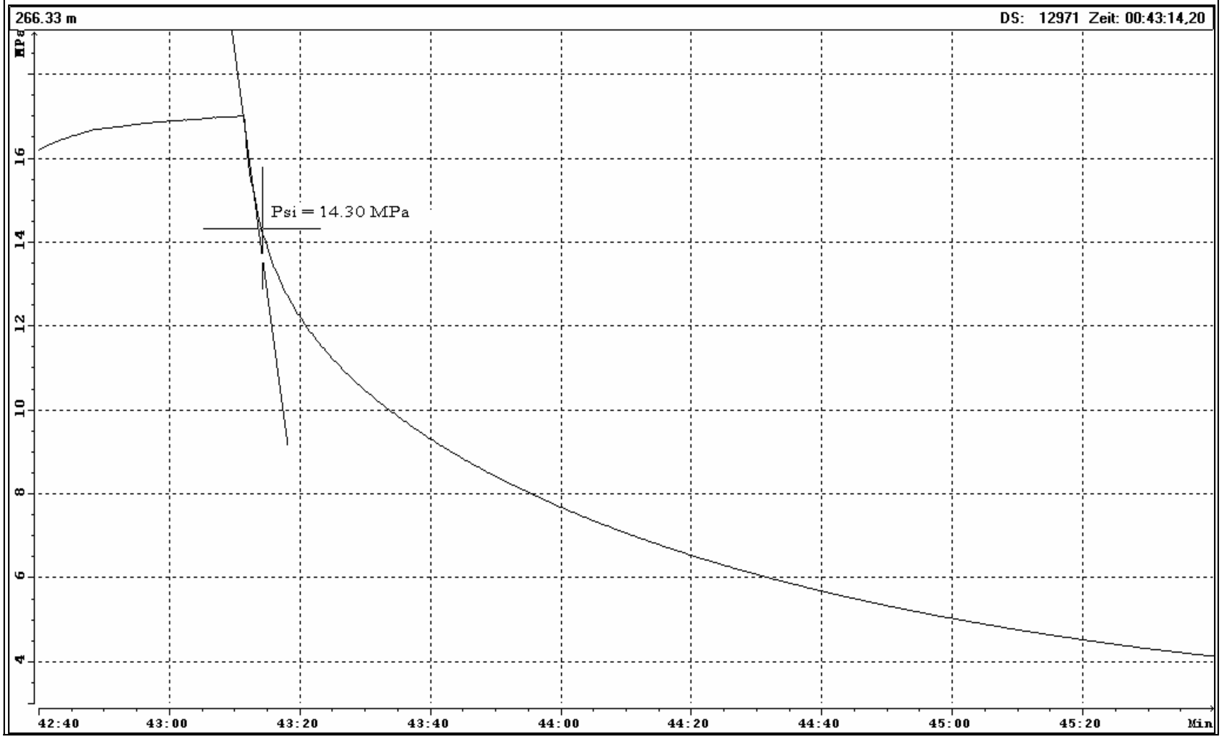
Test at 266.33 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



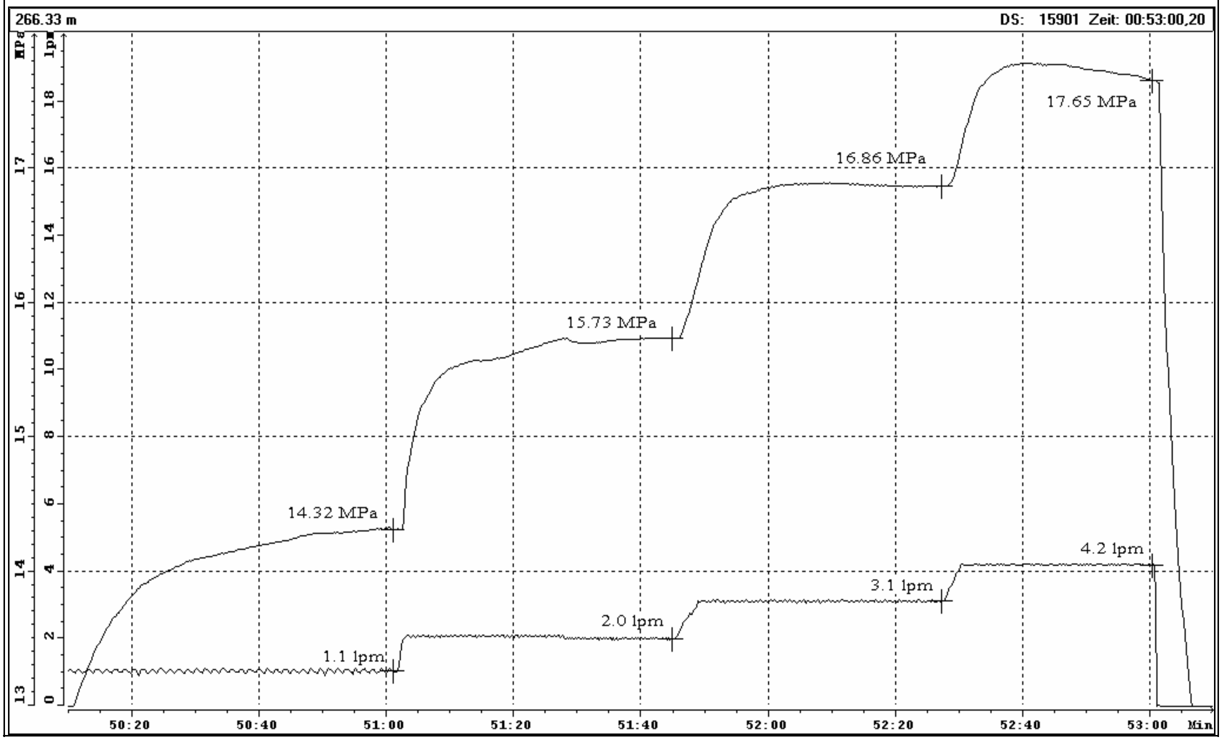
Test at 266.33 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



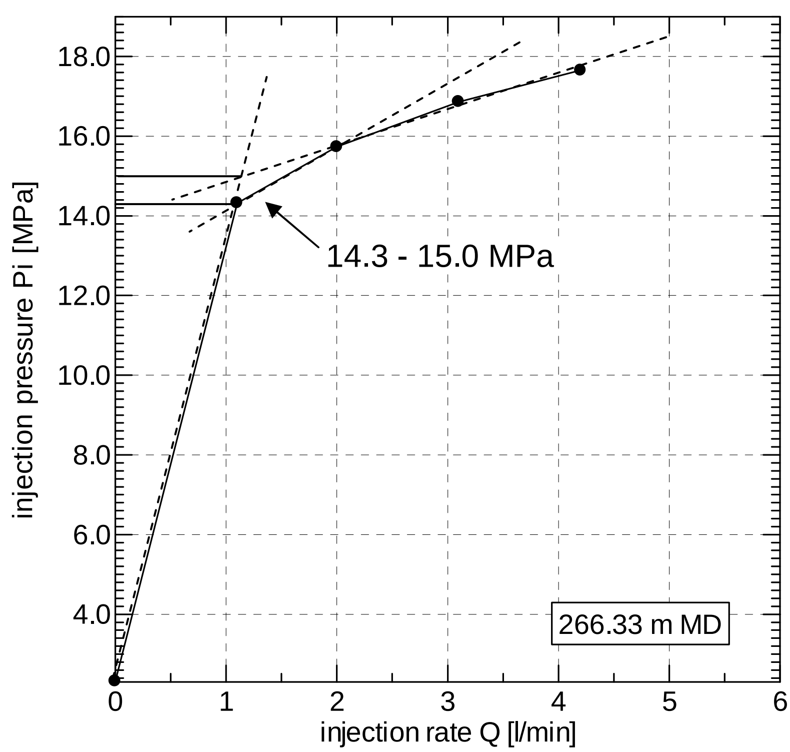
Test at 266.33 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 266.33 m MD: Analysis of Slow - Pump / Step - Rate - Test

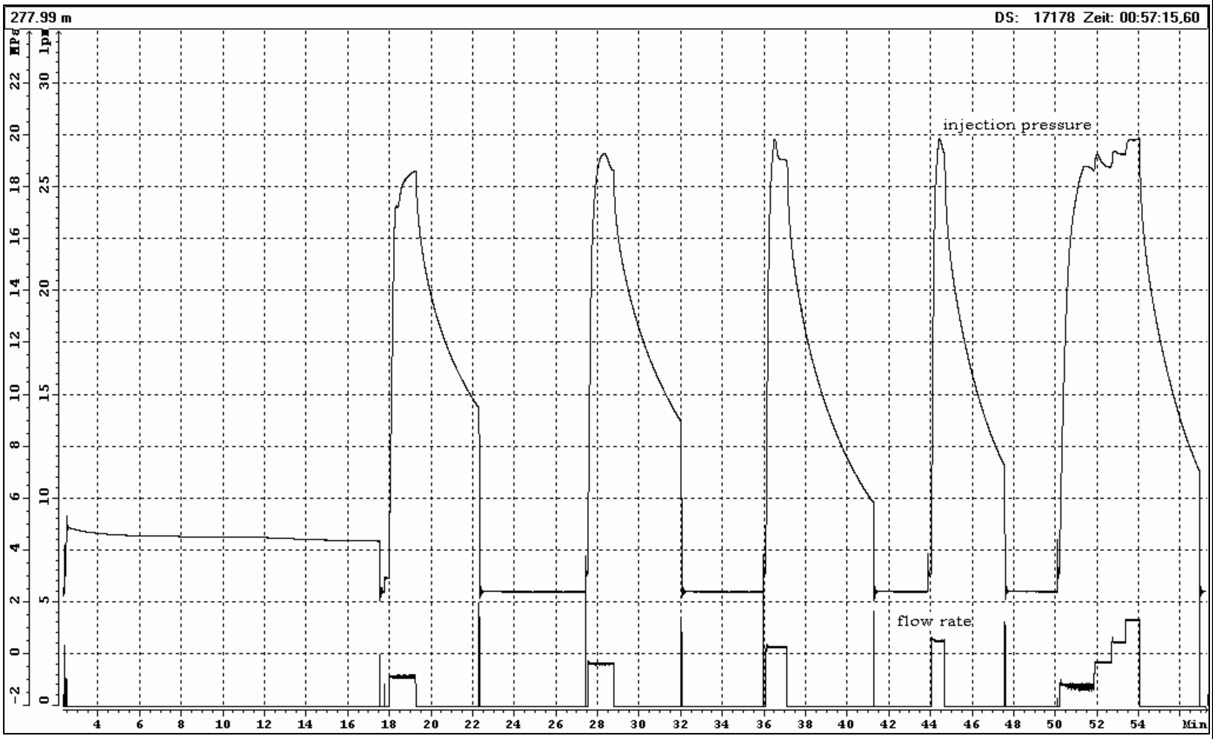


Test at 266.33 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 8 AT 277.99 m MD / 243.63 m TVD

Test at 277.99 m MD : Overview - Plot



P - Test | Frac (1. Refrac) | 2. Refrac | 3. Refrac | 4. Refrac | SP/SR Test

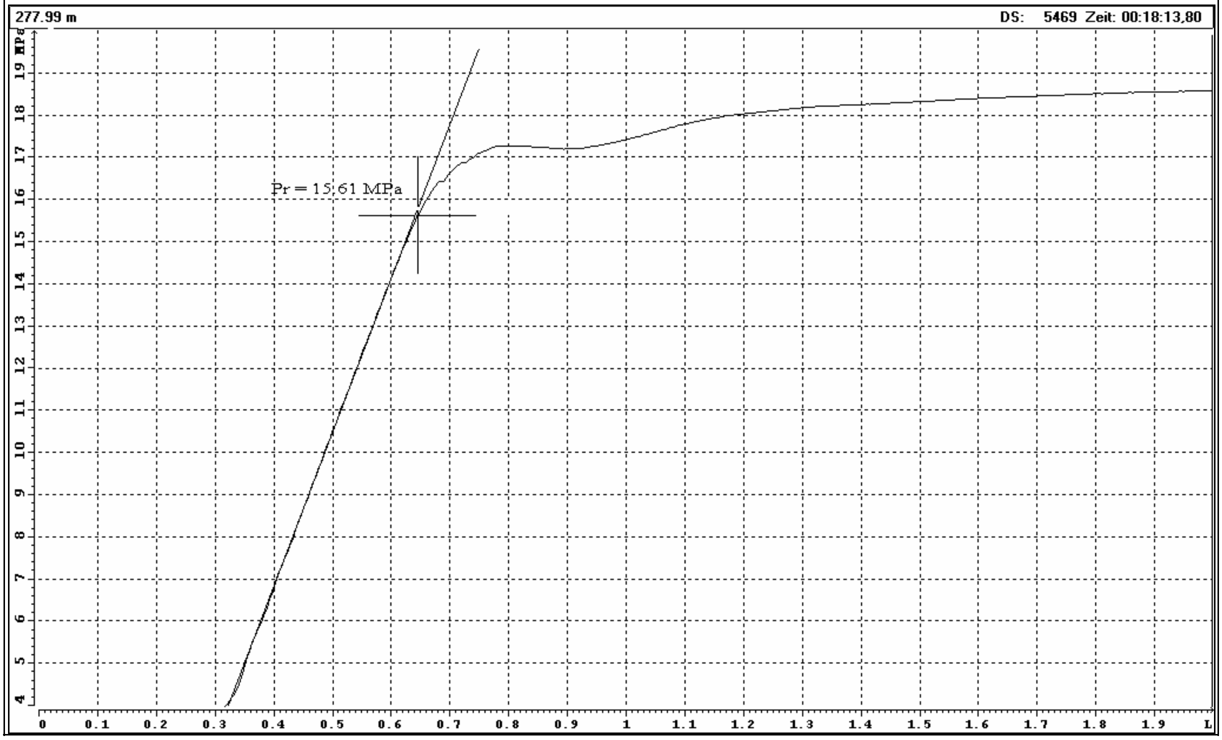
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 0.50 MPa in 893 sec.					
Frac (1. Refrac) - cycle	Qi (lpm) =	1.4	Vi (l) =	1.9	Vr (l) =	0.2
2. Refrac - cycle	Qi (lpm) =	2.0	Vi (l) =	2.6	Vr (l) =	0.2
3. Refrac - cycle	Qi (lpm) =	2.9	Vi (l) =	2.9	Vr (l) =	0.2
4. Refrac - cycle	Qi (lpm) =	3.1	Vi (l) =	2.0	Vr (l) =	0.2
SP/SR - test	Qi (lpm) =	1.0-4.2	Vi (l) =	8.3	Vr (l) =	0.2

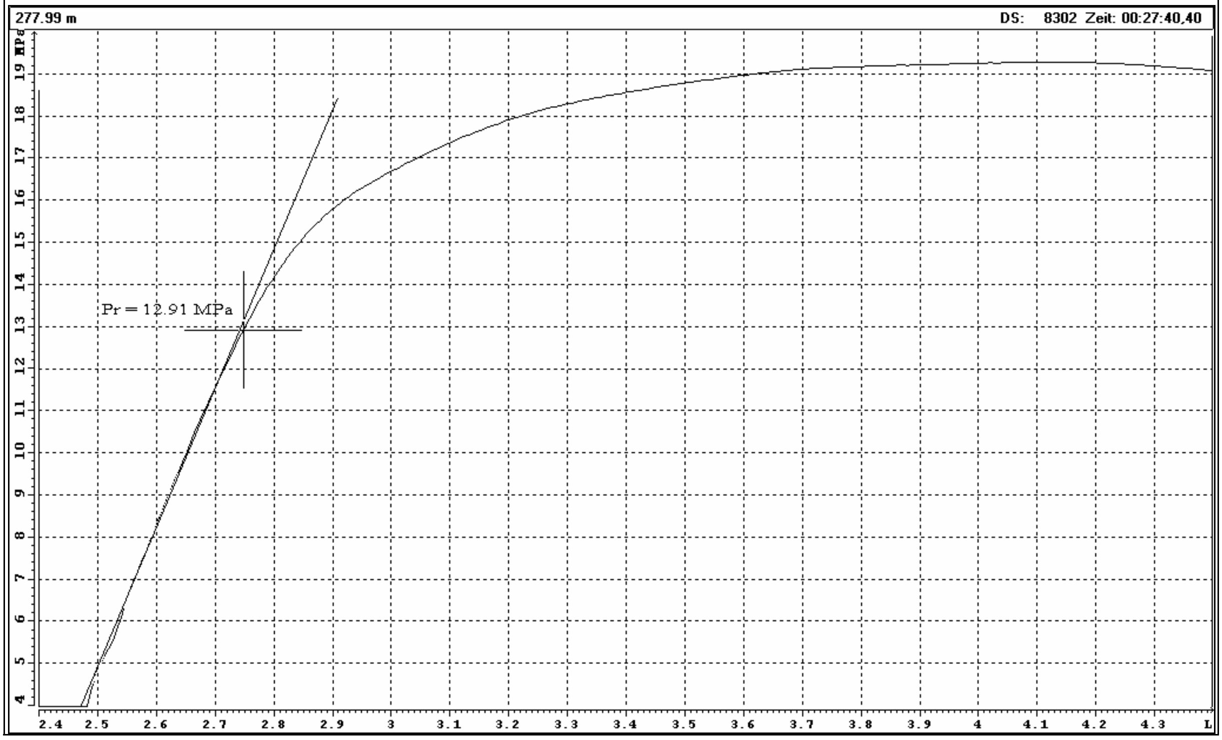
total injected volume (l): 17.7 recovered volume (l): 1.0 or 5.6 %

- Initial test type: HTPF-v
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- Although the shut-in phases are less distinct, the analysis yield consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

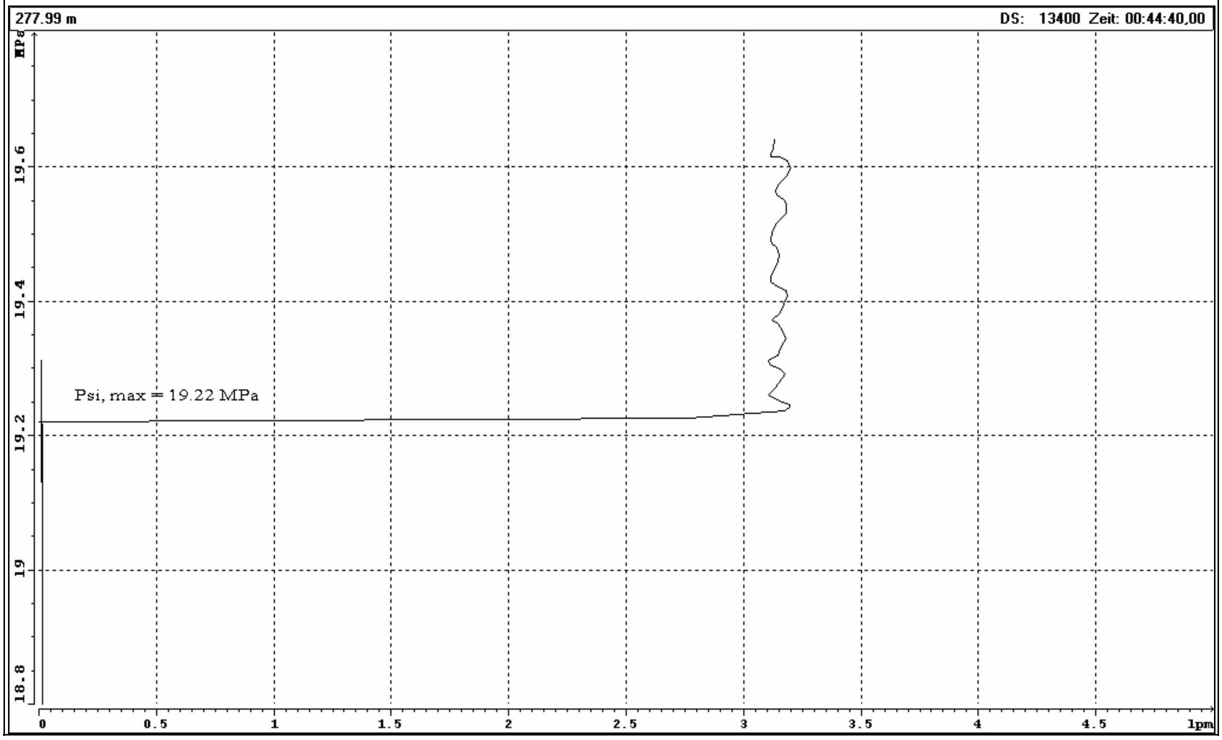
Test at 277.99 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



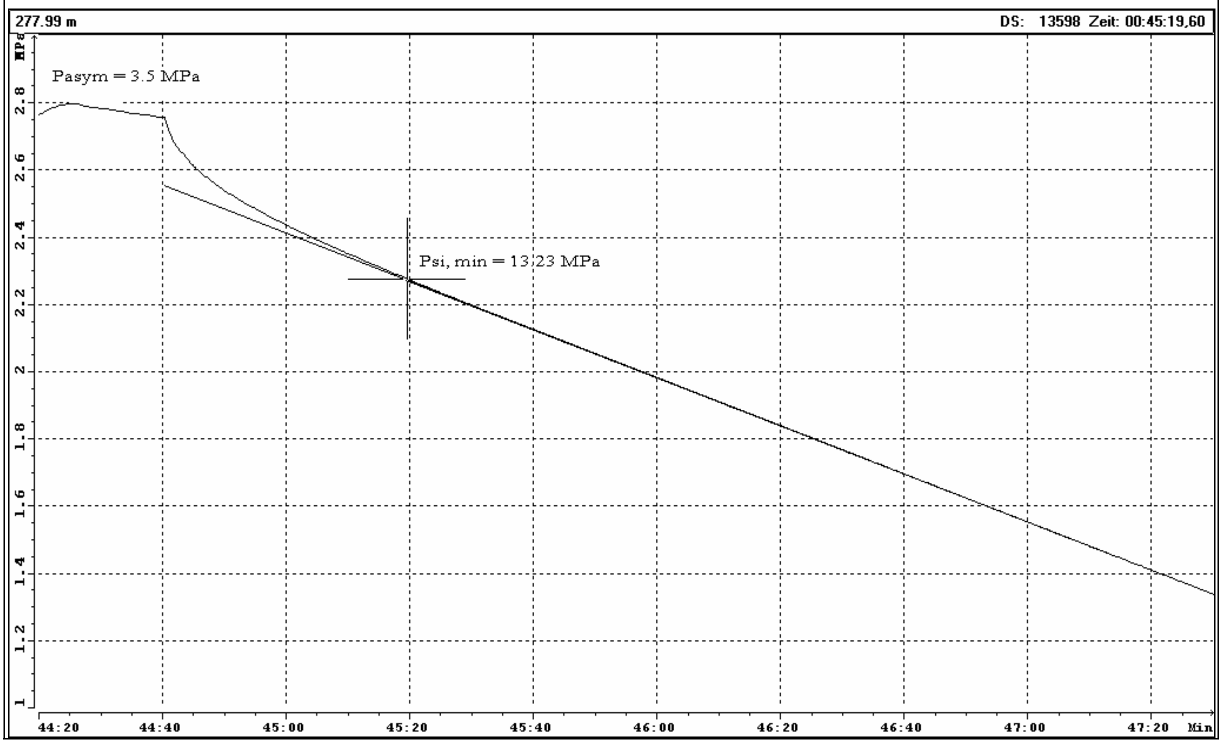
Test at 277.99 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



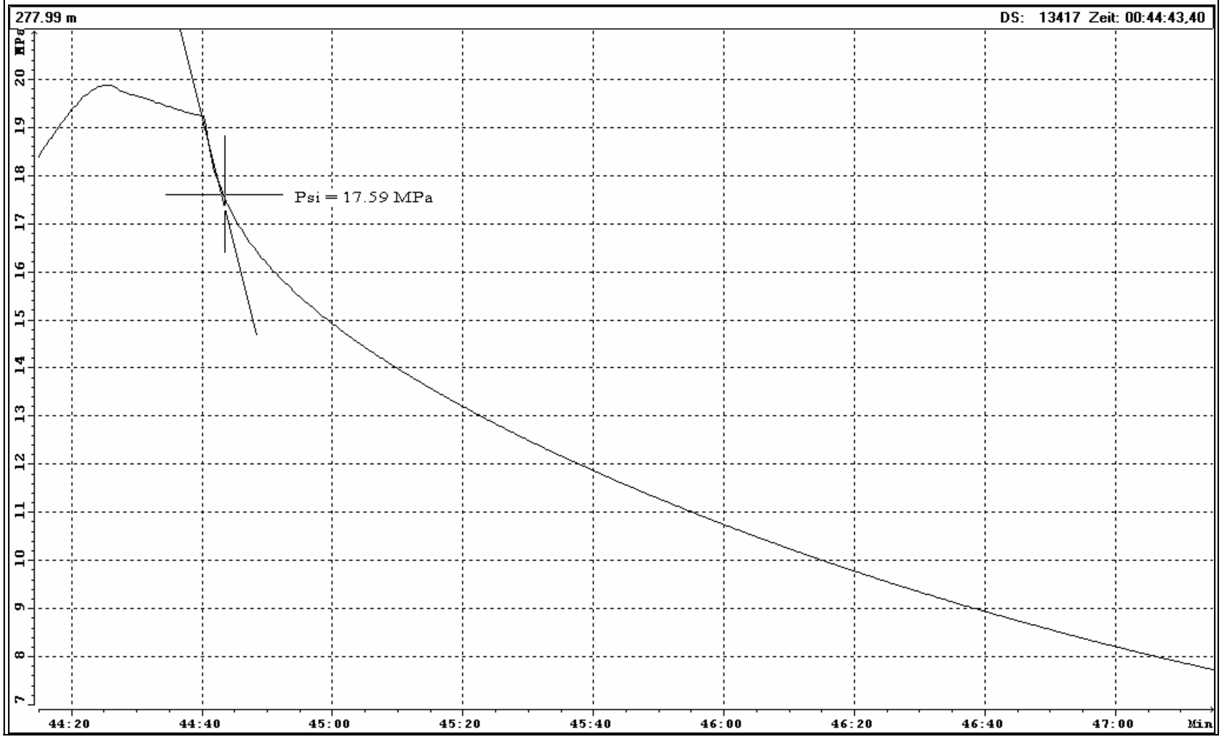
Test at 277.99 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



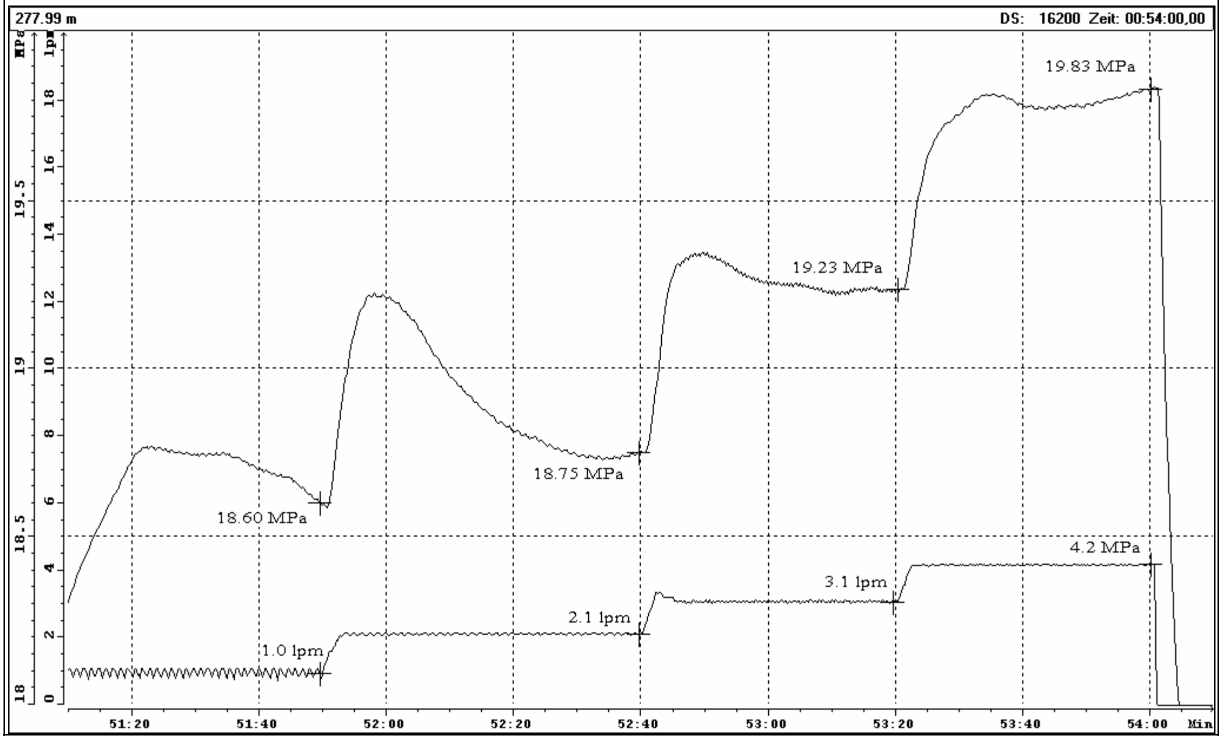
Test at 277.99 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



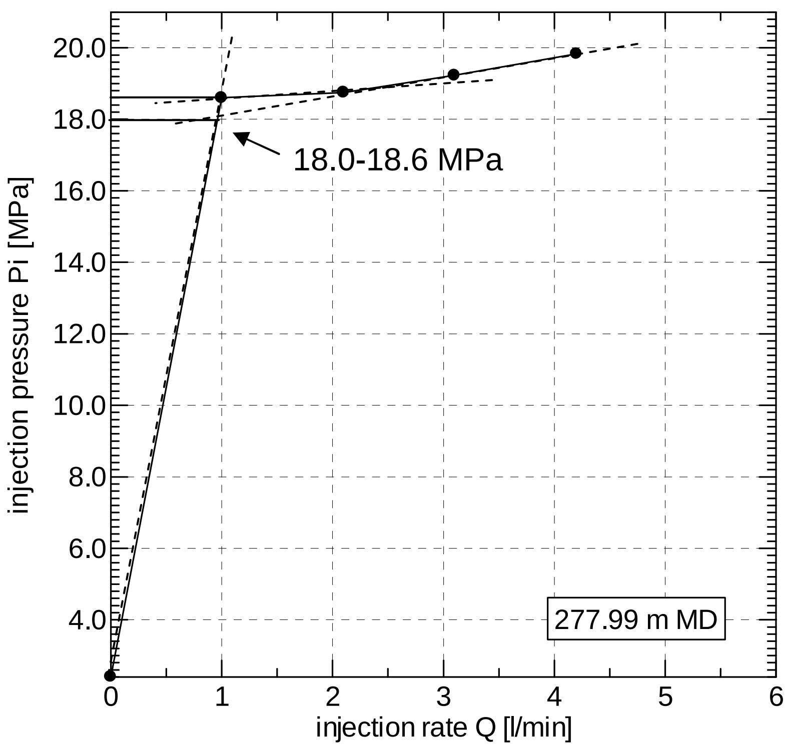
Test at 277.99 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 277.99 m MD: Analysis of Slow - Pump / Step - Rate - Test

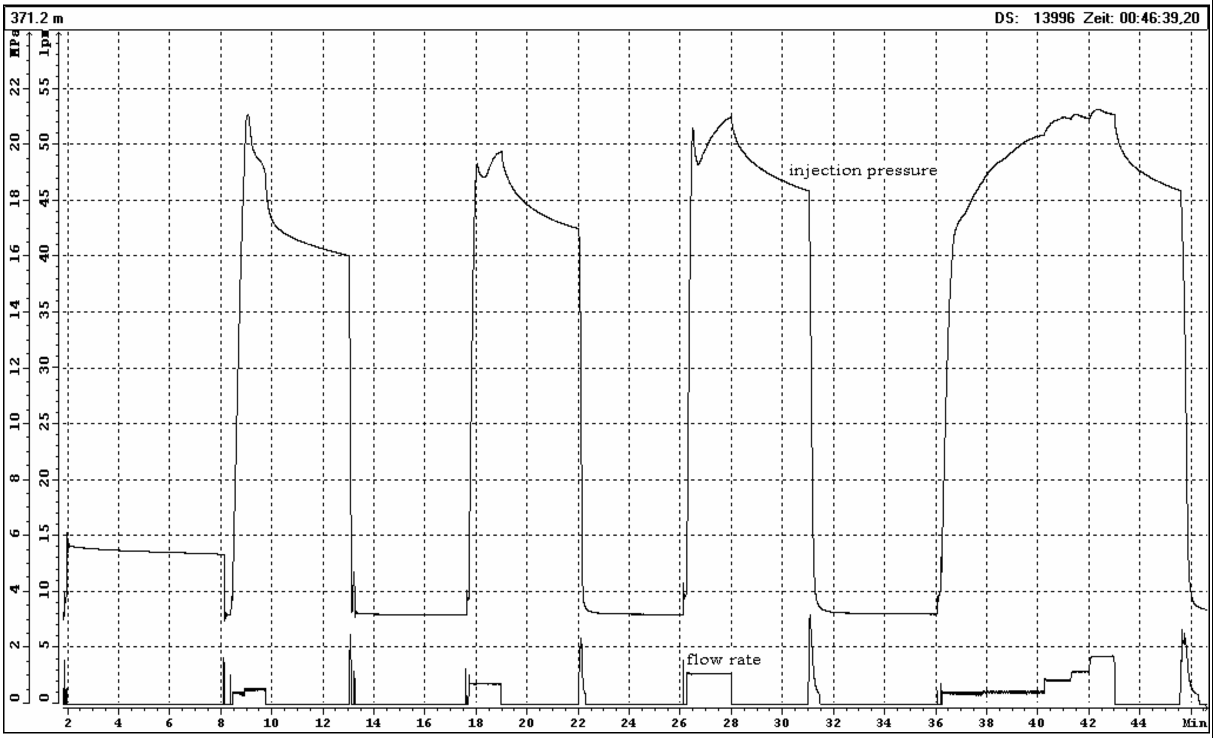


Test at 277.99 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 7 AT 371.2 m MD / 322.95 m TVD

Test at 371.2 m MD: Overview - Plot



P - Test Frac (1. Refrac) 2. Refrac 3. Refrac Slow-Pump/Step-Rate Test

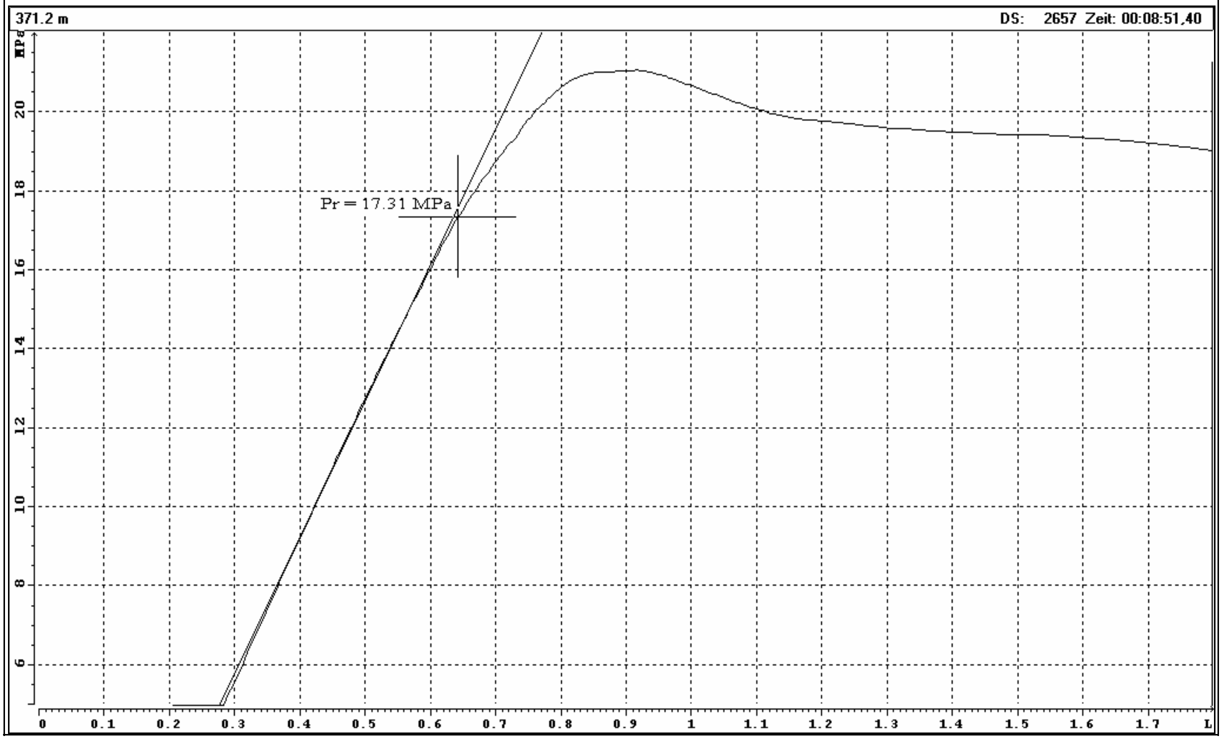
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.28 MPa in 360 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.3	Vi (l) = 1.6	Vr (l) = 0.8
2. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 2.4	Vr (l) = 1.6
3. Refrac - cycle	Qi (lpm) = 2.7	Vi (l) = 4.8	Vr (l) = 3.0
SP/SR - test	Qi (lpm) = 1.0-4.3	Vi (l) = 12.8	Vr (l) = 5.0

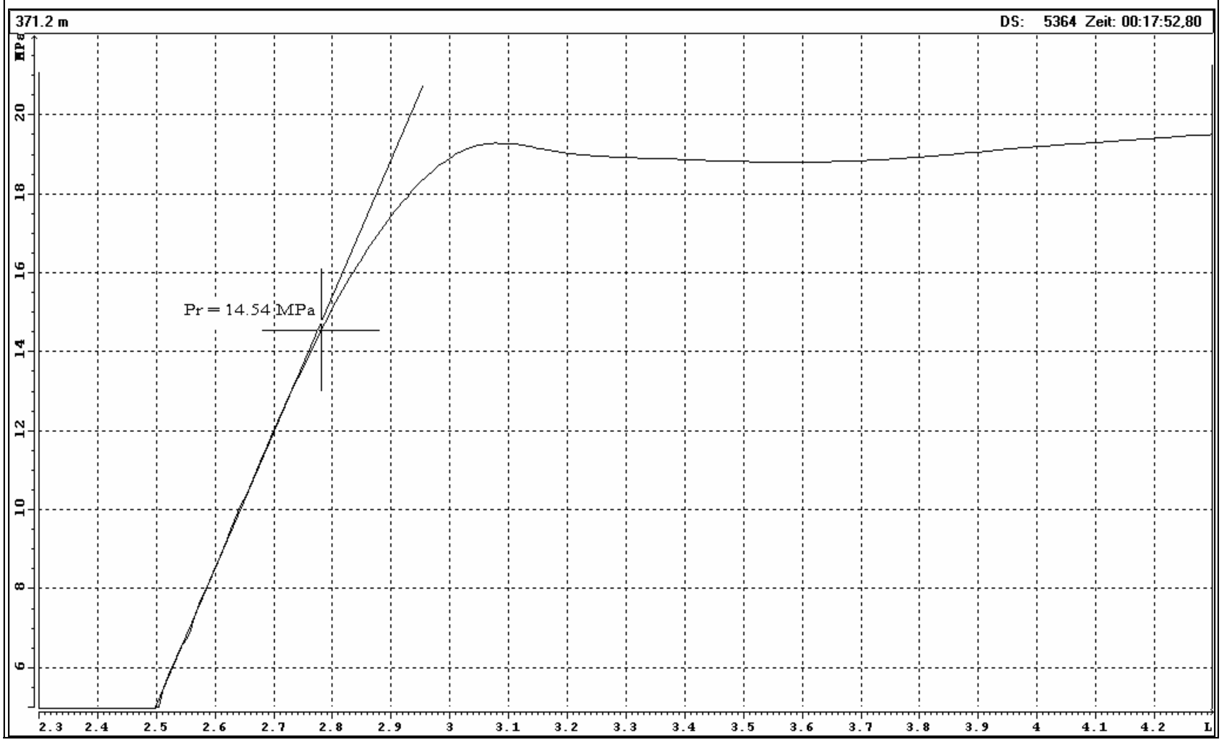
total injected volume (l): 21.6 recovered volume (l): 10.4 or 48.1 %

- Initial test type: HF
- Although the test section contains no visible fracture, the frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV at 17.3 MPa, followed by a pressure increase up to almost 21 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct shut-in pressure values, which, however, increased from 18.2 MPa during the 1. refrac - cycle to 20.6 MPa during the 3. refrac - cycle. Therefore, the shut - in pressure of the 1. refrac - cycle was used for the stress analysis.

