

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 NATARP - 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
 Dipl. Geophys. U. Weber
Report - Date : 16.10.1995
Report - No. : 35.95

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SUMMARY

As a part of the geotechnical site investigation program for the CBM - project Sigillaria License Area of the Ruhr - Carboniferous, hydrofrac stress and slow rate injection / pressure fall - off permeability tests were carried out within the open - hole section of borehole Natarp-1 between 1418 m and 1935 m depth.

In-situ testing was carried out with the MeSy wireline technique which consists of a straddle packer tool tripped on a standard logging cable in the borehole. The test program included 3 slow rate injection / fall - off permeability tests on coal seams and 7 hydraulic / hydrofrac tests for stress- and permeability determination of the coal bearing formation.

The pressure pulse tests conducted yield permeability values of 7 μD to 23 μD for the coalbearing formation and 62 μD for the coal seam section at 1760.3 m. In comparison, the injection / fall - off tests on coal seams yield permeability values of 100 μD at 1760.3 m and 70 μD at 1878.0 m depth.

Formation breakdown required high fluid pressures up to the limits of the packer elements of 30 MPa differential pressure. The observed frac-gradients varied between 0.021 MPa/m and 0.029 MPa/m (0.93 psi/ft - 1.29 psi/ft) and characterizes the fracability of the coal bearing formation.

The stress analysis on the basis of the HUBBERT and WILLIS [1957] approach yield the following preliminary stress profiles for the borehole section between 1415 m to 1880 m TVD:

$$\begin{aligned} S_v, \text{ MPa} &= 0.0245 \cdot \text{TVD, m} (\varrho = 2.5 \text{ g/cm}^3) \\ S_h, \text{ MPa} &= 22.5 + 0.0185 \cdot (\text{TVD, m} - 1415) \\ S_H, \text{ MPa} &= 38.8 + 0.0433 \cdot (\text{TVD, m} - 1415) \end{aligned}$$

Final relations will be given after the analysis of the cased - hole tests conducted in borehole Natarp-1.

1. INTRODUCTION

First information about the coal bed methane (CBM) recovery potential in the Sigillaria Licence Area in the Ruhr Carboniferous were derived from extensive hydraulic permeability and hydrofrac stress tests carried out in the open- and cased - hole sections of borehole Rieth-1 [MeSy - REPORT, 1995 a,b]. Further possibilities to investigate the in - situ rock permeability, the magnitude and gradients of principle stresses as well as the in - situ rock strength in the Ruhr - Carboniferous occurred by drilling the second CBM - exploration borehole Natarp-1, located app. 17 km north-east of borehole Rieth-1.

The present report describes the results of the hydraulic injection test program consisting of 3 injection / fall - off tests on coal seams and 7 hydraulic- and hydrofrac - tests on the coal bearing formation, carried out in the open - hole section of borehole Natarp-1 between 1418 m and 1935 m depth.

