GEO-Meß-Systeme MeSy GmbH

MESY GmbH · Meesmannstraße 49 · D-44807 Bochum · FRG

BOREHOLE TESTING
HYDROFRACTURING
STRESS MEASUREMENTS
System Design · Planning
Lab + Field Measurements

CBM - Project Sigillaria License Area

OPEN - HOLE PERMEABILITY AND HYDROFRAC STRESS MEASUREMENTS IN BOREHOLE RIETH - 1

Final Report

Client	:	CONOCO Mineralöl GmbH, Essen
Contract	:	Ref. - No. GCBM-04 dated 28.03.1995
MeSy - Quotation	:	113.06.94 dated 14.06.1994
		120.07.94 dated 20.07.1994
MeSy - Reporter	:	Dipl. Geophys. G. Klee
		Prof. Dr. F.Rummel
Report - Date	:	11.07.1995
Report - No.	:	27.95

Amtsgericht Bochum 14 HRB 2572
Geschäftsführer: Prof. Dr. F. Rummel

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CONTENT

APPENDIX

SUMMARY

As a part of the site investigation program for the CBM - project Sigillaria License Area within the Ruhr - Carboniferous, two open - hole hydrofrac stress - and permeability tests were conducted in borehole Rieth-1 near Drensteinfurt, Germany. Testing was performed by using the MeSy wireline technology and the MeSy hydrofrac straddle packer system PERFRAC VIII.

The planned test program included up to 9 stress and permeability tests in the Cretaceous and the Carboniferous formation as well as 3 injection / fall - off and stress tests on representative coal seams of the coal - bearing formation. Due to borehole collapse within the Cretaceous during testing in the Carboniferous, only two tests could successfully be completed at 1694 m and 1705 m depth. The results can be summarized as follows:

(i) Rock mass permeability derived from pressure pulse testing is about 6 µDarcy, a typical value for the tight shales of the Ruhr - Carboniferous.

(ii) The stress analysis on the basis of the HUBBERT and WILLIS [1957] approach yield mean horizontal stresses of S_h = 26.2 MPa and S_H = 54.35 MPa at about 1696 m TVD, in comparison to 41.6 MPa for the vertical stress S_v, calculated for a mean overburden rock mass density of 2.5 g/cm^3. The observed horizontal stress magnitudes, normalized with respect to S_v, are in agreement with stress data derived from hydrofrac - tests in coal - mines within the Ruhr - Carboniferous.

1. INTRODUCTION

Borehole Rieth-1 is the first borehole in the Sigillaria License Area in the Ruhr - Carboniferous to investigate the coal bed methane (CBM) recovery potential from the Ruhr coal bearing rock formations. Therefore a series of hydrofrac stress and hydraulic permeability tests was planned for the open - hole section of the borehole. The tests should provide first local information on the magnitudes and gradients of principle stresses, the in - situ rock strength as well as in - situ rock permeability data of the coal seams and the coal bearing rock. Due to borehole collapse in the Cretaceous during testing in the Carboniferous bottom section of the borehole, only two open - hole borehole sections tests could be tested at 1694 m and 1705 m depth. The results obtained from these two tests are presented in this report.

2. TECHNICAL BOREHOLE DATA

Borehole Rieth-1 is located about 22 km south of Münster / app. 4 km south- west of Drensteinfurt, NRW, Germany (geogr. coordinates: N 51.772°, E 7.707°). The borehole location is shown in Figure 2.1, technical borehole data are given in Table 2.1.

The borehole was rotary drilled with an open - hole diameter of 8-½" / 216 mm to a final depth of 1736 m. No core samples were recovered. The lithology below the Cretaceous between app. 1008 m and 1736 m consists of alternating sandstones, shales and coal seams.

Prior to hydrofracturing, a geophysical logging program was carried out by WESTERN ATLAS WIRELINE SERVICES. The caliper - log showed considerable washouts / enlargements down to app. 1450 m depth with only some few section suitable for open - hole packer testing.

Figure 2.1 : Location of borehole Rieth-1.

Table 2.1 : Technical data of borehole Rieth-1.

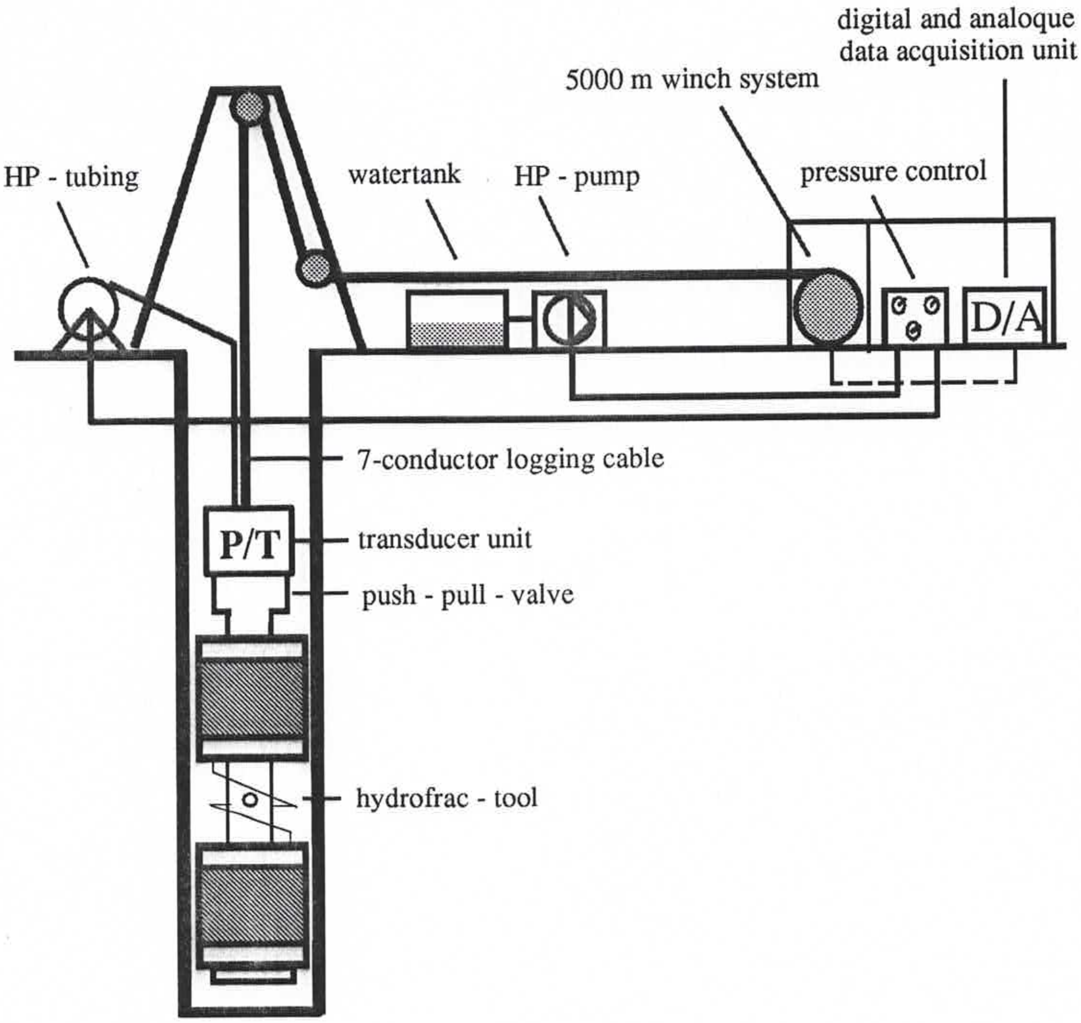
location	about 4 km SW of Drensteinfurt, NRW, Germany	
borehole	Rieth - 1	
Gauß-Krüger-coordinates	RW : 3410748	HW : 5738176
geogr. coordinates	N 51.772°	E 7.707°
altitude a.m.s.l.	67.5 m	
borehole depth	1736 m	
borehole diameter (open-hole section)	8-½" / 216 mm	
casing	0 - 346 m	
casing diameter	9-5/8" 43.5 ppfK - 55 BTC, drift ID 8.6"	
borehole fluid	KCl - water	
borehole fluid density	1.08 g/cm^3	
drilling contractor	Bohrgesellschaft Rhein -Ruhr	

3. TEST - EQUIPMENT

The hydrofrac tests in borehole Rieth-1 were carried out using the MeSy wireline technology, where the straddle packer tool is moved within the borehole on a 7 - conductor logging cable (CAMESA type 7-J 46 RTZ, OD 15/32") by the MeSy winch system MKW 5000. The wireline hydraulic fracturing approach enables a much better pressure and fracture growth control due to its higher system stiffness and the possibility of downhole pressure recording. A schematic view of the system is given in Figure 3.1.

The straddle packer tool was the MeSy PERFRAC VIII system equipped with steel-net - reinforced inflatable packer elements type TAM 7" IE with a diameter of 178 mm and a sealing length of about 1.3 m. The length of the test interval between the two packers was about 2 m.

Figure 3.1 : Scheme of the MeSy wireline hydrofrac system.



The packer elements and the injection interval 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 the top of the packer assembly allows to switch from packer pressurization to injection into the test interval, and the reverse, by releasing or pulling the logging cable.

For pressurization of both, packer elements and the test interval a servo - 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 brine.

The transducer unit on top of the packer assembly contained a temperature transducer (0 - 211 °C) and three strain gauge type pressure transducers to monitor packer (0 - 100 MPa), interval (0 - 60 MPa) and annulus (0 - 40 MPa) pressure. Downhole values as well as surface flow - rate (UNIMESS flow - turbine, type QPT 04, 0 - 10 l/min) were recorded both analogue on a paper strip chart recorder (PHILIPS, type PM 8262, 2 channels, paper speed: 20 mm/min) and digitally (SILVI, 8 channels, 16 bit resolution) with a sampling frequency of 5 Hz.