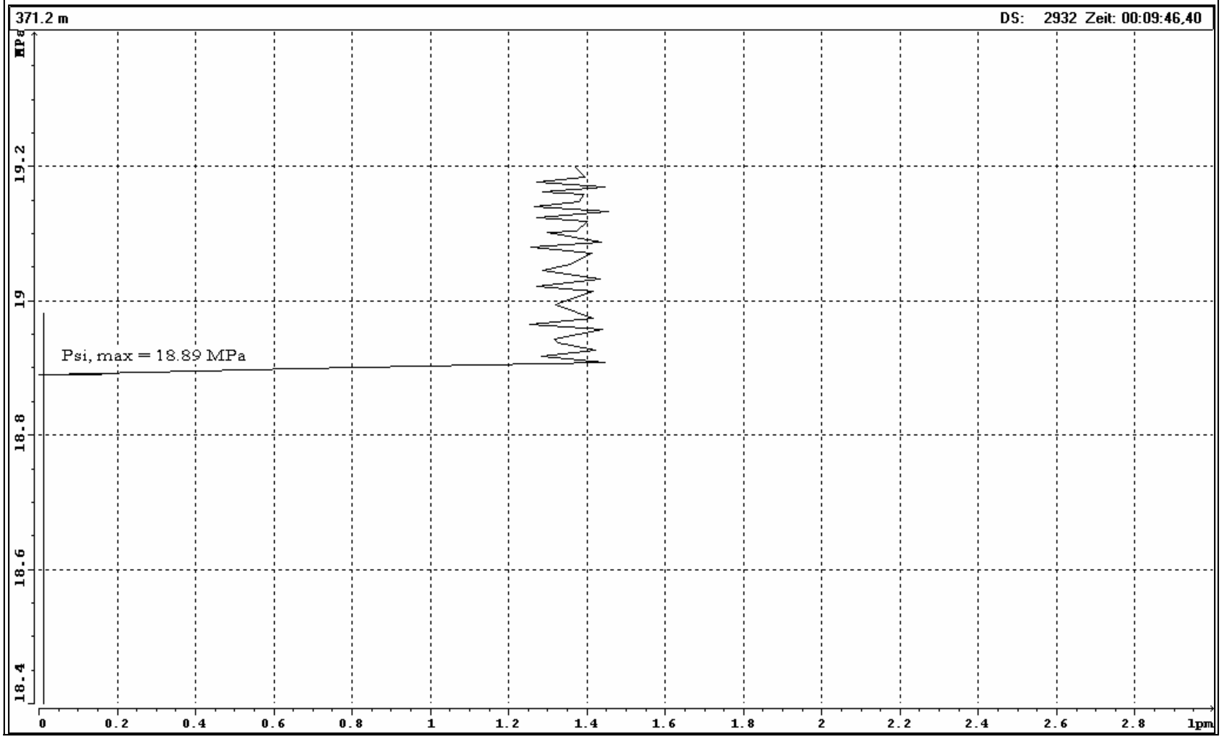
Test at 371.2 m MD: Estimation of P_r (1. Refrac - Cycle)



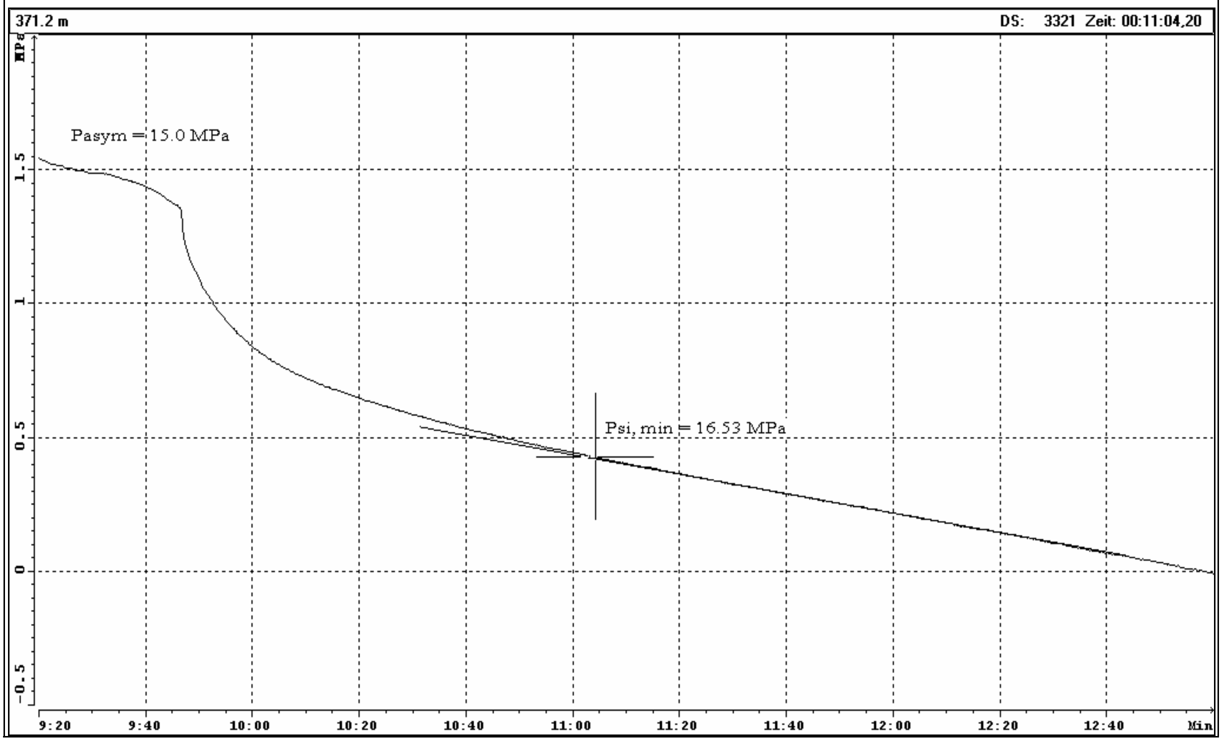
Test at 371.2 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



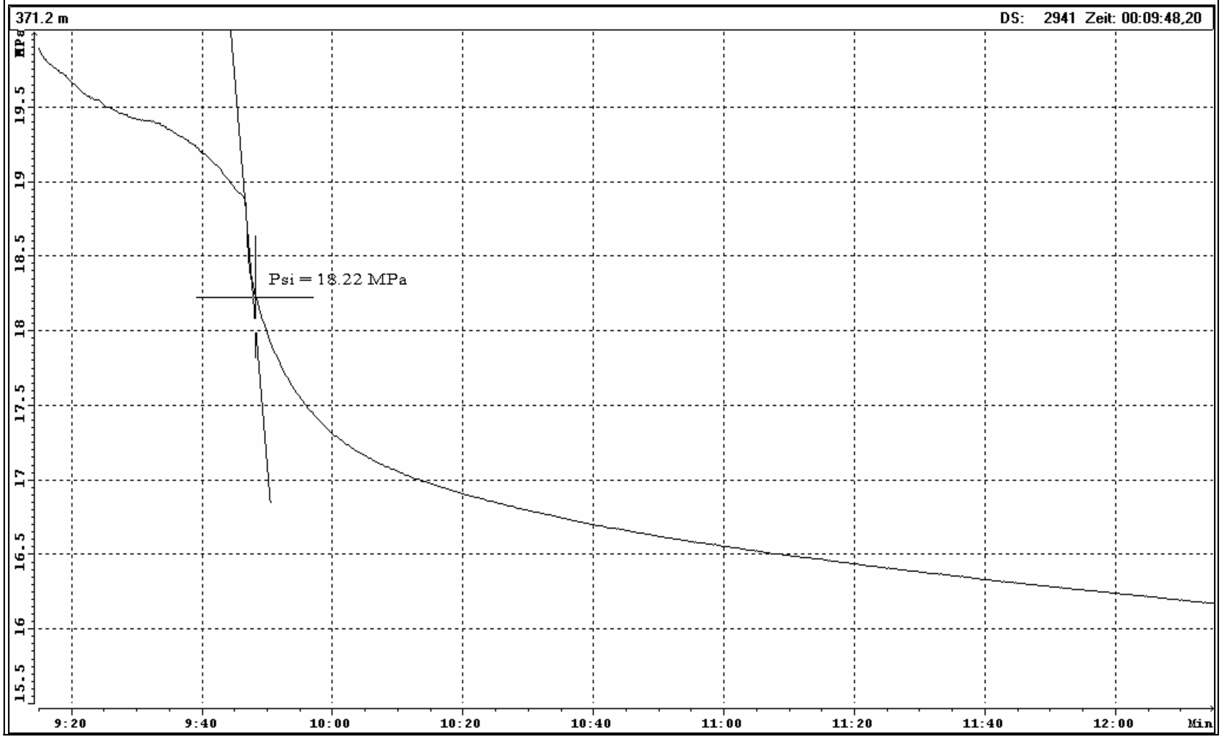
Test at 371.2 m MD: Estimation of $P_{si, max}$ (1. Refrac - Cycle)



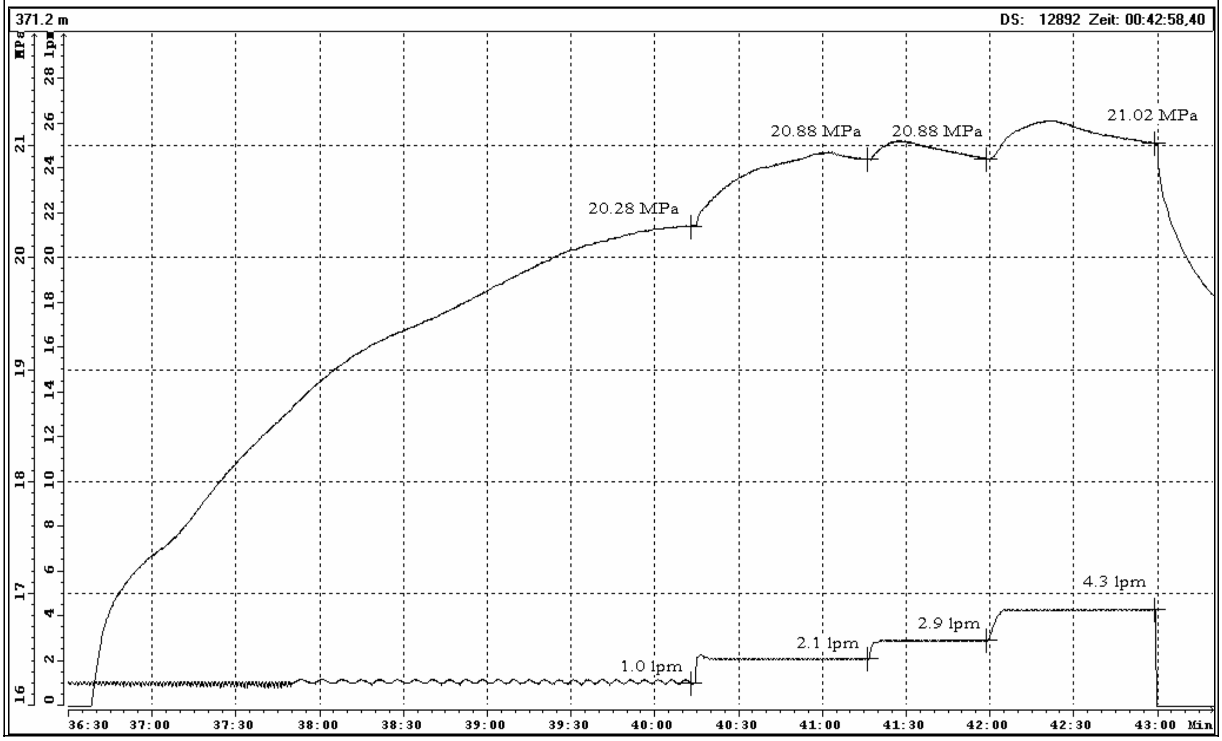
Test at 371.2 m MD: Estimation of $P_{si, min}$ (1. Refrac - Cycle)



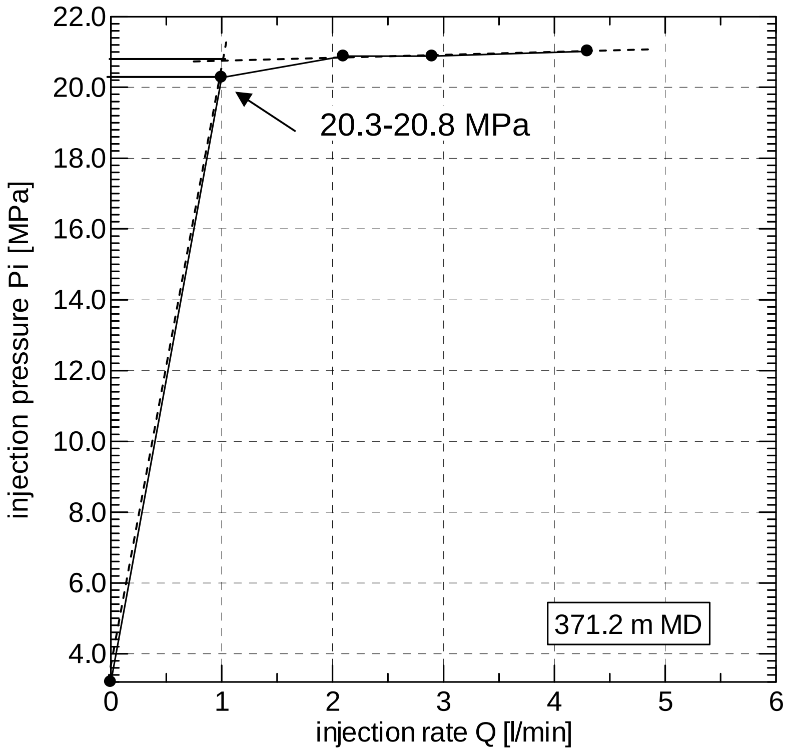
Test at 371.2 m MD: Estimation of P_{si} (1. Refrac - Cycle)



Test at 371.2 m MD: Analysis of Slow - Pump / Step - Rate - Test

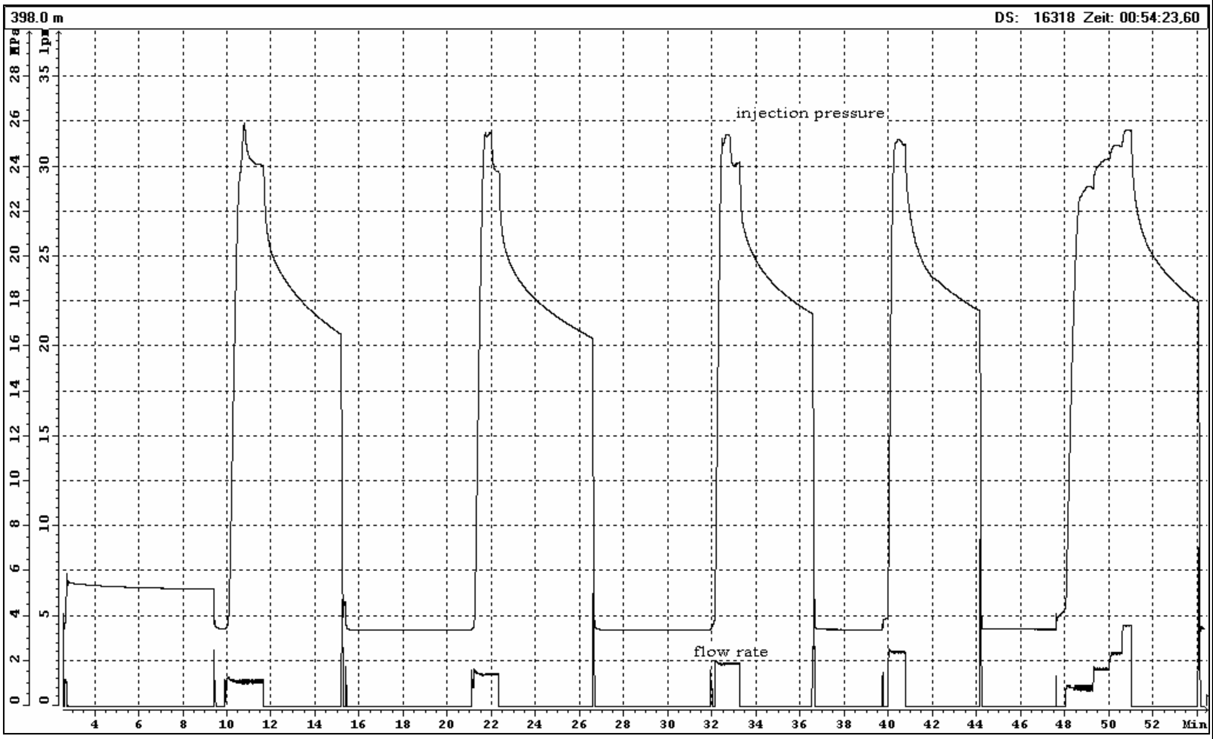


Test at 371.2 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 6 AT 398.0 m MD / 345.30 m TVD

Test at 398.0 m MD: Overview - Plot



P - Test   Frac (1. Refrac)   2. Refrac   3. Refrac   4. Refrac   SP/SR - Test

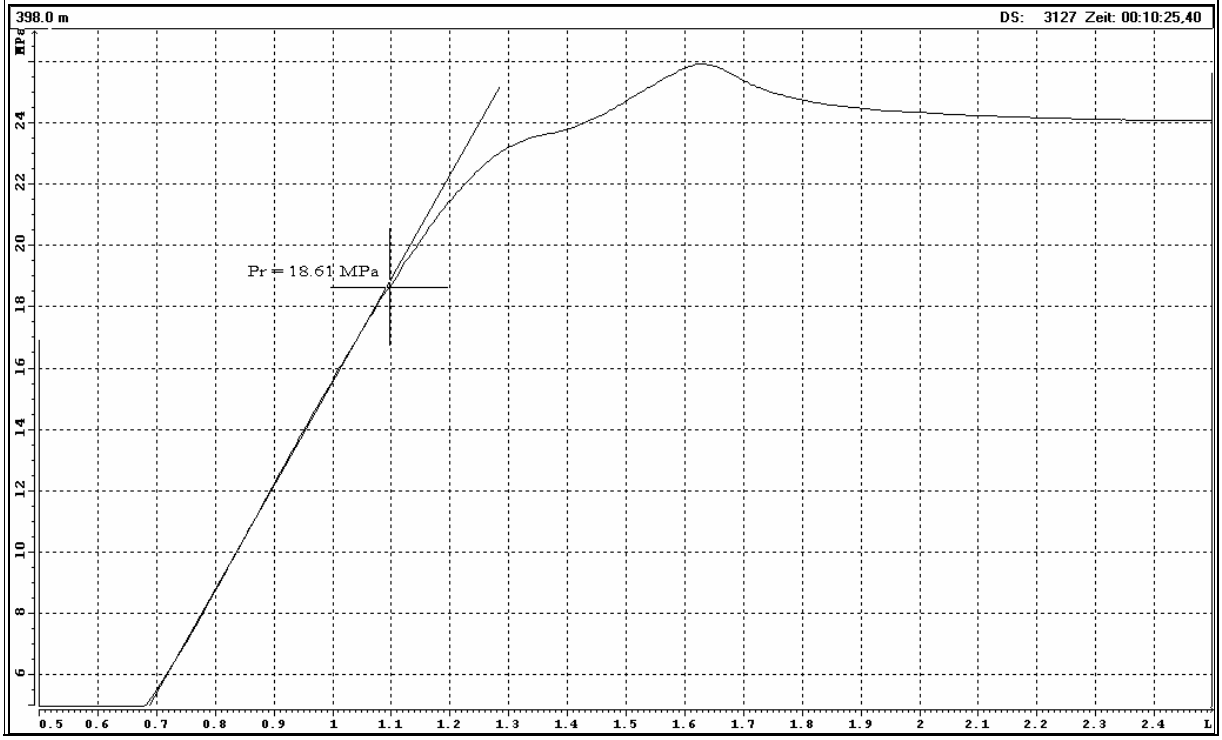
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.27 MPa in 390 sec.					
Frac (1. Refrac) - cycle	Qi (lpm) =	1.4	Vi (l) =	2.5	Vr (l) =	0.8
2. Refrac - cycle	Qi (lpm) =	1.8	Vi (l) =	2.2	Vr (l) =	0.8
3. Refrac - cycle	Qi (lpm) =	2.4	Vi (l) =	2.8	Vr (l) =	0.9
4. Refrac - cycle	Qi (lpm) =	3.0	Vi (l) =	2.4	Vr (l) =	1.0
SP/SR - test	Qi (lpm) =	1.0-4.5	Vi (l) =	6.4	Vr (l) =	1.4

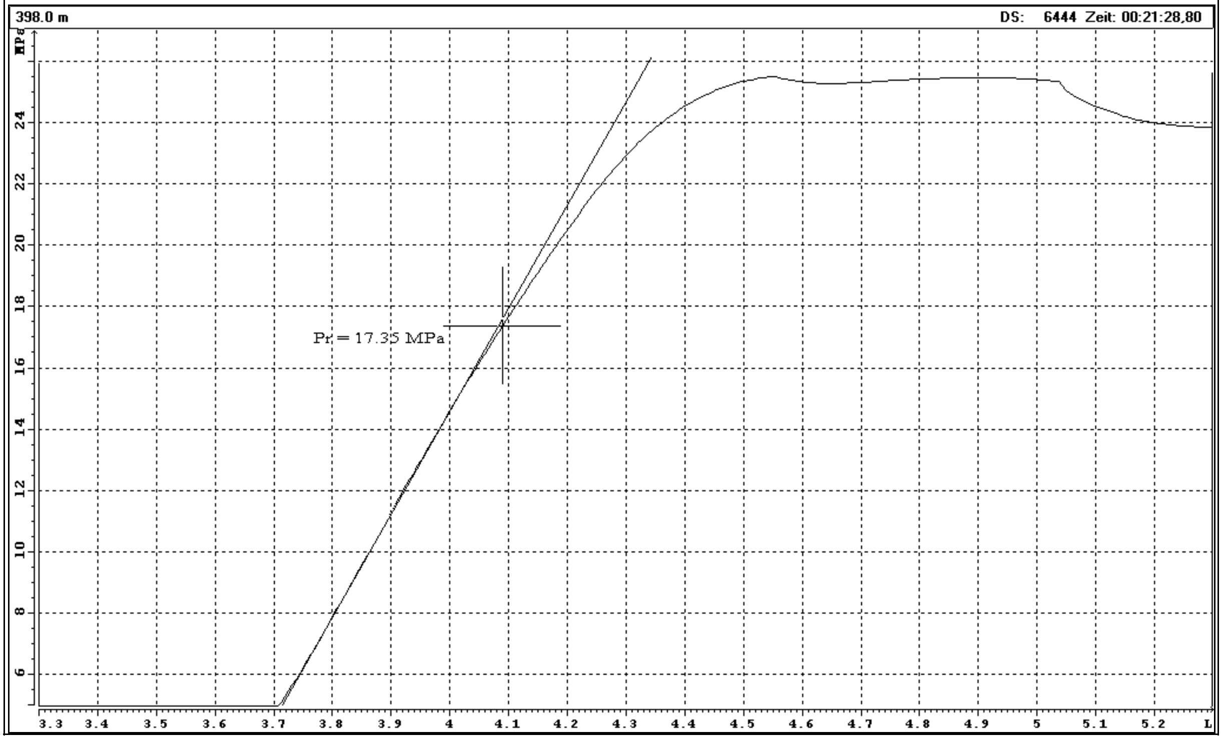
total injected volume (l): 16.3   recovered volume (l): 4.9 or 30.1 %

- Initial test type: HF
- Although the test section contains no visible fracture, the frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 18.6 MPa, followed by a pressure increase up to 25.9 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct shut-in pressure values, which, however, increased after the 3. refrac - cycle from 22.15 MPa to 23.4 MPa during the 4. refrac - cycle. Therefore, the shut - in pressure of the 3. refrac - cycle was used for the stress analysis.

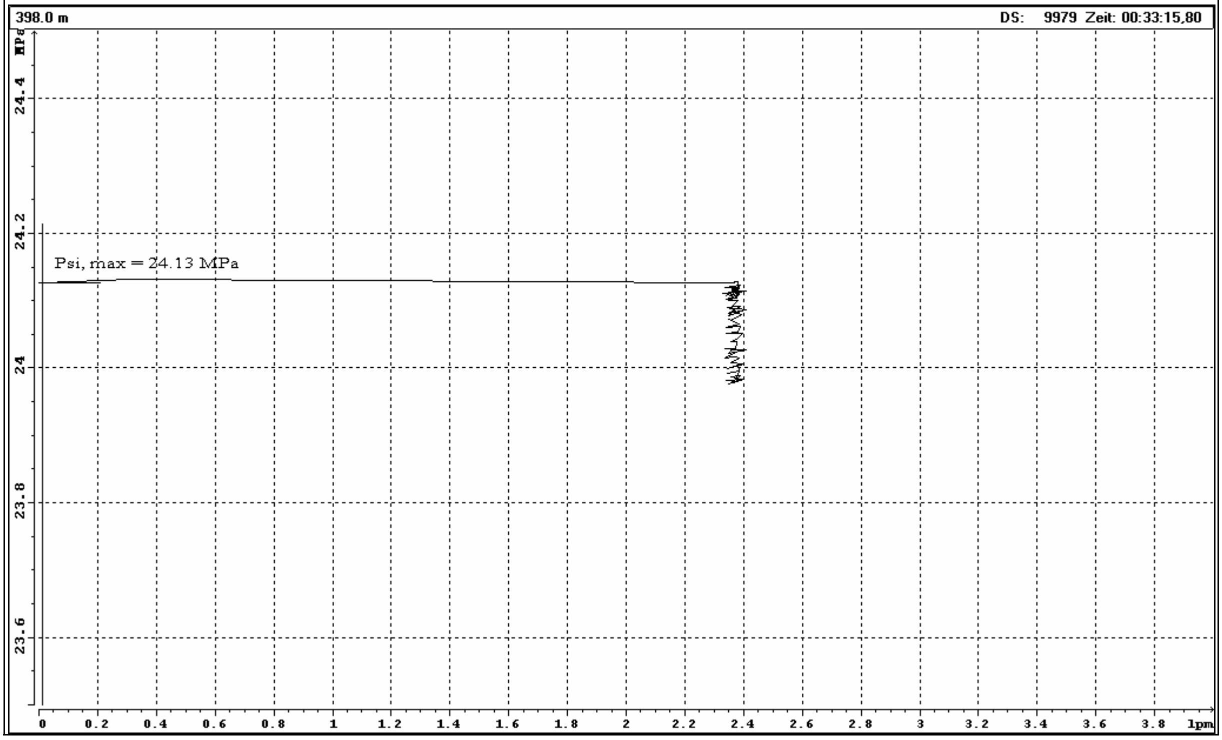
Test at 398.0 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



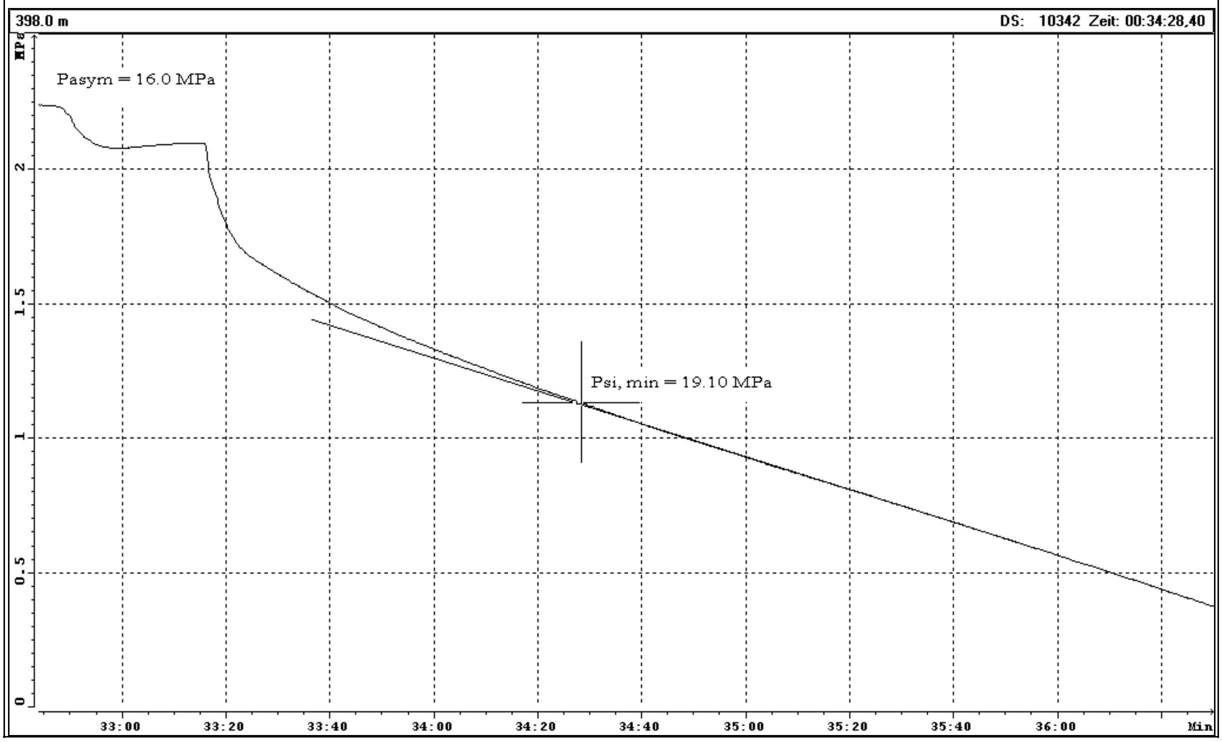
Test at 398.0 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



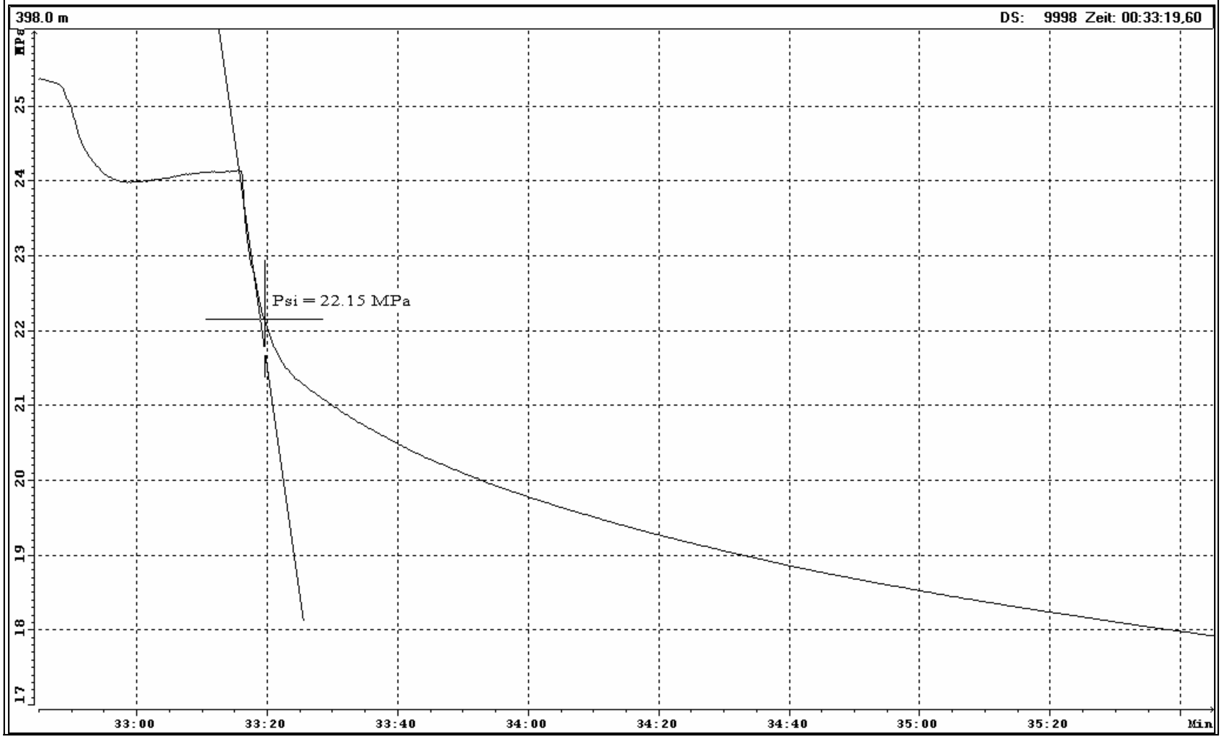
Test at 398.0 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



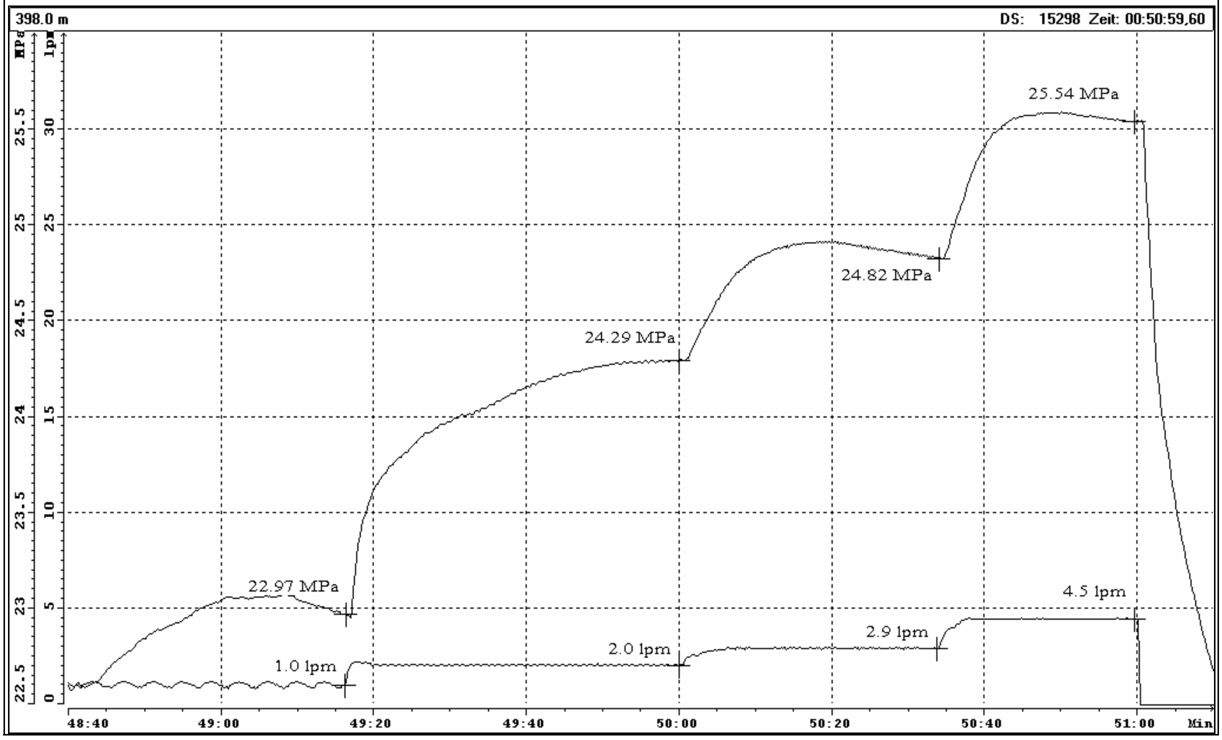
Test at 398.0 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



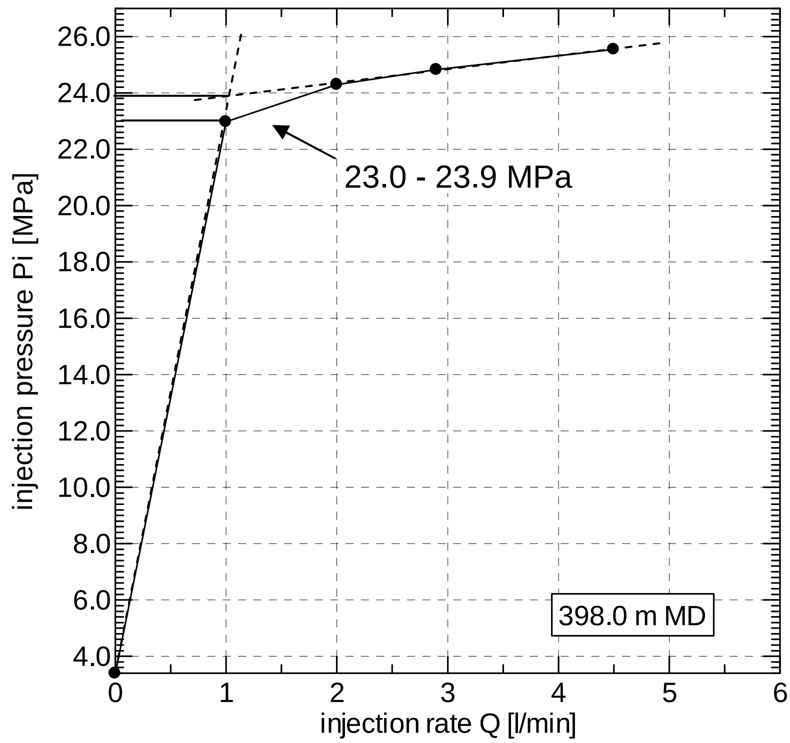
Test at 398.0 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 398.0 m MD: Analysis of Slow - Pump / Step - Rate - Test

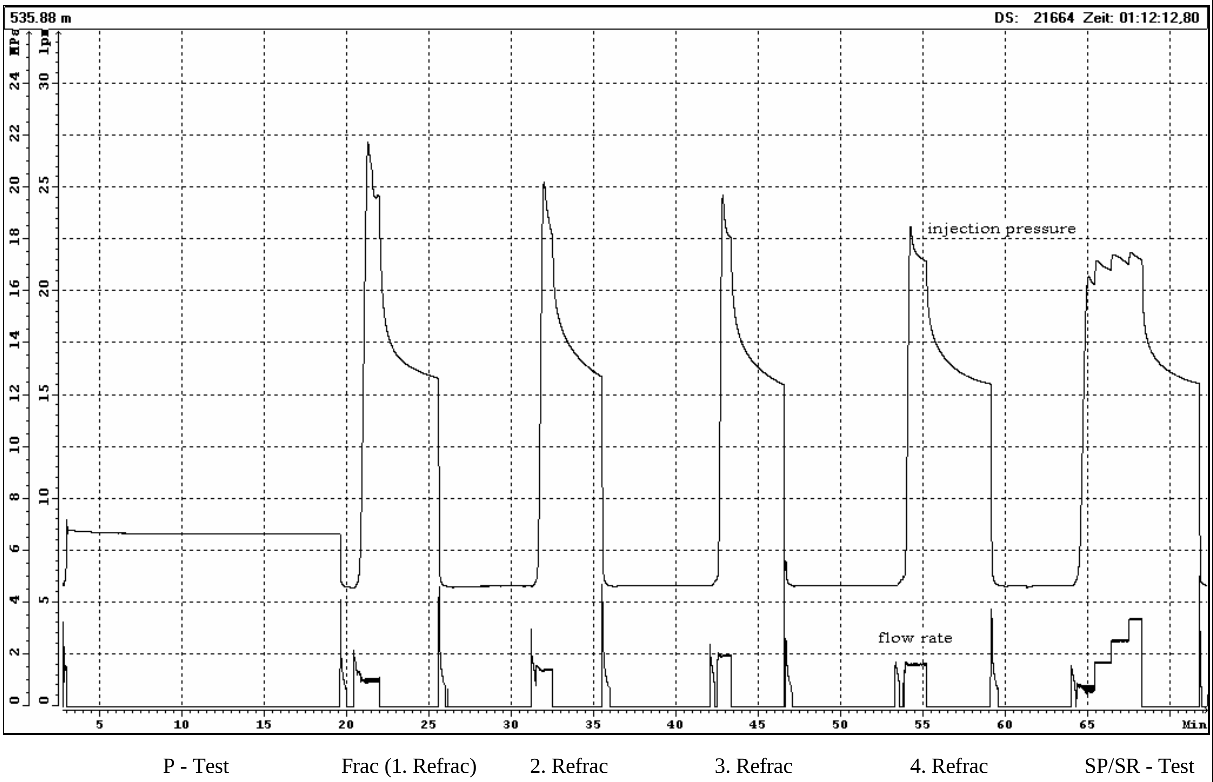


Test at 398.0 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 5 AT 535.88 m MD / 457.03 m TVD