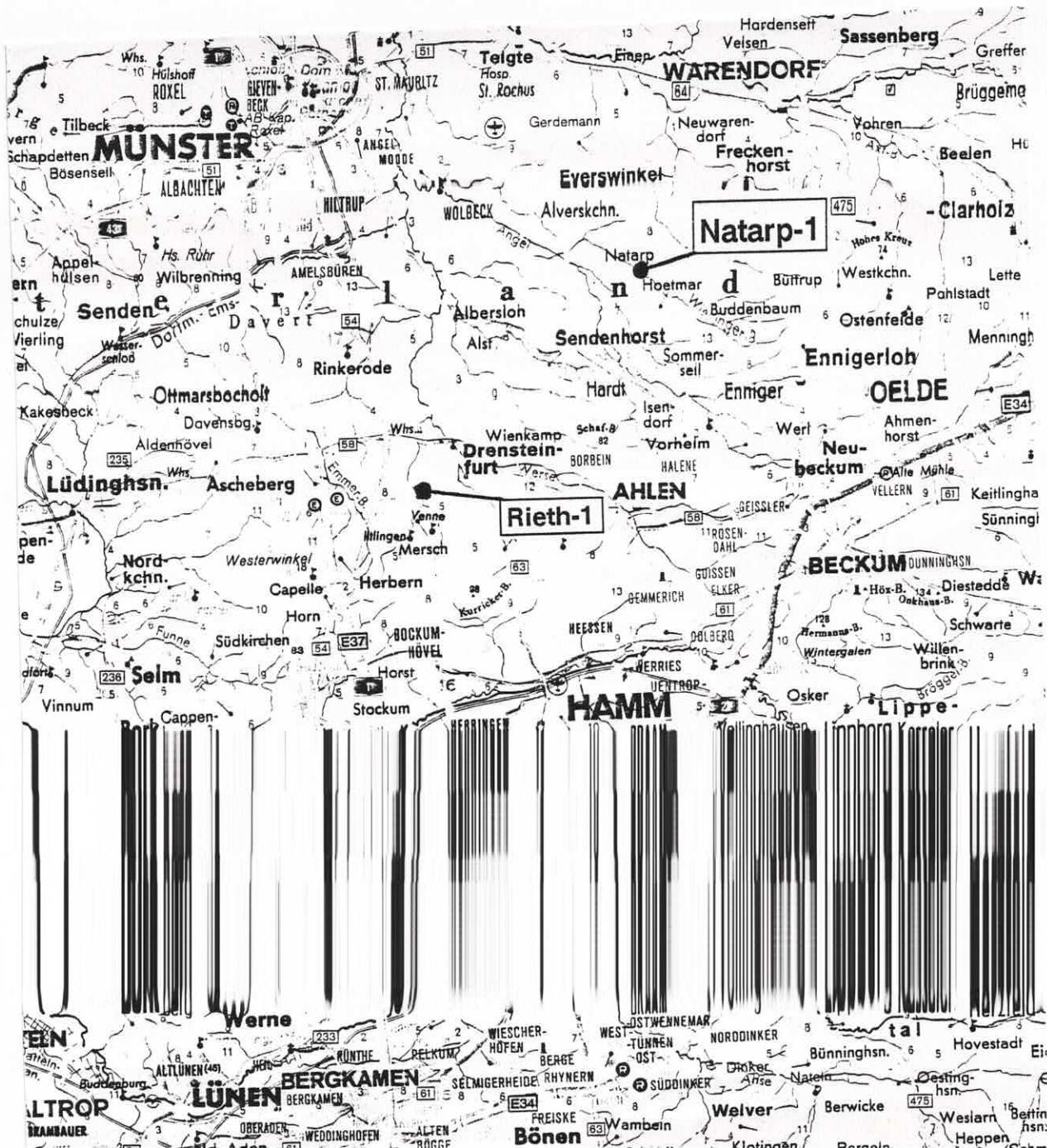
The hydraulic injection tests were carried out at the following test sections:

test no.	test section m	lithology
1	1876.5 - 1879.5	coal - seam
2	1758.8 - 1761.8	coal - seam
3	1479.0 - 1482.0	coal - seam
4	1934.5 - 1945.5	coal bearing (sandstone)
5	1881.5 - 1882.5	coal bearing (silty claystone)
6	1754.5 - 1455.5	coal bearing (silty claystone)
7	1706.5 - 1707.5	coal bearing (claystone)
8	1680.5 - 1681.5	coal bearing (very silty claystone)
9	1586.5 - 1587.5	coal bearing (very silty claystone)
10	1417.5 - 1418.5	coal bearing (sandstone)

2. TECHNICAL BOREHOLE DATA

Borehole Natarp-1 is located about 20 km southeast of Münster / app. 1.5 km north of Hoetmar, NRW, Germany (geogr. coordinates: N 51° 53' 37", E 7° 53' 41"). The borehole location is shown in Figure 2.1, technical borehole data are given in Table 2.1.

Figure 2.1 : Location of borehole Natarp-1.