4. TEST - PROGRAM AND TEST CONDUCTION

On the basis of the borehole logs available and the experience from hydraulic - and hydrofrac testing in the French CBM - project, CONOCO and MeSy together decided on the following test program:

- Conduction of 6 hydrofrac stress and permeability tests in the sandstone and shale formation by using a straddle packer tool with 2 m spacing between the packers (test depths: 1694.0 m, 1651.0 m, 1600.5 m, 1538.5 m, 1503.0 m and 1460.0 m).

- Conduction of 3 hydrofrac stress and permeability tests in the Cretaceous formation due to the borehole enlargements / washouts between 1000 m and 1450 m depth (test depths: 925.0 m, 832.0 m, 740.0 m)

- Conduction of 3 injection / fall - off and stress tests on representative coal - seams of the Carboniferous by using a straddle packer tool with 6 m spacing between the packers (test depths: 1719.0 m, 1674.5 m, 1660.0 m).

During the execution of the first test at 1694 m the borehole collapsed which did not allow to follow the planned test program. The problem was already described in the detailed Operation Report dated 15.05.1995 (APPENDIX A). It therefore was decided to conduct a second test at 1705 m depth (a deeper movement of the tool was not possible) and afterwards to break the safety joints of the logging cable and the coil tubing. Unfortunately, the subsequent fishing operation was not successful and the hydrofrac tool was lost in the borehole.

5. TEST ANALYSIS AND RESULTS

Overview plots of the two tests conducted are given in APPENDIX B. The data analysis was conducted from detailed plots given in APPENDIX C for permeability evaluation and APPENDIX D for stress evaluation.

5.1 ANALYSIS OF PRESSURE PULSE TESTS FOR PERMEABILITY EVALUATION

The estimation of the in - situ rock permeability was conducted by the analysis suggested by COOPER et al. [1967] for slug - tests. For the special conditions of the wireline hydrofrac - system MeSy developed the software code PERM, where theoretical and measured pressure decline curves are matched for a variety of input parameters such as system stiffness, storage coefficient and permeability by using an inversion procedure (master curve method). The result of the calculations is given as the mean of all successful models, which satisfy the L^1 - standard.

The permeability / transmissivity data derived from the pressure pulse tests (APPENDIX C) are summarized in Table 5.1. The permeability is about 6 μDarcy, the transmissivity is about 0.11 cm^2/s.

Table 5.1 : Results of pressure pulse tests for permeability / transmissivity estimation.

depth m	depth below surface TVD m	permeability μDarcy	transmissivity cm^2/s
1694.0	1690.8	6.4 ± 0.4	0.12 ± 0.008
1705.0	1701.8	5.6 ± 0.2	0.10 ± 0.003

5.2 HYDROFRAC - TEST ANALYSIS AND STRESS EVALUATION

The stress estimation is based on the "classical" HUBBERT and WILLIS [1957] method with the following simplified assumptions:

- the overburden stress $S_v = \rho g z$ is a principal stress and borehole deviations from vertical are negligible;
- the rock is homogenous and isotropic;
- the fracturing fluid does not penetrate into the rock prior to fracture initiation;
- the induced vertical fracture is oriented perpendicular with respect to the minimum horizontal stress S_h.

This results in to the following simple relations:

$$P_c = 3 S_h - S_H + P_{co} - P_o \quad (5.1)$$

$$P_{si} = S_h \quad (5.2)$$

$$P_{co} = P_c - P_r \quad (5.3)$$

with

P_c breakdown pressure at frac initiation
P_r fracture re-opening pressure
P_{si} shut-in pressure
P_{co} in-situ hydrofrac tensile strength
P_o pore pressure
S_h minimum horizontal stress
S_H maximum horizontal stress

Because the accuracy of hydrofrac stress analysis strongly depends on the correct interpretation of the pressure - time records obtained during the experiments, an extensive analysis program was used for the identification of the characteristic hydrofrac pressure values:

- The determination of the refrac pressure P_r is based on the analysis of the stiffness of the hydraulic system during the initial pumping cycle. Assuming a constant system stiffness, the pressure P linearly increases with the injected volume V. The opening of the fracture is then defined from the P vs V plot as the pressure deviation from linear.

- The shut - in pressure P_{si} is determined from the following three step procedure:

  A plot of pressure P vs injection flow - rate Q enables to determine the exact pressure value at which the hydraulic flow stops (Q = 0). Therefore the P vs Q plot yields a upper - bound estimate of the shut - in pressure.

  A Muskat - type plot yields the lower - bound of the shut - in pressure, assuming that the linear part of the plot characterizes radial flow, e.g. the stimulated fracture is nearly closed.

  Within these limits the shut - in pressure, which corresponds to the rock stress acting normal to 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.

The cross - plots used for the determination of the characteristic hydrofrac pressure values are presented in APPENDIX C, the data are listed in Table 5.2. Fracture re - opening was observed at pressures of 26.3 MPa at 1694 m depth and 22.4 MPa at 1705 m depth (although the pressure record at this depth shows about 1 min after the first opening a further pressure increase with a second opening event at 26.4 MPa, which is not fully understood yet). The shut - in pressure values vary between 26.75 MPa and 25.7 MPa. Both tests do not show a typical formation breakdown. Therefore the in - situ frac gradient and the in - situ tensile strength determination was not possible.

Table 5.2 : Refrac - pressure P_r and Shut - in pressure P_{si} derived from hydrofrac testing in borehole Rieth-1.

depth m	depth below surface TVD m	P_r MPa	P_{si} MPa
1694.0	1690.8	26.26	26.75
1705.0	1701.8	22.42-(26.40)	25.71

Neglecting the pore pressure, the resulting stress data according to eqs. 5.1 - 5.3 are given in Table 5.3. The vertical stress is calculated for a mean overburden rock mass density of 2.5 g/cm^3. The analysis yields mean horizontal stresses of S_h = 26.2 MPa and S_H = 54.35 MPa for a depth of 1696 m TVD.

Table 5.3 : Result of stress evaluation using the HUBBERT and WILLIS approach.

depth	depth below surface TVD	S_v (ρ = 2.5 g/cm^3)	S_h	S_H
m	m	MPa	MPa	MPa
1694.0	1690.8	41.47	26.75	53.99
1705.0	1701.8	41.74	25.71	54.71
mean	1696.3	41.60	26.23	54.35

The stress data yields the following stress gradients (calculated by assuming zero horizontal stresses at surface) and stress ratios (Tab. 5.4).

Table 5.4 : Stress gradients and stress ratios.

depth	depth below surface TVD	S_h / TVD	S_H / TVD	S_h / S_v	S_H / S_v
m	m	MPa/m	MPa/m		
1694.0	1690.8	0.0158	0.0319	0.65	1.30
1705.0	1701.8	0.0151	0.0321	0.62	1.31
mean	1696.3	0.0155	0.0320	0.63	1.31

6. DISCUSSION OF RESULTS

(i) Due to the borehole collapse, the open - hole tests in borehole Rieth-1 were not as successful as expected. Only two permeability and stress tests could be carried out at 1694 m and 1705 m depth.

(ii) The observed rock mass permeability of 6 μDarcy characterizes the tight shales within the coal - bearings. Similar permeability values were observed in coal - mines of the Ruhr - Carboniferous and in the French Carboniferous [MeSy REPORT NO. 28.94, 1994 and NO. 08.95, 1995].

(iii) Both tests do not show a typical formation breakdown. The classical HUBBERT and WILLIS approach yields in - situ horizontal stresses of S_h = 26.2 MPa and S_H = 54.35 MPa at about 1696 m TVD, in comparison to 41.6 MPa for the vertical stress S_v. Although the data base of only two tests is limited, the observed stress data, normalized with respect to S_v, are in agreement with the results of extensive in - mine hydrofrac stress measurements within the Ruhr - Carboniferous (Fig. 6.1, 6.2).

(iv) Further information about the magnitude of the minimum horizontal stress S_h will be derived from the analysis of the cased - hole tests conducted in borehole Rieth-1.

Figure 6.1 : Normalized stresses S_h / S_v as a function of depth derived from hydrofrac stress measurements in Germany [HYDROFRAC STRESS DATA BASE, 1994].