Test at 535.88 m MD : Overview - Plot



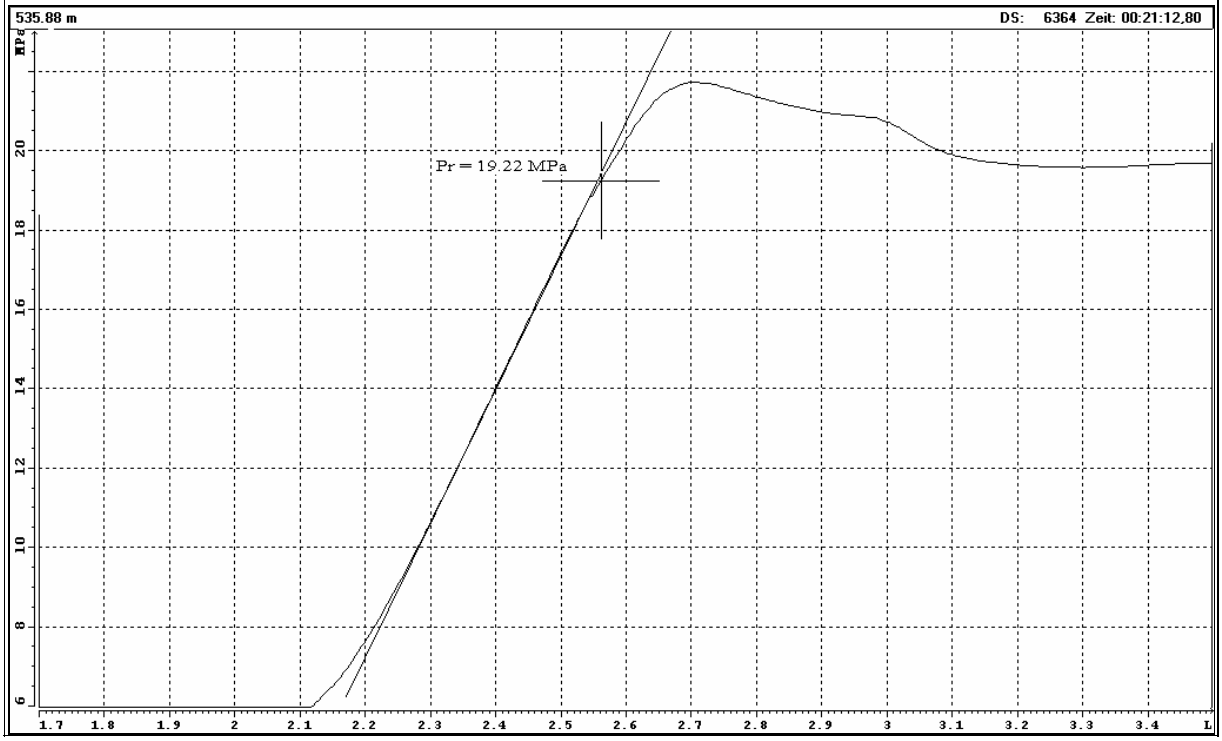
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 0.13 MPa in 984 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.3	Vi (l) = 2.3	Vr (l) = 1.4
2. Refrac - cycle	Qi (lpm) = 1.8	Vi (l) = 2.3	Vr (l) = 1.7
3. Refrac - cycle	Qi (lpm) = 2.5	Vi (l) = 2.5	Vr (l) = 1.7
4. Refrac - cycle	Qi (lpm) = 2.0	Vi (l) = 3.2	Vr (l) = 1.7
SP/SR - test	Qi (lpm) = 0.9-4.2	Vi (l) = 10.3	Vr (l) = 2.0

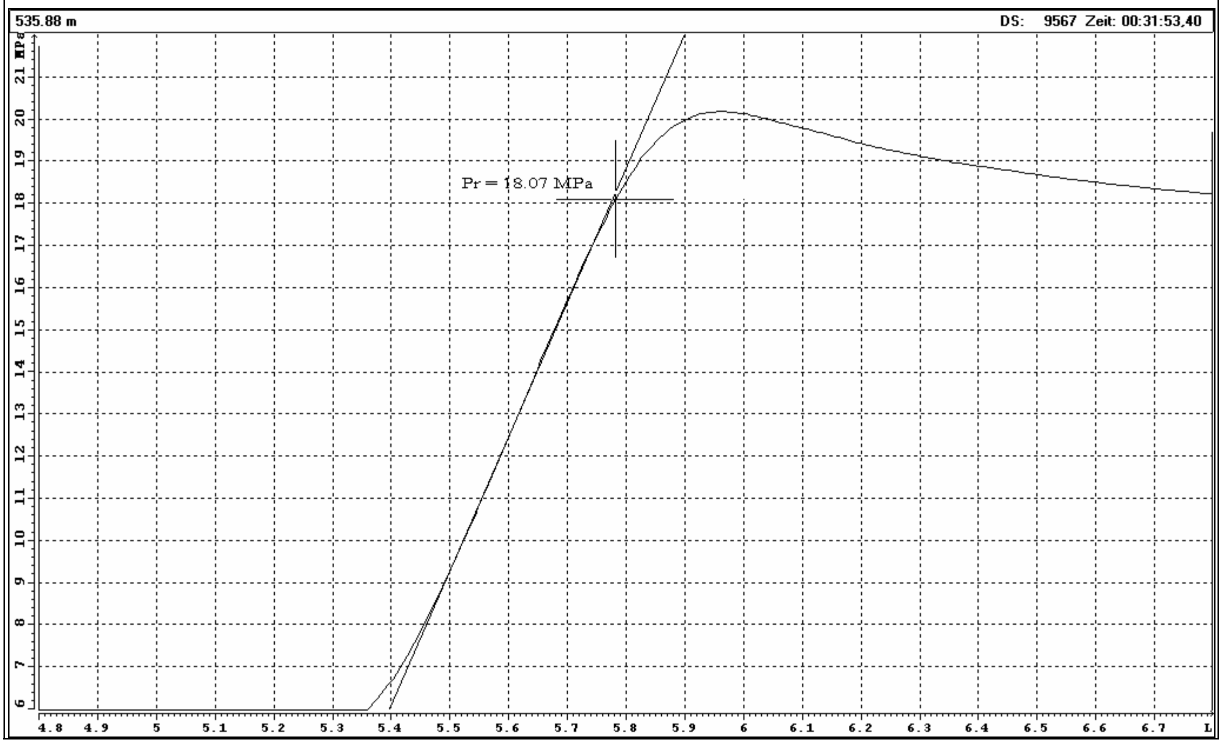
total injected volume (l): 20.6 recovered volume (l): 8.5 or 41.3 %

- Initial test type: HTPF-v
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

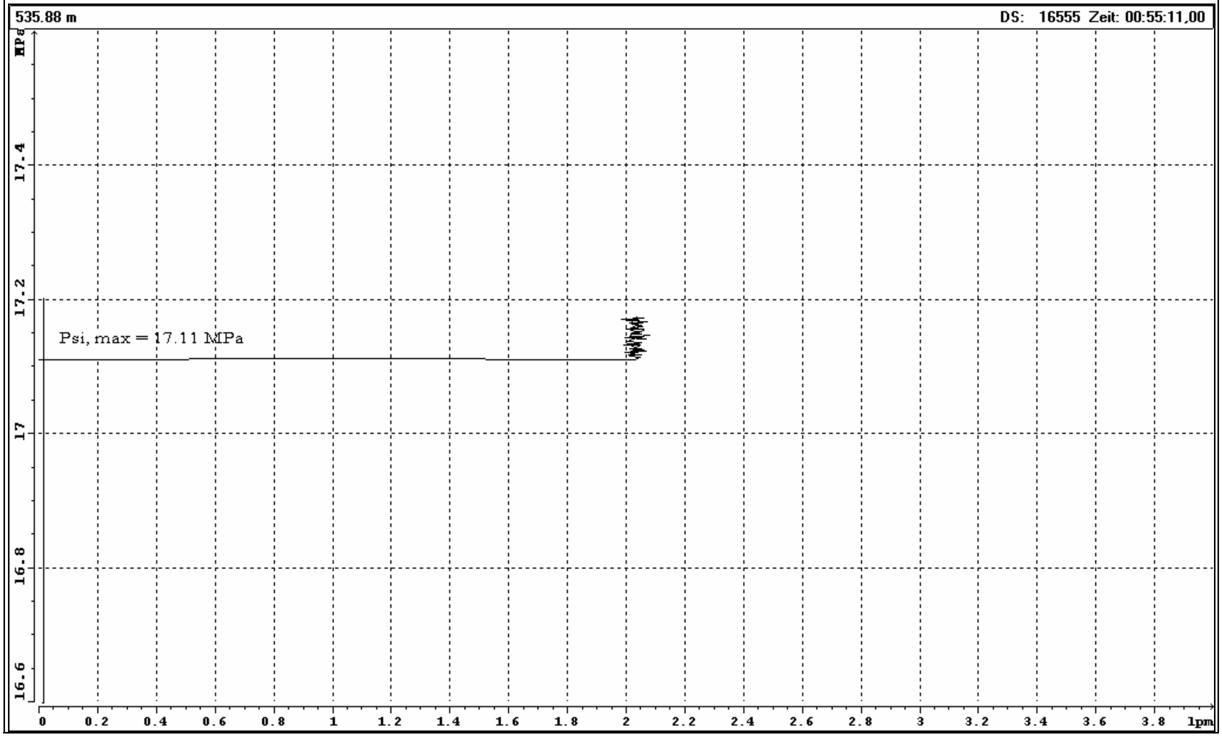
Test at 535.88 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



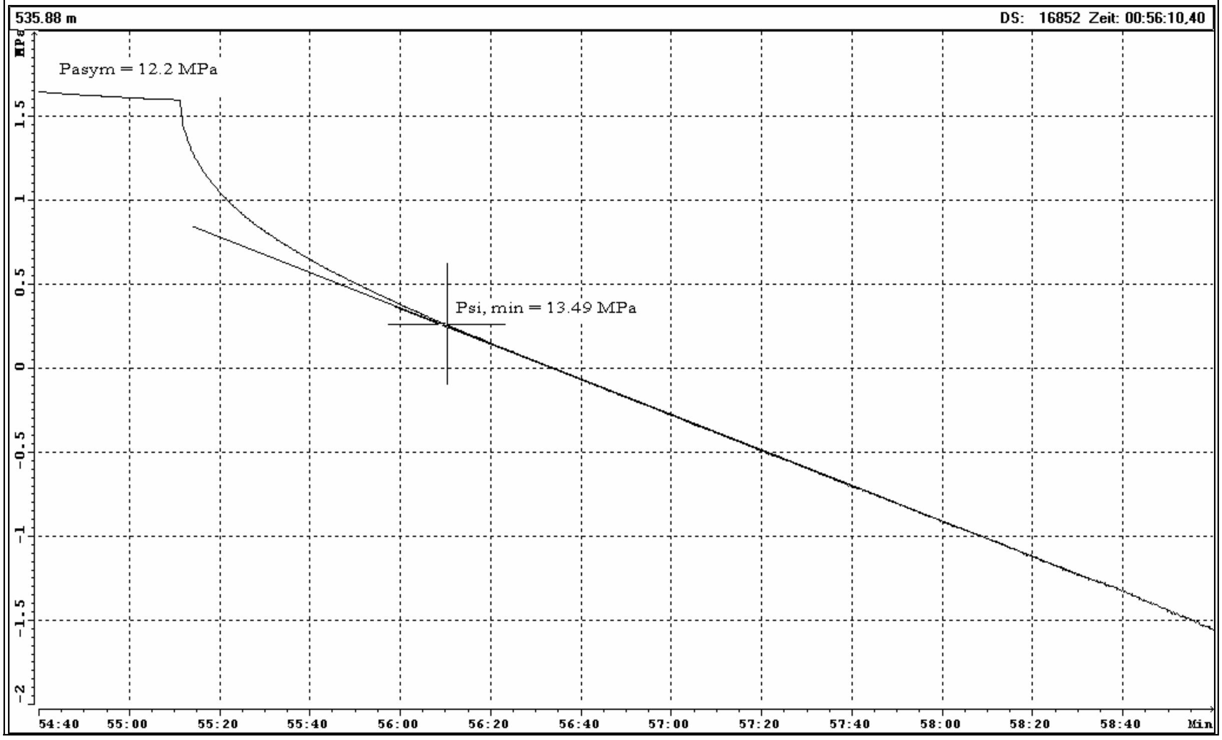
Test at 535.88 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



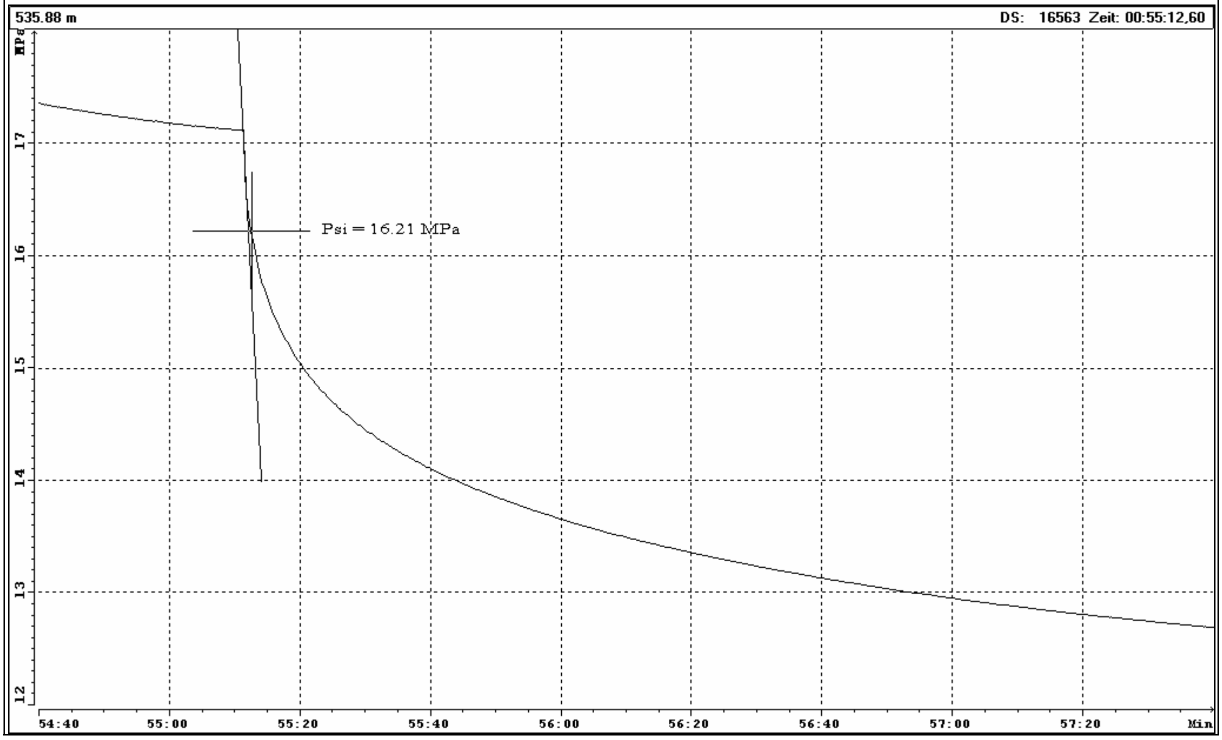
Test at 535.88 m MD: Estimation of $P_{si, max}$ (4. Refrac - Cycle)



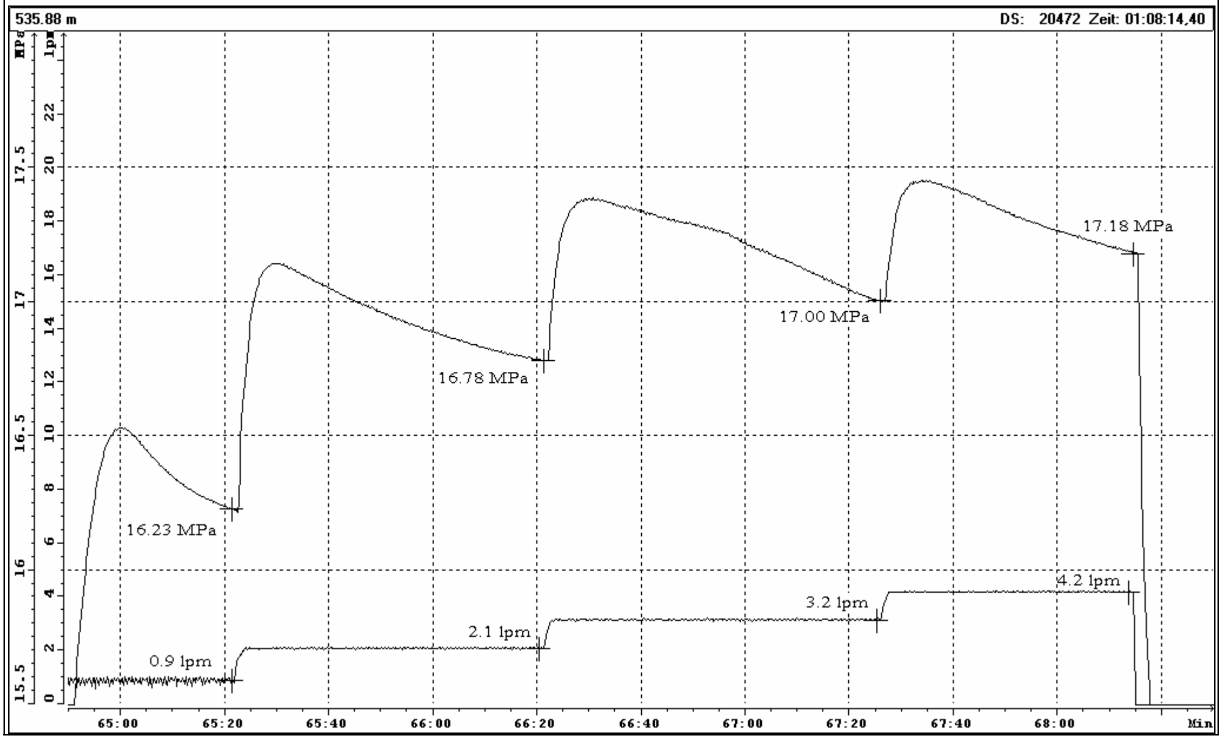
Test at 535.88 m MD: Estimation of $P_{si, min}$ (4. Refrac - Cycle)



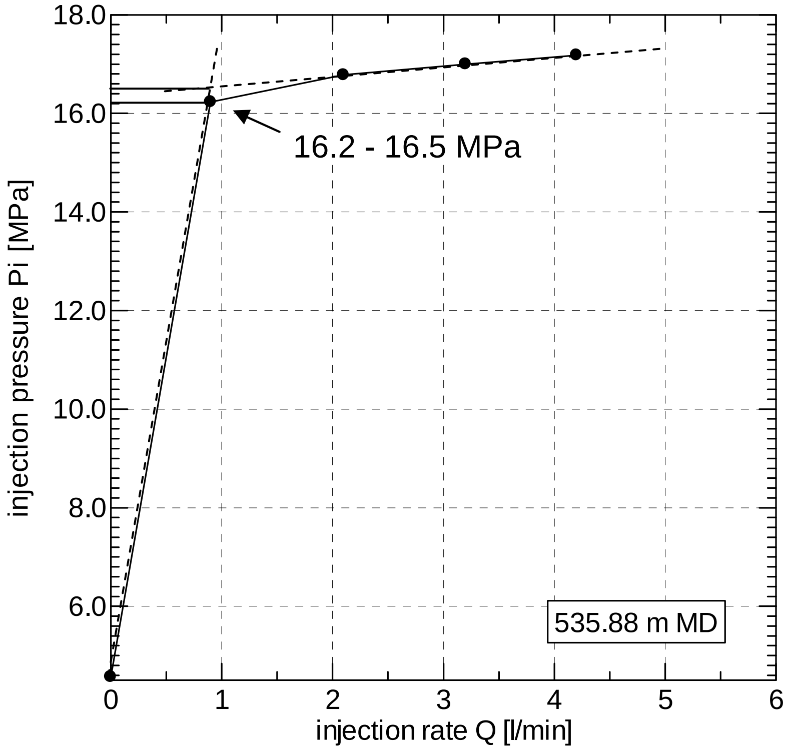
Test at 535.88 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 535.88 m MD: Analysis of Slow - Pump / Step - Rate - Test

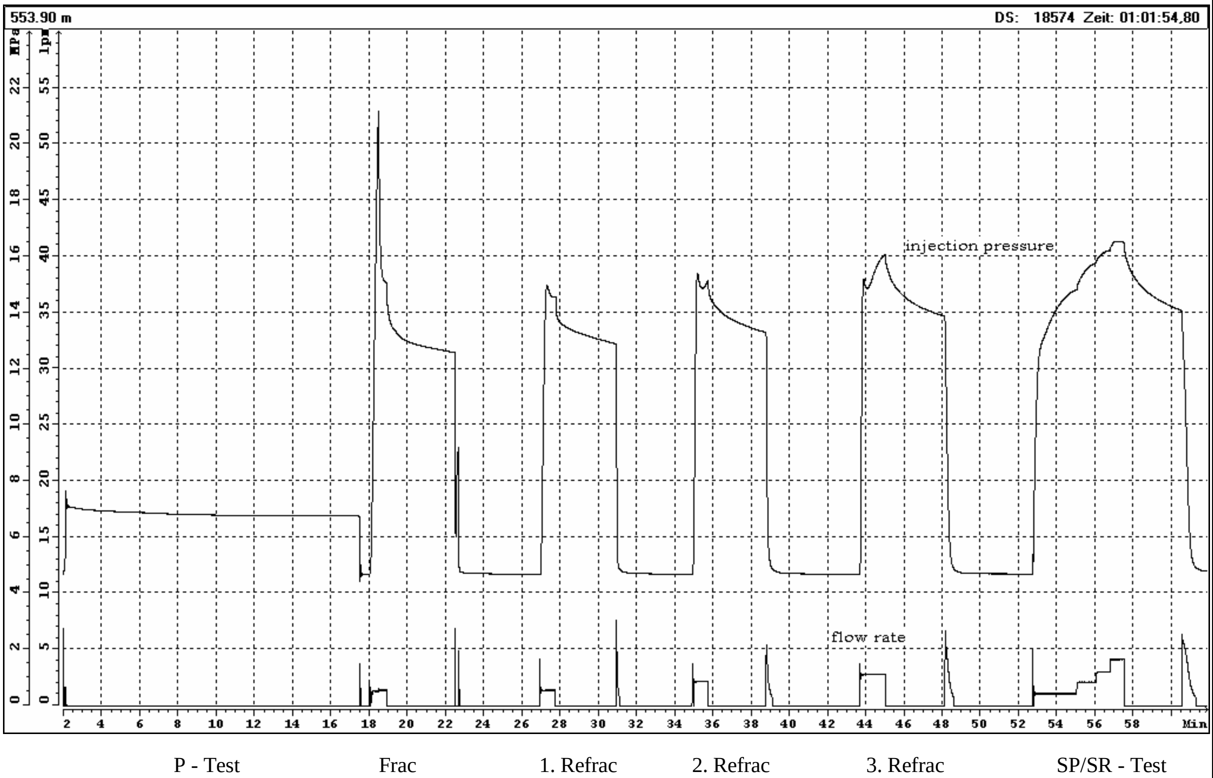


Test at 535.88 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 4 AT 553.90 m MD / 471.33 m TVD

Test at 553.90 m MD : Overview - Plot



TEST SUMMARY / ANALYSIS / REMARKS

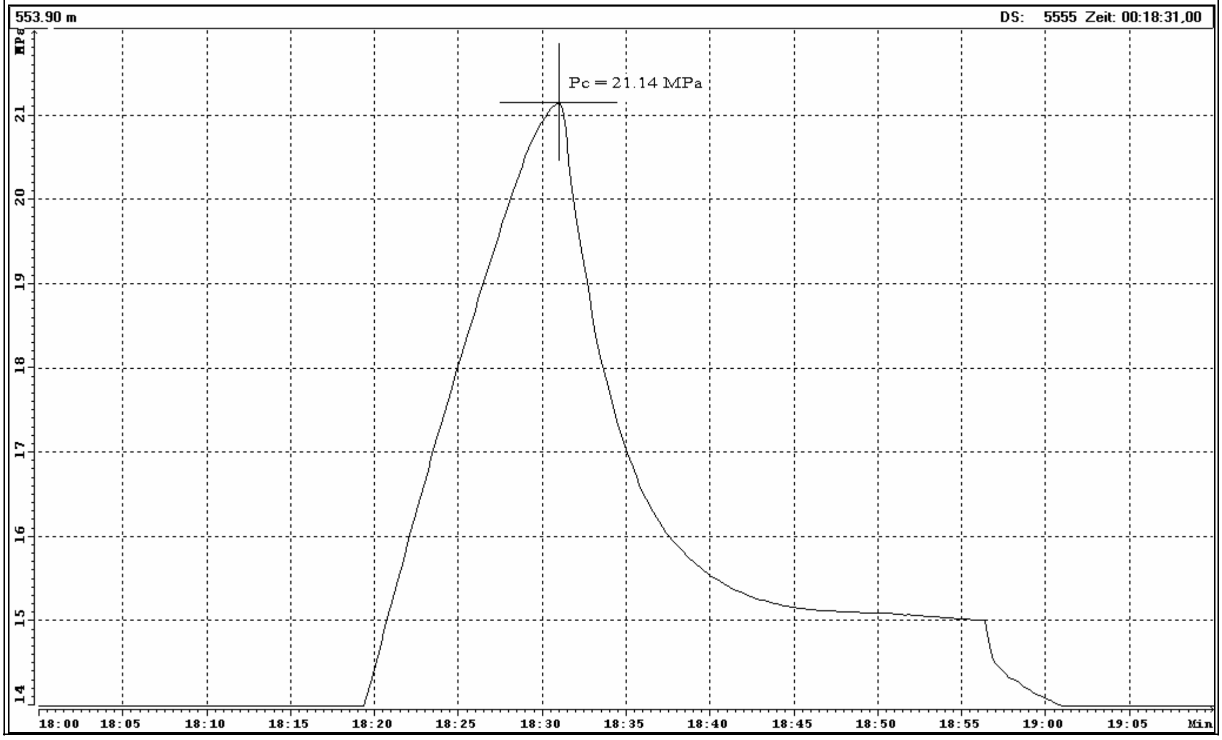
P - Test : pressure decrease: 0.34 MPa in 913 sec. (minor increase of pressure at the end of the shut-in period)

Frac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.2	Vr (l) = 0.8
1. Refrac - cycle	Qi (lpm) = 1.4	Vi (l) = 1.2	Vr (l) = 1.0
2. Refrac - cycle	Qi (lpm) = 2.2	Vi (l) = 1.8	Vr (l) = 1.4
3. Refrac - cycle	Qi (lpm) = 2.8	Vi (l) = 3.8	Vr (l) = 2.3
SP/SR - test	Qi (lpm) = 1.0-4.2	Vi (l) = 9.9	Vr (l) = 5.0

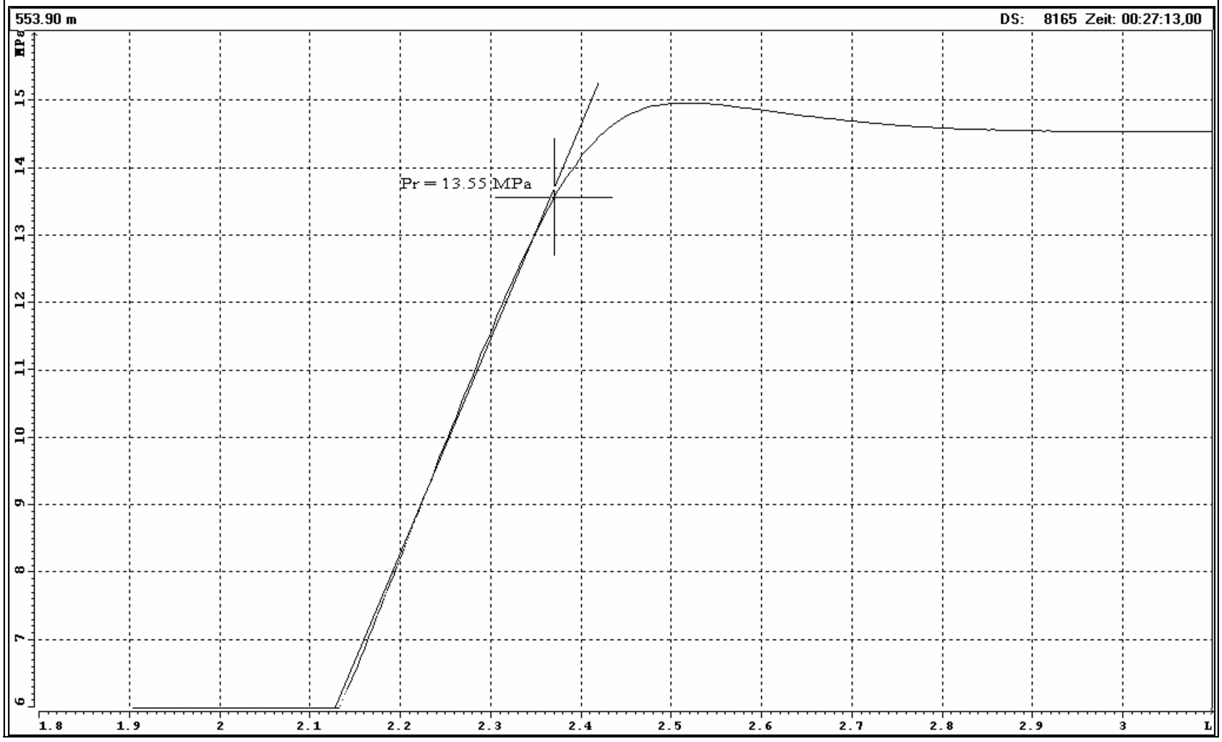
total injected volume (l): 17.9 recovered volume (l): 10.5 or 58.7 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct shut-in pressure values, which, however, increased from 14.0 MPa during the 1. refrac - cycle to 15.7 MPa during the 3. refrac - cycle. Therefore, the shut - in pressure of the 1. refrac - cycle was used for the stress analysis.

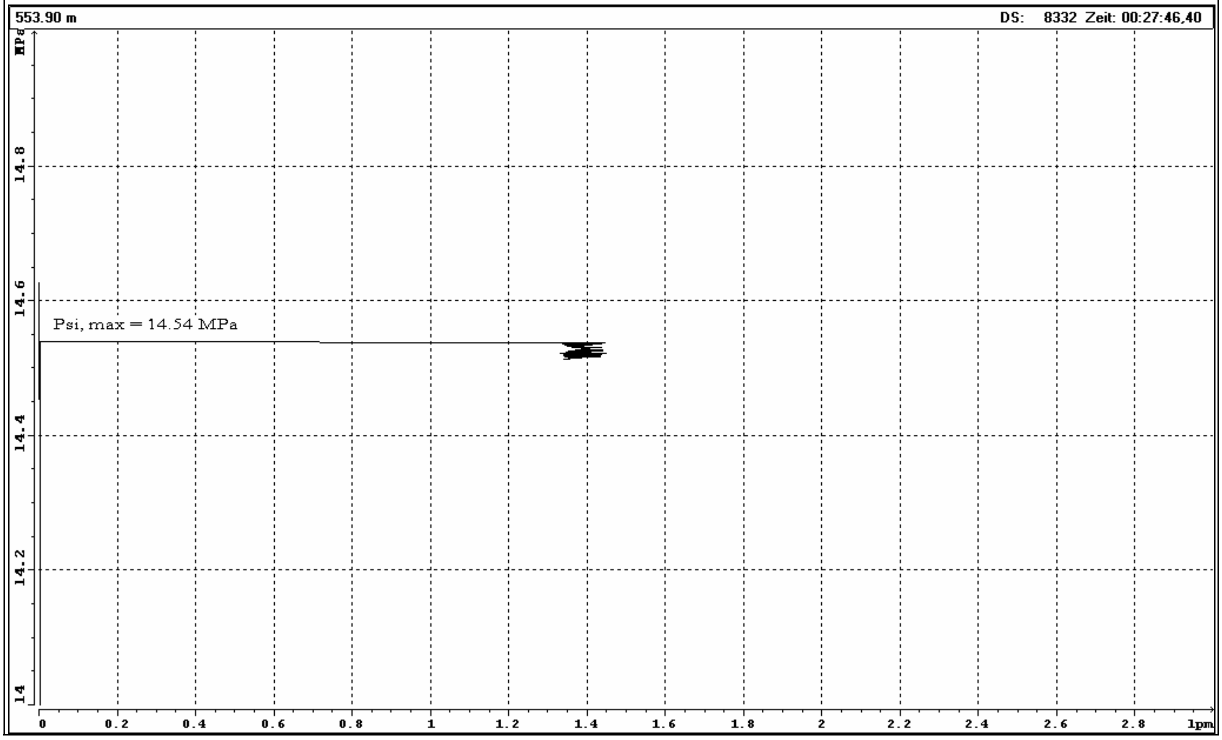
Test at 553.90 m MD: Estimation of P_c (Frac - Cycle)



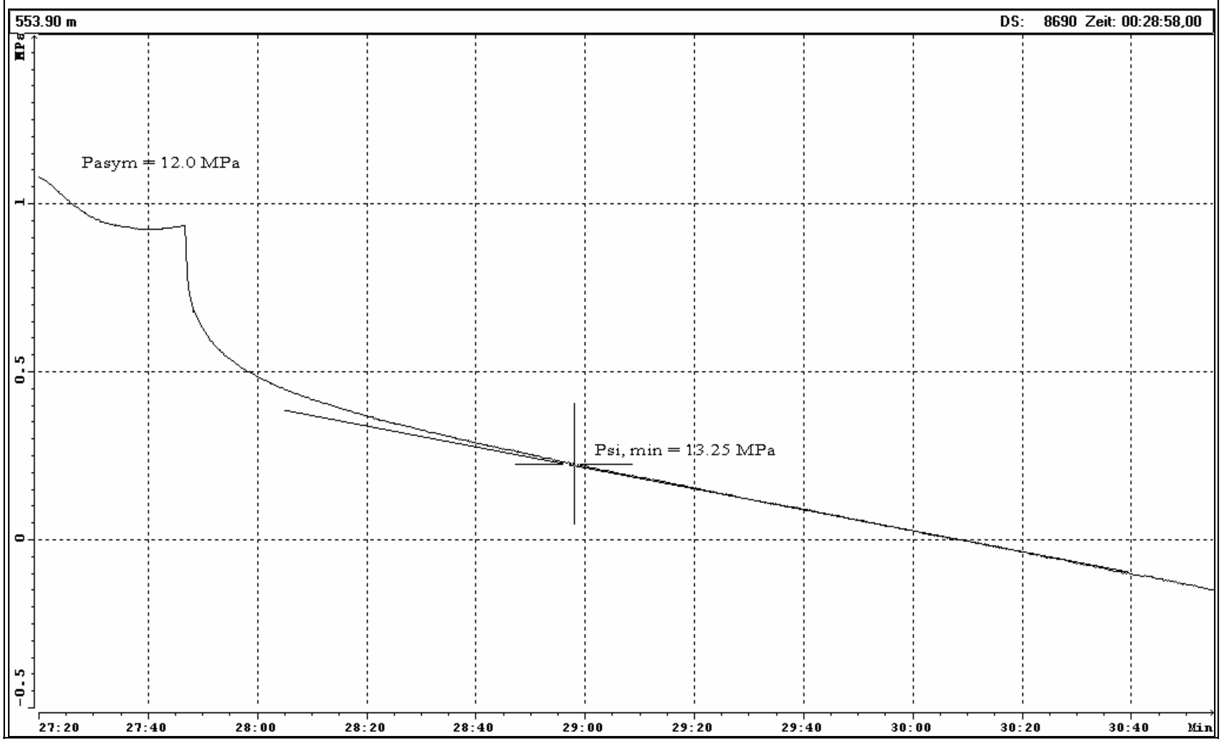
Test at 553.90 m MD: Estimation of P_r (1. Refrac - Cycle)



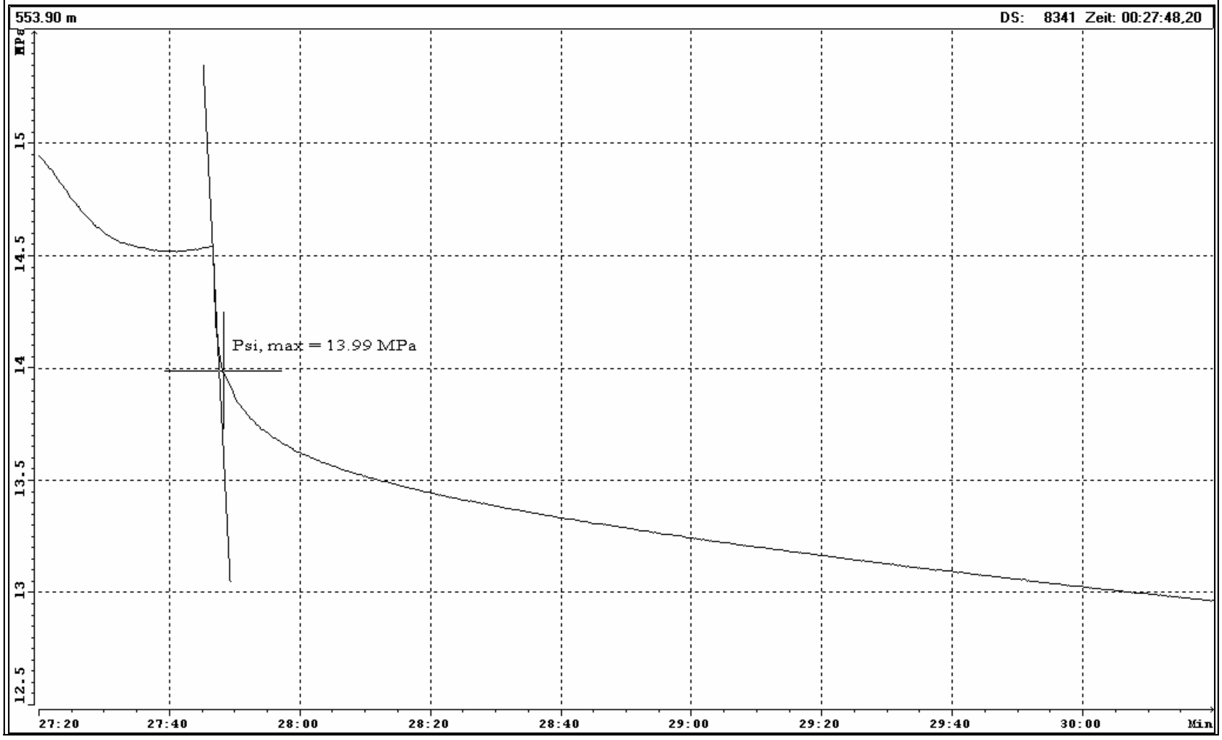
Test at 553.90 m MD: Estimation of $P_{si, max}$ (1. Refrac - Cycle)



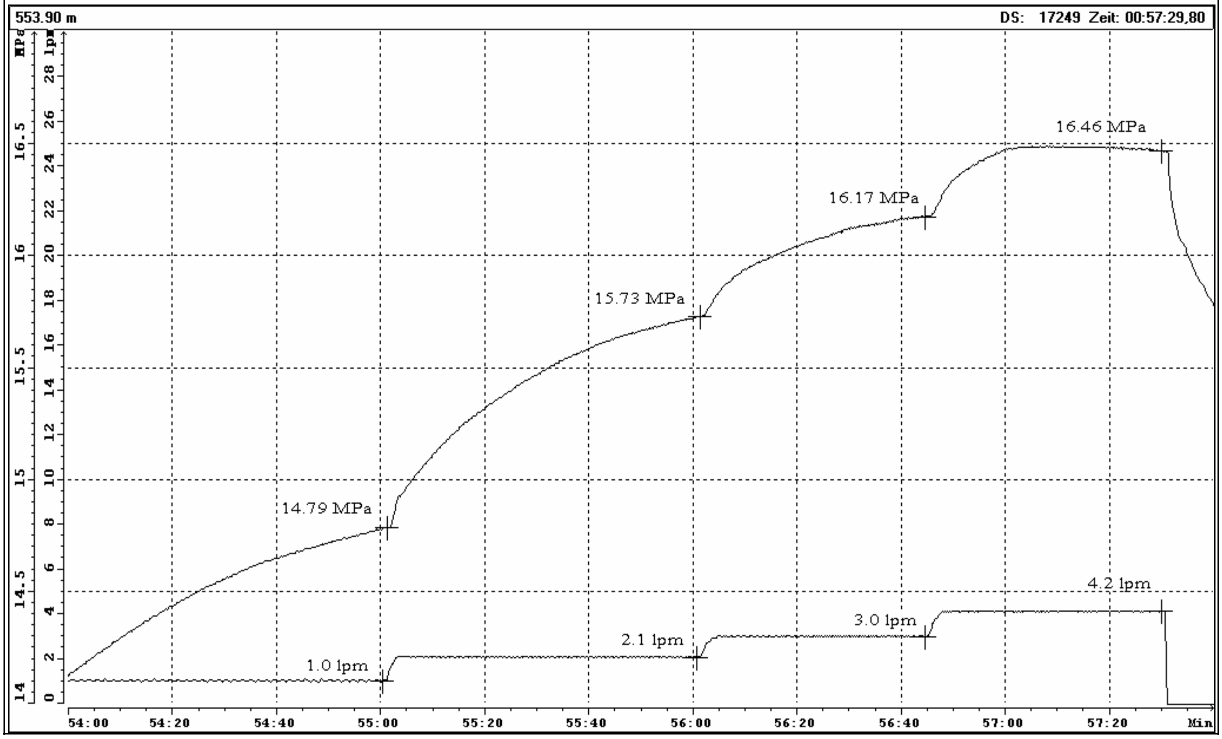
Test at 553.90 m MD: Estimation of $P_{si, min}$ (1. Refrac - Cycle)