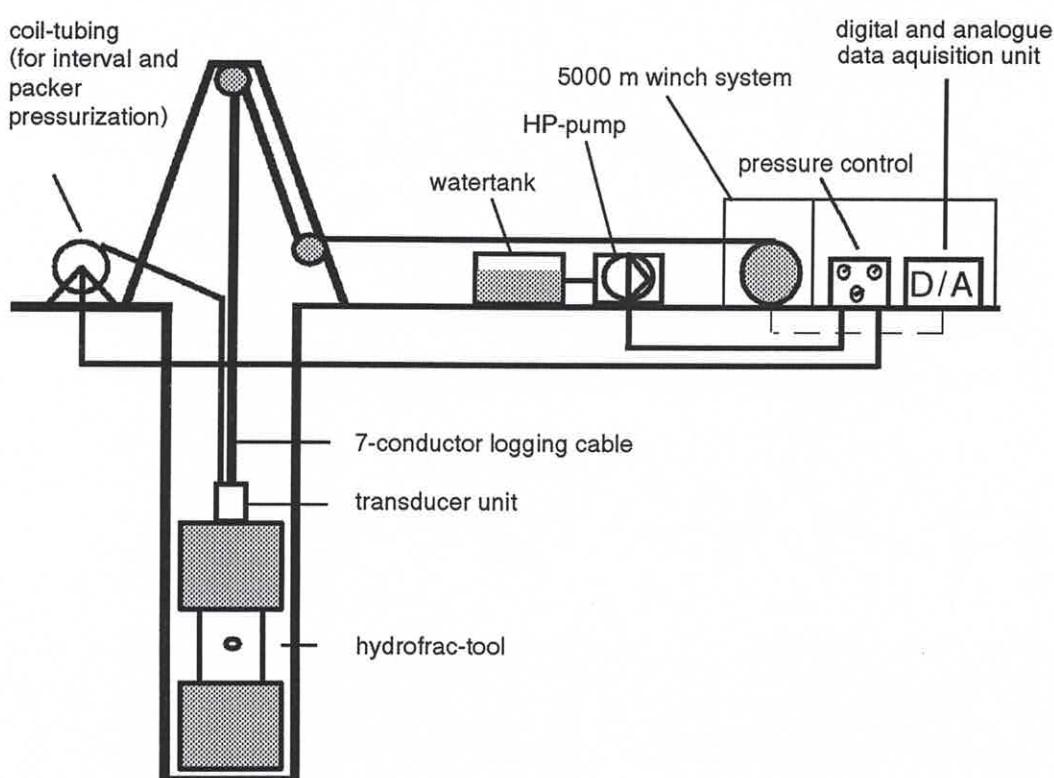


For packer pressurization an air - driven pump (MAXIMATOR, type GW 100) was used. For interval pressurization an electric driven three plunger pump (SPECK, type HP 400 / 2 - 12) with a capacity of 40 MPa / 0.17 l/min - 12 l/min was used. The injection fluid was KCL - brine with a density of 1.13 g/cm³.

The downhole transducer unit on top of the packer assembly was equipped with a temperature transducer (0 - 211 °C) and two strain gauge type pressure transducers (KELLER, type PA 23, 0 - 60 MPa). The injection rate was measured by an electronic turbine type flow - meter (UNIMESS, type QPT 04, 0 - 10 l/min) or a special stand pipe with a calibrated volume scale. The uphole interval pressure was measured by a pressure transducer (KELLER, type PA-23, 0-100 MPa).

The data acquisition system consisted of an analogue paper strip chart recorder (BBC, type SE-400, 4 channels) and a digital PC-based system (EASYEST, 5 channels: resolution: 12 bit, sampling rate: 1 Hz during injection / fall - off tests and 5 Hz during hydrofrac tests).

Figure 3.1 : Scheme of the MeSy wireline hydrofrac - system.



4. TEST - PROGRAM AND TEST CONDUCTION

On the basis of the borehole logs available and the experience from hydraulic - and hydrofrac testing in the borehole Rieth-1, Conoco and MeSy together decided on the following test program:

- Conduction of 3 injection / fall - off tests on representative coal seams of the Carboniferous by using a straddle packer tool with 3 m spacing between the packers
- Conduction of 7 hydrofrac stress and permeability tests in the coal bearings by using a straddle packer tool with 1 m spacing between the packers.