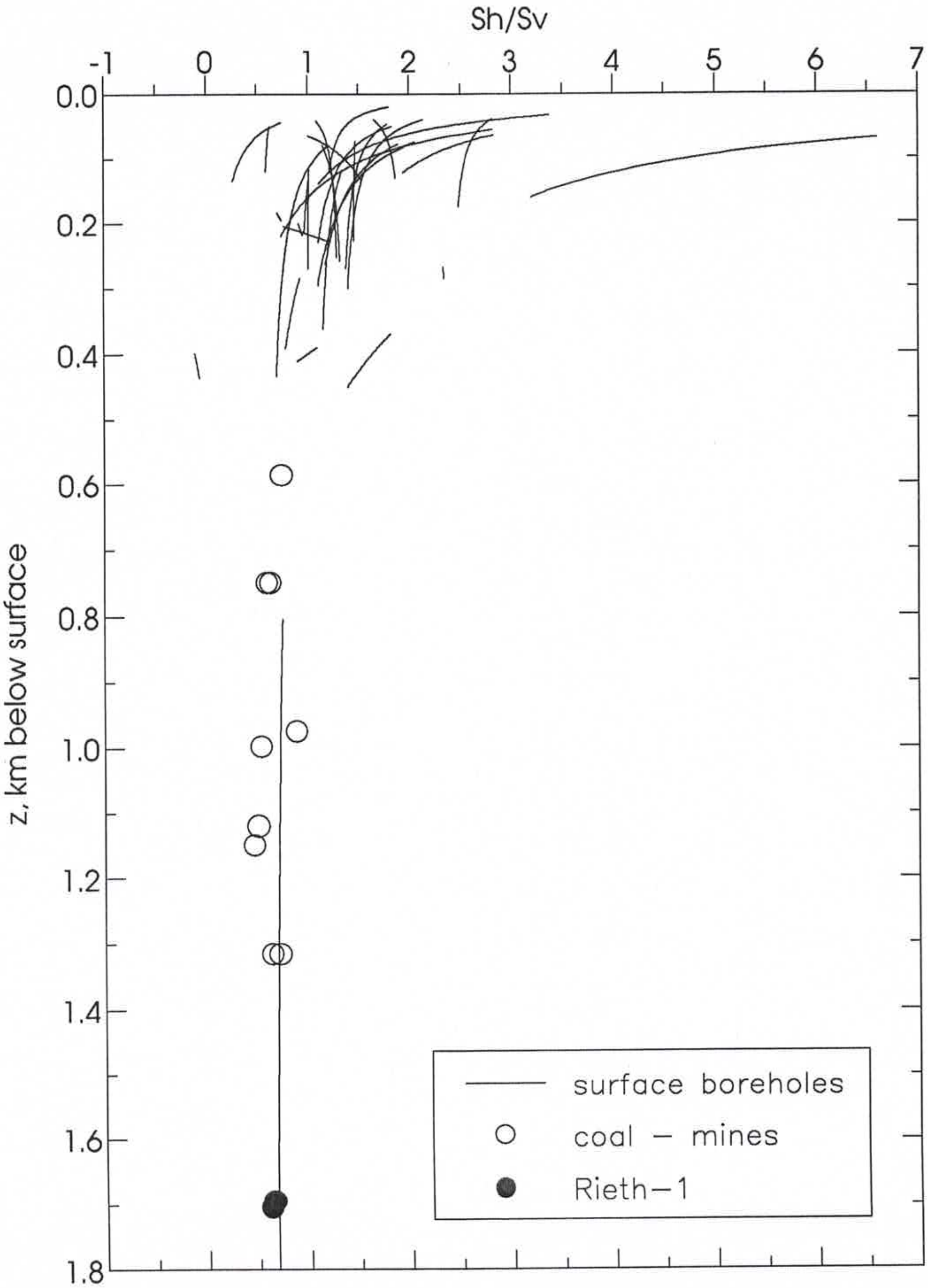
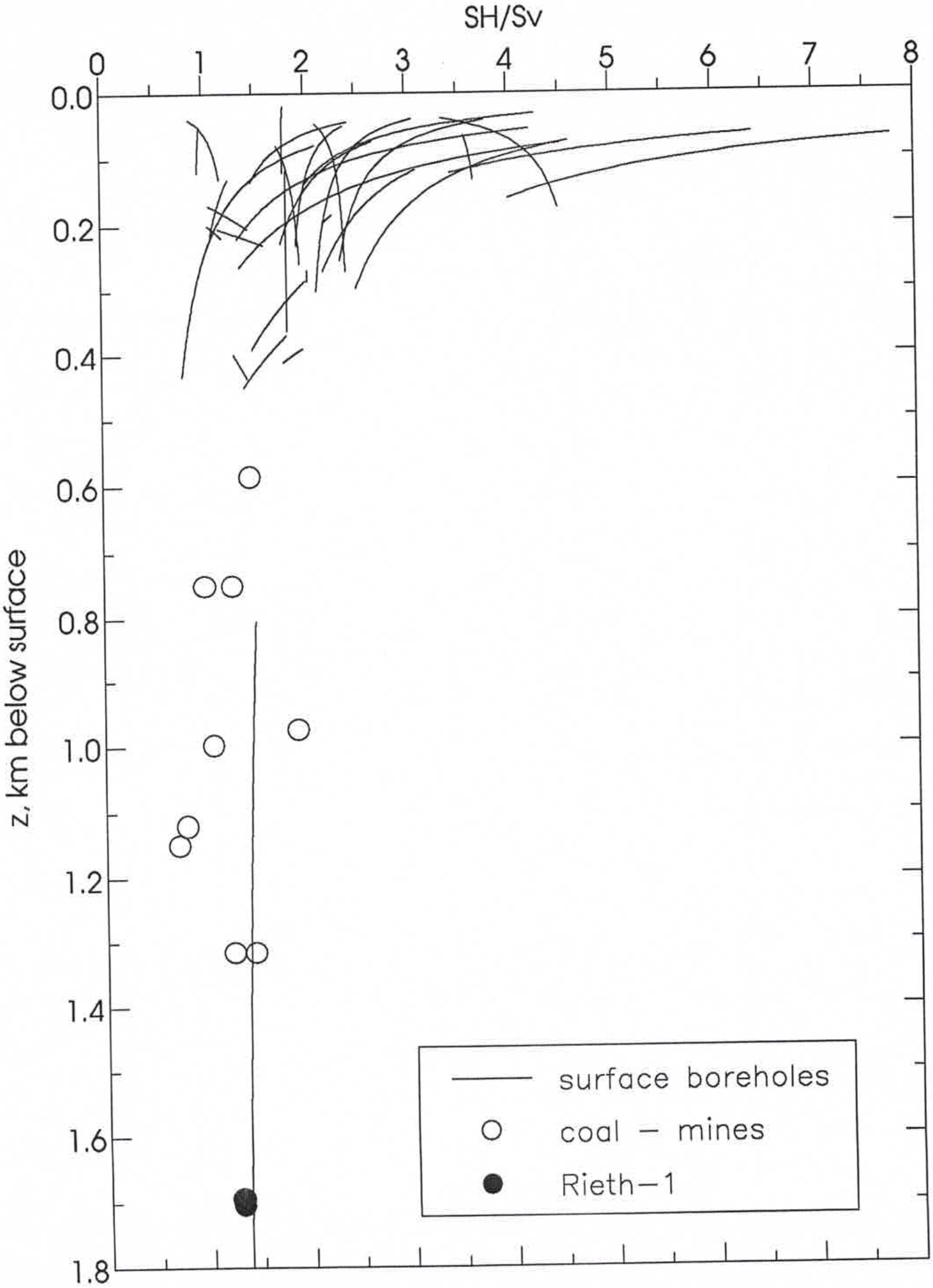


Figure 6.2 : Normalized stresses S_H / S_v as a function of depth derived from hydrofrac stress measurements in Germany [HYDROFRAC STRESS DATA BASE, 1994].



7. REFERENCES

COOPER, H.H., J.D. BREDEHOEFT and I.S. PAPADOPULUS (1967) : Response of a Finite Diameter Well to an Instantaneous Charge of Water. Water Resources Research, vol. 3, pp. 263 - 269.

HUBBERT, M.K. and D.K. WILLIS (1957) : Mechanics of Hydraulic Fracturing. Trans AIME, vol. 210, pp. 153 - 163.

HYDROFRAC STRESS DATA BASE (1994). *Institute of Geophysics, Ruhr - University Bochum.*

MeSy - REPORT (1994) : Compilation of existing hydrofrac in - situ stress data for the Ruhr - Carboniferous. Report - No. 28.94, 09.12.94.

MeSy - REPORT (1995) : Permeability and hydrofrac stress measurements in borehole Lorettes-1. Report - No. 08.95, 10.02.95.

8. ACKNOWLEDGEMENT

We appreciate the contract given by CONOCO Mineralöl GmbH, Essen. For constructive comments and participation during in - situ testing we are particularly grateful to Mr. K. Thomas (CONOCO, Essen) and Mr. P. Wilson (CONOCO, Houston).

Infrastructural information and assistance during in - situ testing were provided by the responsible drilling supervisors Mr. V. Hartong and Mr. L. van Zanten (CONOCO) and by the personnel of the drilling company Bohrgesellschaft Rhein - Ruhr.

The in - situ test were conducted by the MeSy personnel P. Hegemann, G. Klee, T. Przybilla, H. Vogt and U. Weber during 24 hours daily work periods.

APPENDIX A

Operation Report dated 15.05.95

GEO-Meß-Systeme GmbH

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BOREHOLE TESTING
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OPEN - HOLE PERMEABILITY AND HYDROFRAC STRESS MEASUREMENTS IN BOREHOLE RIETH-1

Operation Report

Client:	CONOCO Mineralöl GmbH, Essen
Contract:	Ref. - No. GCBM-04 dated 28.03.1995
MeSy-Quotation:	113.06.94 dated 14.06.1994 120.07.94 dated 20.07.1994
MeSy-Reporter:	Dipl.-Geophys. G.Klee
Date:	15.05.1995

Project:	CBM project Sigillaria License Area
Location:	about 4 km SW of Drensteinfurt, Germany
Borehole:	Rieth-1
Purpose:	open-hole permeability and hydrofrac stress measurements
Test-Period:	10.-11.05.1995
Participants:	Mr. K. Thomas (Conoco Essen) Mr. P. Wilson (Conoco Houston) Dipl. Ing. P.Hegemann (MeSy, partly) Dipl. Geophys. G. Klee (MeSy) Dipl. Geophys. T. Przybilla (MeSy) Prof. Dr. F.Rummel (MeSy, partly) Dipl. Ing. H.Vogt (MeSy) Dipl. Geophys. U.Weber (MeSy)