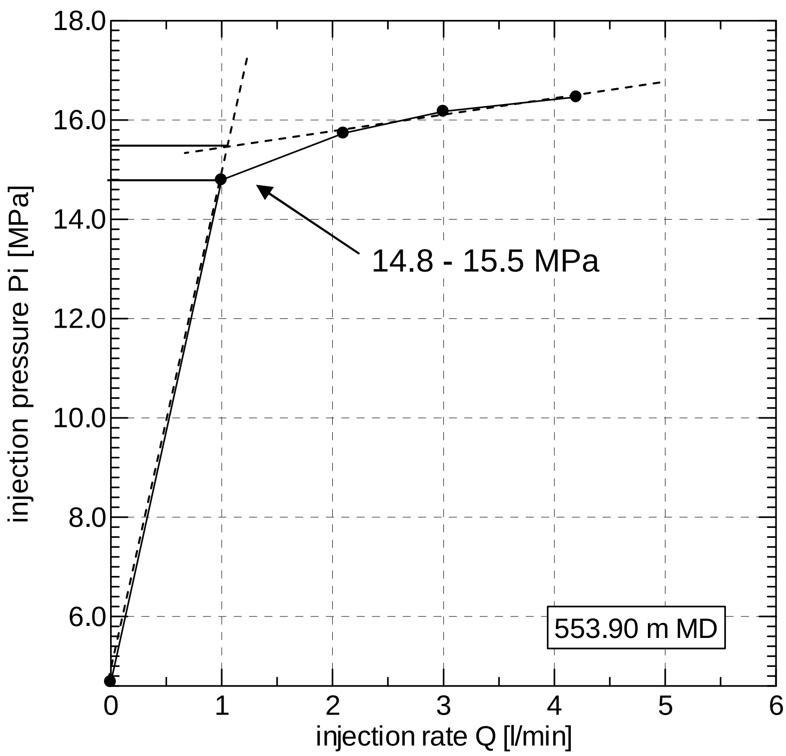
Test at 553.90 m MD: Estimation of P_{si} (1. Refrac - Cycle)



Test at 553.90 m MD: Analysis of Slow - Pump / Step - Rate - Test

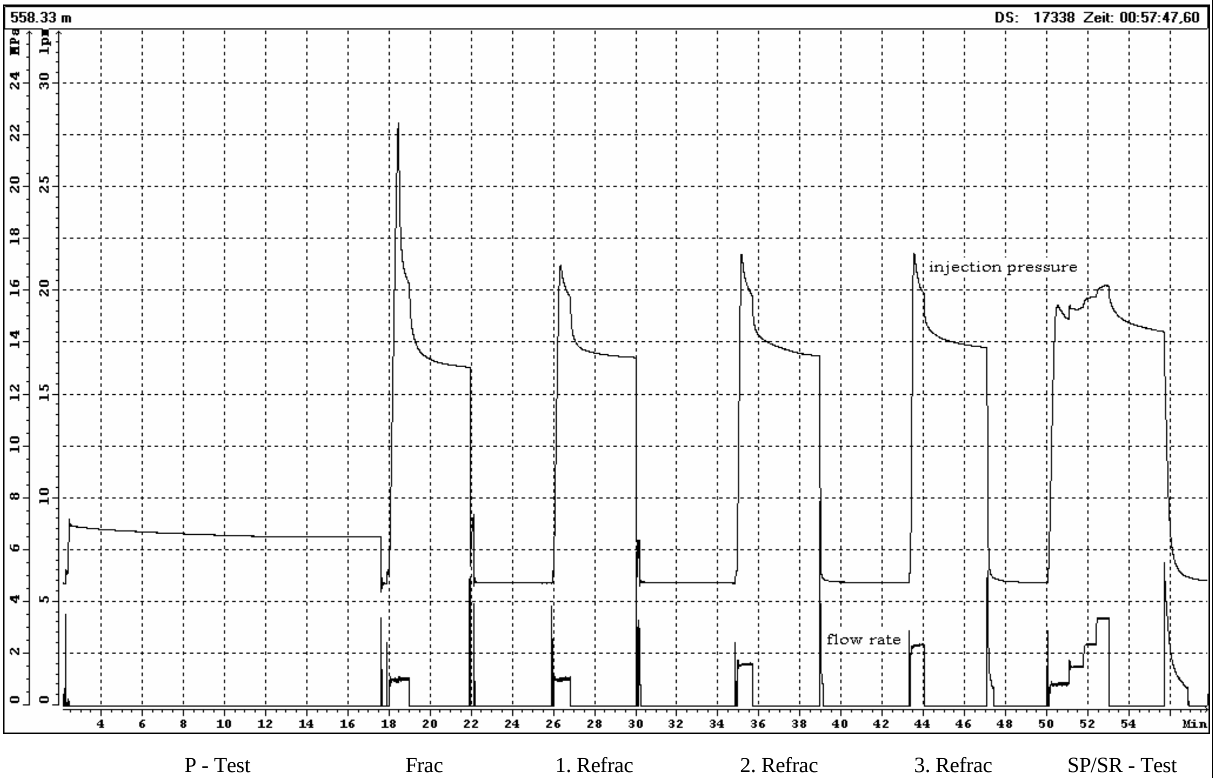


Test at 553.90 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 3 AT 558.33 m MD / 474.84 m TVD

Test at 558.33 m MD: Overview - Plot



TEST SUMMARY / ANALYSIS / REMARKS

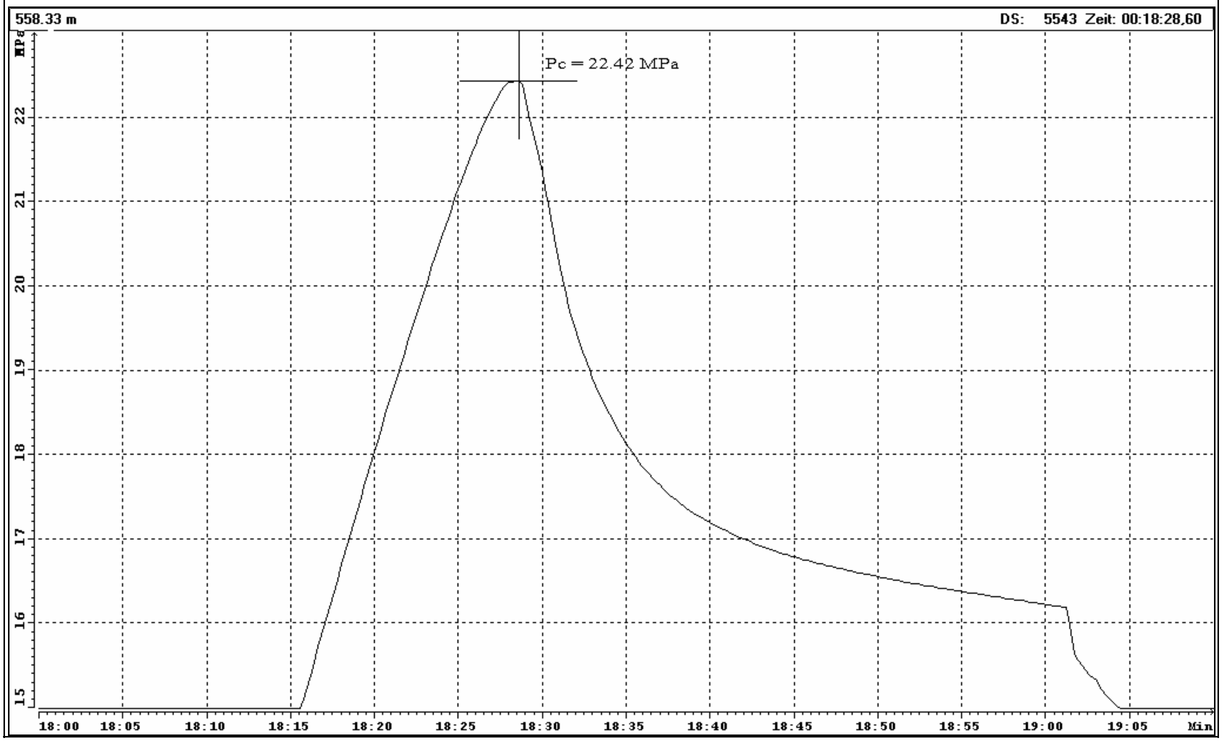
P - Test : pressure decrease: 0.42 MPa in 903 sec.

Frac - cycle	Qi (lpm) =	1.3	Vi (l) =	1.4	Vr (l) =	0.9
1. Refrac - cycle	Qi (lpm) =	1.3	Vi (l) =	1.2	Vr (l) =	1.1
2. Refrac - cycle	Qi (lpm) =	2.0	Vi (l) =	1.6	Vr (l) =	1.5
3. Refrac - cycle	Qi (lpm) =	2.9	Vi (l) =	2.0	Vr (l) =	1.9
SP/SR - test	Qi (lpm) =	1.0-4.2	Vi (l) =	6.8	Vr (l) =	5.0

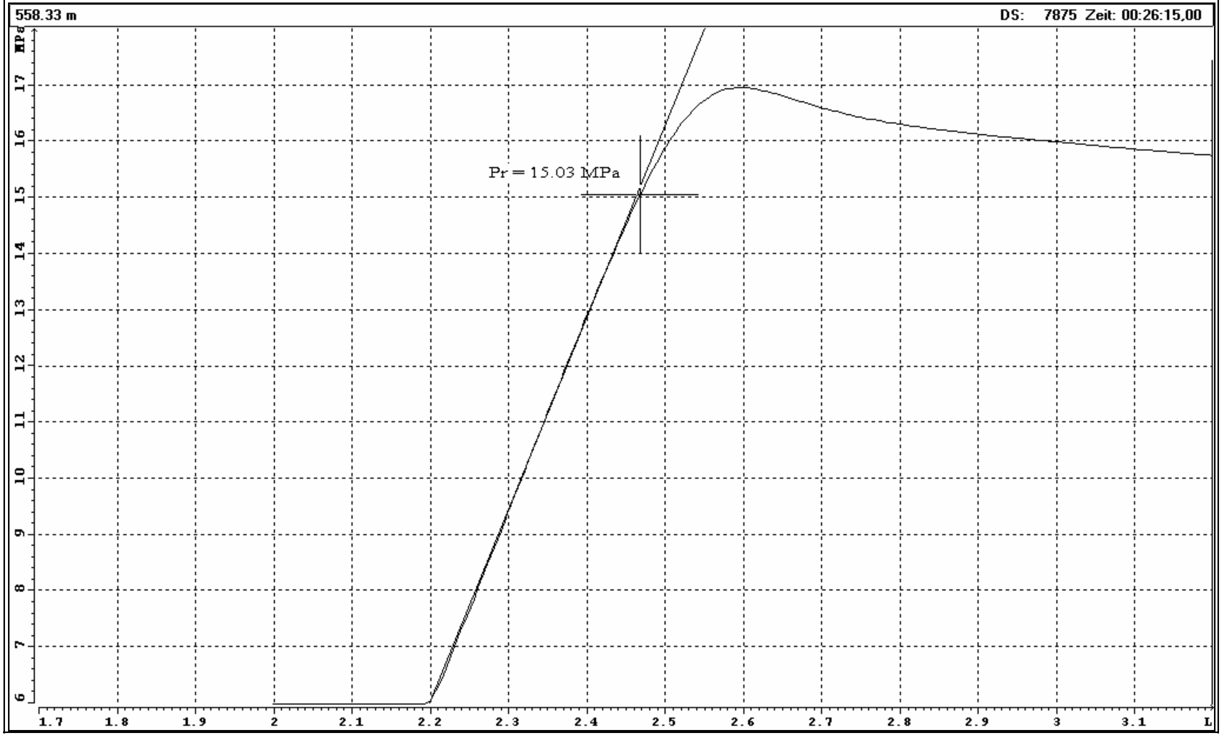
total injected volume (l): 13.0 recovered volume (l): 10.4 or 80.0 %

- Initial test type: HTPF-v
- Although the test section contains a pre-existing fracture, the frac - cycle is characterized by the initiation of a fracture with a distinct breakdown event.
- The refrac - pressure was determined from the 1. and 2. refrac - cycle since the later cycle with higher injection flow-rate yield a slightly higher fracture re-opening pressure.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the analysis, the shut - in pressure of the 3. refrac - cycle was used.

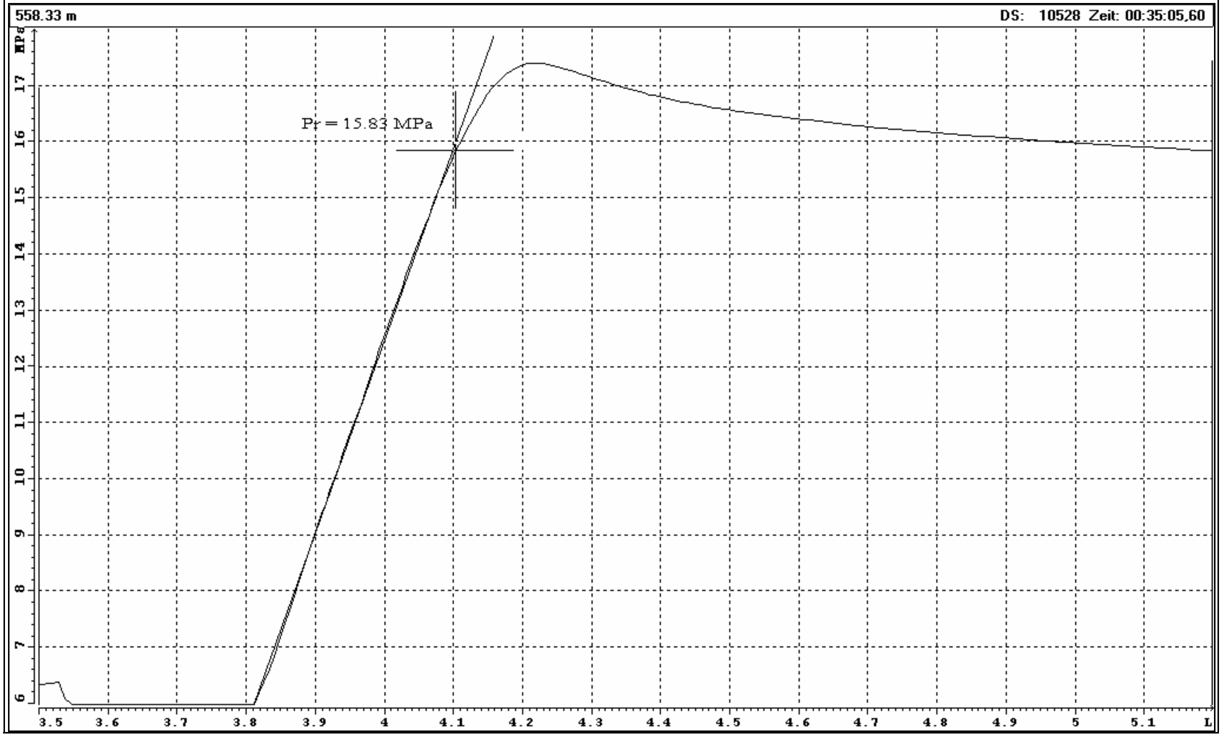
Test at 558.33 m MD: Estimation of P_c (Frac - Cycle)



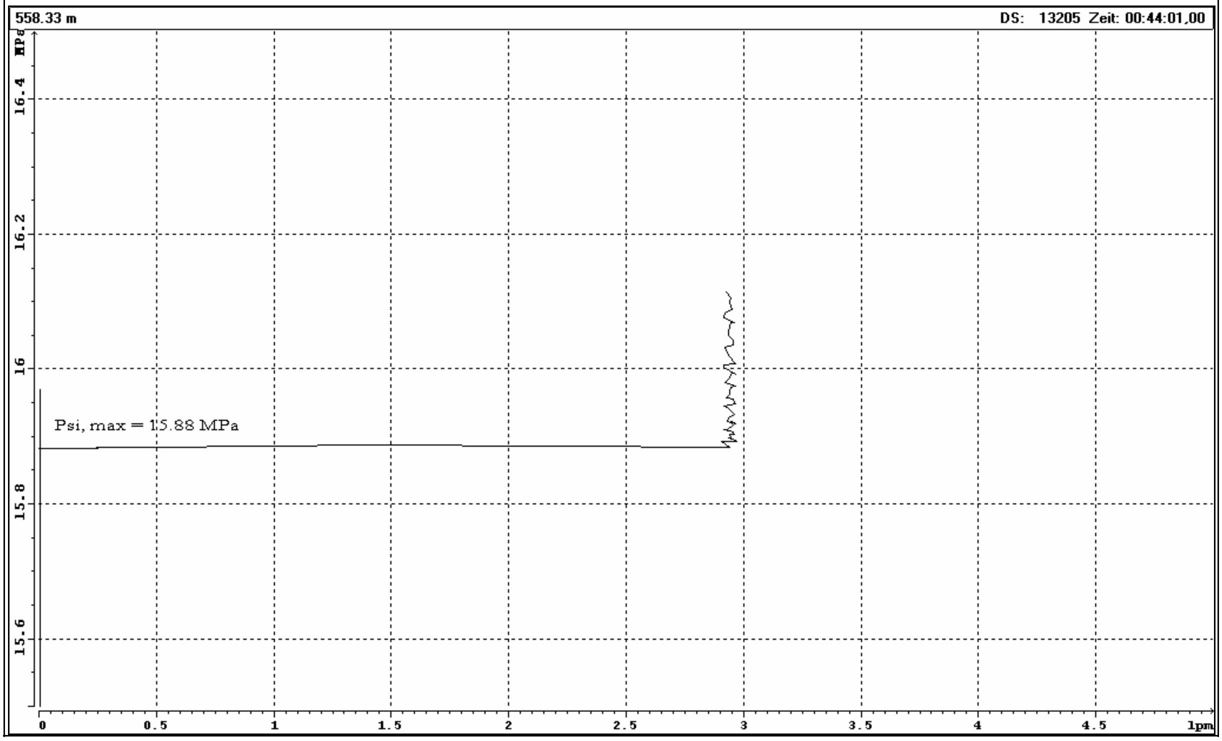
Test at 558.33 m MD: Estimation of P_r (1. Refrac - Cycle)



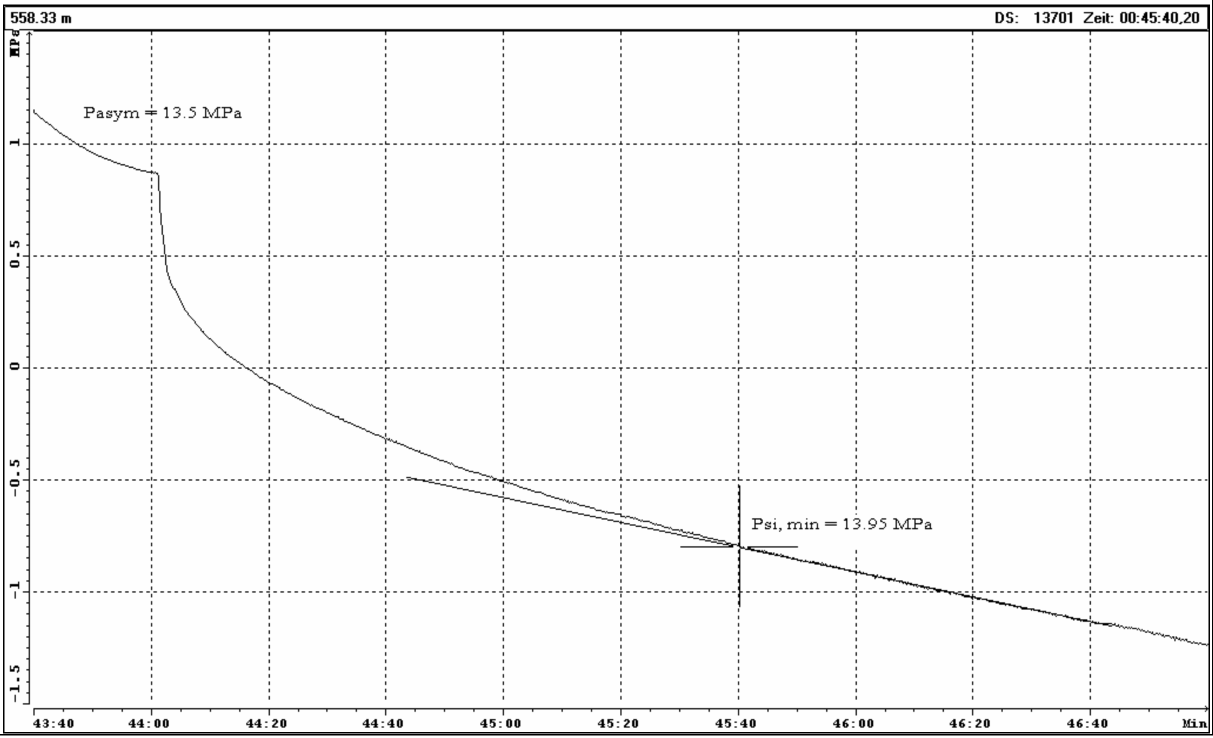
Test at 558.33 m MD: Estimation of P_r (2. Refrac - Cycle)



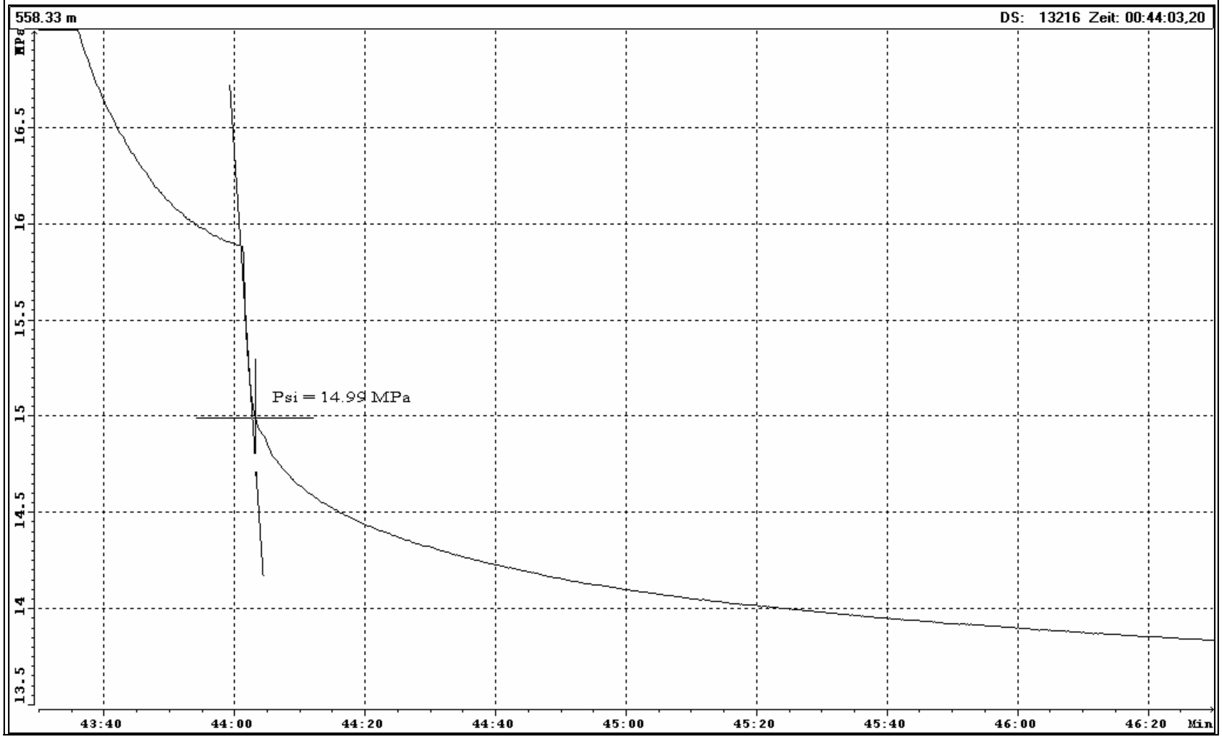
Test at 558.33 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



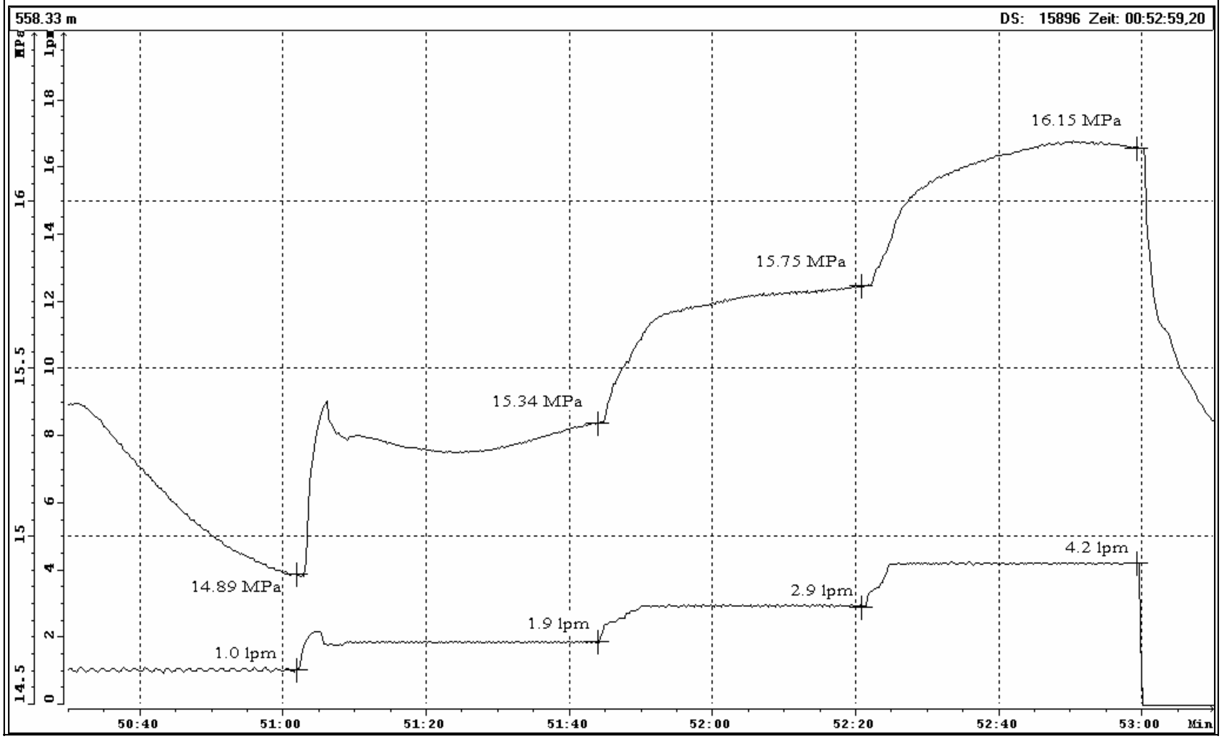
Test at 558.33 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



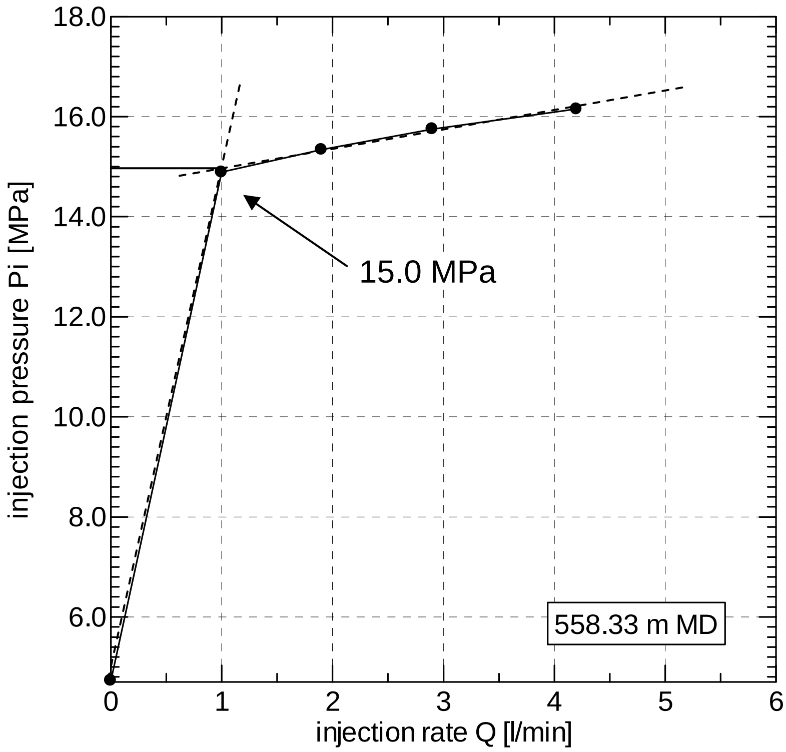
Test at 558.33 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 558.33 m MD: Analysis of Slow - Pump / Step - Rate - Test

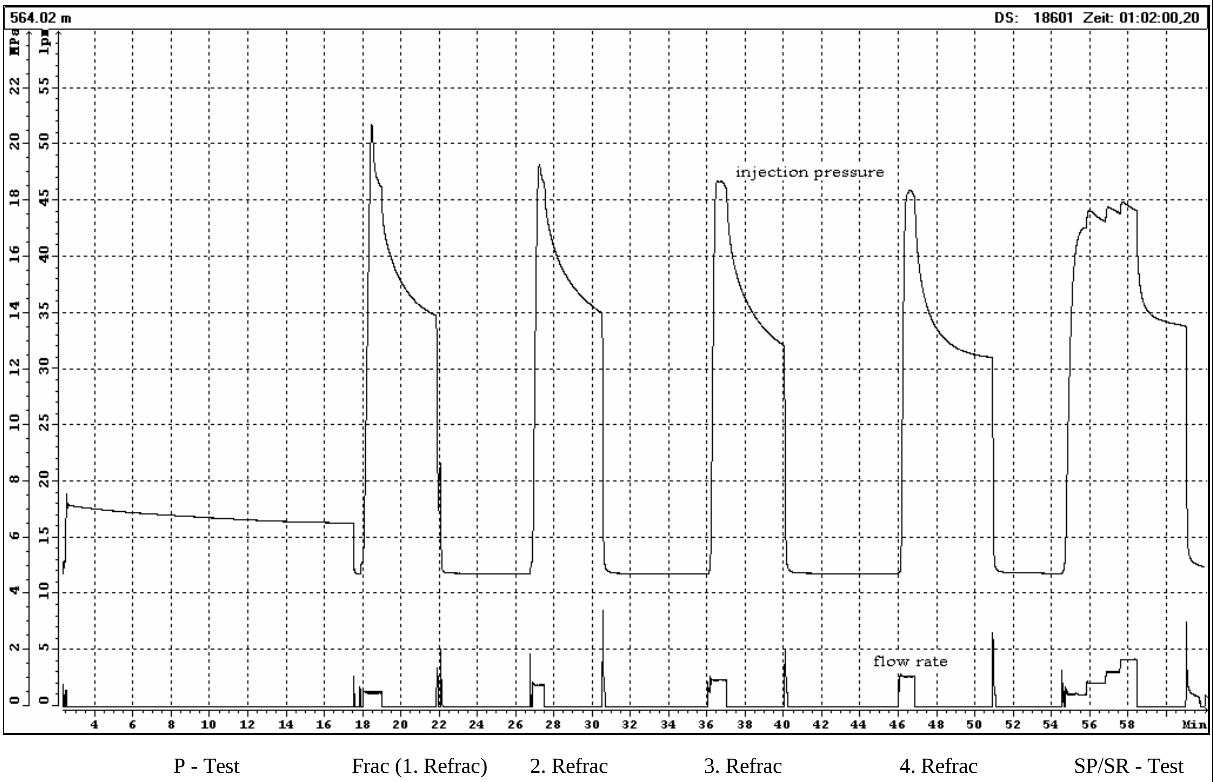


Test at 558.33 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 2 AT 564.02 m MD / 479.34 m TVD

Test at 564.02 m MD : Overview - Plot



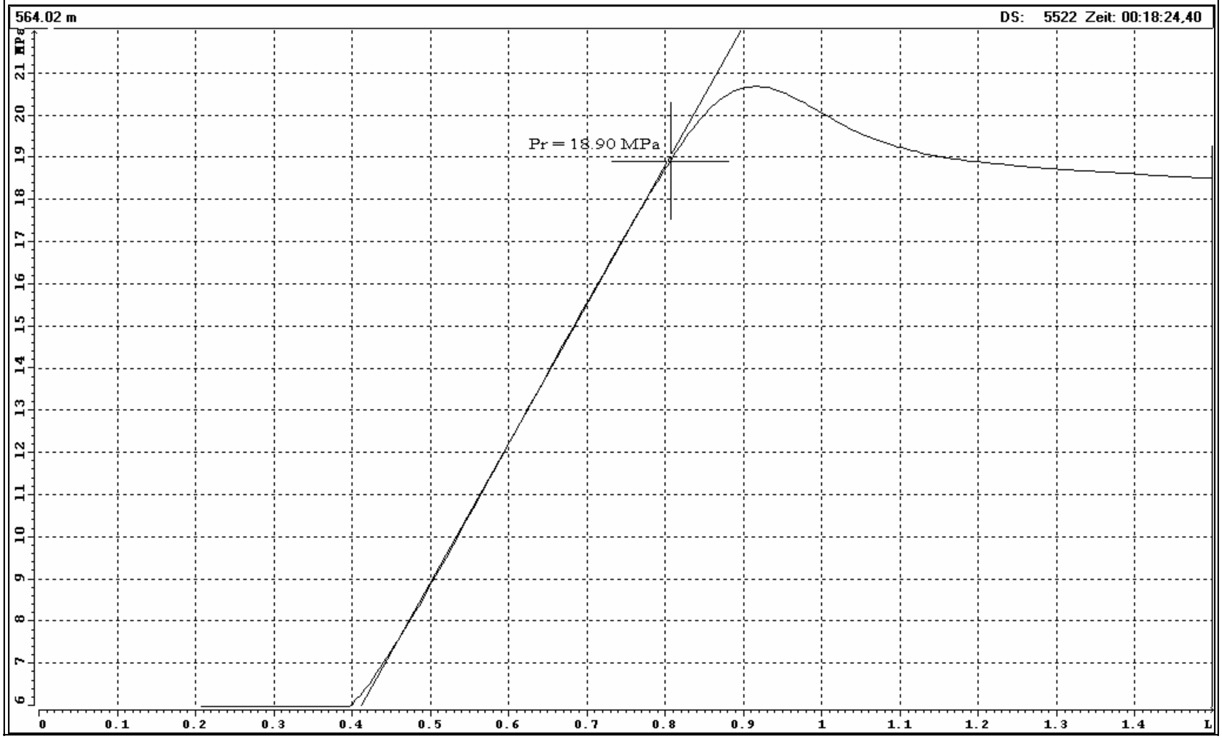
TEST SUMMARY / ANALYSIS / REMARKS

P - Test :	pressure decrease: 0.63 MPa in 890 sec.		
Frac (1. Refrac) - cycle	Qi (lpm) = 1.3	Vi (l) = 1.3	Vr (l) = 0.8
2. Refrac - cycle	Qi (lpm) = 1.9	Vi (l) = 1.3	Vr (l) = 1.2
3. Refrac - cycle	Qi (lpm) = 2.4	Vi (l) = 2.3	Vr (l) = 1.5
4. Refrac - cycle	Qi (lpm) = 2.7	Vi (l) = 2.2	Vr (l) = 1.7
SP/SR - test	Qi (lpm) = 1.1-4.2	Vi (l) = 9.5	Vr (l) = 5.0

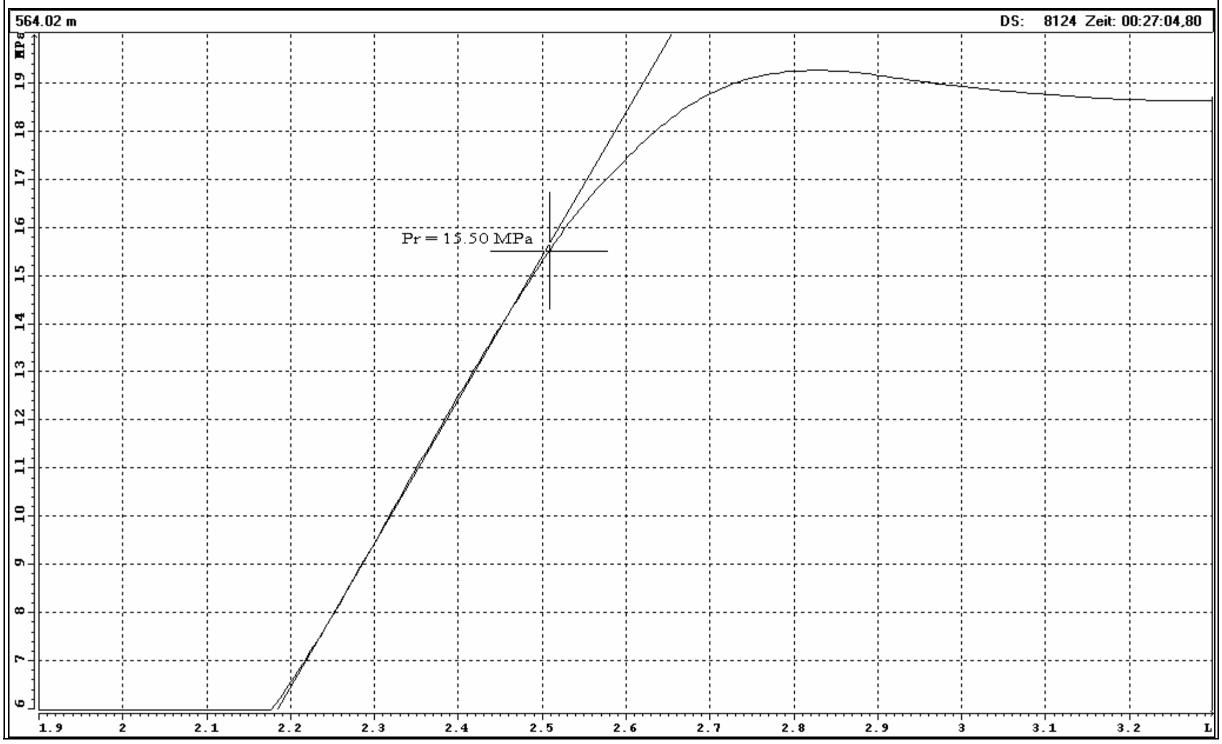
total injected volume (l): 16.6 recovered volume (l): 10.2 or 61.5 %

- Initial test type: HTPF-h
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct and consistent shut-in pressure values. For the stress analysis, the shut - in pressure of the 4. refrac - cycle was used.