The test procedure during the injection / fall - off tests followed closely the recommendations "CASED - HOLE INJECTION PROCEDURE FOR RIETH-1", prepared by WILSON and HINCHCLIFF [19.05.1995]. Due to a packer leakage at the beginning of test no. 3 at 1480.5 m depth, the injection / fall - off test was abandoned. At the end of test no. 1 at 1878.0 m depth an interruption of the electric power - supply caused a lost of the recorded digital data (the data were subsequent digitized from the analogue pressure record).

The hydrofrac stress measurements consisted of the initial breakdown (frac) test cycle and several subsequent refrac test cycles. Prior to each frac cycle a pressure pulse test was carried out to determine the in - situ rock permeability of the test section. However at 1935.0 m (test no. 4) and 1707.0 m (test no. 7) no formation breakdown could be achieved with the pressure capacity of the packer elements with a limit of 30 MPa differential pressure.

The open - hole test program is summarized in Table 4.1. Further details can be taken from the MeSy Operation Report dated 07.08.95 (APPENDIX A).

Table 4.1 : Test program conducted in borehole Natarp-1 during 02.08.95 to 05.08.95.

mi: main injection test
 pp: pressure pulse test

pfo: pressure fall - off test
 f: frac test

test no.	test interval m	test sequence	test duration
			min
1	1876.5 - 1879.5	mi	45
		pfo	103
2	1758.8 - 1761.8	pp	15
		mi	60
		pfo	113
3 ¹⁾	1479.0 - 1482.0	/	57
4 ²⁾	1934.5 - 1935.5	pp	8
		f	12
5	1881.5 - 1882.5	pp	7
		f	58
6	1754.5 - 1755.5	pp	7
		f	78
7	1706.5 - 1707.5	pp	8
		f	32
8	1680.5 - 1681.5	pp	8
		f	126
9	1586.5 - 1587.5	pp	8
		f	75
10	1417.5 - 1481.5	pp	8
		f	110

¹⁾ : test abandoned due to a packer leakage

²⁾ : failure of packer burst disk valve

5. TEST ANALYSIS AND RESULTS

Overview plots of the injection / pressure fall - off tests are given in APPENDIX B. Overview plots of the hydrofrac tests as well as cross - plots used for the stress analysis are presented in APPENDIX C. The analysis of the pressure pulse tests for permeability evaluation is given in APPENDIX D.

5.1 INJECTION / PRESSURE FALL - OFF TESTS

The main injection / pressure fall - off tests were evaluated by Conoco. Therefore, MeSy only supplies the corresponding overview plots (APPENDIX B). Conoco's first analysis yields permeability values for the coal seam test sections ranging between 70 μD and 100 μD . The data are presented in Table 5.1.

Table 5.1 : Permeability data for coal seam sections.

test no.	mean interval depth m	permeability μD	lithology
1	1878.0	70	coal seam
2	1760.3	100	coal seam
3 ¹⁾	1480.5	-	coal seam

¹⁾: test abandoned due to a packer leakage.

5.2 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 L¹ - standard.

The permeability / transmissivity data derived from the pressure pulse tests (APPENDIX D) are summarized in Table 5.2. The test on the coal seam section at 1760.3 m (test no. 2) yield a permeability of 62 μD in comparison to 100 μD derived from the corresponding injection / fall - off test (compare Tab. 5.1). The permeability of the coal bearing sections ranges between 7 μD and 23 μD with a mean value of $11 \pm 5 \mu\text{D}$.

Table 5.2 : Results of pressure pulse tests for permeability / transmissivity estimation.

test no.	mean inter- val depth	depth below surface	permeability	transmissivity	lithology
	m	m	μD	cm^2/s	
10	1418.0	1415.2	10	0.05	coal bearings
9	1587.0	1584.2	7	0.03	dto.
8	1681.0	1678.2	9	0.05	dto.
7	1707.0	1704.2	10	0.05	dto.
6	1755.0	1752.2	8	0.04	dto.
2	1760.3	1658.2	62	0.21	coal seam
5	1882.0	1879.2	23	0.11	coal bearings
4	1935.0	1932.2	9	0.04	dto.