TIME TABLE OF TESTING

date	time	event
May 95		preparation of equipment
09.05.95		arrival of winch system MKW-5000 at Rieth drill-site
10.05.95	13.30-16.00	log-analysis for test-interval selection at MeSy-office (K.Thomas, P.Wilson, G.Klee)
	15.00	departure of MeSy engineers T.Przybilla and H.Vogt from Bochum
	16.30	arrival at drill-site
	16.45	departure of MeSy engineers P.Hegemann, G.Klee and U.Weber from Bochum
	17.45/18.00	arrival at drill-site
	16.45-21.50	set - up of winch, double-packer tool (2 m interval-length) and surface equipment
	20.15	problems with the power-supply, MeSy UPS damaged
	21.50	tool at zero-mark (middle of test-interval), venting of the hydraulic system
	22.12	start tripping into hole
	22.23-22.35	test of tool in the casing at 15 m depth
	23.30	departure of P.Hegemann
11.05.95	02.10	tool at 1710.0 m, cable load: 1.16 tons

date	time	event
11.05.95	02.10-02.17	upward movement, cable load: 1.67 tons
	02.17	tool at 1694.0 m
	02.20-03.48	**test 1 at 1694.0** [1] *pressure pulse tests and three refrac-cycles with 1.0, 3.5 and 5.0 l/min conducted*
	04.15	end of packer deflation, tool stuck at 1692.51 m, 2.0 tons
	04.15-07.00	several un-successful attempts to get the tool free (inflation of packer elements, circulation through pressure-release-valve, circulation through test-interval) - tool stuck not caused by hydraulic problems
	07.00	downward movement to at 1704 m, tool free (load: 1.2 tons), upward movement only to 1700 m possible with 3.0 tons
	08.30	situation information to Prof. Rummel
	09.30	decision by Conoco: attempt to move the tool stepwise deeper in order to carry out a possible break of the weak-point in the cable-head at the bottom of the well
	09.35	downward movement to 1706.0 m, 1.1 tons, upward movement to 1701.9 m possible with 3.0 tons
	09.48	downward movement to 1710.0 m, 0.8 tons (tool not free), upward movement to 1702.13 m possible with 3.0 tons
	10.00	downward movement to 1709.24 m, 0.88 tons, upward movement to 1702.09 m possible with 3.0 tons
	10.04	downward movement to 1709.24 m, 0.84 tons, upward movement to 1702.63 m possible with 3.0 tons
	10.08	downward movement to 1709.01 m, 1.0 tons, upward movement to 1702.67 m possible with 3.0 tons
	10.12	downward movement to 1709.0 m, 0.9 tons, upward movement to 1702.56 m possible with 3.0 tons
	10.16	downward movement to 1710.0 m, 0.85 tons

1 all depth marks were measured from rig floor (3.2 m above ground level) and corresponds to the middle of the test-interval

date	time	event
11.05.95	10.19-10.28	circulation of 50 l through test-interval
	10.30	upward movement to 1702.97 m, 3.0 tons
	10.31-11.16	short down- and upward movements, tool can be moved up to 1699.23 m with 3.0 tons
	11.20	downward movement to 1702.44 m, load increase from 1.1 to 1.4 tons
	11.21-12.21	short down- and upward movements, tool can be moved up to 1698.36 m with 3.0 tons
	12.26	downward movement to 1713 m, tool not free
	12.30	arrival of Prof. Rummel
	12.35	upward movement to 1702.70 m possible with 3.0 tons
	12.38	load increase to 3.2 tons
	13.53	upward movement to 1697.94 m possible
	13.58	load increase to 3.3 tons
	14.08	upward movement to 1697.62 m possible
	14.55	load increase to 3.4 tons
	15.00	upward movement to 1697.47 m possible
	15.10	downward movement to 1709.0 m, 0.52 tons
	15.15-15.30	circulation of 100 l through test-interval
	15.43	upward movement to 1701.98 m with 3.5 tons possible
	16.00-17.15	discussion about further procedure, decision: - circulation of 25 l through the test-interval - conduction of a test at present depth - break of weak-point within the cable-head
	17.00	arrival of MeSy-engineer P.Hegemann
	17.20-17.35	change of MeSy flowmeter
	17.40-17.45	circulation of 25 l through test-interval
	17.48	tool at 1705.0 m, 2.5 tons (overload to guarantee injection into the packer-elements)
	17.49-18.52	**test 2 at 1705.0** *pressure pulse test and three refrac-cycles with 0.9, 3.0 and 5.5 l/min conducted*
	18.55-19.06	safety meeting
	19.10-19.17	lowering of the upper turn-over wheel to about 2 m above rig-floor
	19.20-19.28	break of weak-point within the cable-head with 3.7 tons cable-load ***(top fish at about 1702 m)***
	19.30	start tripping out of hole

date	time	event
11.05.95	20.48	complete wireline, coil-tubing and all cable-clamps out of hole
	20.48-21.30	rig-down of the equipment
	21.45	departure from drill-site
	23.00	arrival in Bochum
12.05.95	07.00-13.30	participation of MeSy-engineer G.Klee on the first recovery of the fishing-tool preparation of a back-up PERFRAC VIII hydrofrac-tool at MeSy
13.05.95	11.30-14.30	participation of Prof. Rummel on the fishing-operation
15.05.95	13.00-15.45	maintenance of the hydrofrac-equipment at drill-site

Field Data Records

Overview - Plots
of Downhole Injection - and Packer Pressure
and Surface Injection - Flow - Rate Records
of Conducted Tests

upper window:

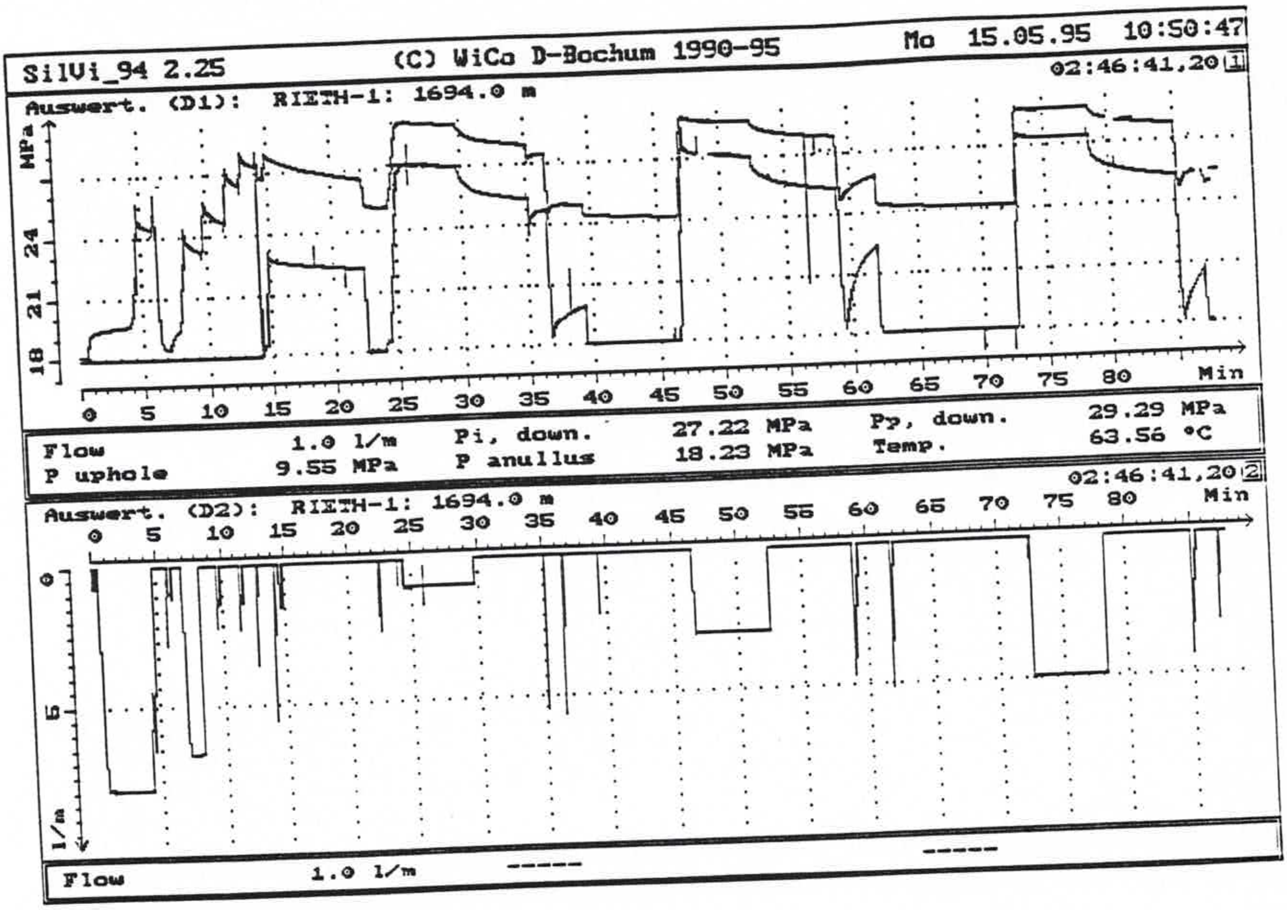
x - axis:	time, minutes
y - axis:	injection pressure (lower curve), MPa
	packer pressure (upper curve), MPa
+:	indicates maximum injection pressure