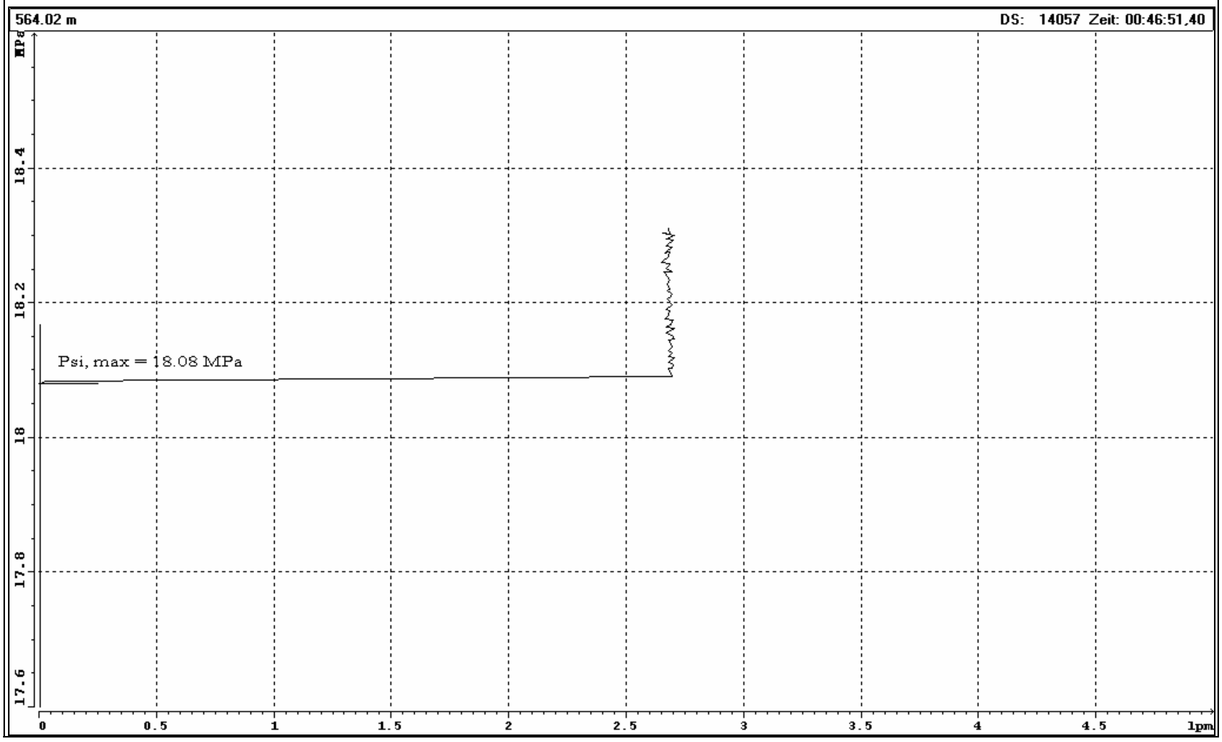
Test at 564.02 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



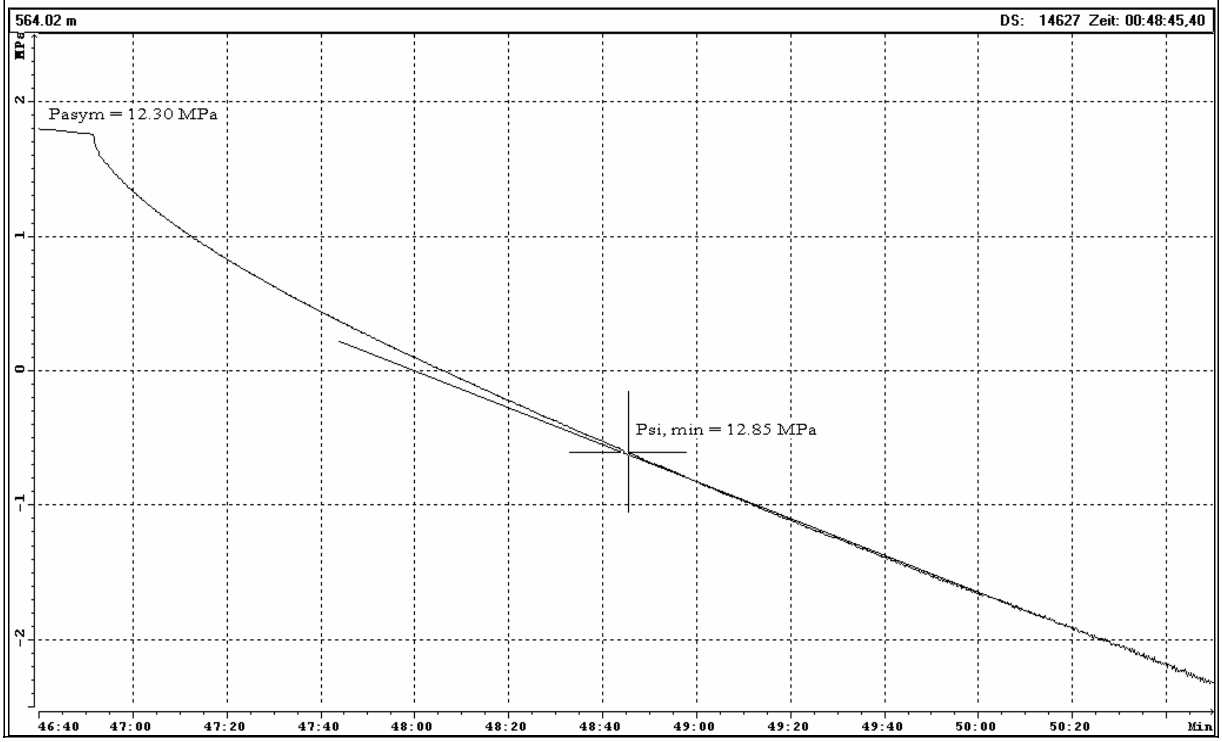
Test at 564.02 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



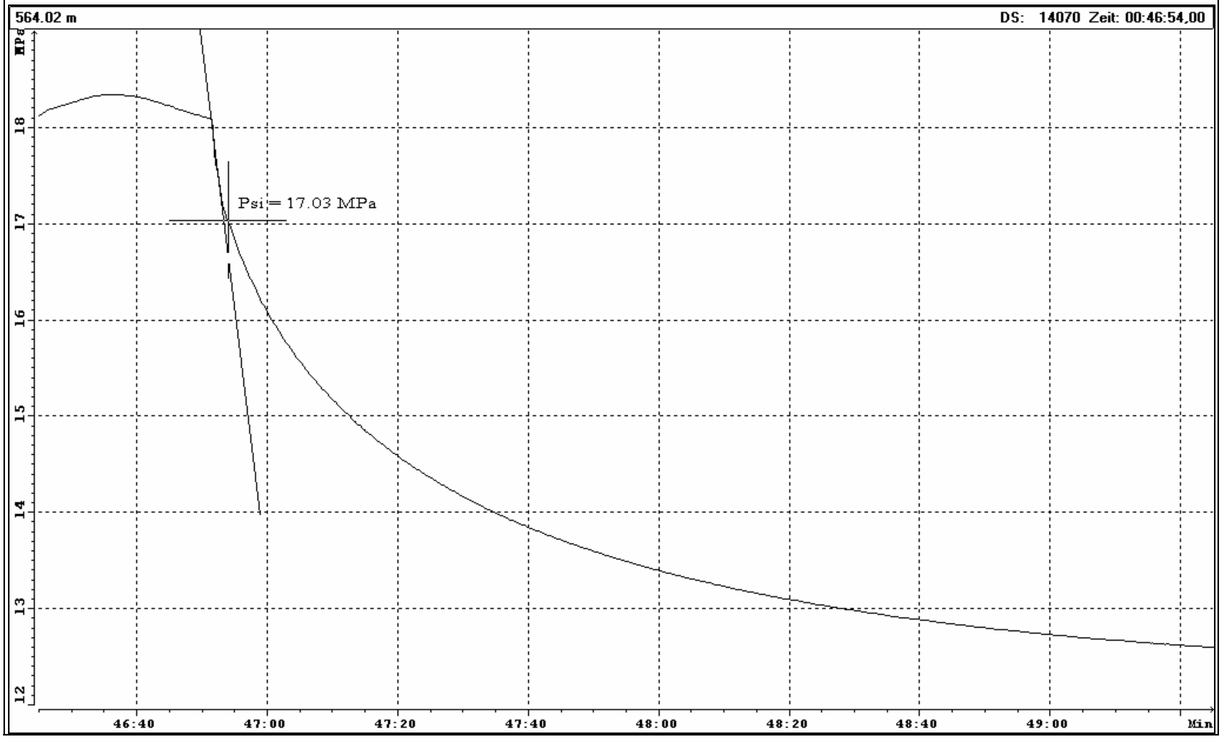
Test at 564.02 m MD: Estimation of $P_{si,\,max}$ (4. Refrac - Cycle)



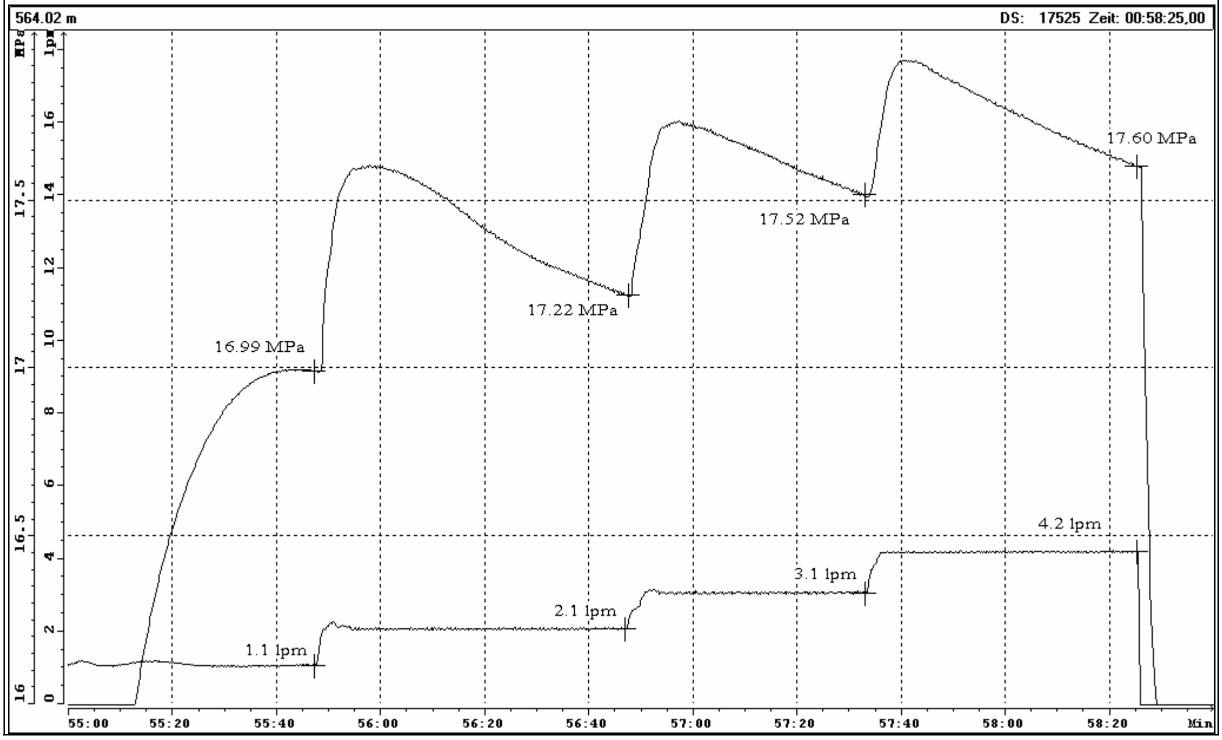
Test at 564.02 m MD: Estimation of $P_{si,\,min}$ (4. Refrac - Cycle)



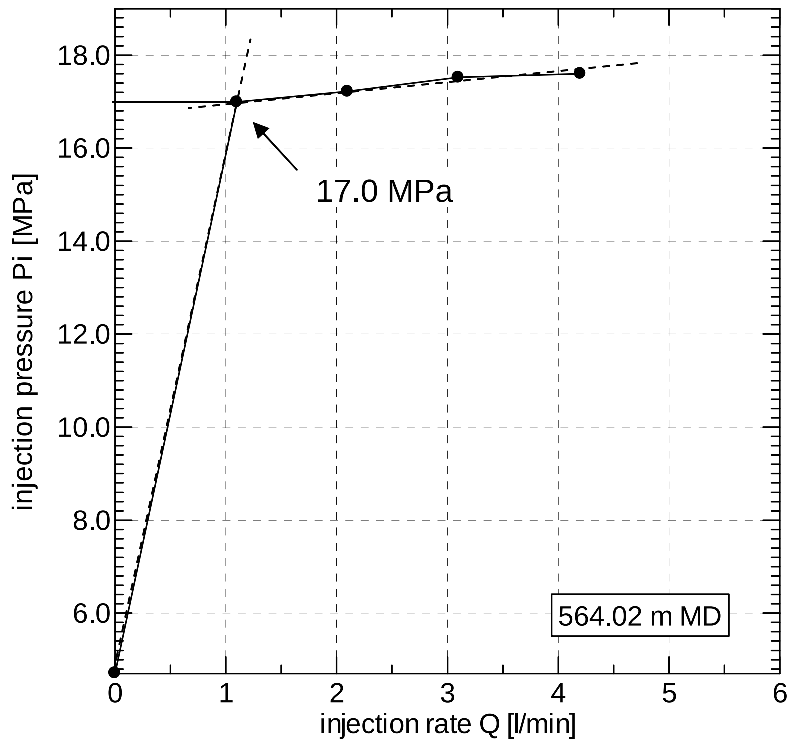
Test at 564.02 m MD: Estimation of P_{si} (4. Refrac - Cycle)



Test at 564.02 m MD: Analysis of Slow - Pump / Step - Rate - Test

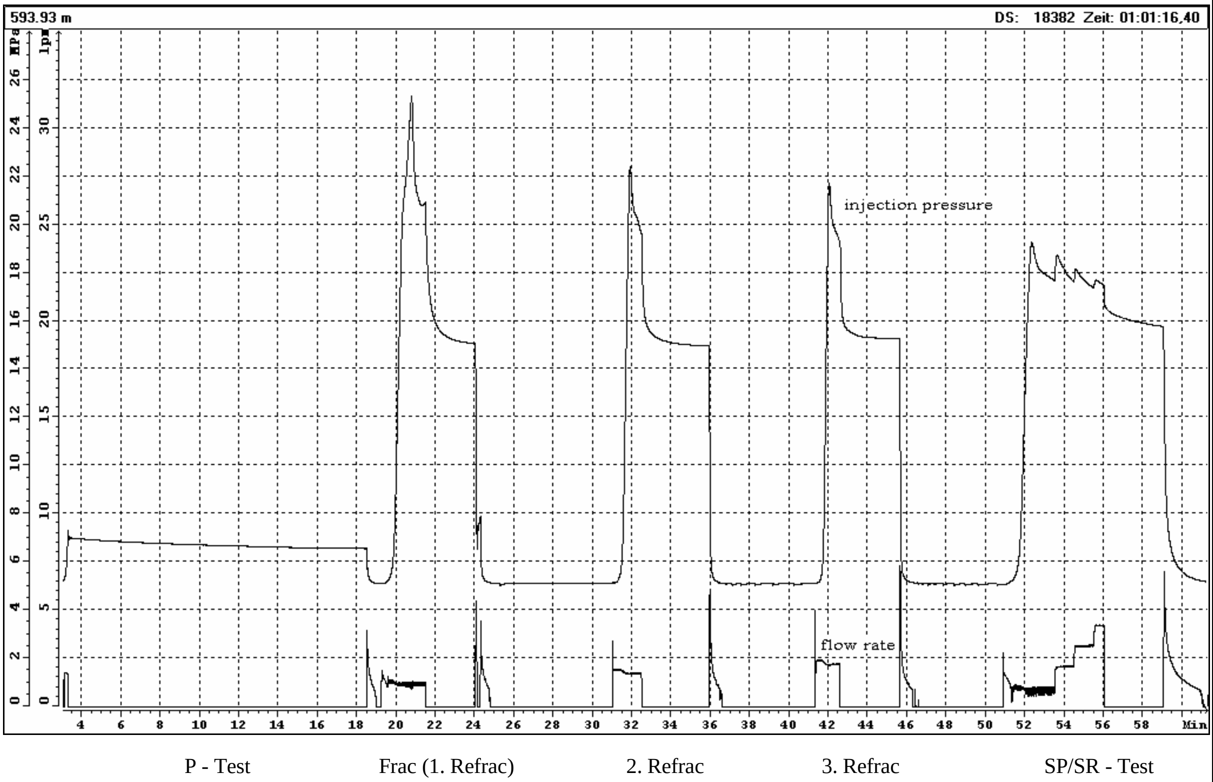


Test at 564.02 m MD: Examination of P_{si} (Step - Rate - Test)



TEST NO. 1 AT 593.93 m MD / 502.91 m TVD

Test at 593.93 m MD: Overview - Plot



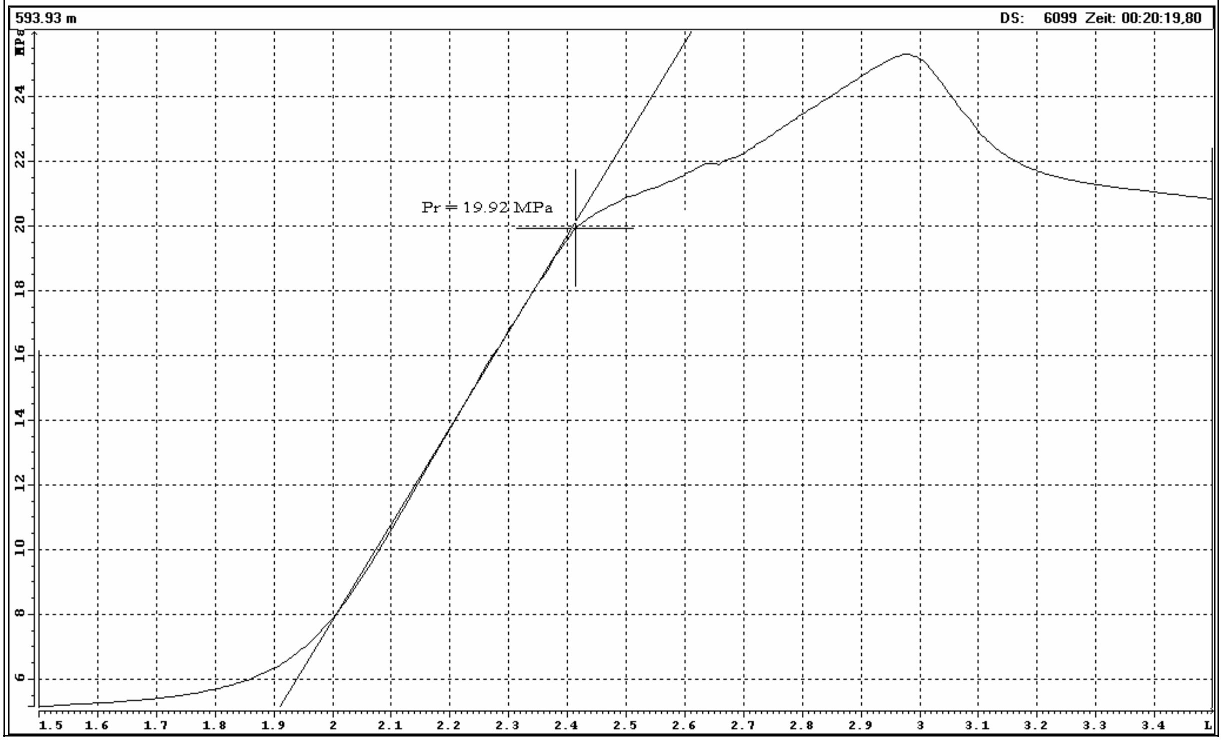
<u>TEST SUMMARY / ANALYSIS / REMARKS</u>

P - Test :	pressure decrease: 0.44 MPa in 903 sec.					
Frac (1. Refrac) - cycle	Qi (lpm) =	1.2	Vi (l) =	2.8	Vr (l) =	2.2
2. Refrac - cycle	Qi (lpm) =	1.7	Vi (l) =	2.7	Vr (l) =	2.3
3. Refrac - cycle	Qi (lpm) =	2.3	Vi (l) =	2.9	Vr (l) =	3.0
SP/SR - test	Qi (lpm) =	0.9-4.2	Vi (l) =	9.9	Vr (l) =	8.5

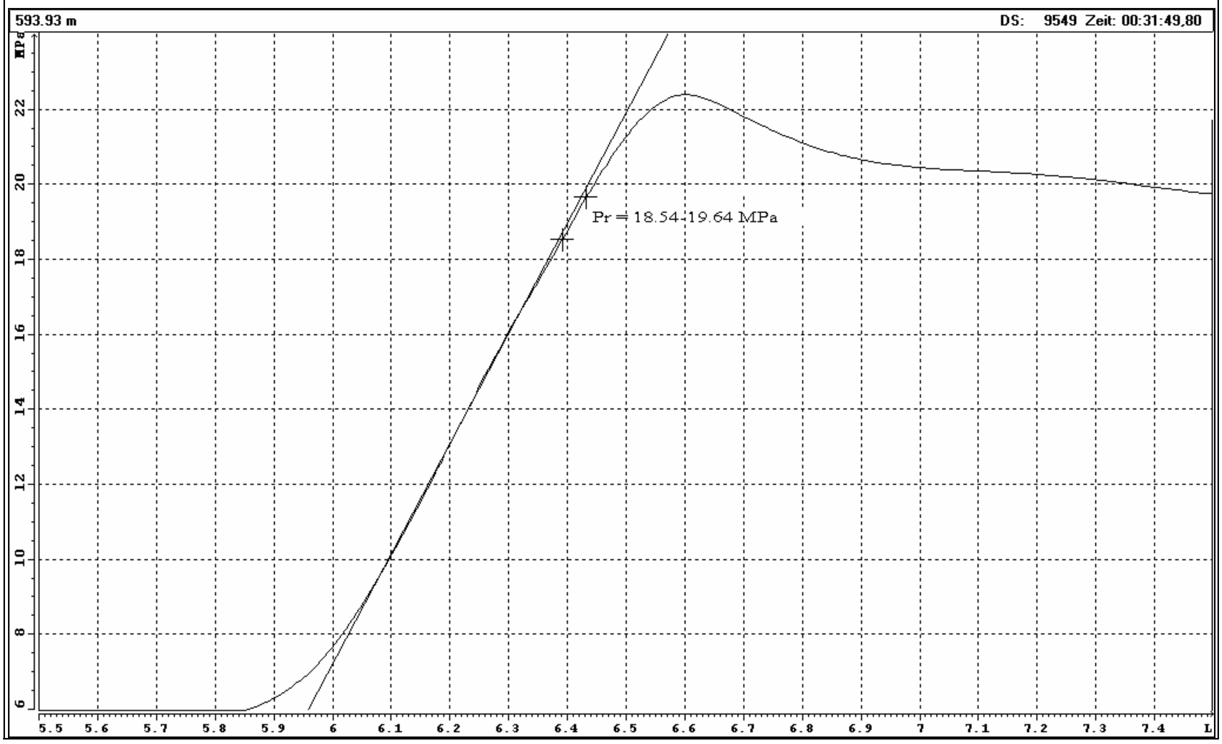
total injected volume (l): 18.3 recovered volume (l): 16.0 or 87.4 %

- Initial test type: HTPF-v
- The frac (1. refrac) - cycle is characterized by the stimulation of an existing fracture (no breakdown event).
- The refrac - pressure was determined from the 1. refrac - cycle. The analysis of the fracture opening phase shows a decrease of system stiffness dP/dV already at 19.9 MPa, followed by a pressure increase up to 25.3 MPa. In comparison to the first cycle, the subsequent refrac - cycles yield lower fracture re-opening pressure values.
- The shut-in phases yield distinct shut-in pressure values. For the stress analysis, the shut - in pressure of the 3. refrac - cycle was used.

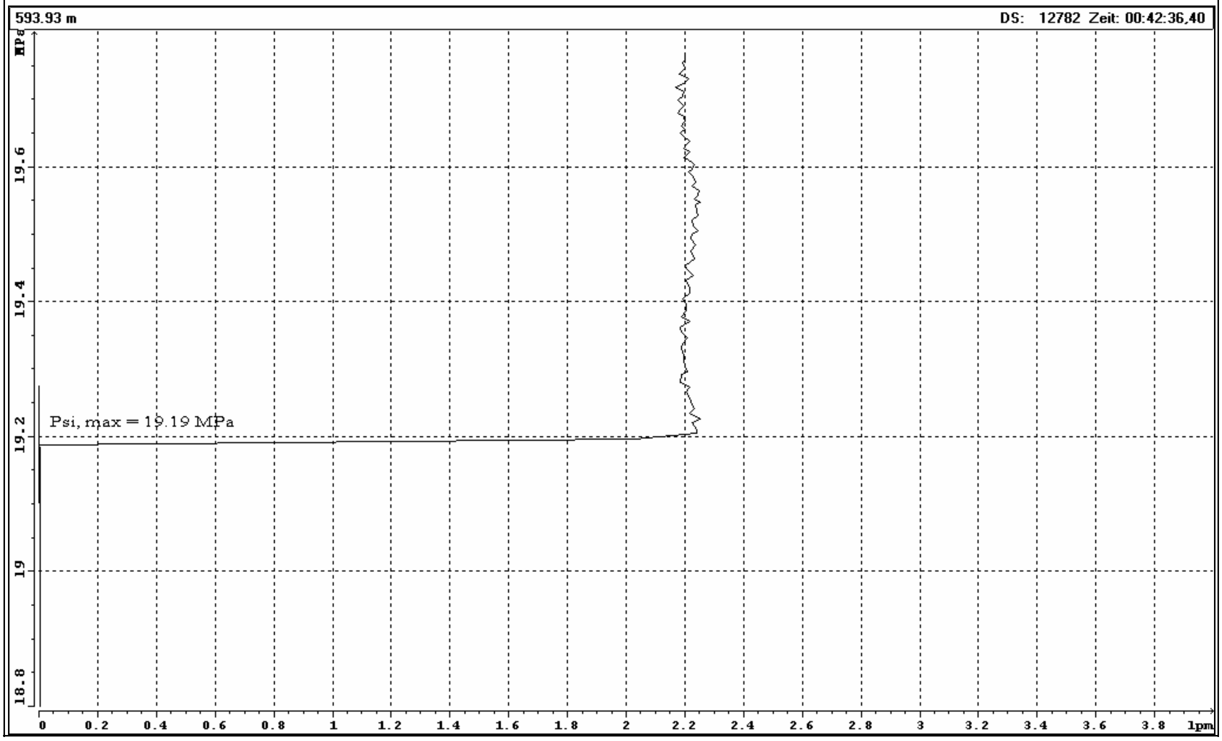
Test at 593.93 m MD: Estimation of P_r (Frac (1. Refrac) - Cycle)



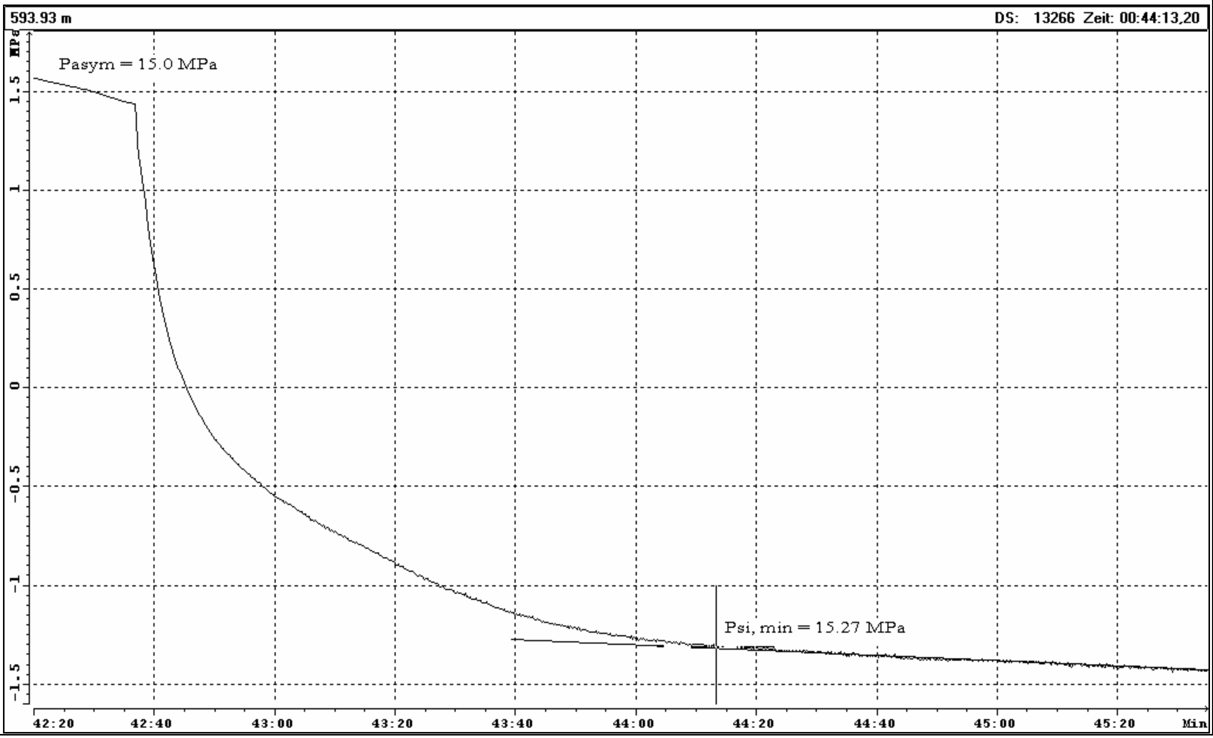
Test at 593.93 m MD: Estimation of P_r (2. Refrac - Cycle, for comparison)



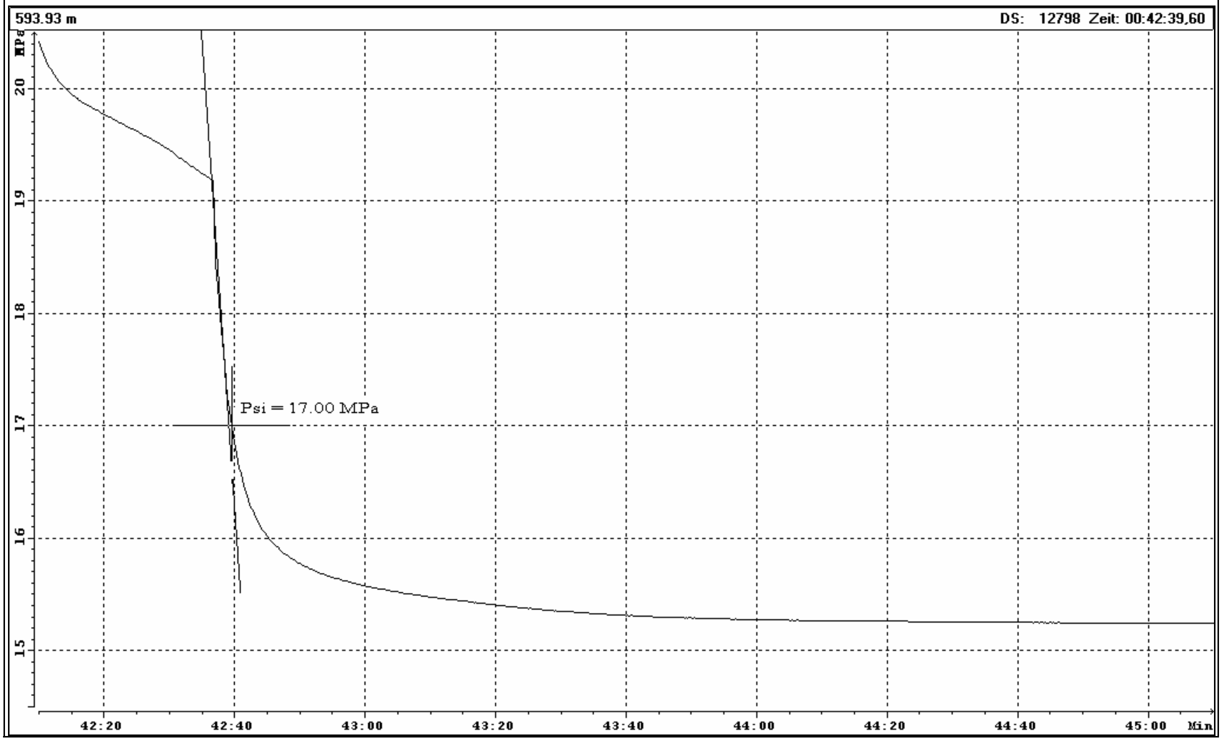
Test at 593.93 m MD: Estimation of $P_{si, max}$ (3. Refrac - Cycle)



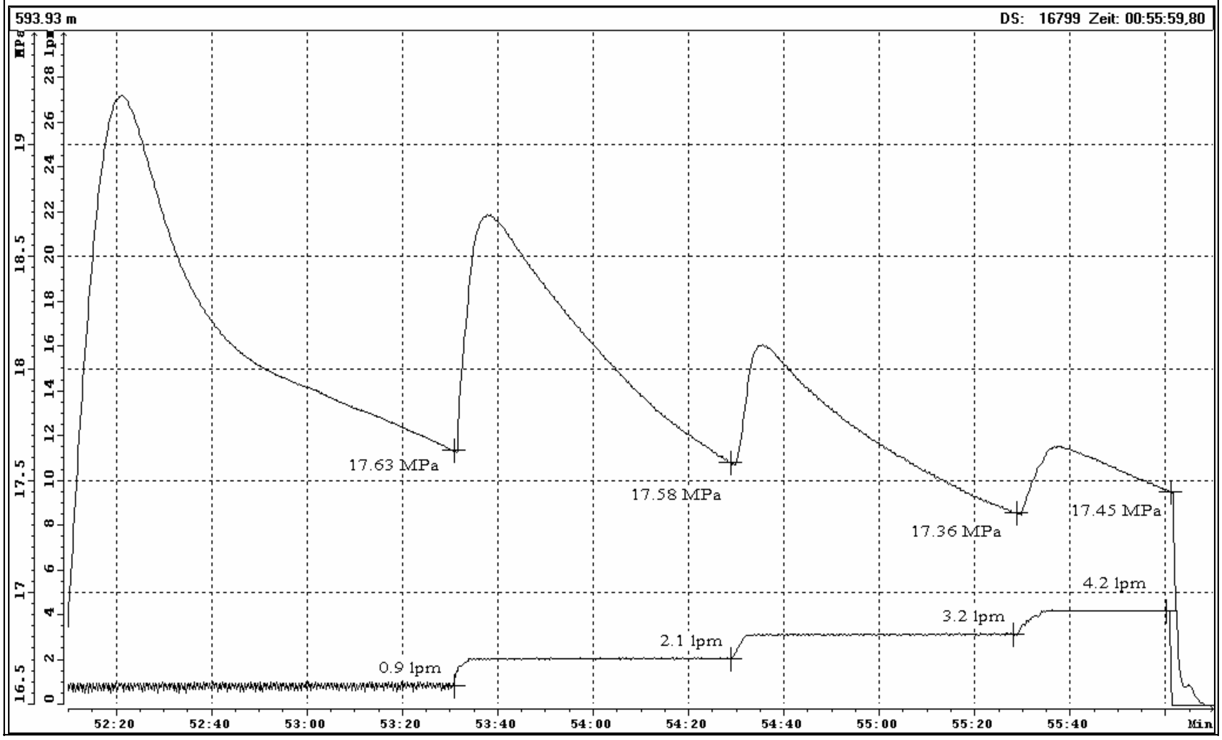
Test at 593.93 m MD: Estimation of $P_{si, min}$ (3. Refrac - Cycle)



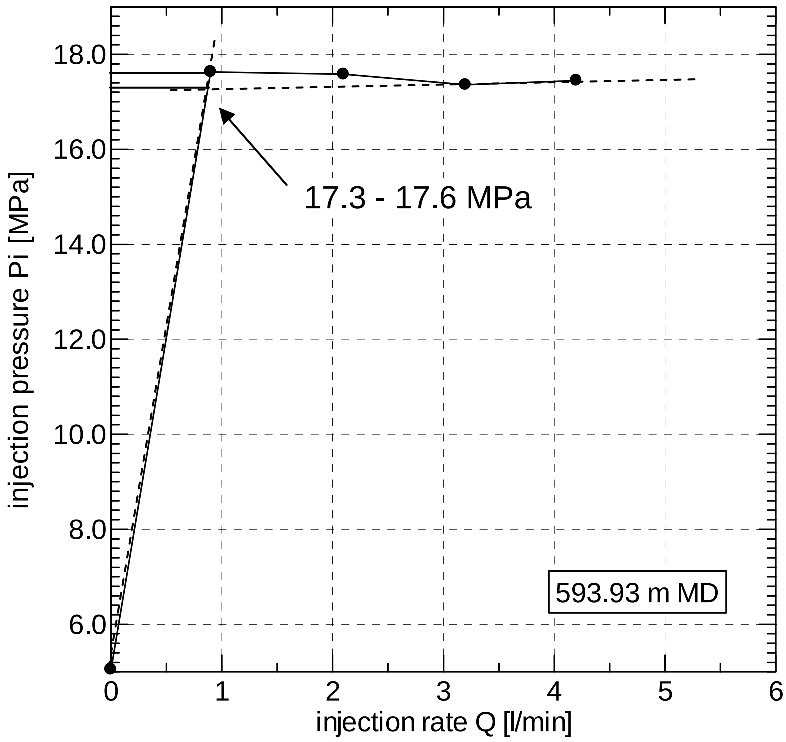
Test at 593.93 m MD: Estimation of P_{si} (3. Refrac - Cycle)



Test at 593.93 m MD: Analysis of Slow - Pump / Step - Rate - Test



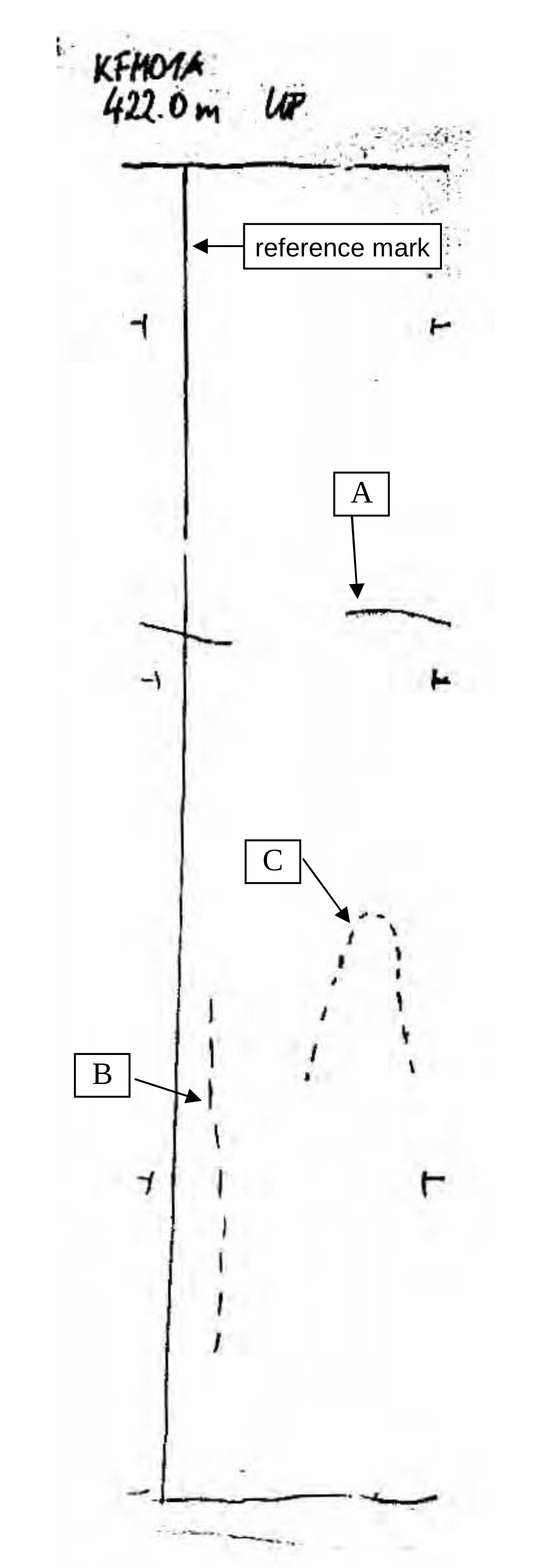
Test at 593.93 m MD: Examination of P_{si} (Step - Rate - Test)

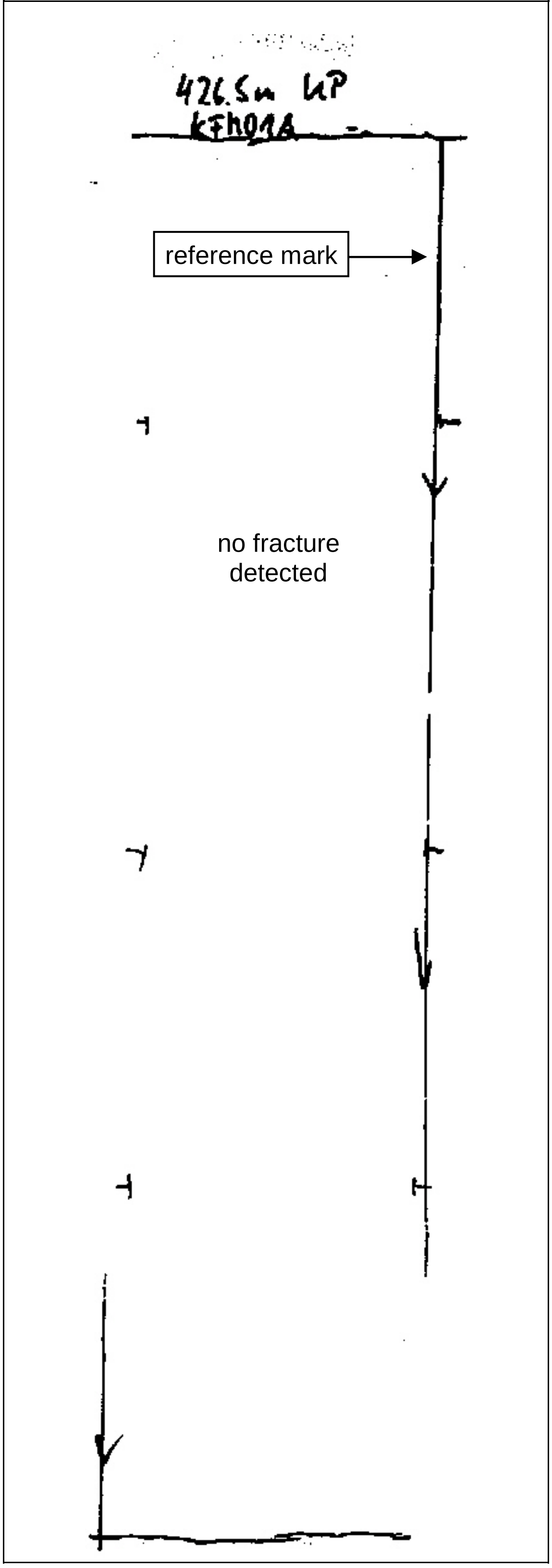


Appendix C1

Fracture Traces obtained from Impression Packer Testing
Borehole No. KFM01A

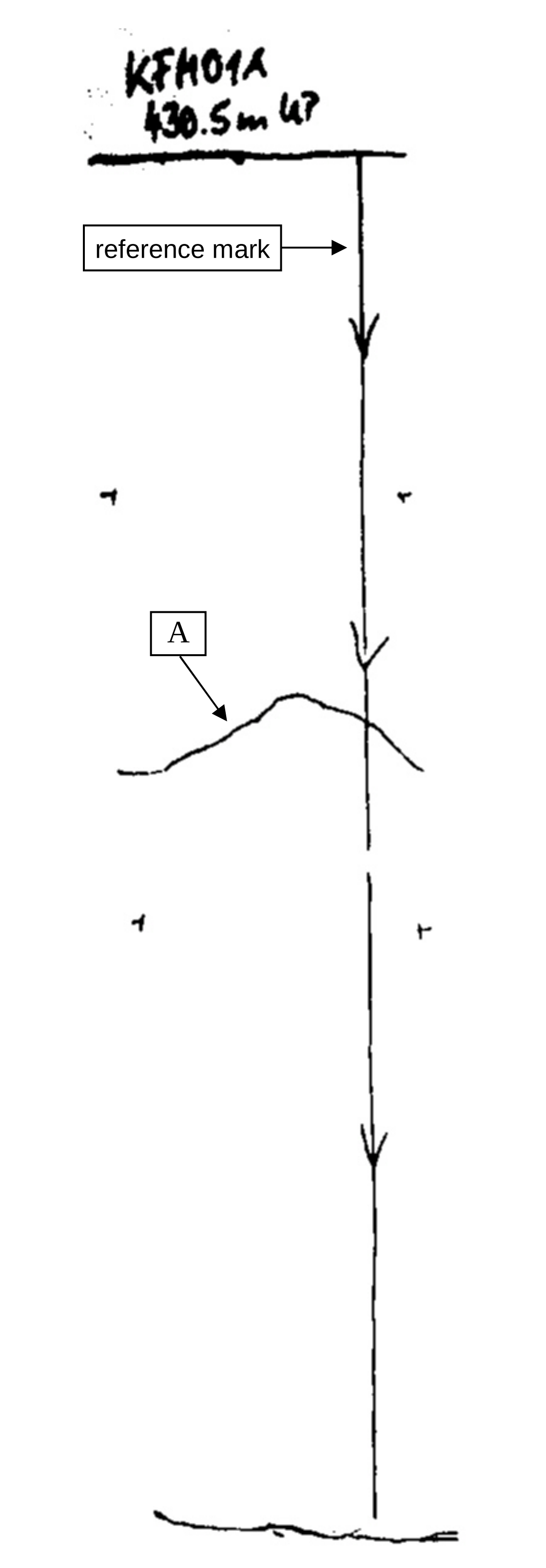
Test at 422.0 m MD / 419.00 m TVD	Test at 426.5 m MD / 423.45 m TVD
borehole dip / direction: 9° / N 308° angle from vertical to ref. mark: 28°	borehole dip / direction: 9° / N 308° angle from vertical to ref. mark: -28°