5.3 FRAC - PRESSURE AND FRAC - GRADIENT

Subsequent to the pressure pulse tests for permeability determination, the interval pressure was increased to induce a fracture in the borehole wall rock formation. Detailed pressurization plots to identify the breakdown pressure P_c are given in APPENDIX C. The corresponding frac - gradient then is defined by

$$k = \frac{P_c}{TVD}$$

where TVD is the true vertical depth. The test results are listed in Table 5.3 and are shown graphically in Figure 5.1.

The maximum pressure values observed at the test sections at 1935.0 m and 1707.0 m are also included in Table 5.3 although the data do not correspond to formation breakdown pressure P_c since no fracture was initiated with the pressure capacity of the packer elements of 30 MPa differential pressure. Therefore, the given frac - gradients for test no. 4 and 7 represent lower limits of the true k - value.

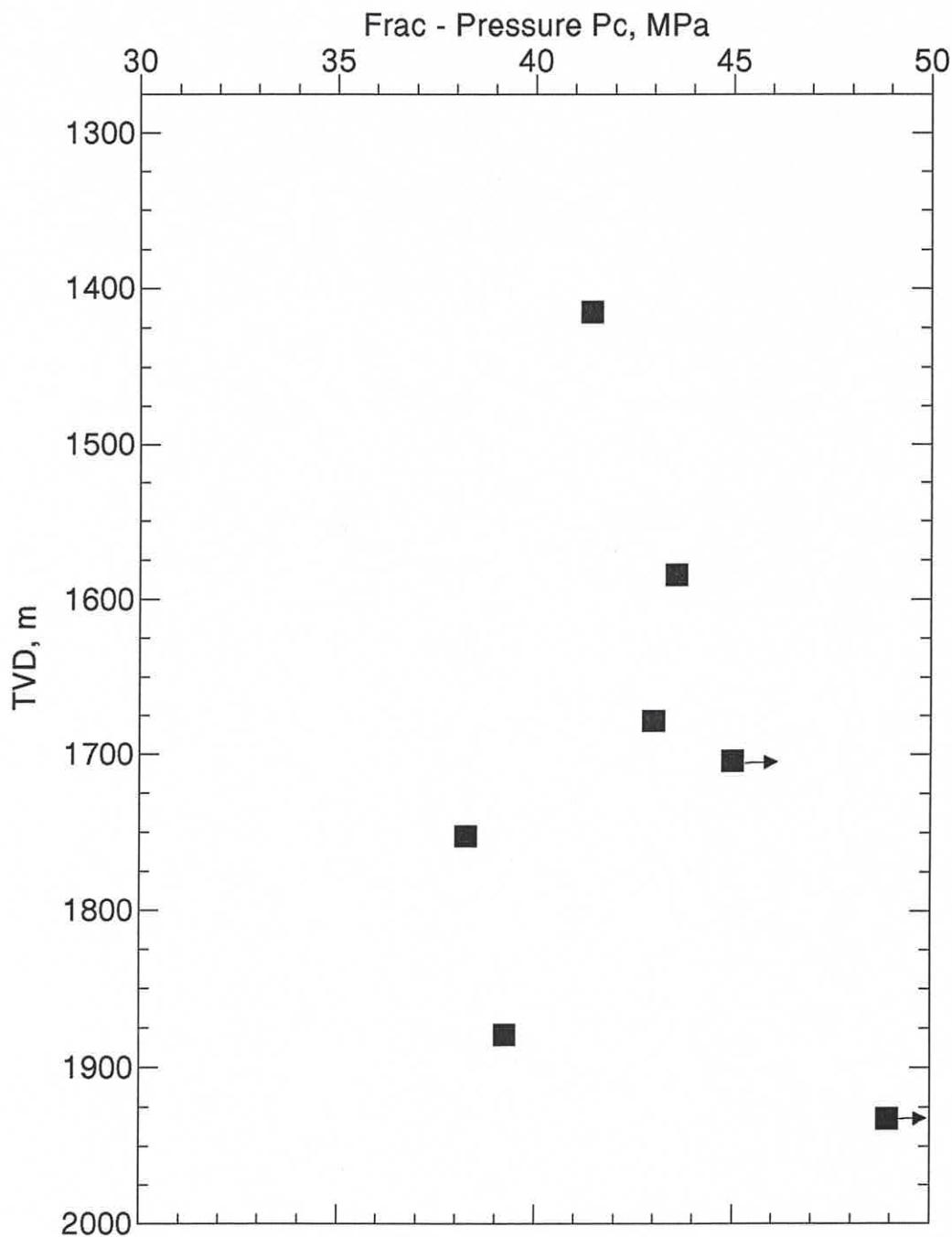
The observed high k - values between 0.021 and 0.029 MPa/m (0.93 to 1.29 psi/ft) with a mean value of 0.025 ± 0.003 MPa/m (1.11 ± 0.13 psi/ft) characterize the fracability of the coal bearing rock formation with fine - grained sand- and claystones of low permeability.