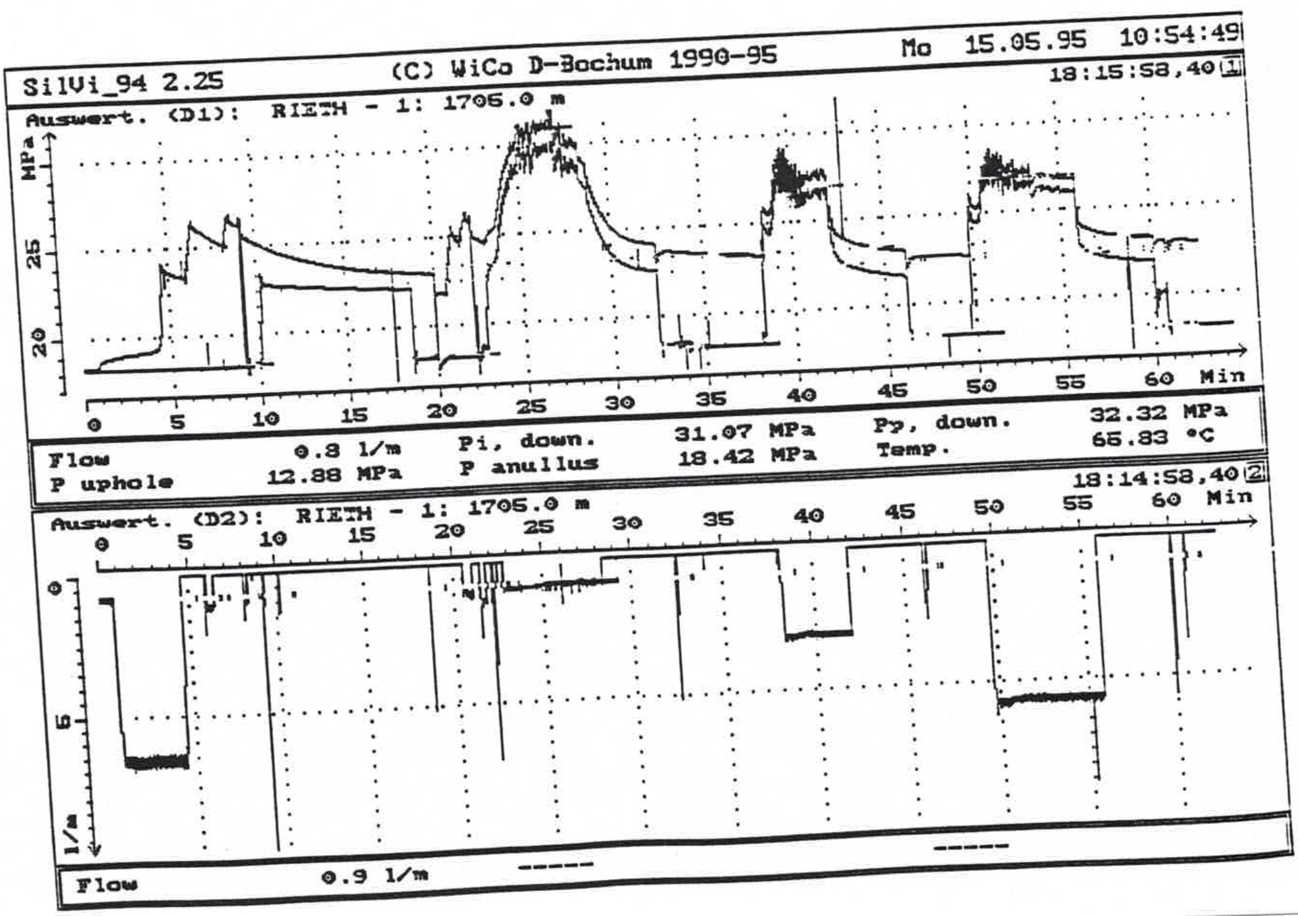
lower window:

x - axis:	time, minutes
y - axis:	injection flow-rate, l/min
+:	indicates flow-rate at maximum injection pressure

Flow:	surface injection flow-rate, l/min
$P_{i,\ down.}$:	downhole injection pressure, MPa
$P_{p,\ down.}$:	downhole packer pressure, MPa
P_{uphole}:	uphole pressure, MPa
$P_{annulus}$:	annulus pressure, MPa
$T_{emp.}$:	downhole temperature, °C

data corresponds to + - position (maximum injection pressure)


SilVi_94 2.25
(C) WiCo D-Bochum 1990-95
Mo 15.05.95 10:50:47
02:46:41,20 1
Auswert. (D1): RIETH-1: 1694.0 m
MPa
18
21
24
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 Min
Flow 1.0 l/m
P uphole 9.55 MPa
Pi, down. 27.22 MPa
P anullus 18.23 MPa
Py, down. 29.29 MPa
Temp. 63.56 °C
02:46:41,20 2
Auswert. (D2): RIETH-1: 1694.0 m
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 Min
0
5
l/m
Flow 1.0 l/m


SilVi_94 2.25
(C) WiCo D-Bochum 1990-95
Mo 15.05.95 10:54:49
18:15:58,40 1
Auswert. (D1): RIETH - 1: 1705.0 m
MPa
20
25
0 5 10 15 20 25 30 35 40 45 50 55 60 Min
Flow 0.8 l/m
P uphole 12.88 MPa
Pi, down. 31.07 MPa
P anullus 18.42 MPa
Py, down. 32.32 MPa
Temp. 65.83 °C
18:14:58,40 2
Auswert. (D2): RIETH - 1: 1705.0 m
0 5 10 15 20 25 30 35 40 45 50 55 60 Min
0
5
l/m
Flow 0.9 l/m

APPENDIX B

Overview - Plots of
Downhole Injection - and Packer Pressure
and Surface Flow - Rate Records
of Conducted Tests

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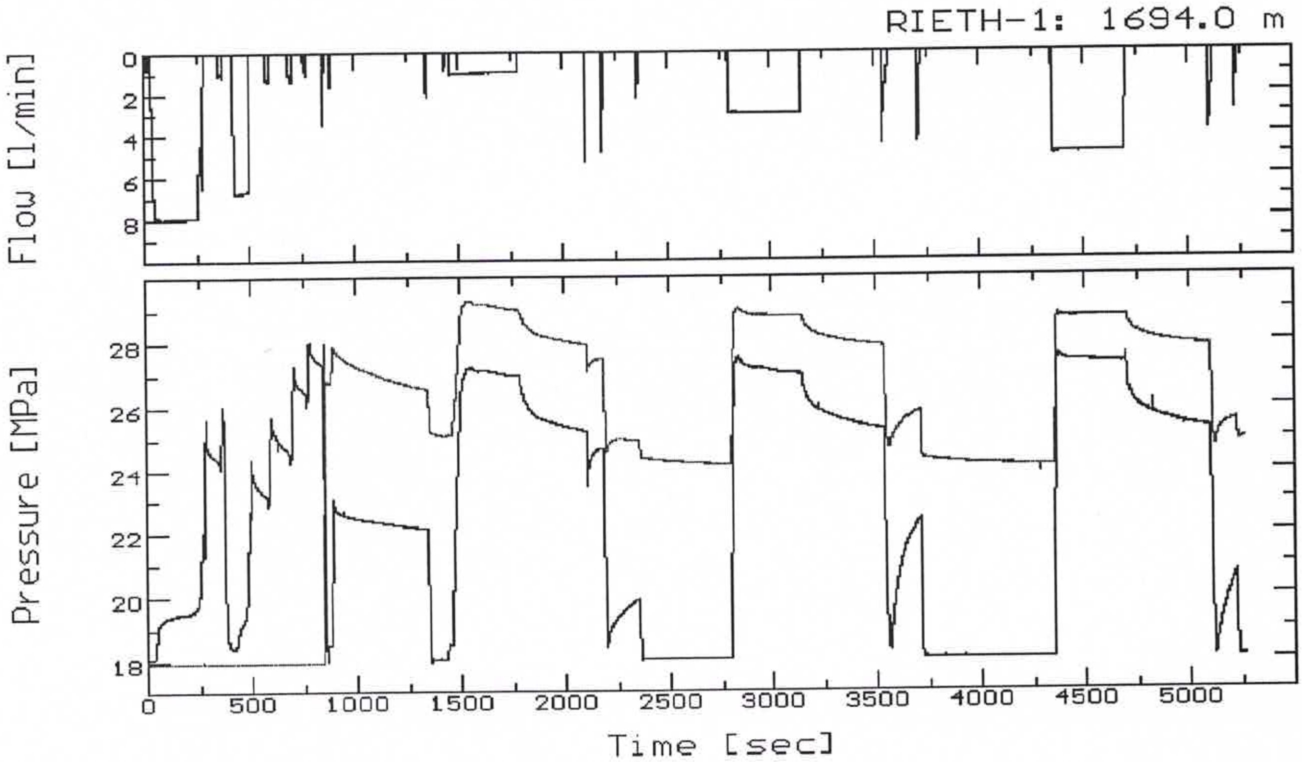
OPEN - HOLE TEST 1 AT 1694.0 m