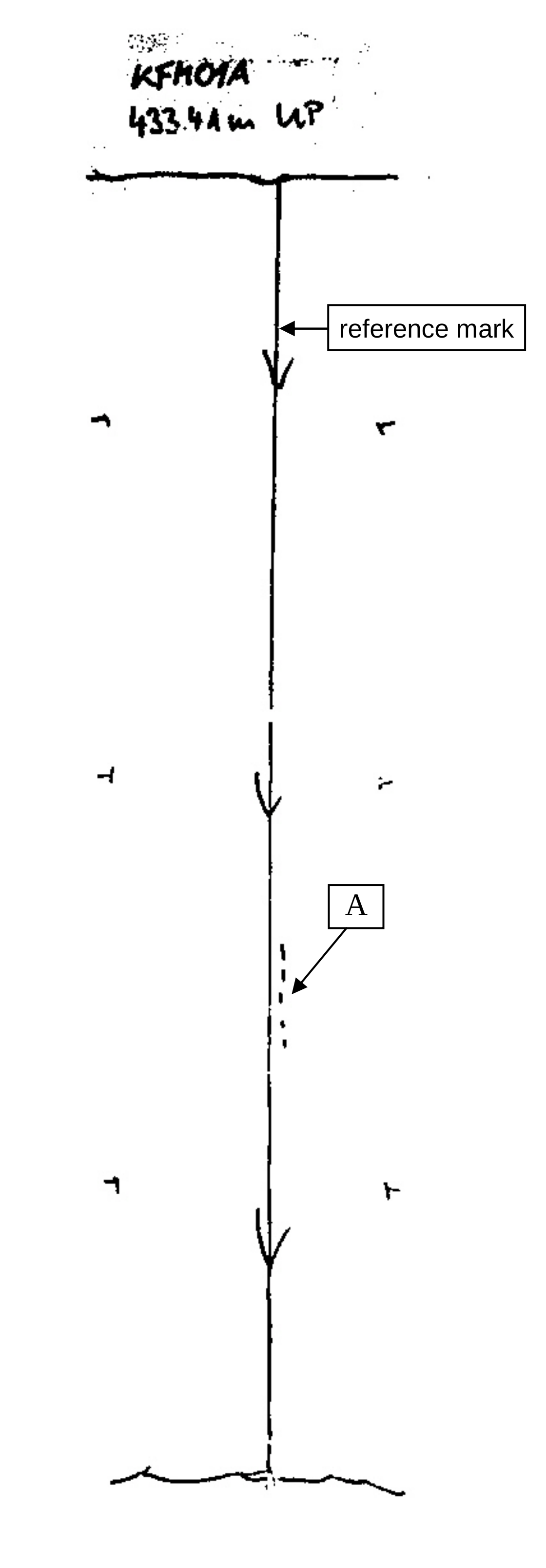
Test at 430.5 m MD / 427.40 m TVD

borehole dip / direction: 9° / N 308°
angle from vertical to ref. mark: 26°



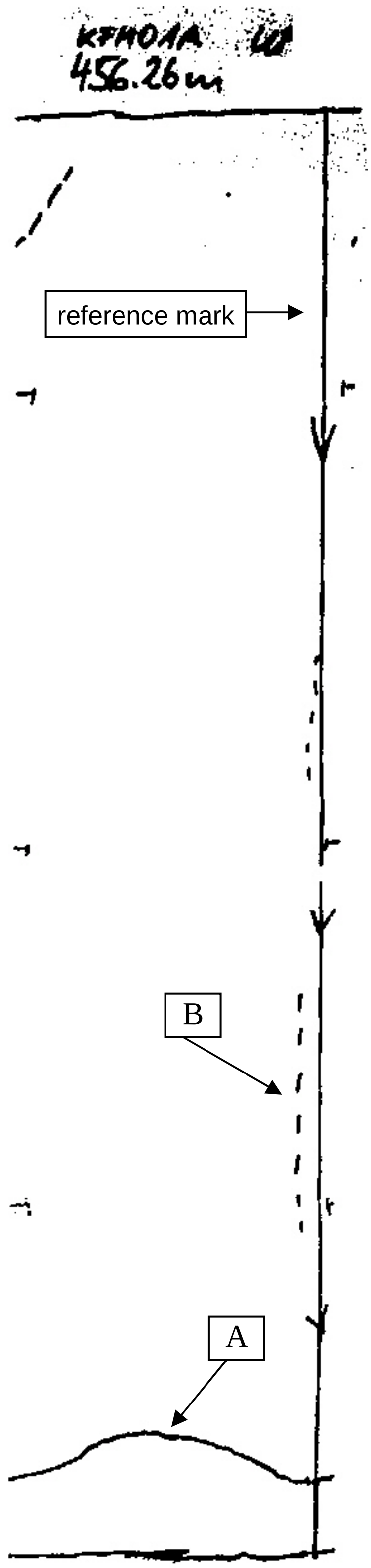
Test at 433.41 m MD / 430.28 m TVD

borehole dip / direction: 9° / N 308°
angle from vertical to ref. mark: -40°



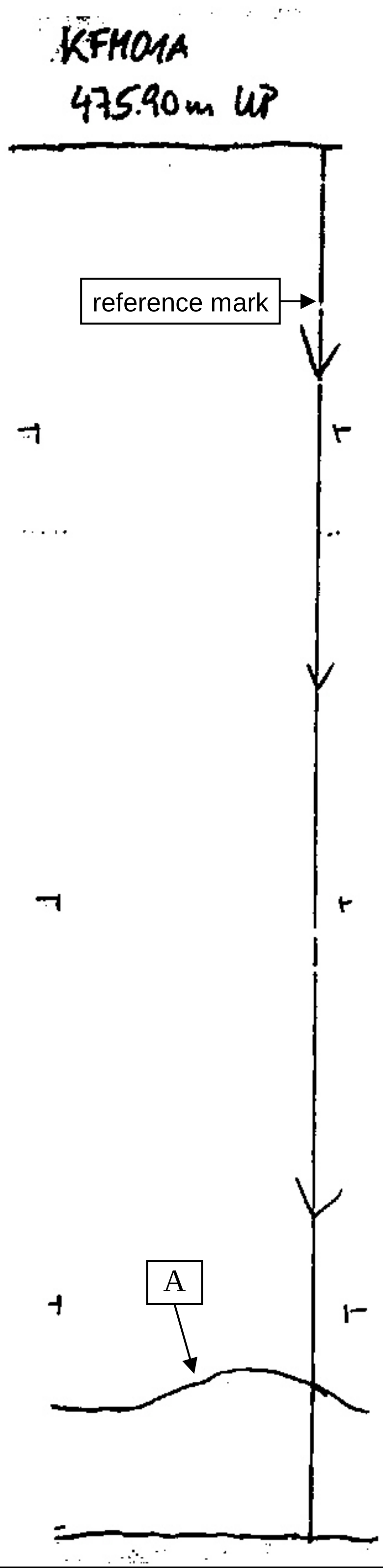
Test at 456.26 m MD / 452.87 m TVD

borehole dip / direction: 9° / N 308°
angle from vertical to ref. mark: -28°



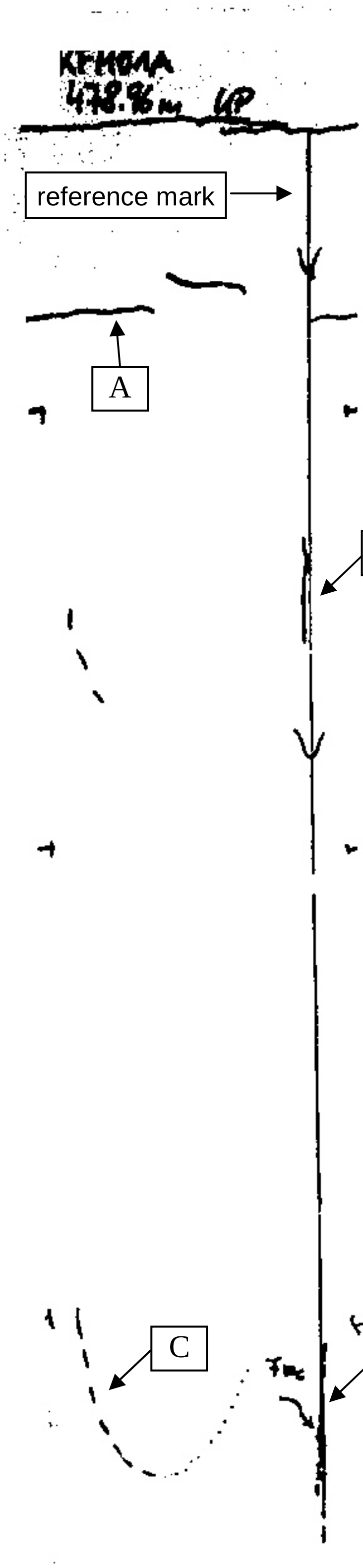
Test at 475.90 m MD / 472.27 m TVD

borehole dip / direction: 9° / N 307°
angle from vertical to ref. mark: 57°



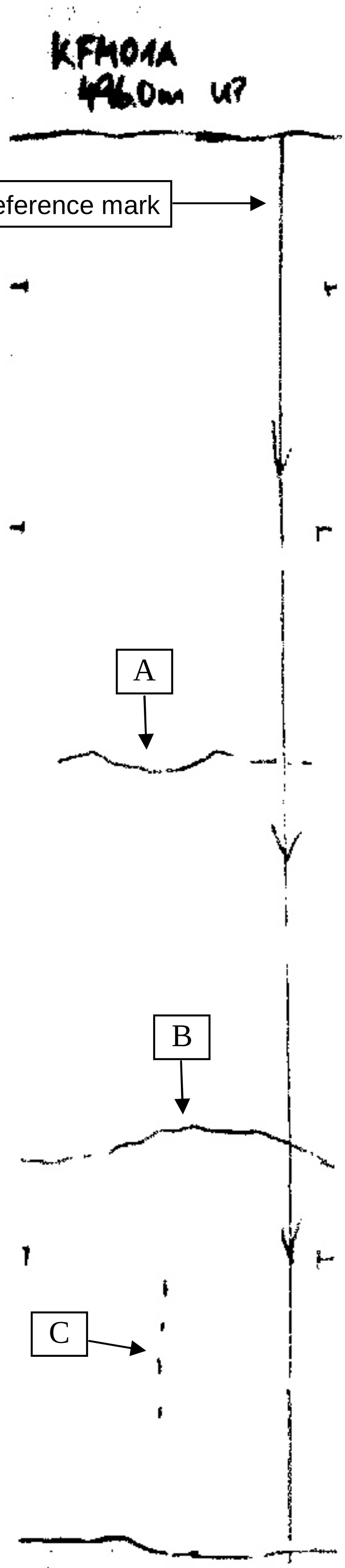
Test at 478.96 m MD / 475.29 m TVD

borehole dip / direction: 9° / N 307°
angle from vertical to ref. mark: 47°



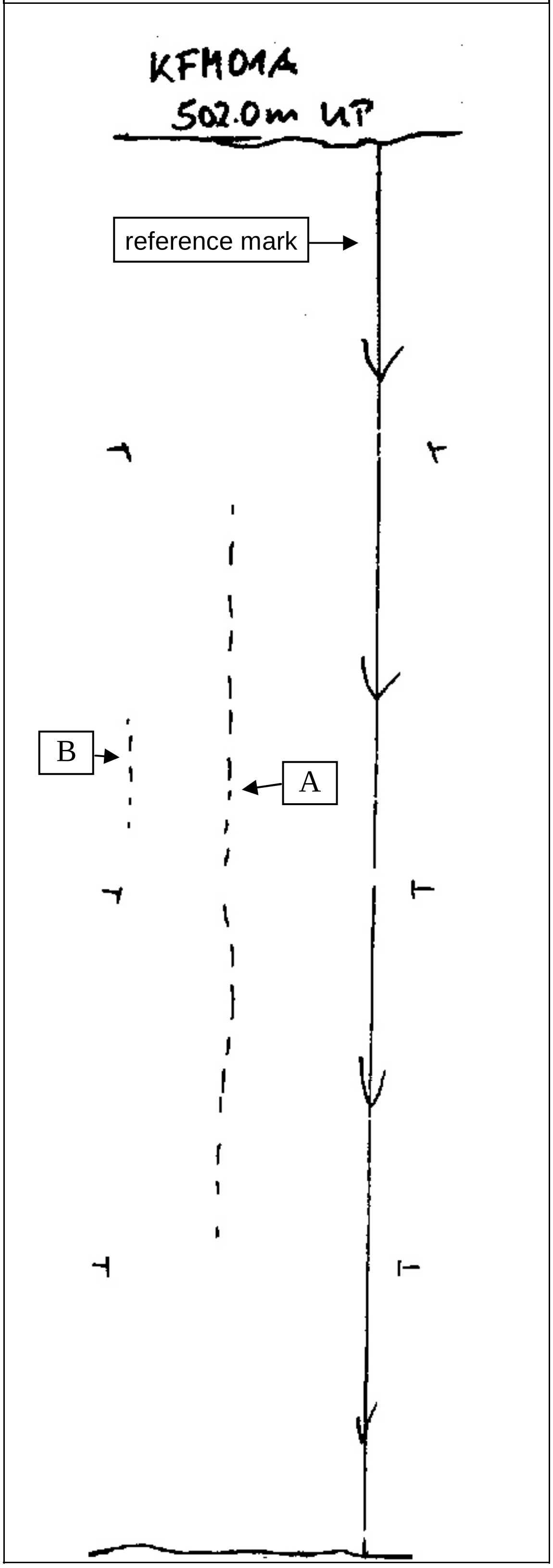
Test at 496.0 m MD / 492.11 m TVD

borehole dip / direction: 9.5° / N 308°
angle from vertical to ref. mark: 45°



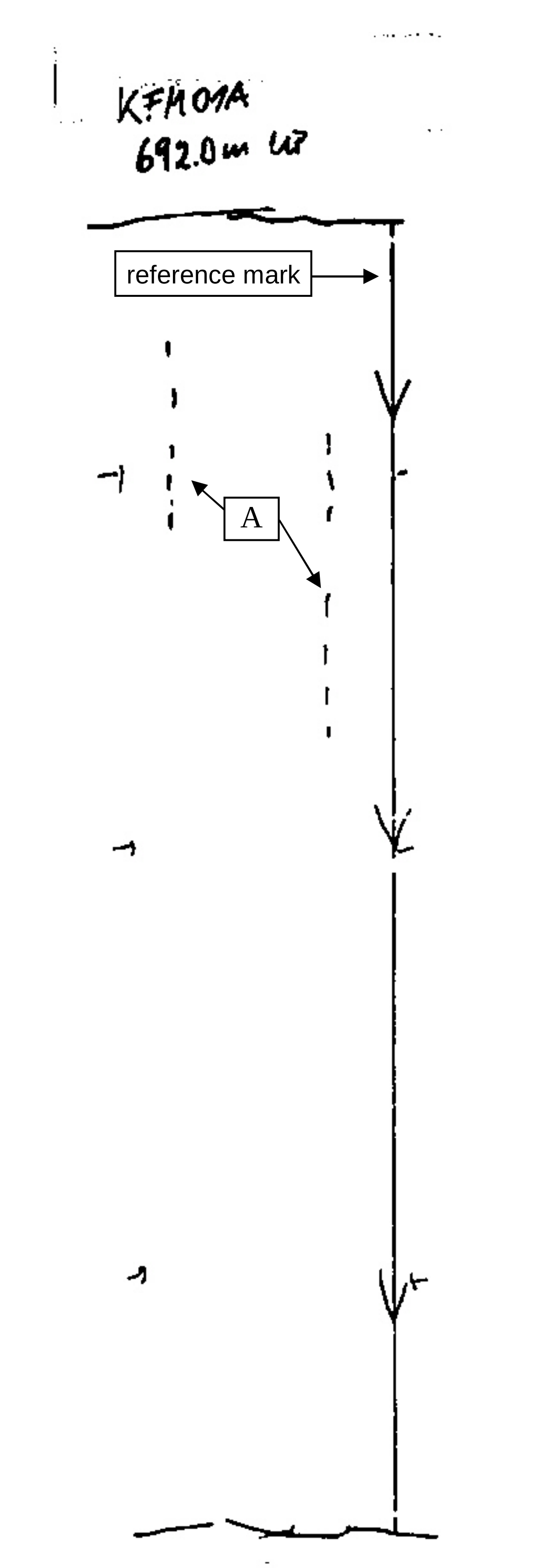
Test at 502.0 m MD / 498.03 m TVD

borehole dip / direction: 10° / N 308°
angle from vertical to ref. mark: 52°



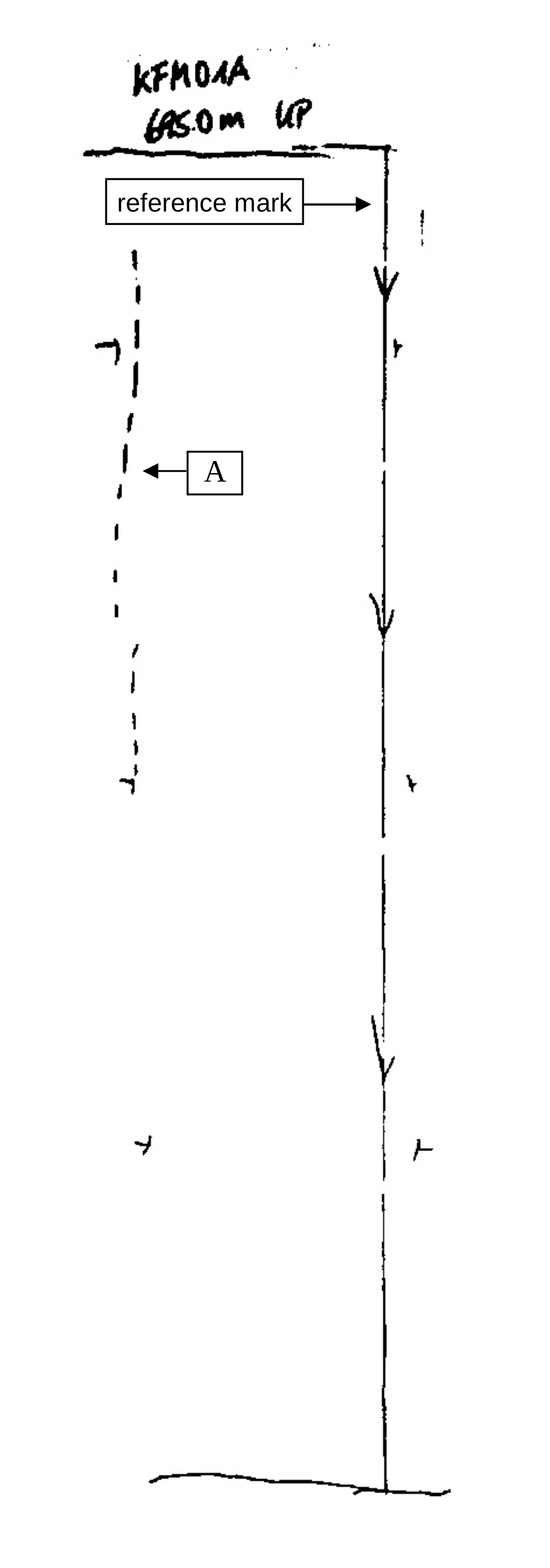
Test at 692.0 m MD / 684.58 m TVD

borehole dip / direction: 12° / N 305°
angle from vertical to ref. mark: 41°



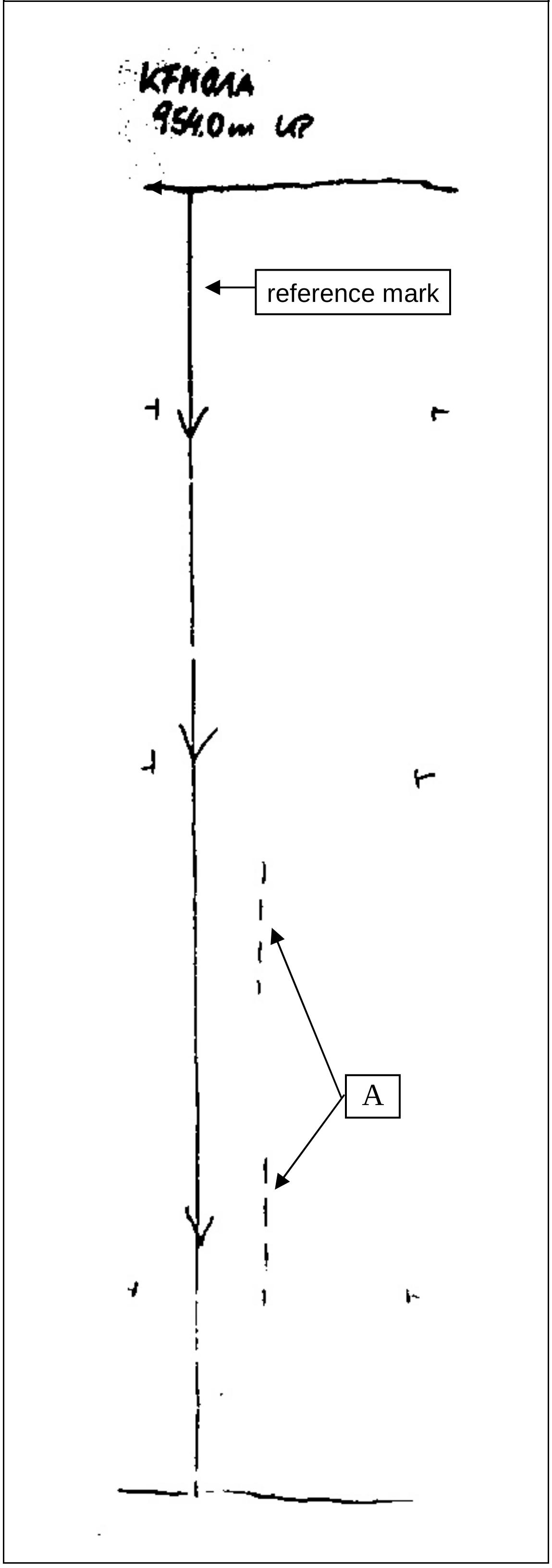
Test at 695.0 m MD / 687.51 m TVD

borehole dip / direction: 12° / N 305°
angle from vertical to ref. mark: 37°



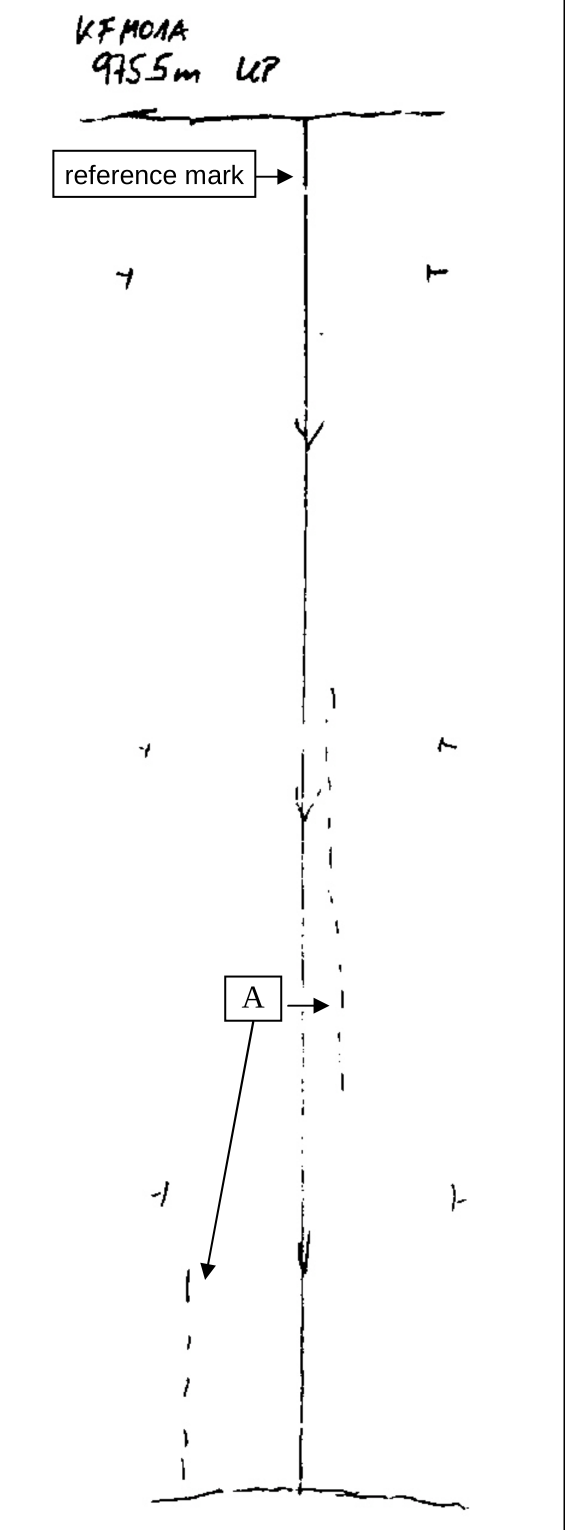
Test at 954.0 m MD / 939.52 m TVD

borehole dip / direction: 15° / N 308.5°
angle from vertical to ref. mark: 41°



Test at 975.5 m MD / 960.32 m TVD

borehole dip / direction: 15° / N 308°
angle from vertical to ref. mark: 16°

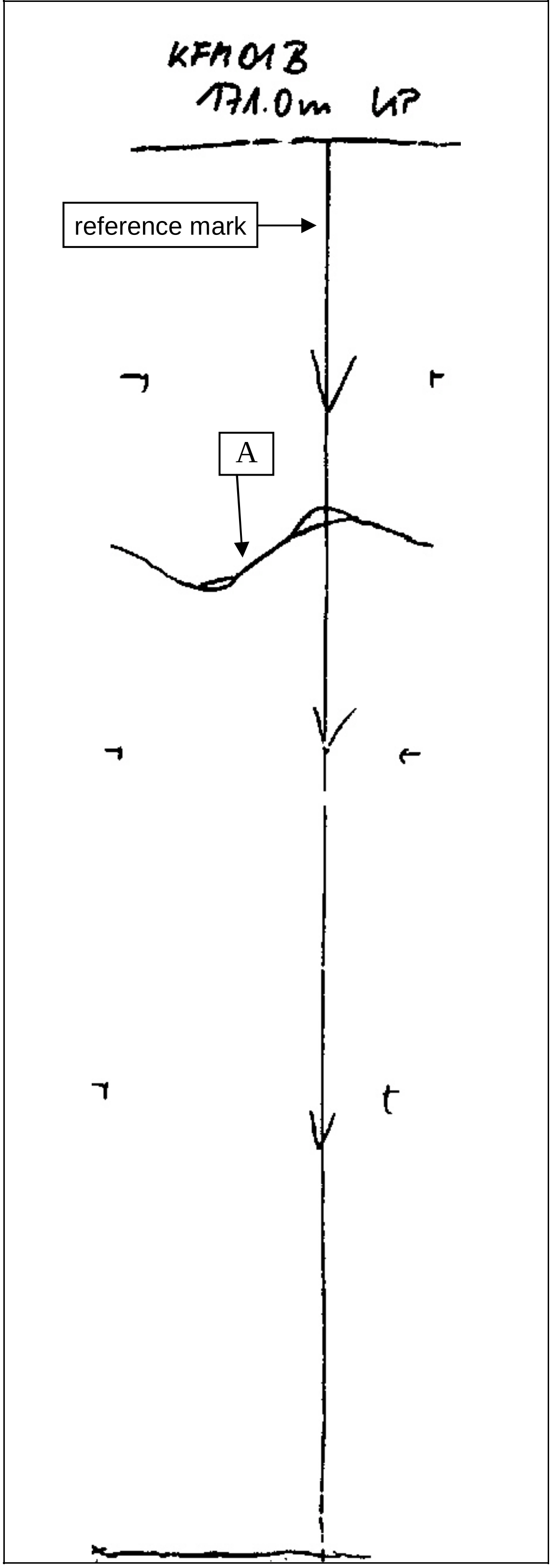


Appendix C2

Fracture Traces obtained from Impression Packer Testing
Borehole No. KFM01B

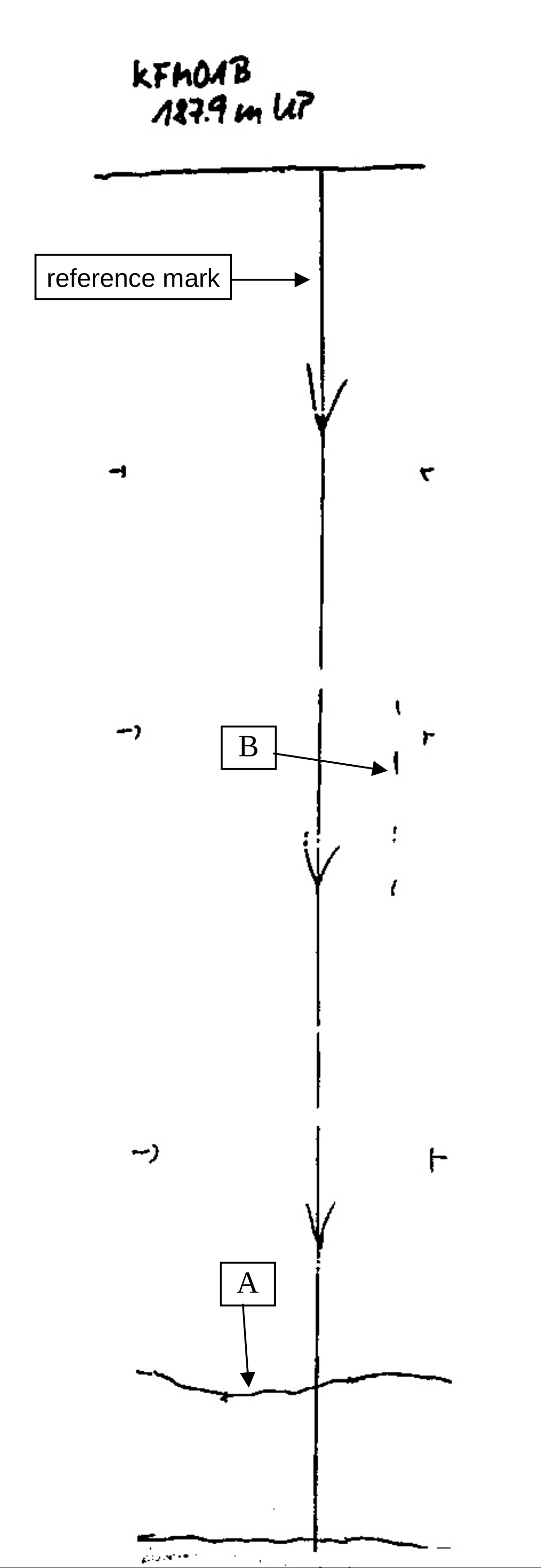
Test at 171.00 m MD / 167.07 m TVD

borehole dip / direction: 14° / N 271°
angle from vertical to ref. mark: -134°



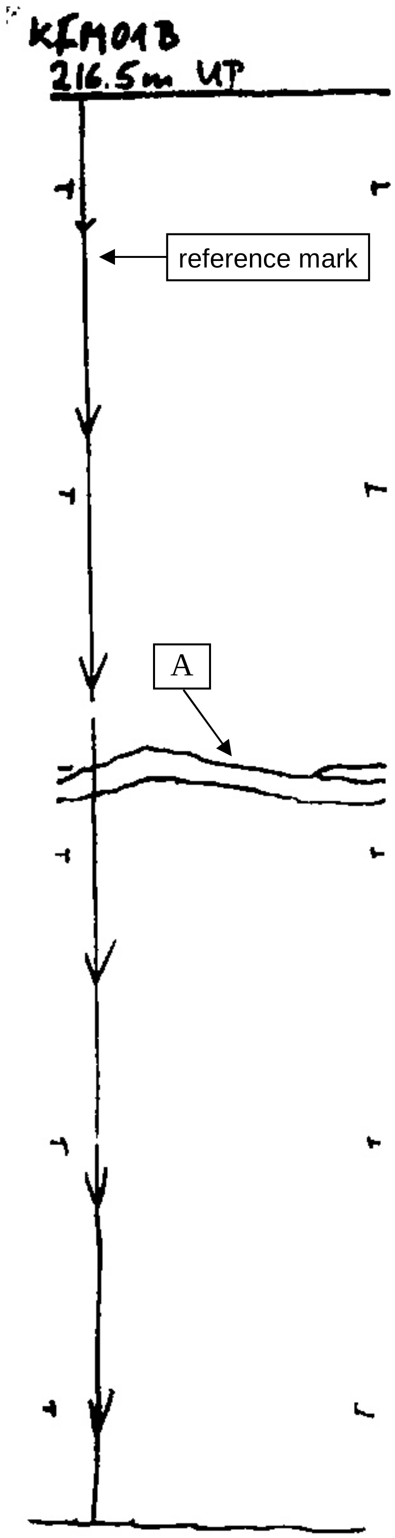
Test at 187.90 m MD / 183.46 m TVD

borehole dip / direction: 14° / N 271°
angle from vertical to ref. mark: -110°



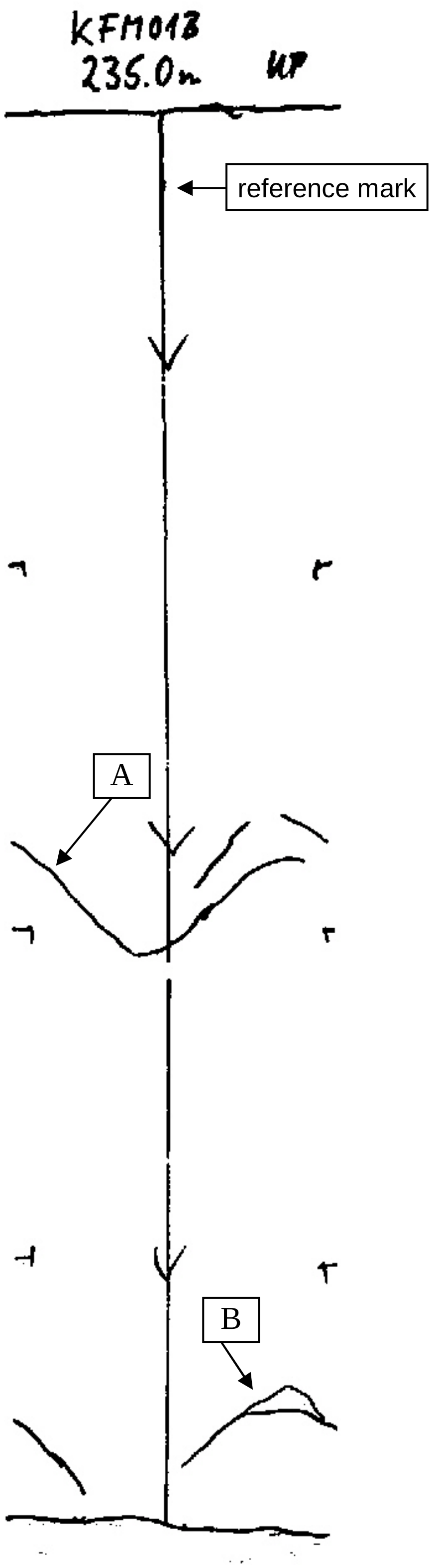
Test at 216.50 m MD / 211.13 m TVD

borehole dip / direction: 15° / N 270°
angle from vertical to ref. mark: -68°



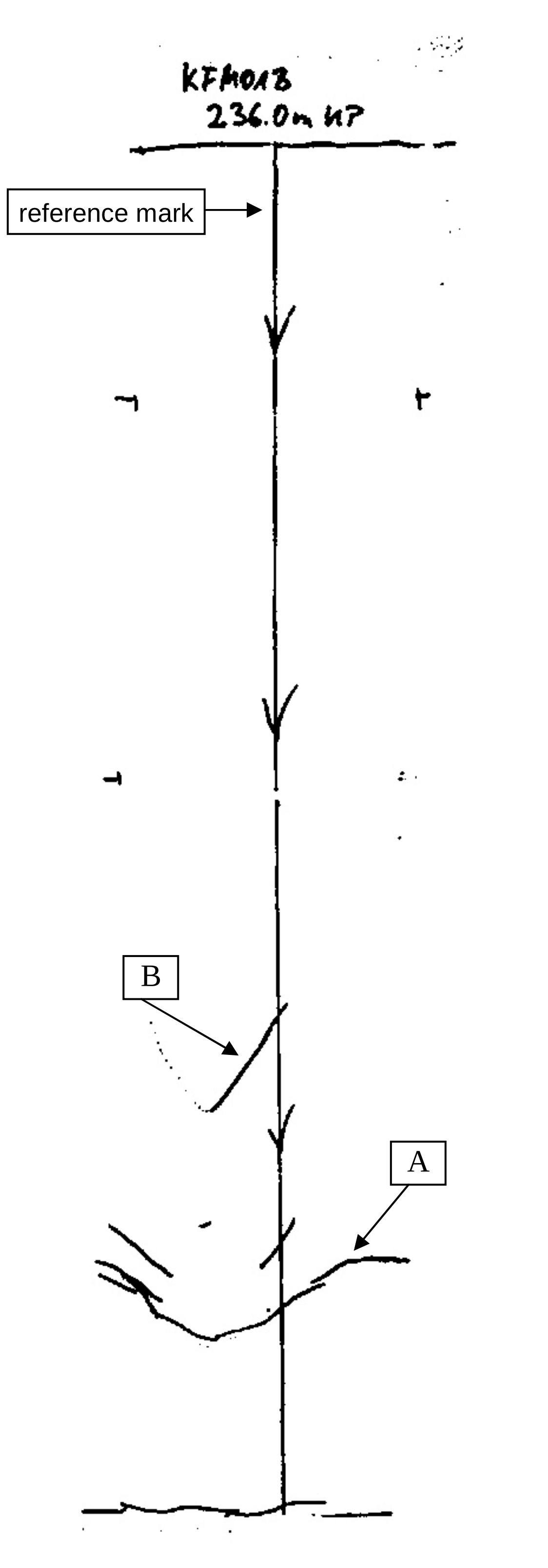
Test at 235.0 m MD / 228.97 m TVD

borehole dip / direction: 16° / N 270°
angle from vertical to ref. mark: -65°



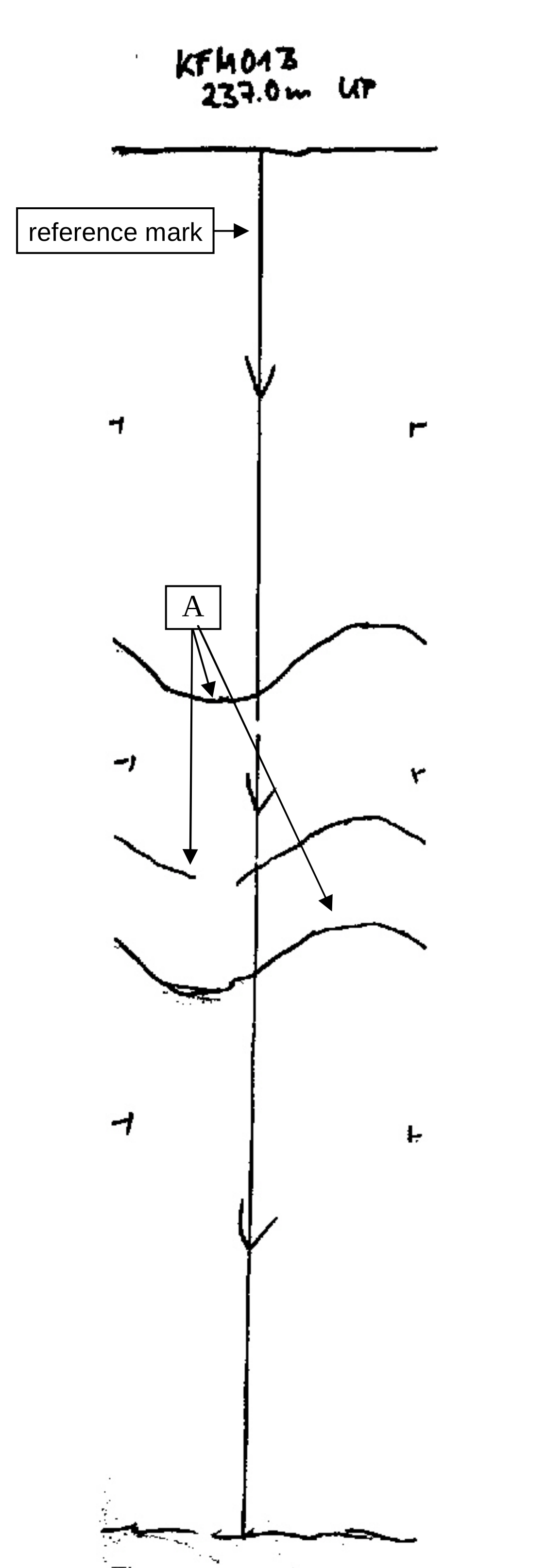
Test at 236.0 m MD / 229.94 m TVD

borehole dip / direction: 16° / N 270°
angle from vertical to ref. mark: -89°



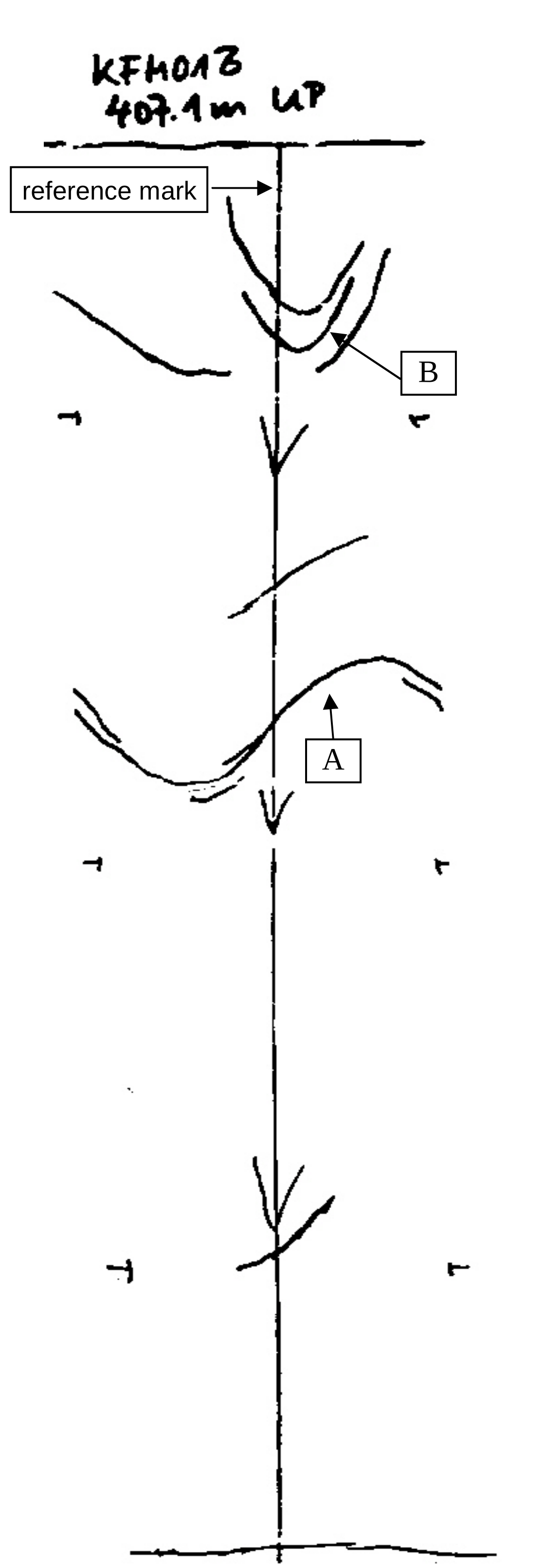
Test at 237.0 m MD / 230.90 m TVD

borehole dip / direction: 16° / N 270°
angle from vertical to ref. mark: -80°



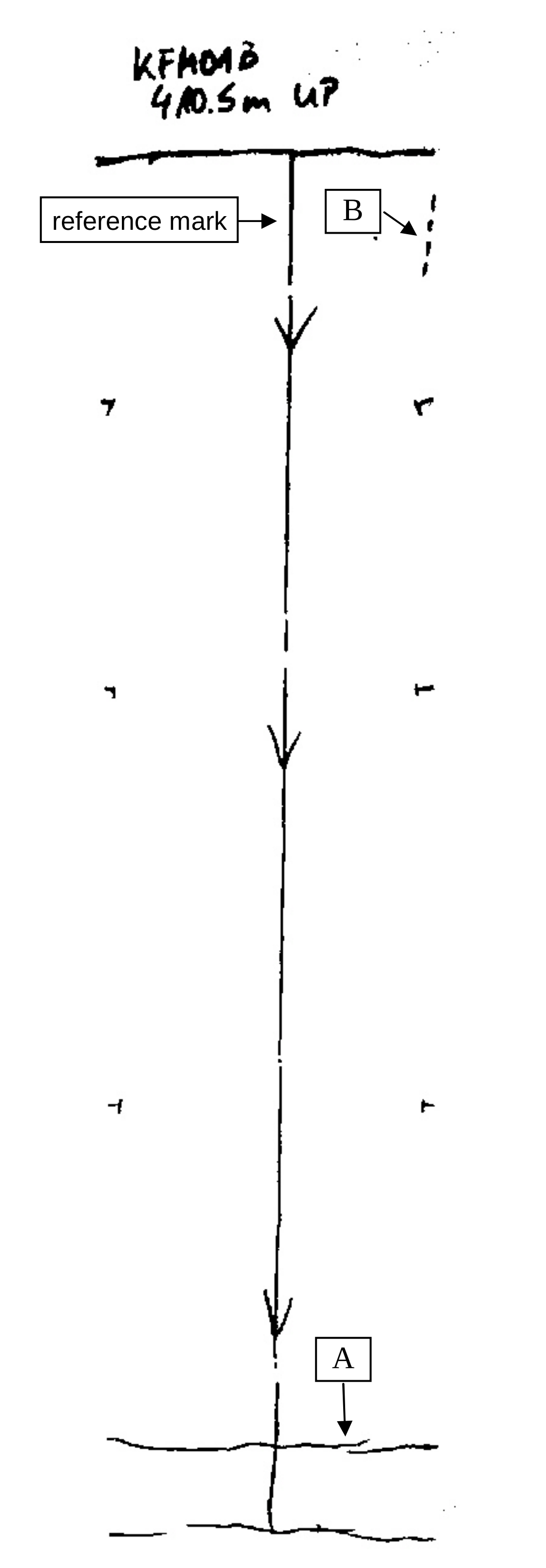
Test at 407.1 m MD / 393.77 m TVD

borehole dip / direction: 18° / N 272°
angle from vertical to ref. mark: -115°

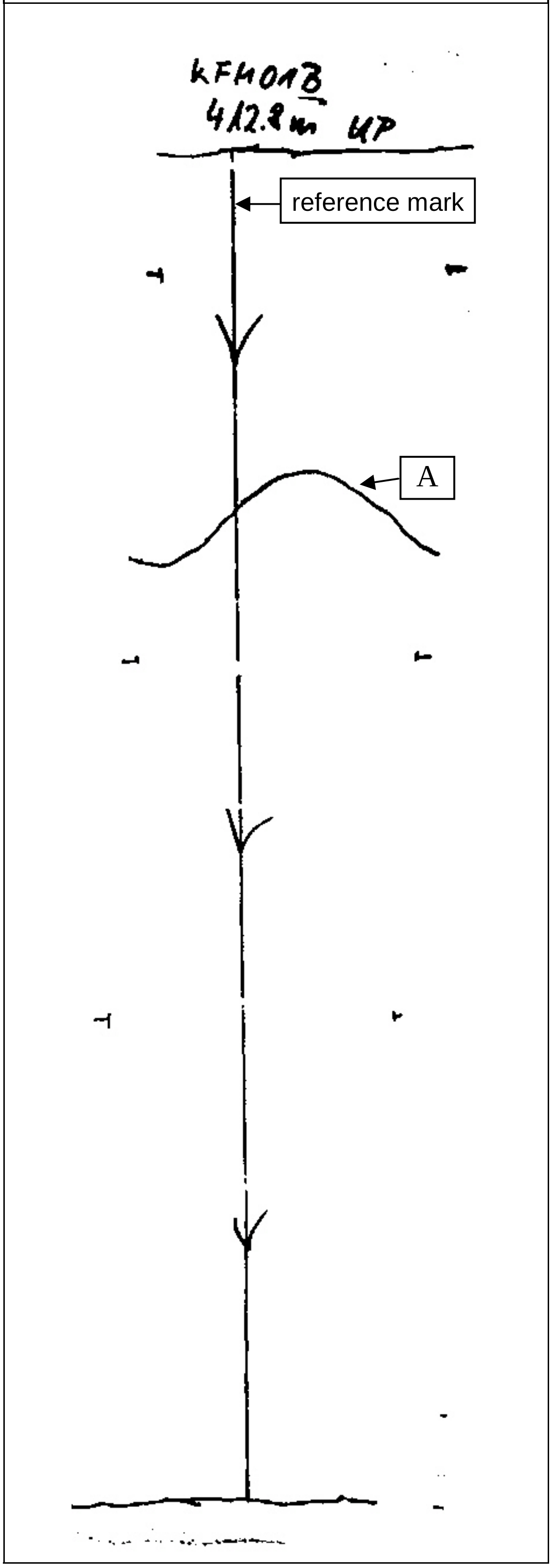


Test at 410.5 m MD / 397.00 m TVD

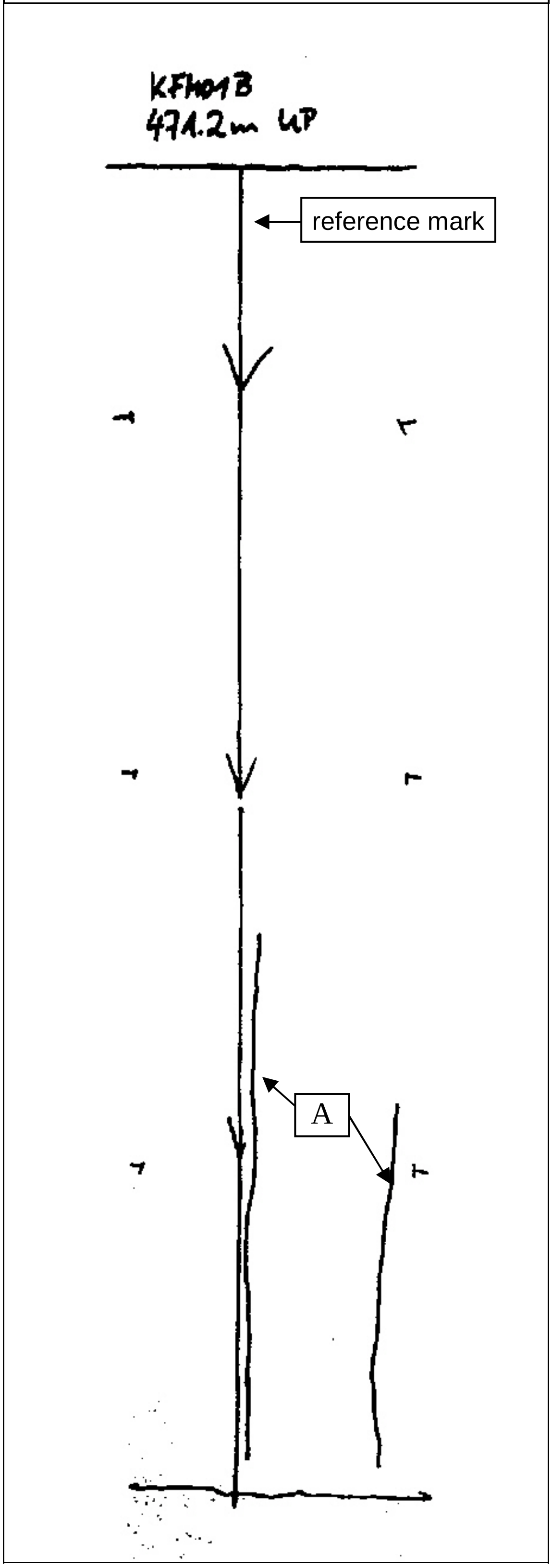
borehole dip / direction: 18° / N 272°
angle from vertical to ref. mark: -118°



Test at 412.8 m MD / 399.18 m TVD
borehole dip / direction: 18° / N 272° angle from vertical to ref. mark: -117°

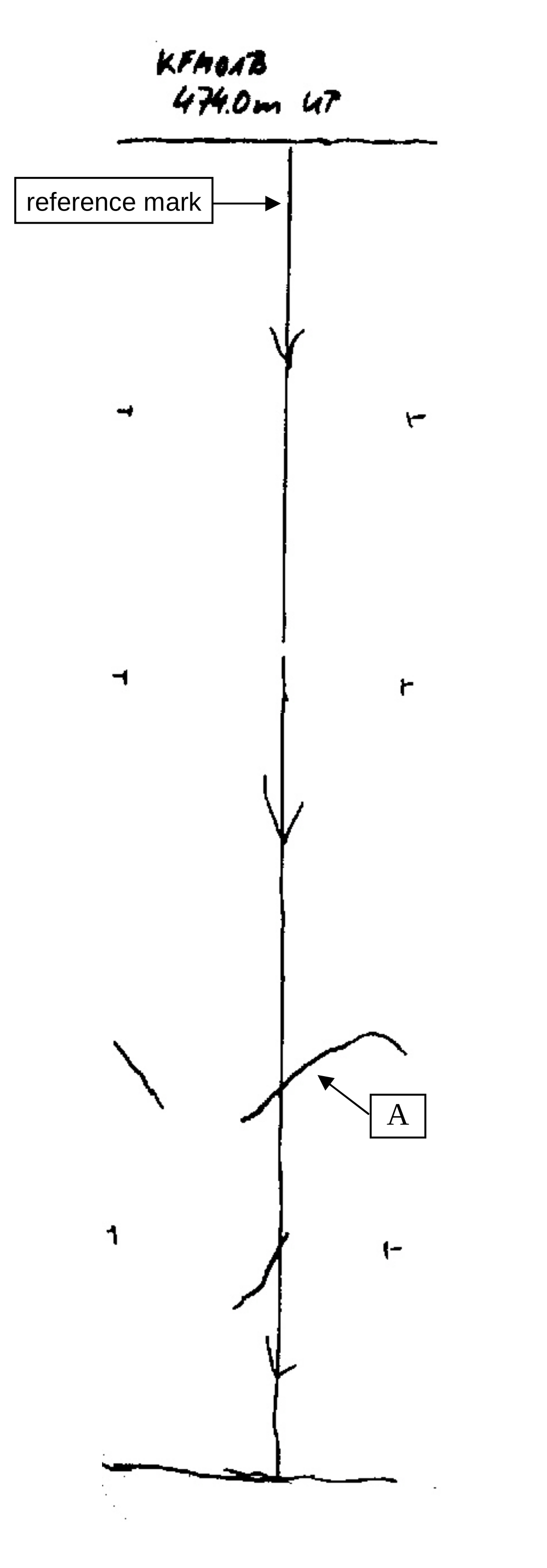


Test at 471.2 m MD / 454.68 m TVD
borehole dip / direction: 18° / N 273° angle from vertical to ref. mark: -122°



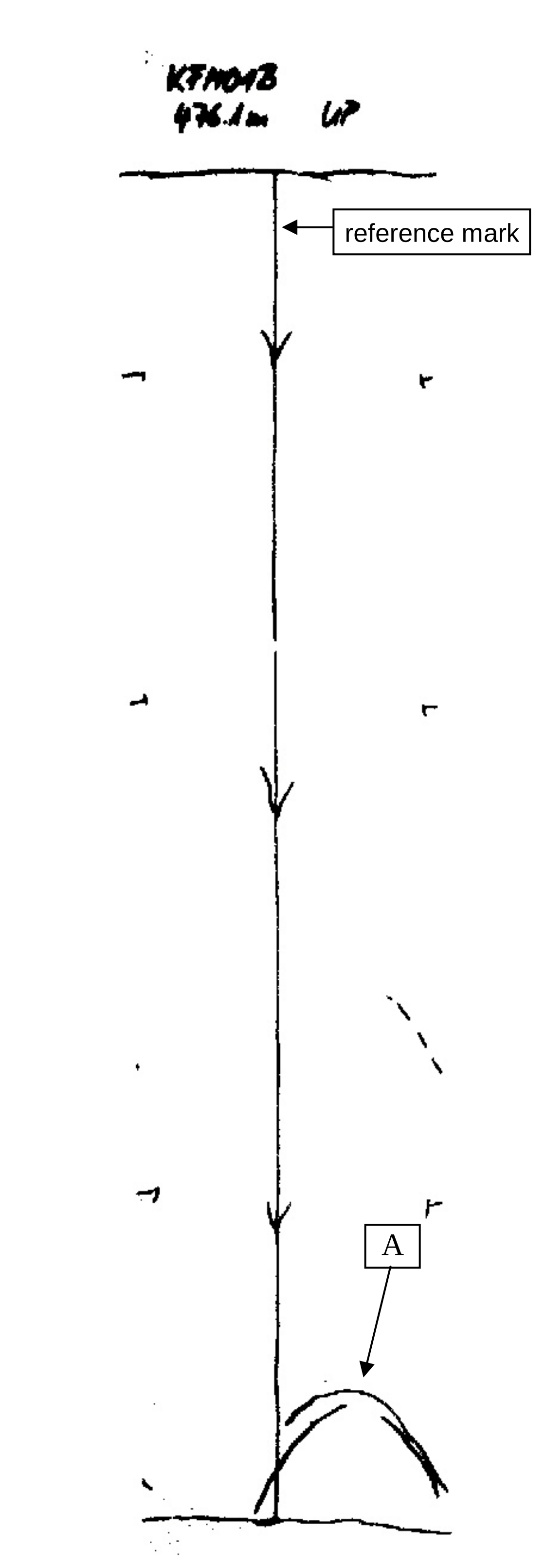
Test at 474.0 m MD / 457.33 m TVD

borehole dip / direction: 18° / N 273°
angle from vertical to ref. mark: -130°



Test at 476.1 m MD / 459.32 m TVD

borehole dip / direction: 18° / N 273°
angle from vertical to ref. mark: -136°

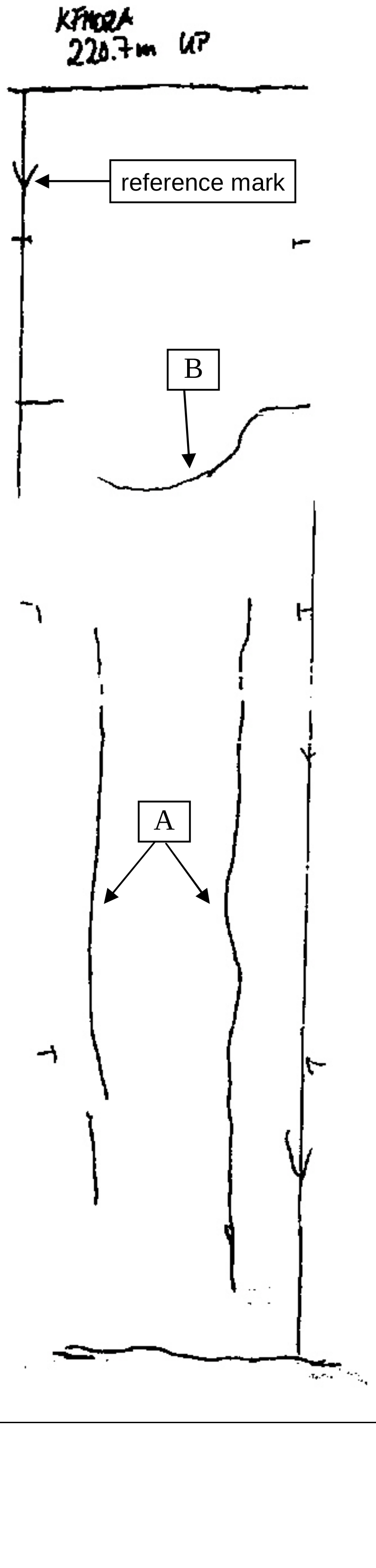


Appendix C3

Fracture Traces obtained from Impression Packer Testing
Borehole No. KFM02A

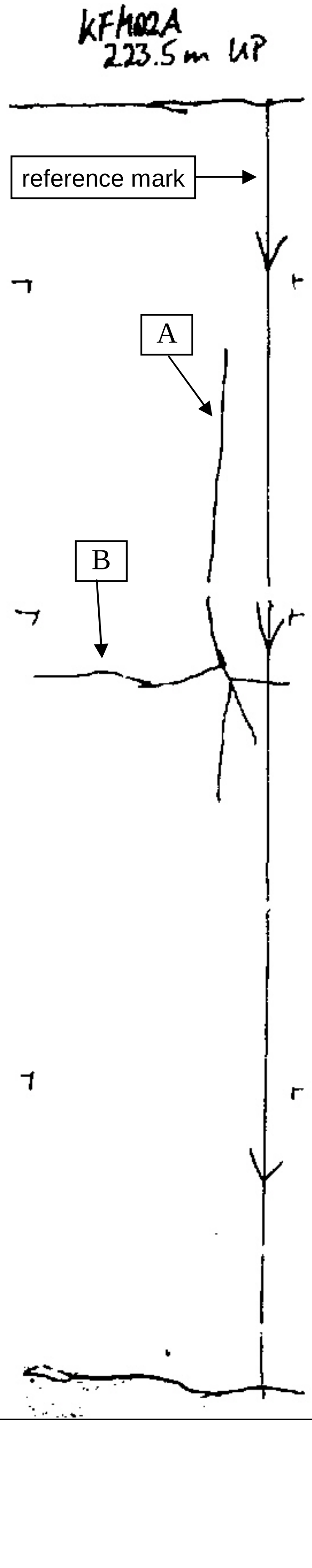
Test at 220.7 m MD / 220.09 m TVD

borehole dip / direction: 5° / N 292°
angle from vertical to ref. mark: -86°

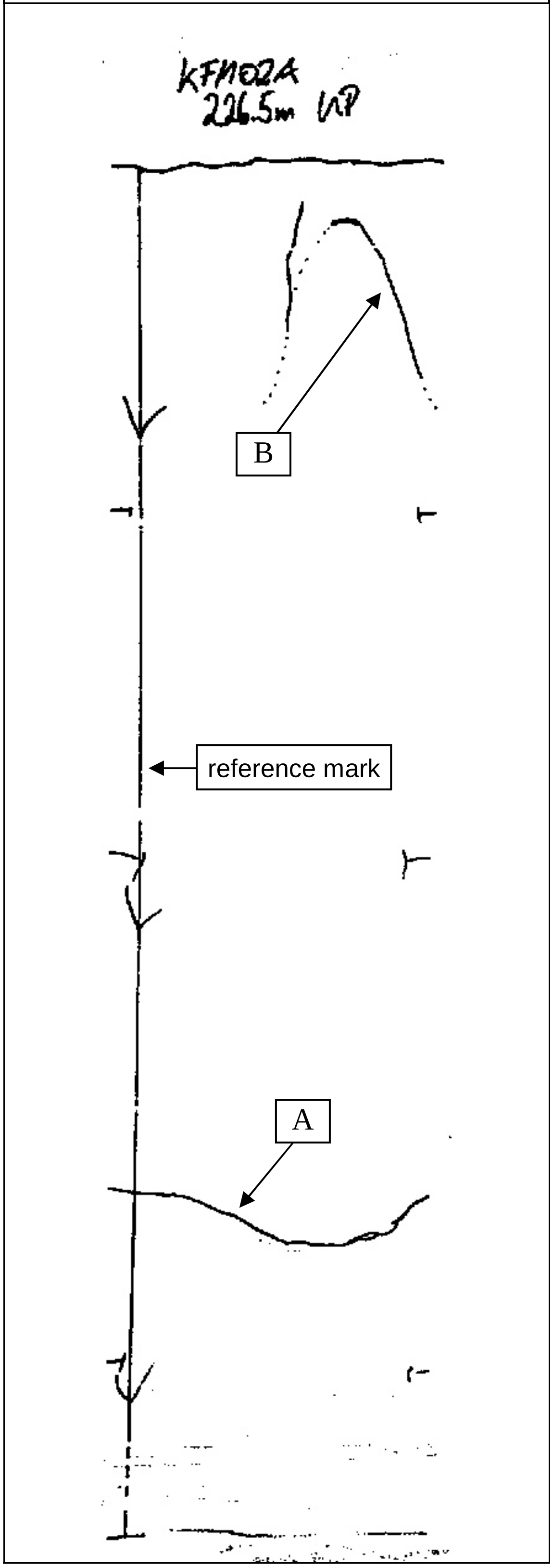


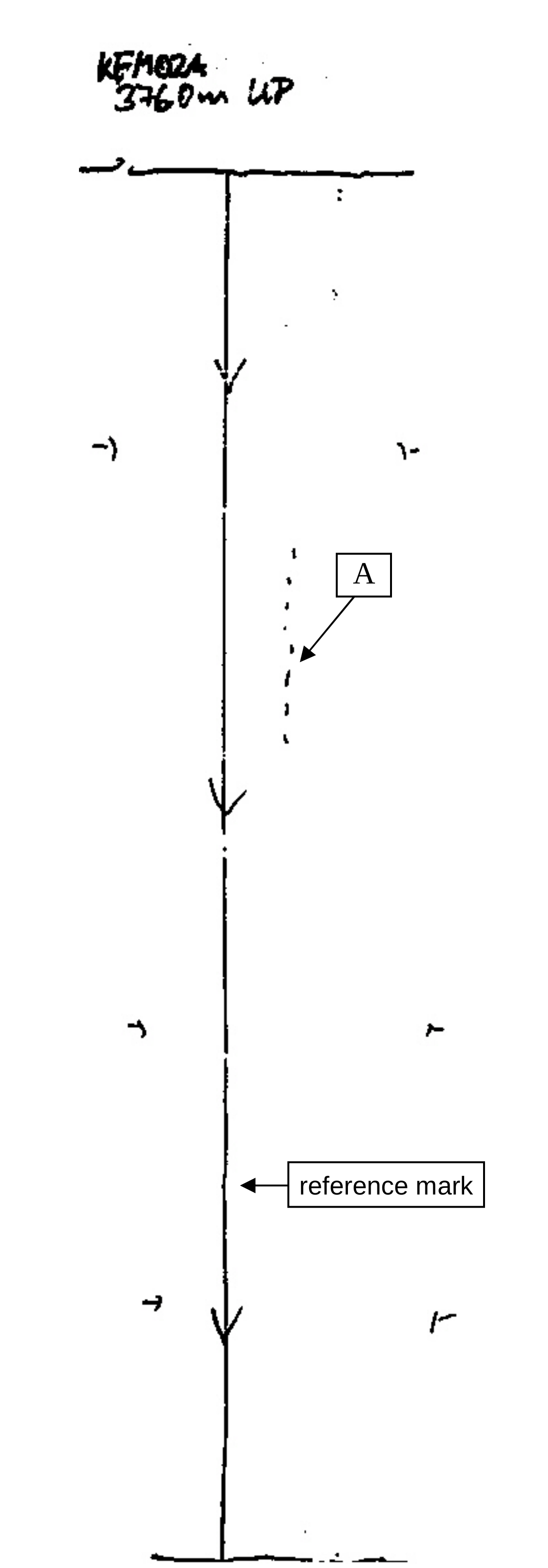
Test at 223.5 m MD / 222.88 m TVD

borehole dip / direction: 5° / N 292°
angle from vertical to ref. mark: -52°



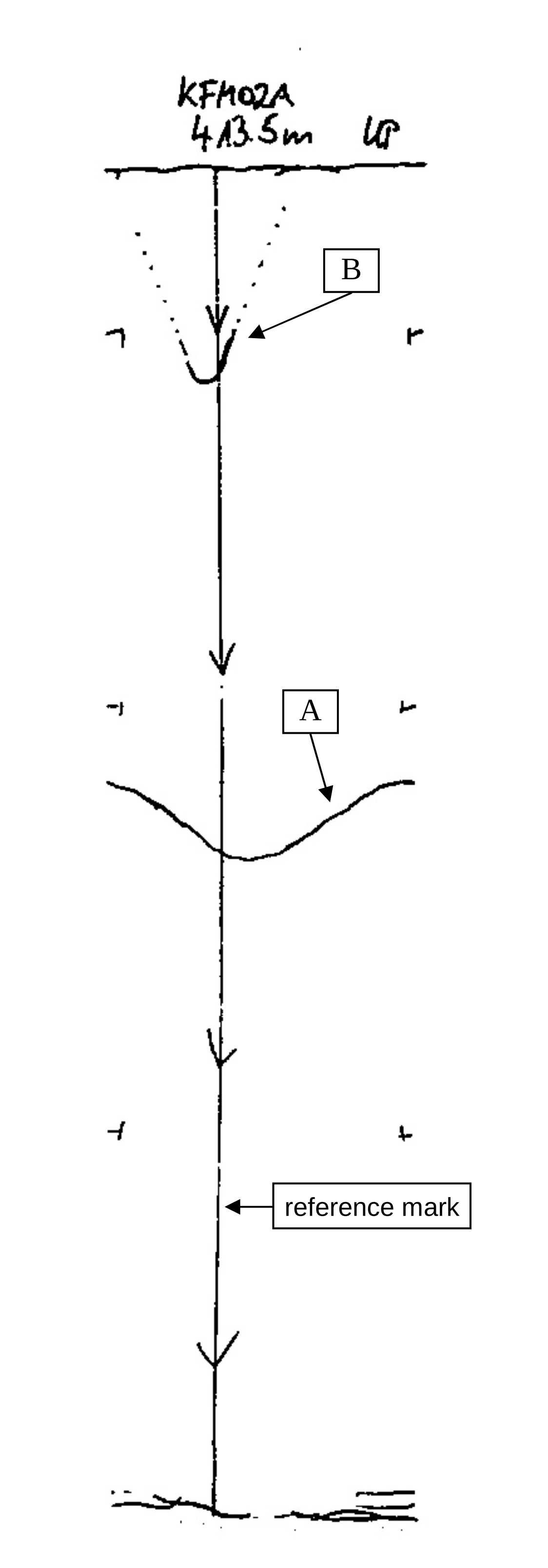
Test at 226.5 m MD / 225.87 m TVD	Test at 376.0 m MD / 374.78 m TVD
borehole dip / direction: 5° / N 293° angle from vertical to ref. mark: -37°	borehole dip / direction: 5° / N 296° angle from vertical to ref. mark: 159°