Overview - Plot



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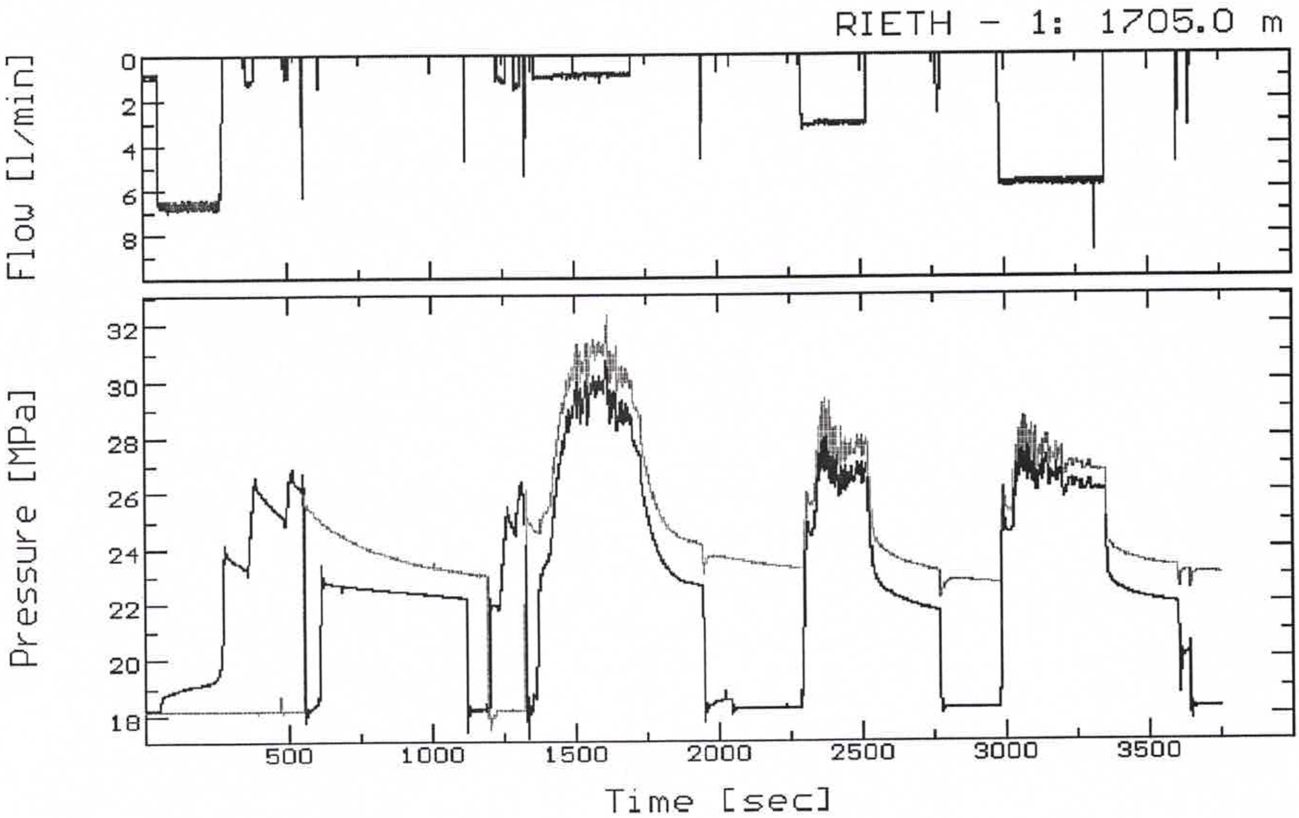
OPEN - HOLE TEST 2 AT 1705.0 m

Overview - Plot



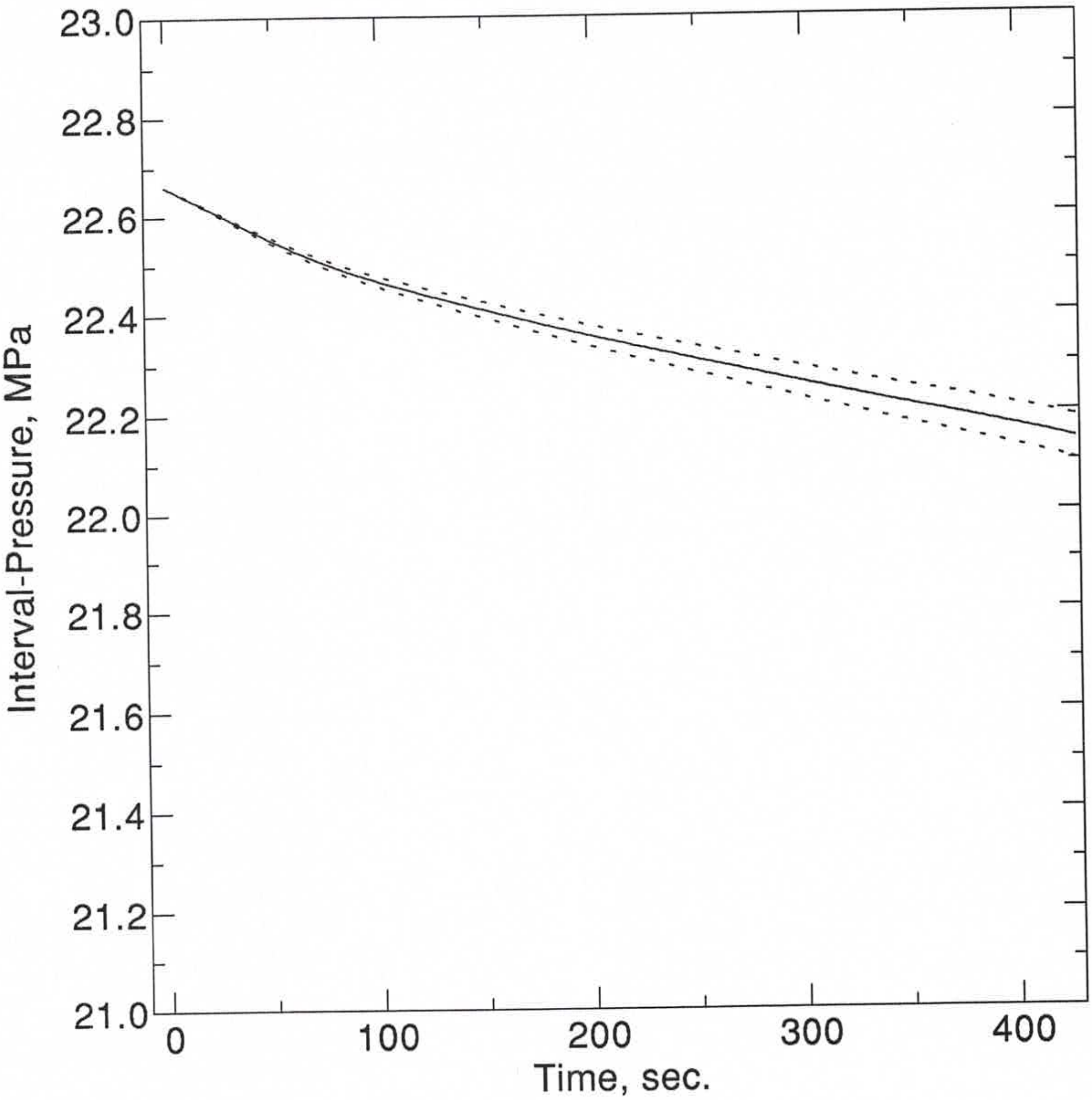
APPENDIX C

Analysis of Pressure Pulse Tests for Permeability / Transmissivity Evaluation

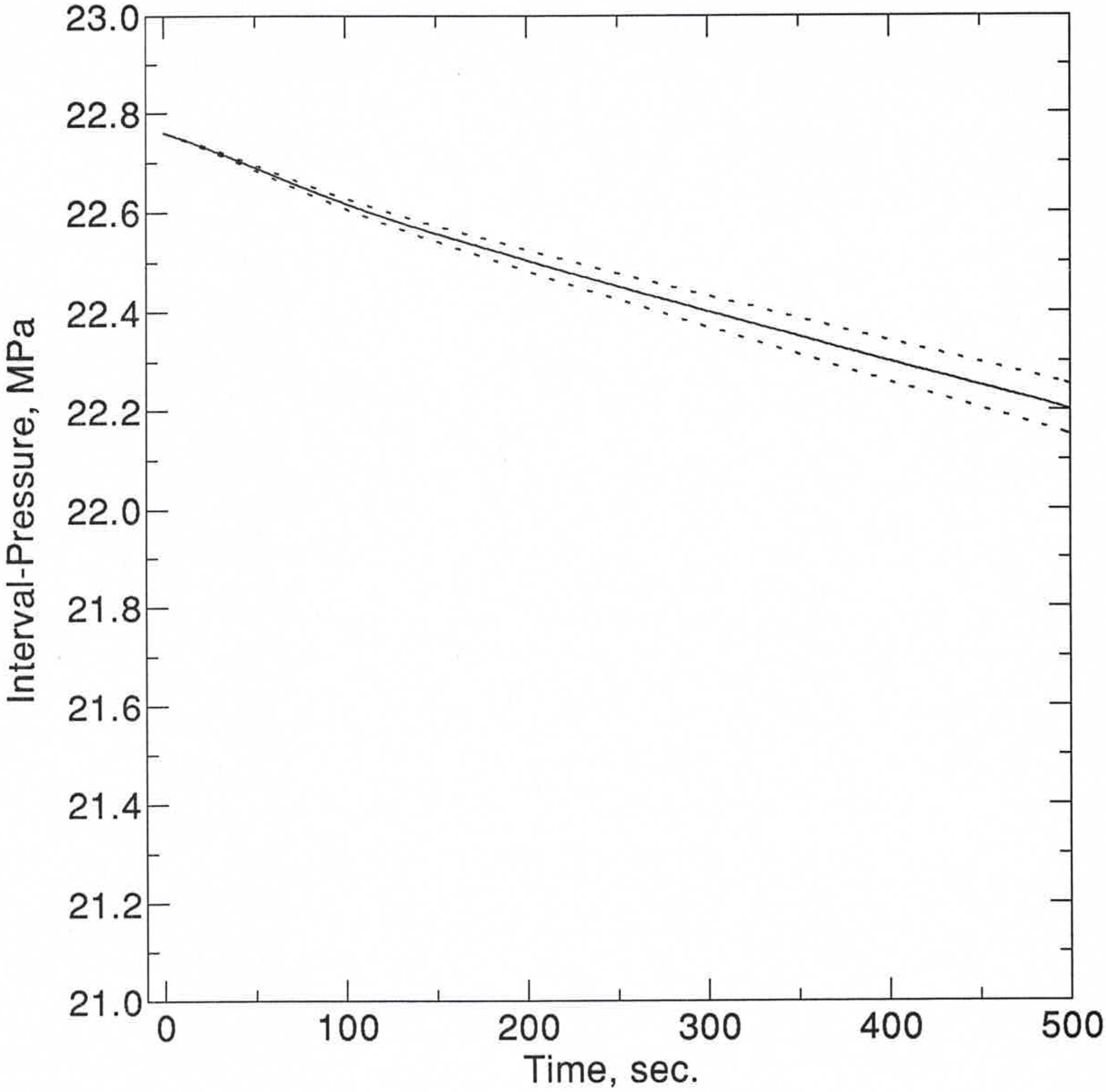
remarks :