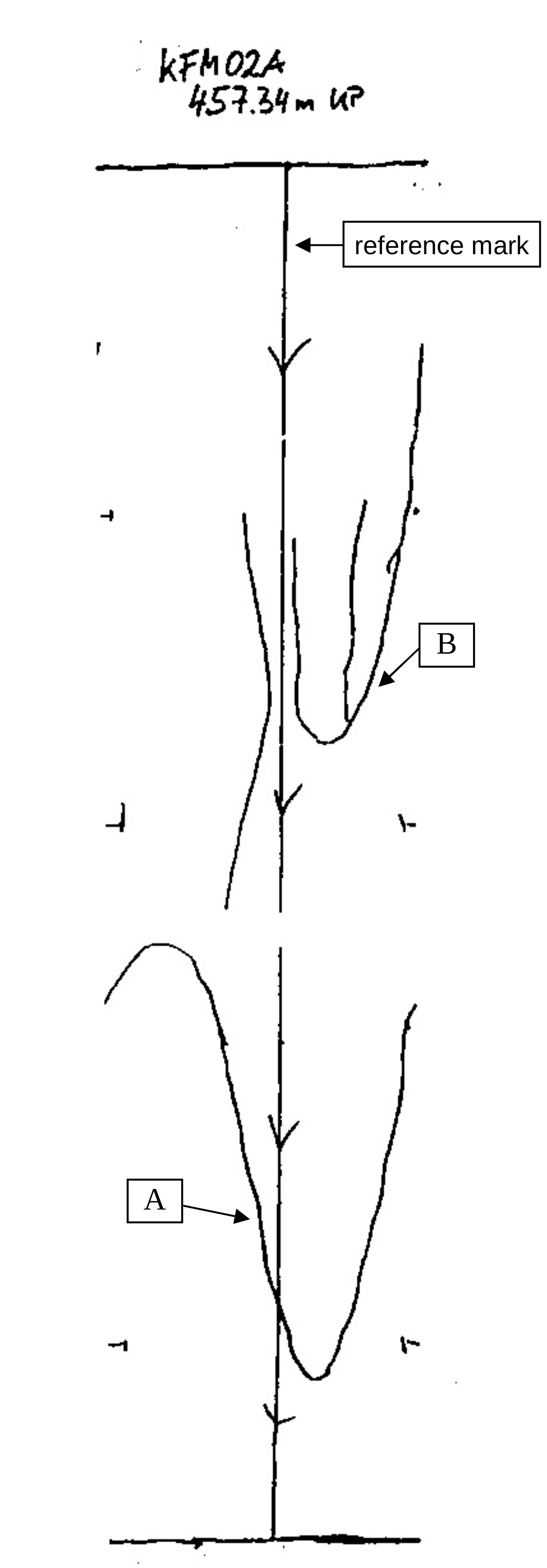
Test at 413.5 m MD / 412.12 m TVD

borehole dip / direction: 5° / N 297°
angle from vertical to ref. mark: 168°



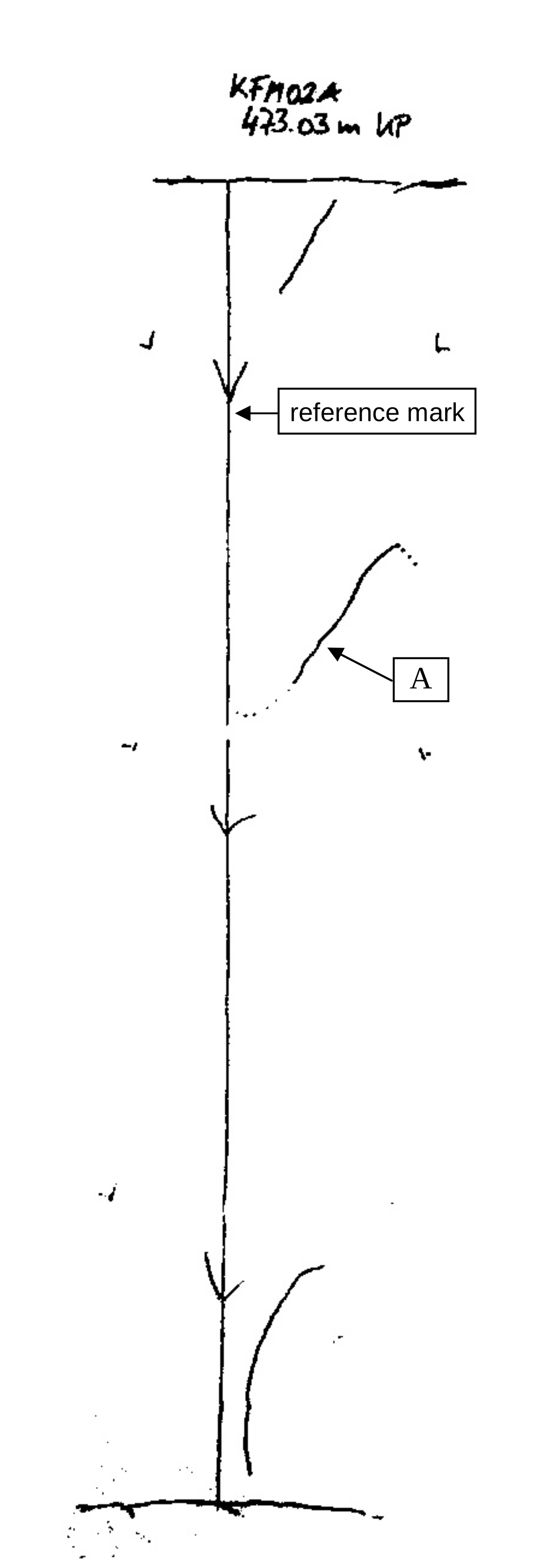
Test at 457.34 m MD / 455.77 m TVD

borehole dip / direction: 5° / N 299°
angle from vertical to ref. mark: -137°



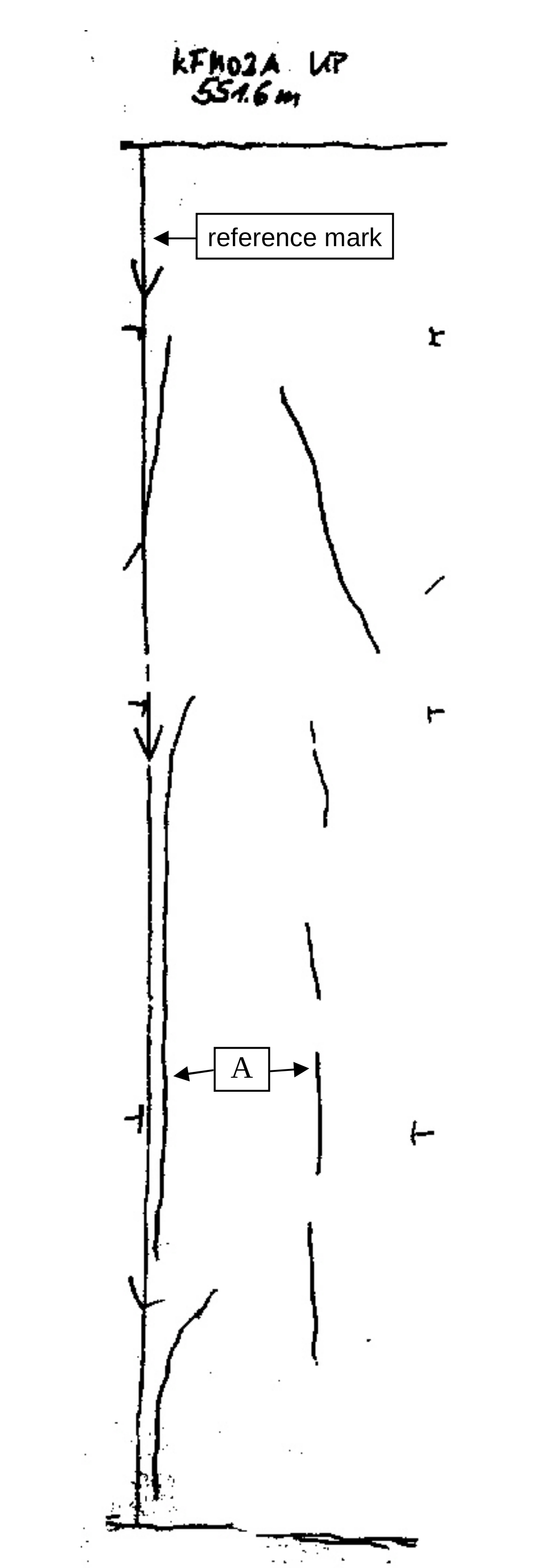
Test at 473.03 m MD / 471.39 m TVD

borehole dip / direction: 5.5° / N 302°
angle from vertical to ref. mark: 103°



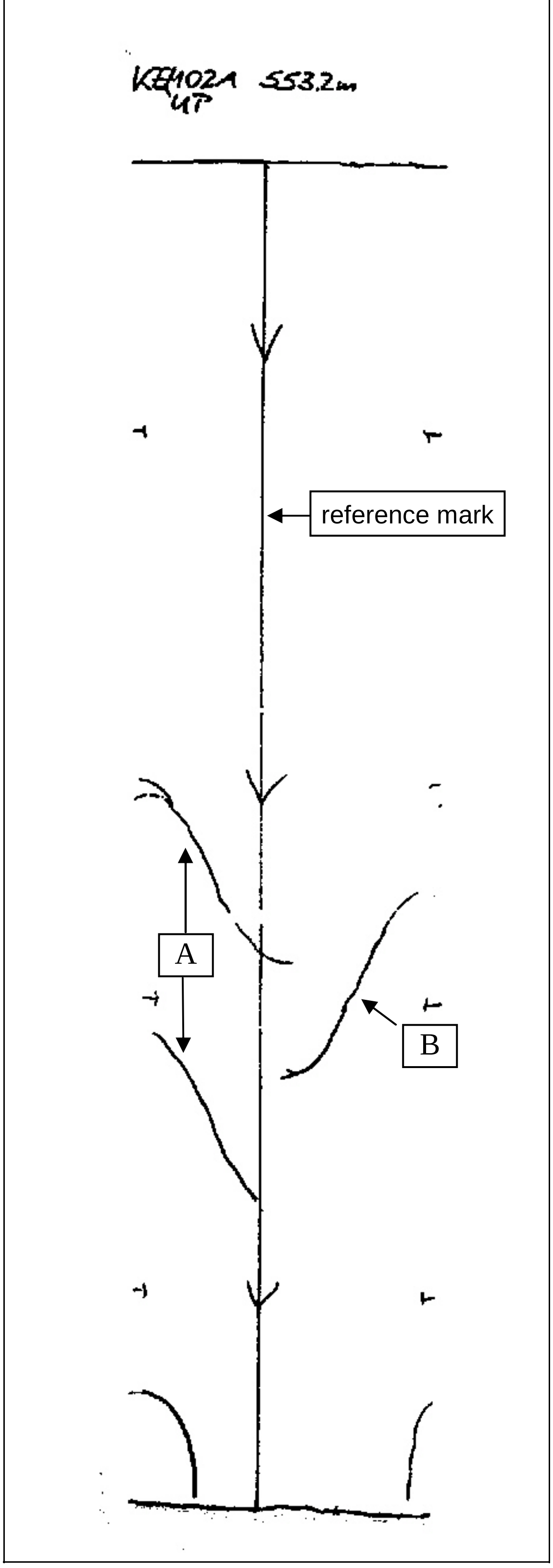
Test at 551.6 m MD / 549.53 m TVD

borehole dip / direction: 6° / N 301°
angle from vertical to ref. mark: -155°



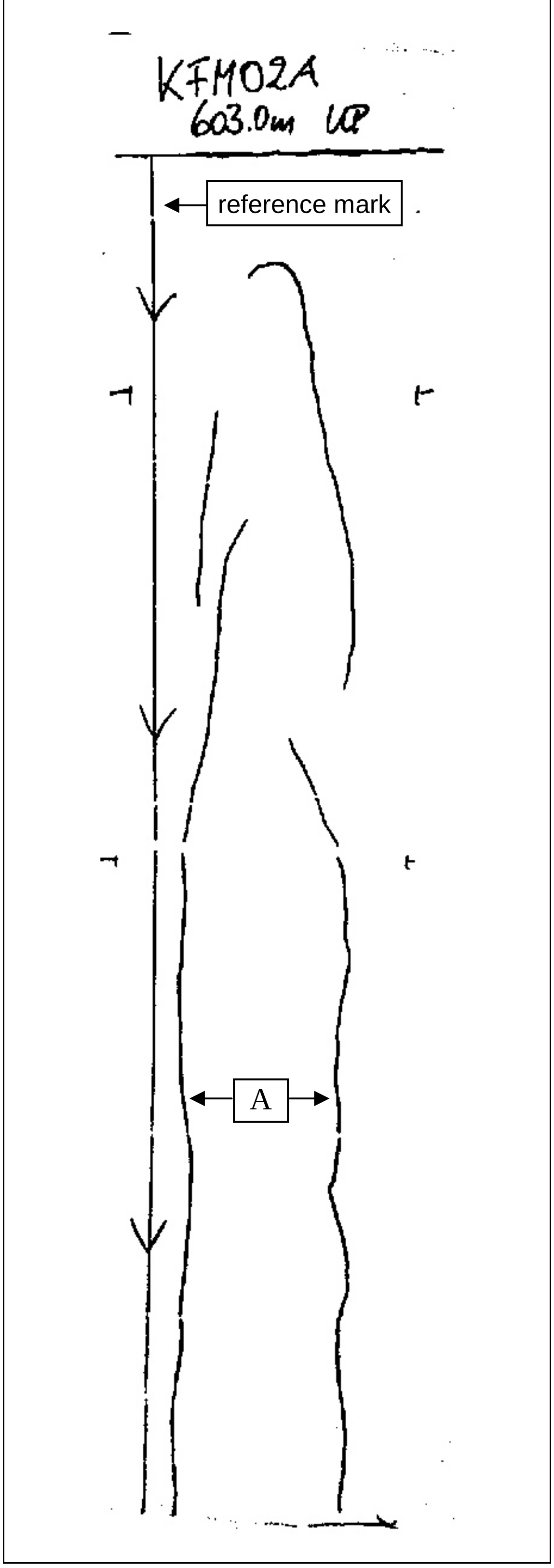
Test at 553.2 m MD / 551.12 m TVD

borehole dip / direction: 6° / N 301°
angle from vertical to ref. mark: -40°

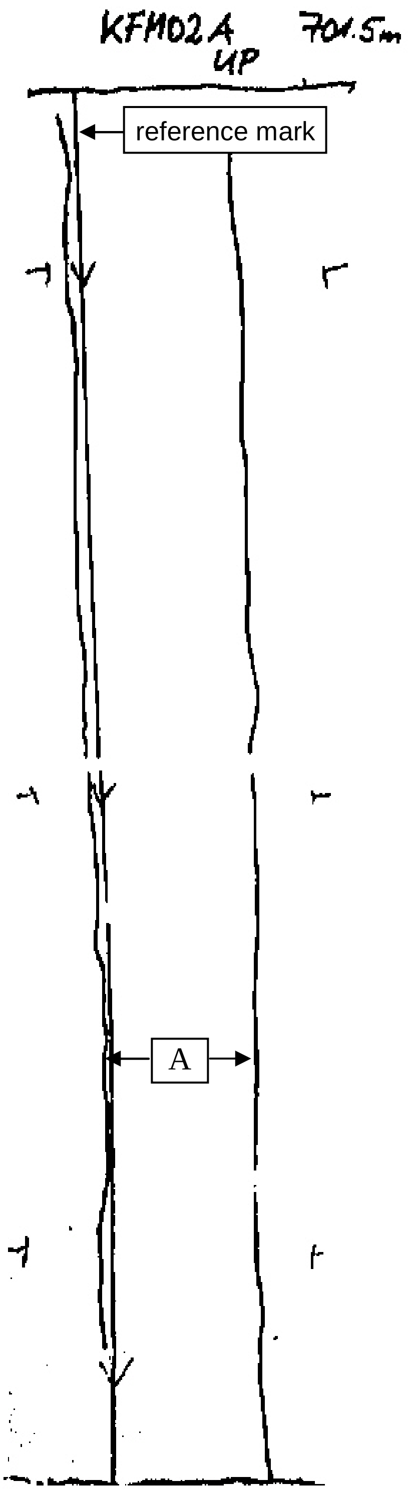


Test at 603.0 m MD / 600.58 m TVD

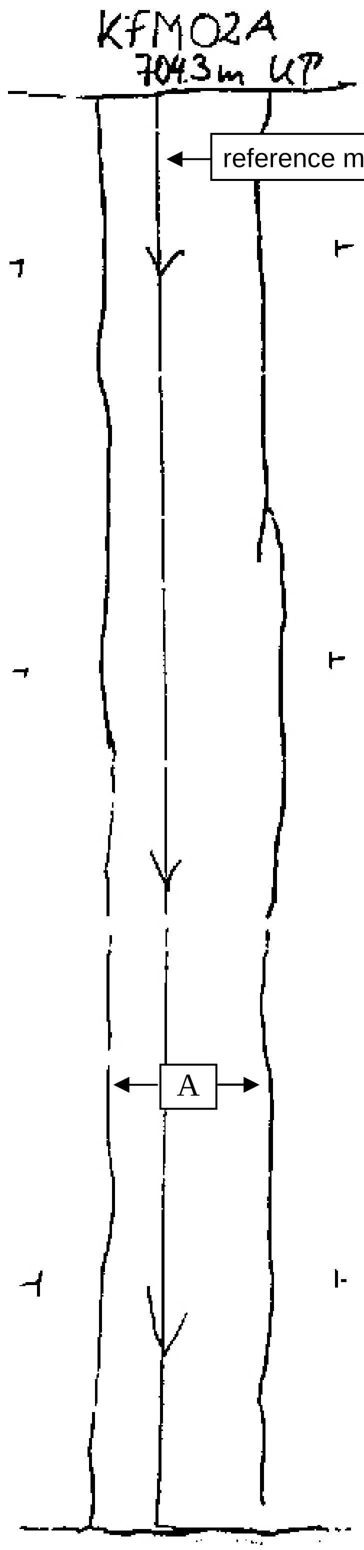
borehole dip / direction: 7° / N 305°
angle from vertical to ref. mark: -134°



Test at 701.5 m MD / 698.30 m TVD
borehole dip / direction: 7° / N 306° angle from vertical to ref. mark: 2°

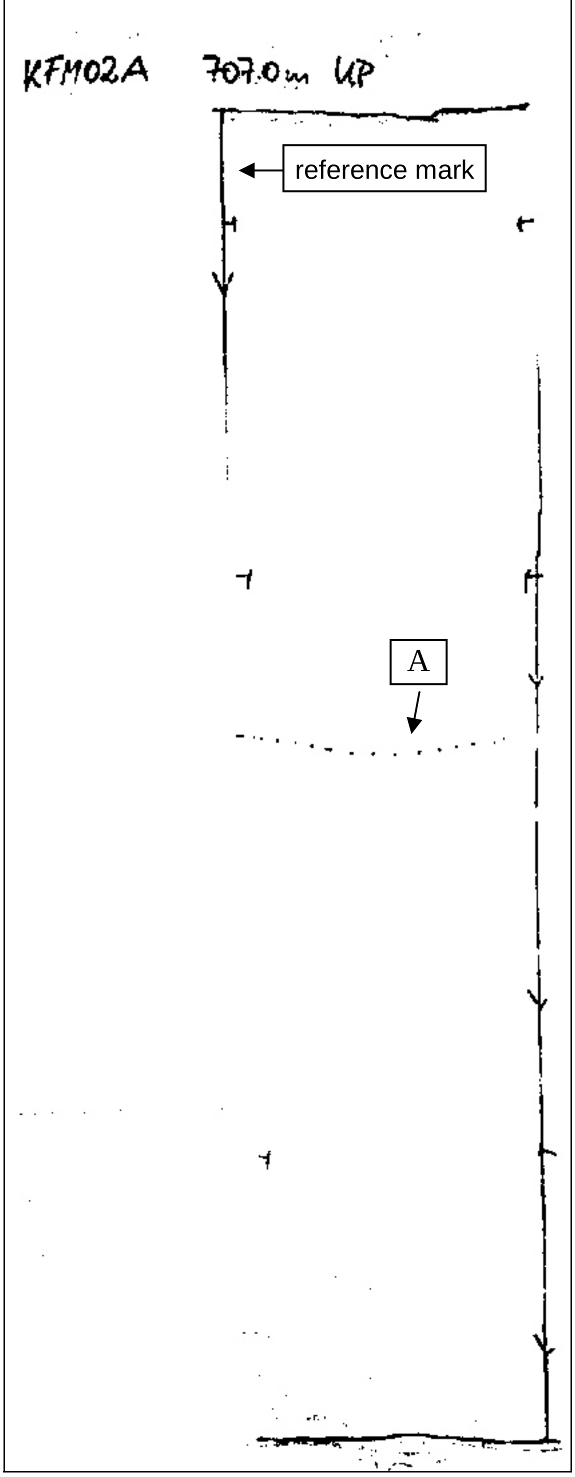


Test at 704.3 m MD / 701.08 m TVD
borehole dip / direction: 7° / N 306° angle from vertical to ref. mark: 130°



Test at 707.0 m MD / 703.75 m TVD

borehole dip / direction: 7° / N 306°
angle from vertical to ref. mark: -99°

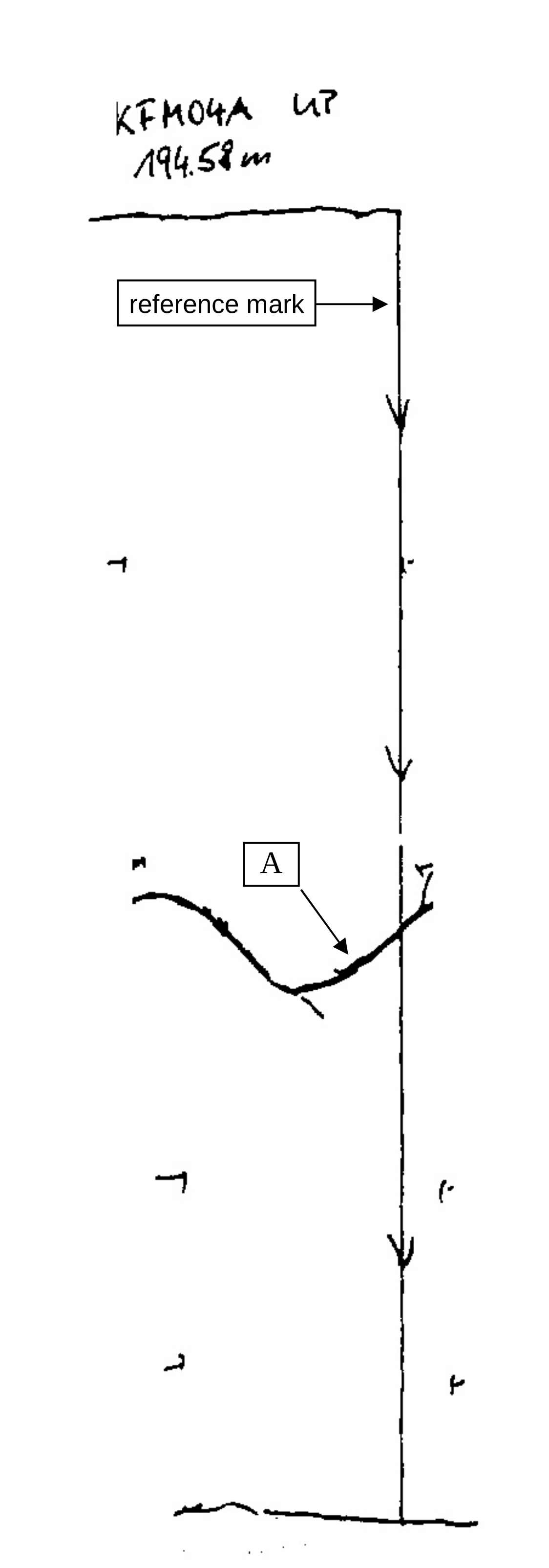


Appendix C4

Fracture Traces obtained from Impression Packer Testing
Borehole No. KFM04A

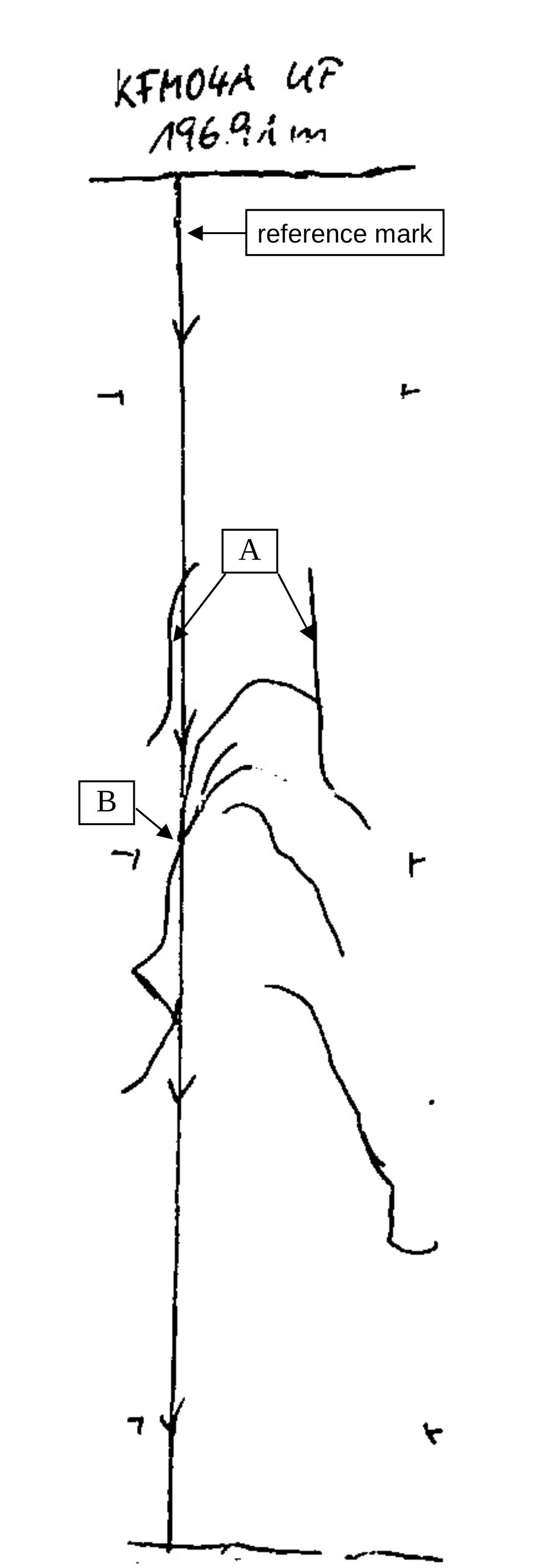
Test at 194.58 m MD / 171.43 m TVD

borehole dip / direction: 29° / N 44°
angle from vertical to ref. mark: -110°



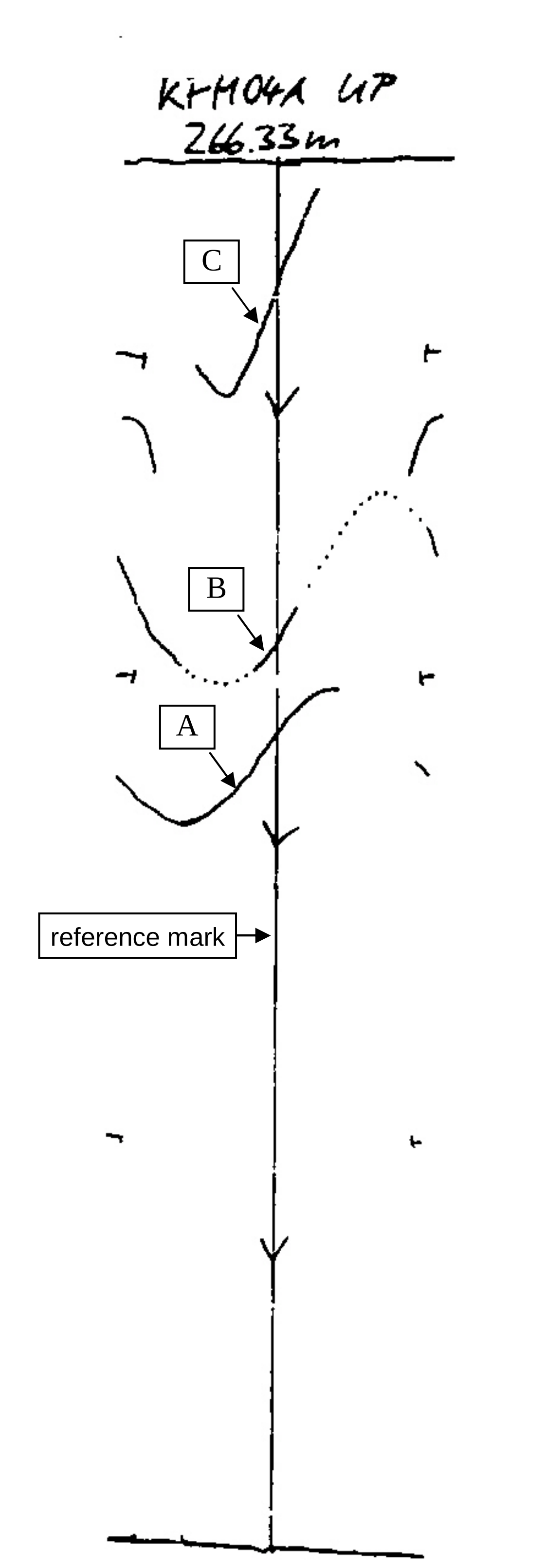
Test at 196.91 m MD / 173.47 m TVD

borehole dip / direction: 29° / N 44°
angle from vertical to ref. mark: -120°



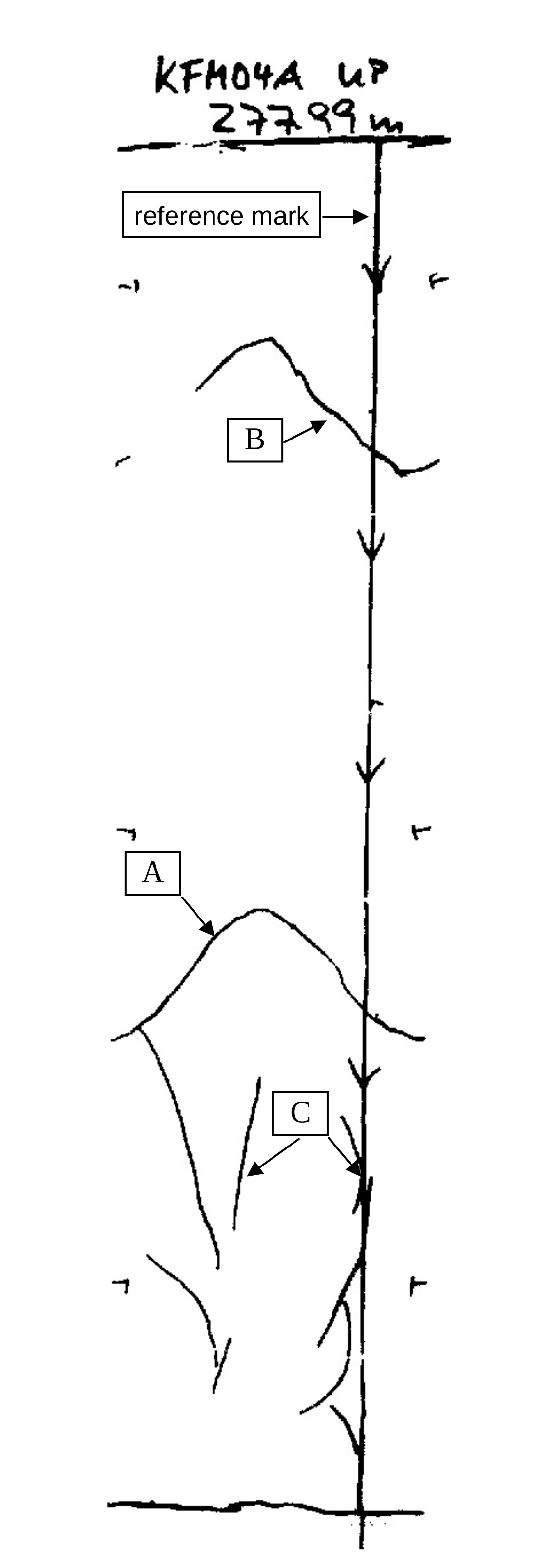
Test at 266.33 m MD / 233.61 m TVD

borehole dip / direction: 30° / N 44°
angle from vertical to ref. mark: -120°



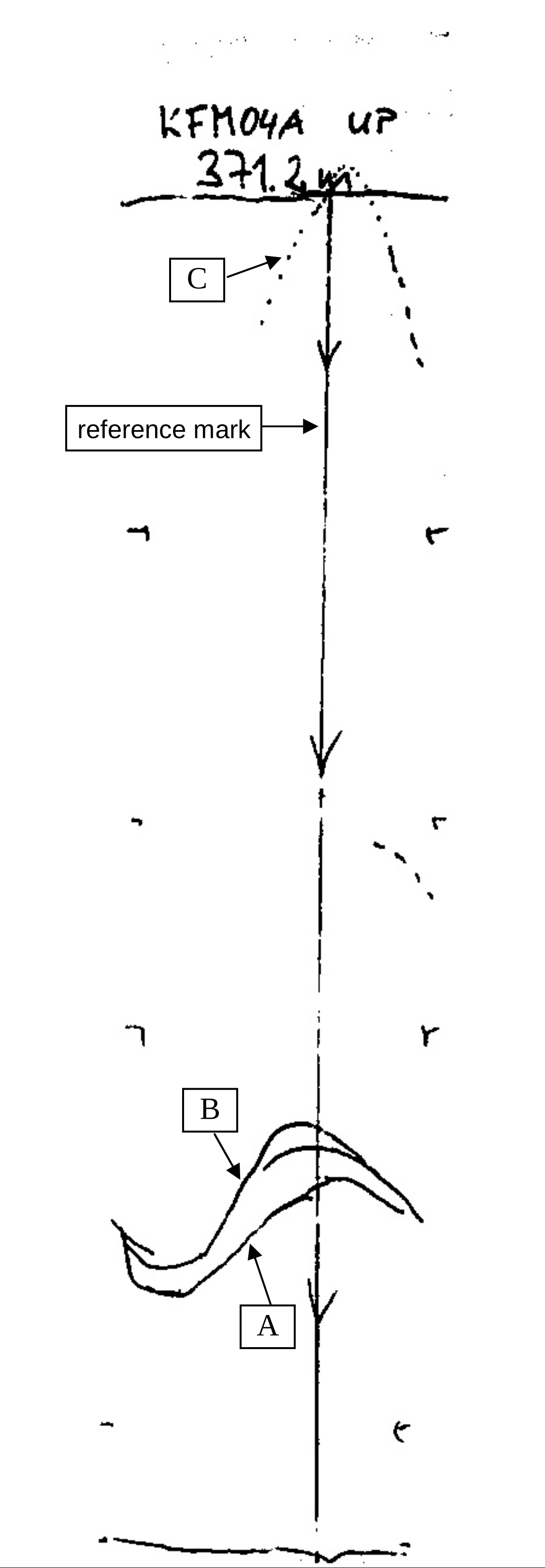
Test at 277.99 m MD / 243.63 m TVD

borehole dip / direction: 30° / N 44°
angle from vertical to ref. mark: -120°



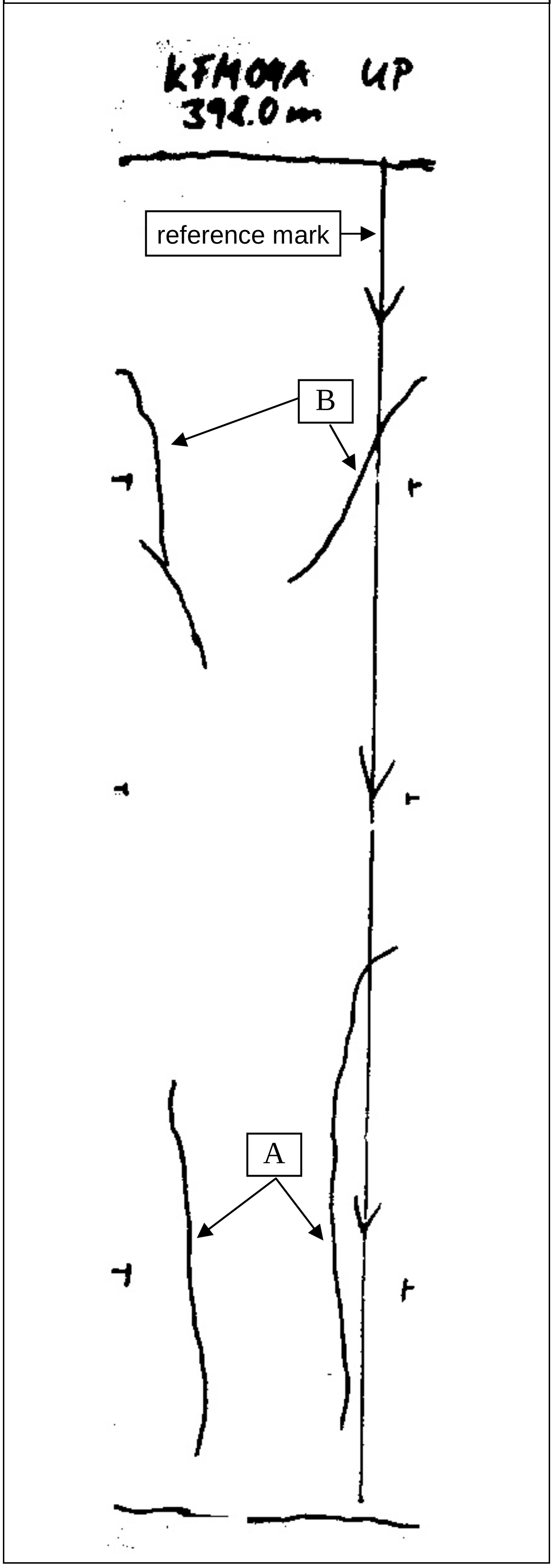
Test at 371.2 m MD / 322.95 m TVD

borehole dip / direction: 32° / N 42°
angle from vertical to ref. mark: -155°



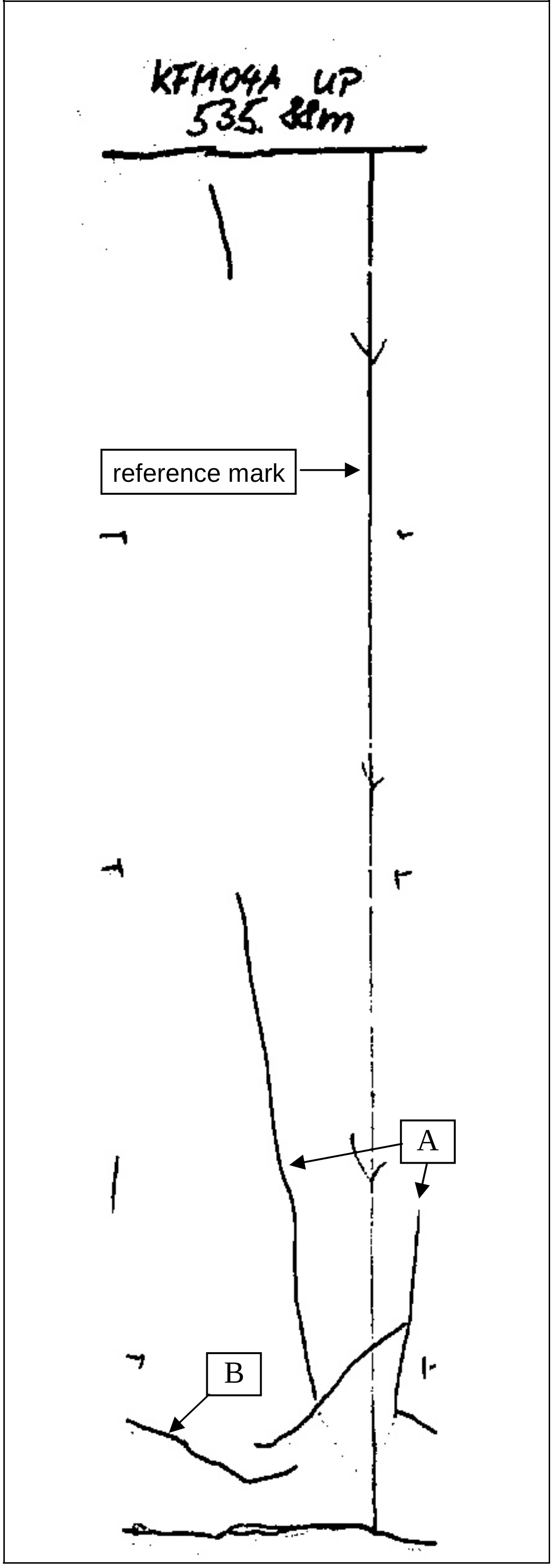
Test at 398.0 m MD / 345.30 m TVD

borehole dip / direction: 33° / N 42°
angle from vertical to ref. mark: -130°



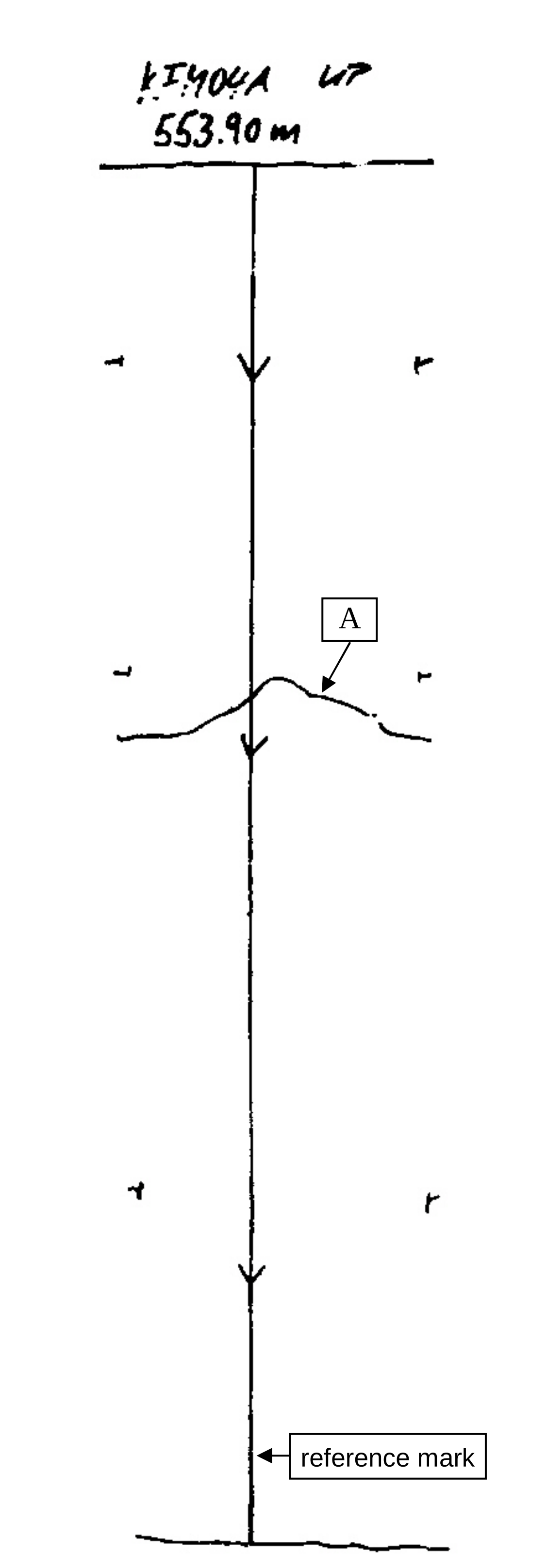
Test at 535.88 m MD / 457.03 m TVD

borehole dip / direction: 37° / N 43°
angle from vertical to ref. mark: -130°



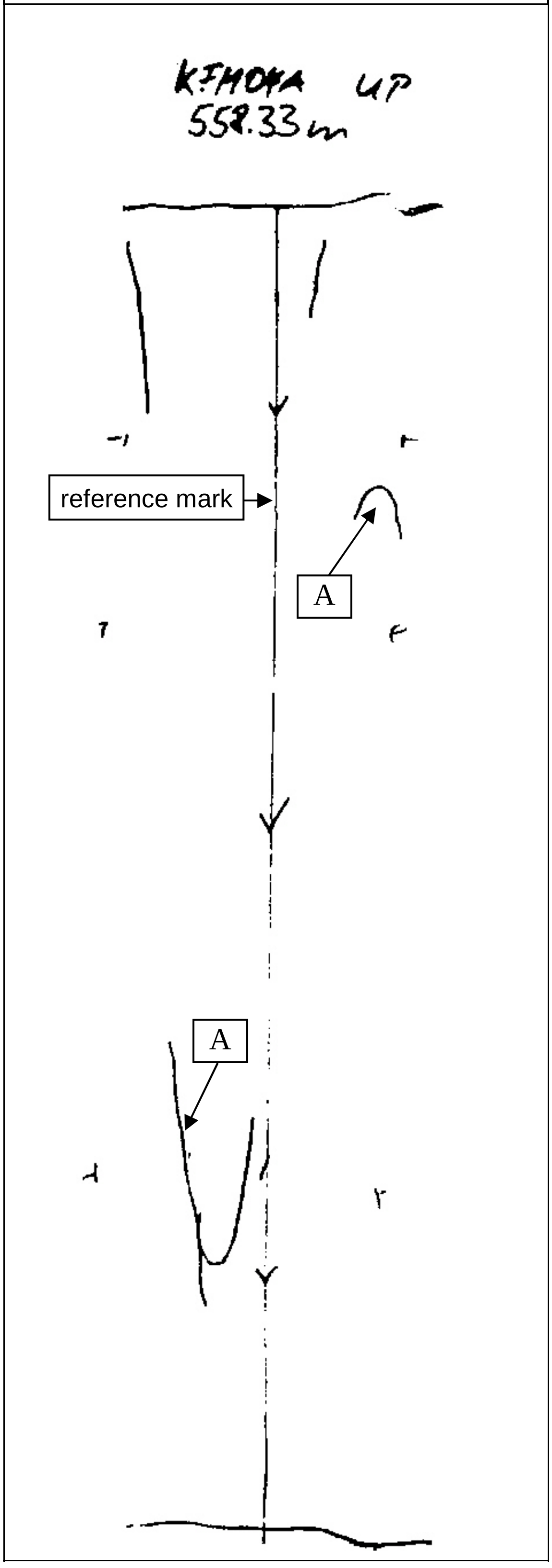
Test at 553.90 m MD / 471.44 m TVD

borehole dip / direction: 37° / N 43°
angle from vertical to ref. mark: -138°



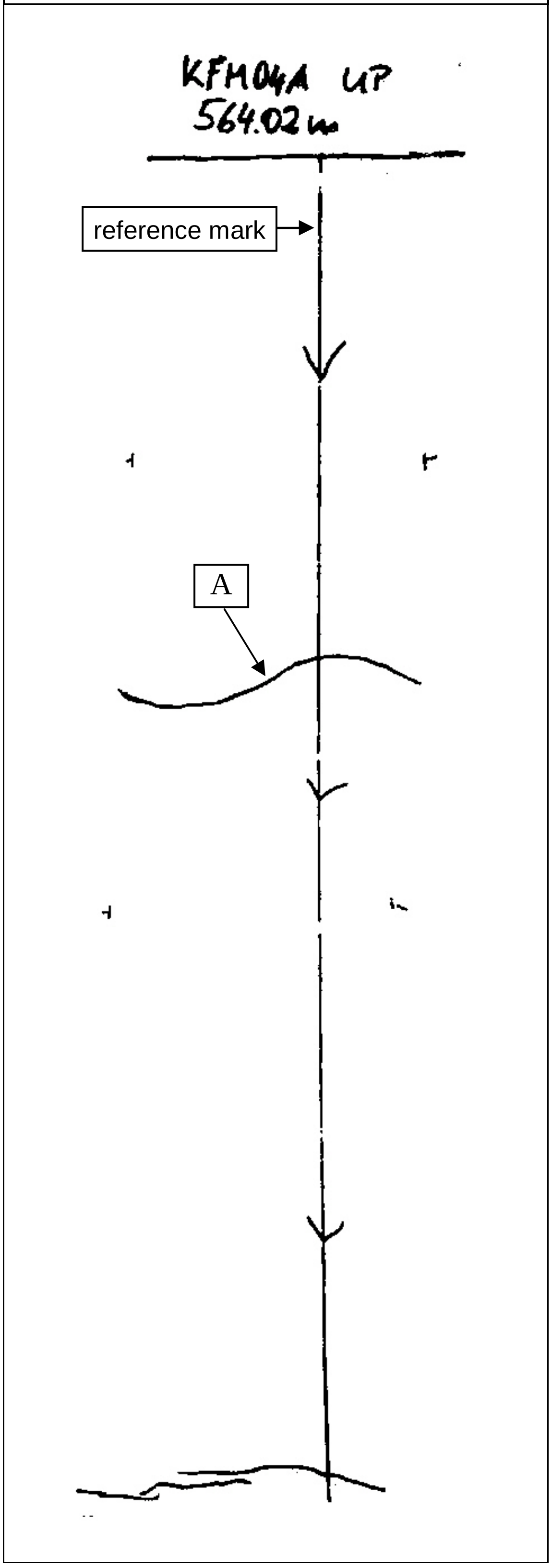
Test at 558.33 m MD / 474.84 m TVD

borehole dip / direction: 37° / N 42°
angle from vertical to ref. mark: -140°



Test at 564.02 m MD / 479.34 m TVD

borehole dip / direction: 37° / N 42°
angle from vertical to ref. mark: -155°



Test at 593.93 m MD / 502.91 m TVD

borehole dip / direction: 38° / N 43°
angle from vertical to ref. mark: -165°