- the solid line represents the measured data
- the broken lines represents the max. difference between measured and theoretically calculated pressure decline curves

Test 1: 1694.0 m



Test 2: 1705.0 m



APPENDIX D

Pressure Record Analysis
for Stress Estimation

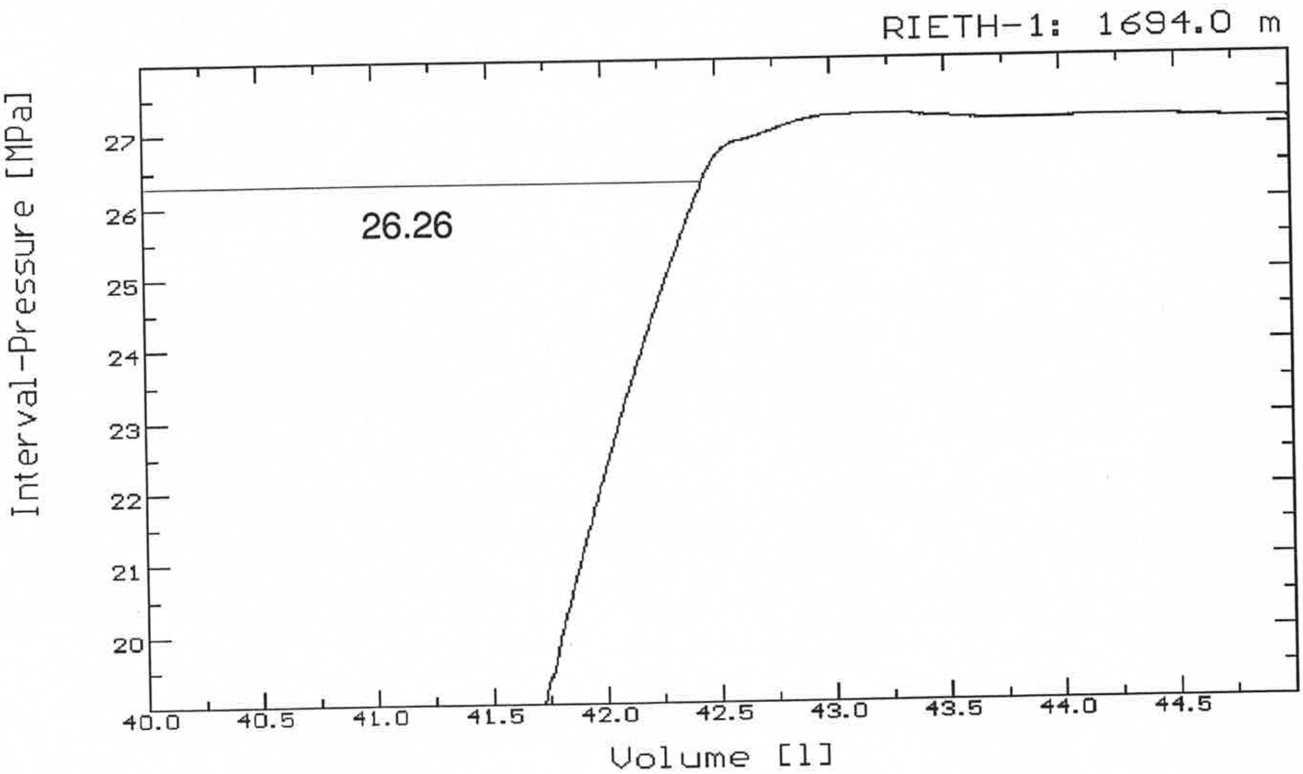
remarks :

for the tests at 1694.0 m and 1705.0 m the analysis contains:

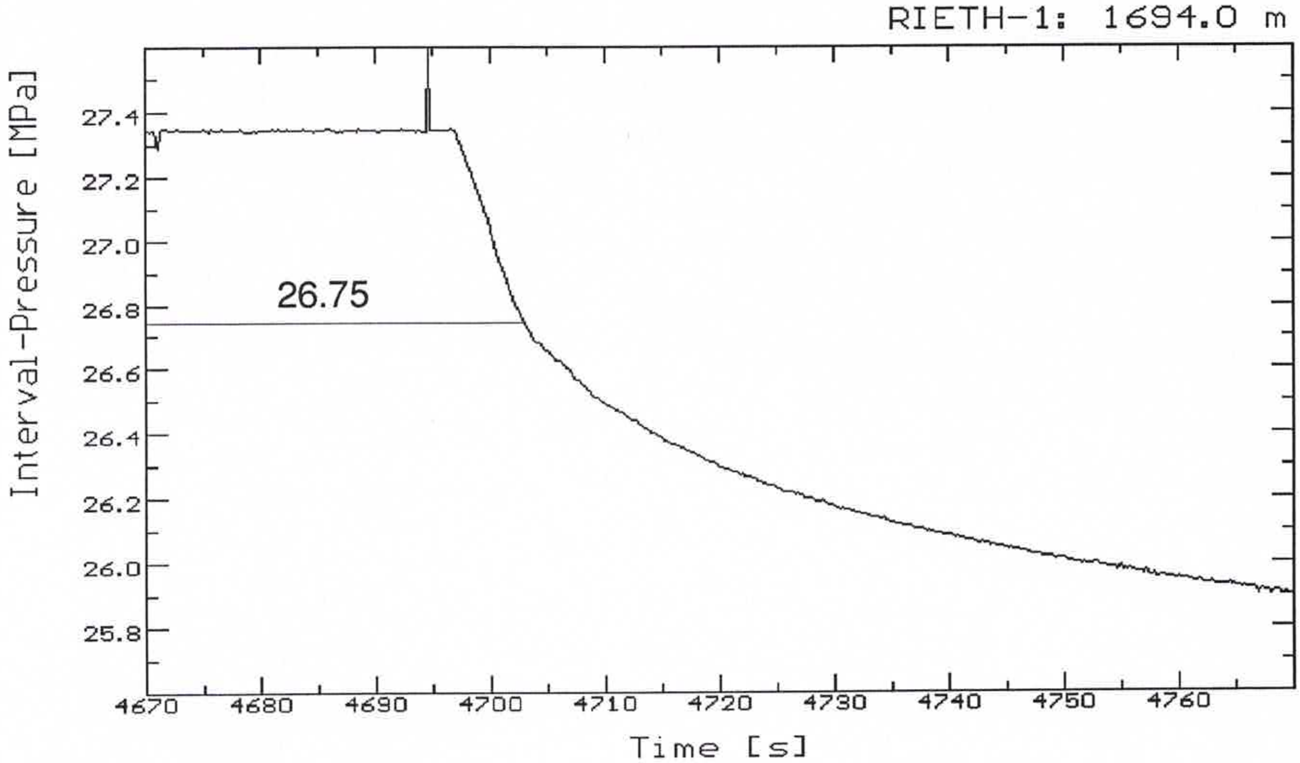
- a pressure vs volume plot for the determination of P_r
- several plots for the determination of P_{si}

OPEN - HOLE TEST 1 AT 1694.0 m

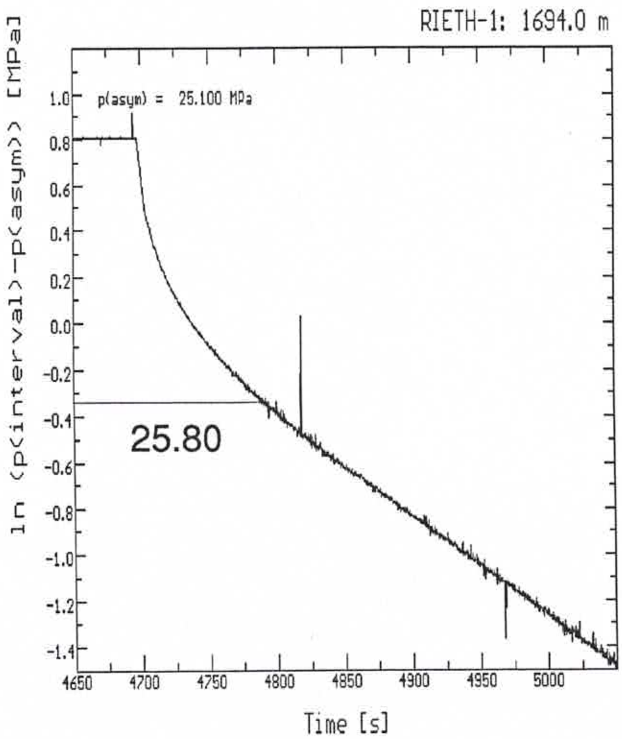
Estimation of Refrac-Pressure



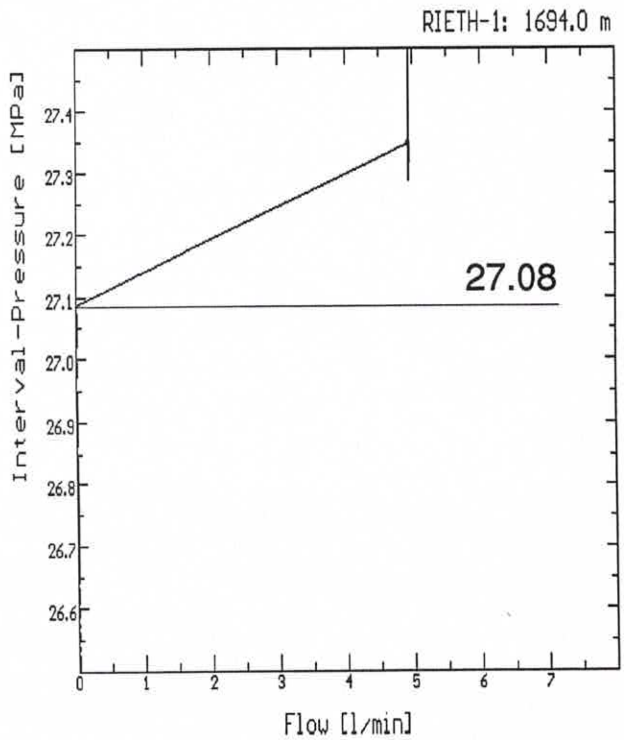
Estimation of Shut-In-Pressure P_{si}



Estimation of $P_{si,min}$



Estimation of $P_{si,max}$



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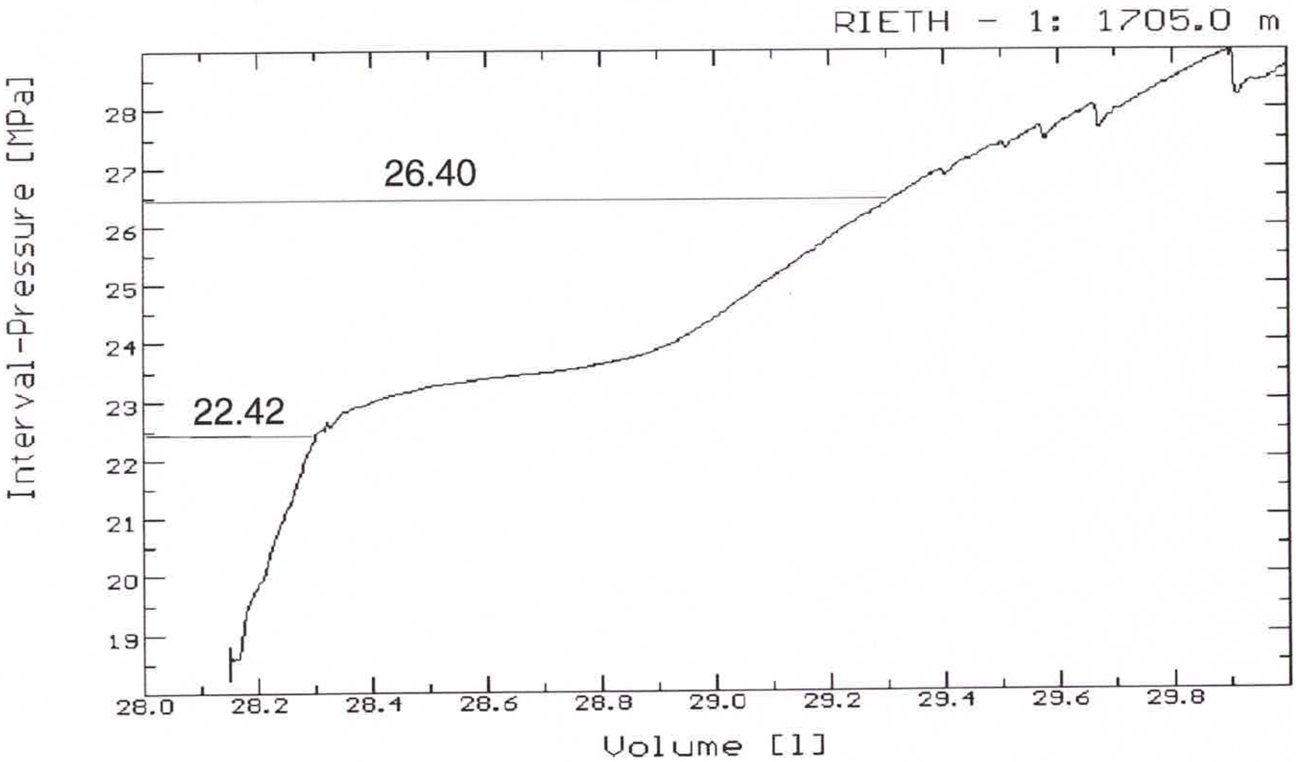
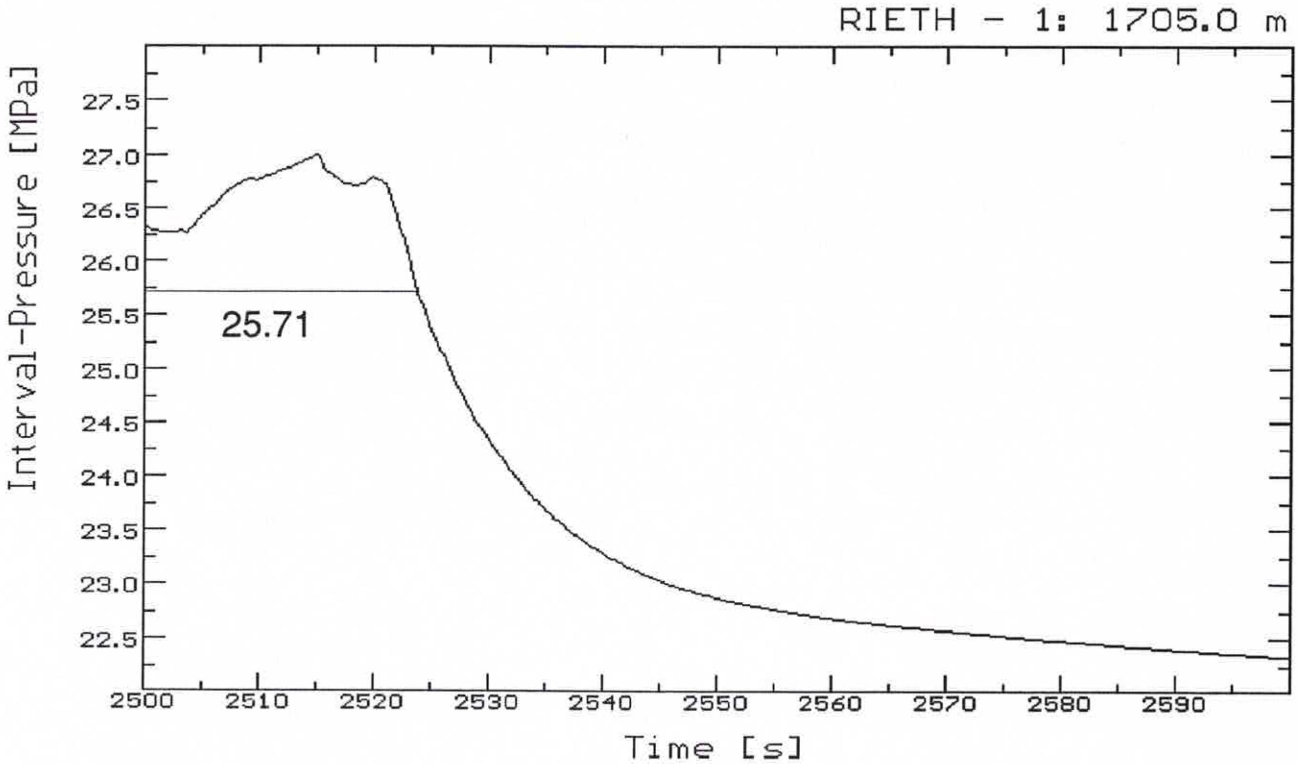
OPEN - HOLE TEST 2 AT 1705.0 m

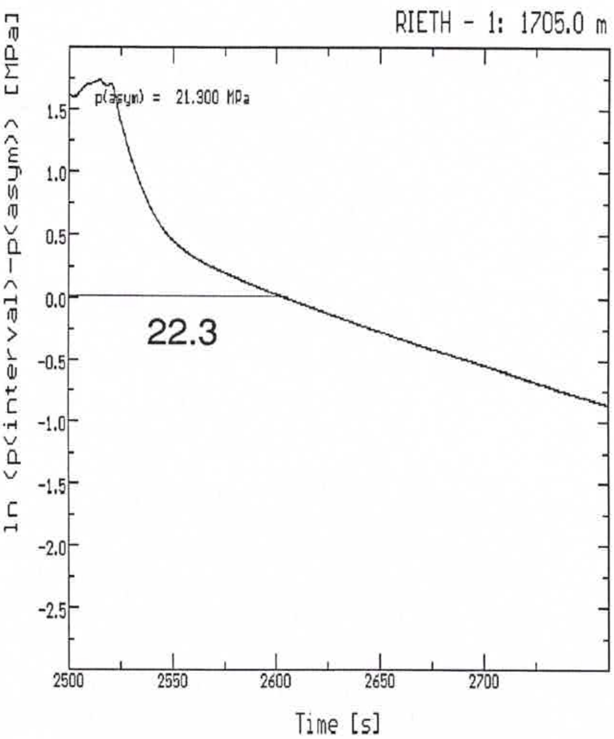
Estimation of Refrac-Pressure



Estimation of Shut-In-Pressure P_{si}



Estimation of $P_{si,min}$



Estimation of $P_{si,max}$