Table 5.3 : Frac - or maximum interval pressure P_c and resulting frac - gradient k.

test no.	test depth m	TVD m	P_c MPa	k MPa/m
10	1418.0	1415.2	41.42	0.0293
9	1587.0	1584.2	43.57	0.0275
8	1681.0	1678.2	43.00	0.0256
7 ¹⁾	1707.0	1704.2	> 45.00	> 0.0264
6	1755.0	1752.2	38.26	0.0218
5	1882.0	1879.2	39.25	0.0209
4 ¹⁾	1935.0	1932.2	> 48.94	> 0.0253

¹⁾ : no breakdown

Figure 5.1 : Frac - pressure P_c vs. true vertical depth TVD observed during open - hole hydrofrac - testing in borehole Natarp-1.



5.4 HYDROFRAC STRESS TEST ANALYSIS AND RESULTS

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 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

Since most of the assumptions are not valid (isotropy, homogeneity, rock impermeability) the stress analysis requires most accurate pressure data for interpretation. Therefore, an extensive pressure analysis program was carried out for the identification of characteristic hydrofrac pressure values.

The determination of the **refrac pressure P_r** considers the system stiffness (during the initial pumping cycle). Assuming a constant system stiffness initially the pressure

P linearly increases with the injection fluid volume V. Therefore, a deviation from the linear P vs. V plot indicates the opening of a fracture.

The **shut - in pressure P_{si}** is determined by a three step analysis of the pressure plots:

- from a pressure P vs. flow - rate Q plot where the moment at which hydraulic flow stops ($Q = 0$) an upper bound of P_{si} can derived;
- from a Muskat plot a lower - bound of P_{si} can derived , assuming that the linear part of the plot characterizes radial flow, i.e. the stimulated fracture is nearly closed;
- within the two limits, the P_{si} - value marks the transition from a rapid linear pressure drop to a diffusion dominated pressure decrease; the transition can be determined by the tangent method (inflection point method).

The cross - plots used for the determination of the characteristic hydrofrac pressure values are presented in APPENDIX C. The refrac- and shut - in pressure data are listed in Table 5.4 and are graphically shown in Figure 5.2 and 5.3. Table 5.4 also contains the resulting in - situ hydraulic tensile strength $P_{co} = P_c - P_r$ (compare with Tab. 5.3).

Table 5.4 : Refrac - pressure P_r , in - situ hydraulic tensile strength $P_{co} = P_c - P_r$ and Shut - in pressure P_{si} derived from open hole hydrofrac testing in bore-hole Natarp-1.

test no.	depth m	depth below surface TVD m	P_r MPa	P_{co} MPa	P_{si} MPa
10	1418.0	1415.2	27.89	13.53	23.13
9	1587.0	1584.2	36.76	6.81	25.67
8	1681.0	1678.2	30.71	12.29	25.67
7 ¹⁾	1707.0	1704.2	-	-	-
6	1755.0	1752.2	28.32	9.94	29.16
5	1882.0	1879.2	37.68	1.57	31.74
4 ¹⁾	1935.0	1932.2	-	-	-

¹⁾: no breakdown

Figure 5.2 : Refrac - pressure P_r , vs. true vertical depth TVD derived from open - hole hydrofrac testing in borehole Natarp-1.

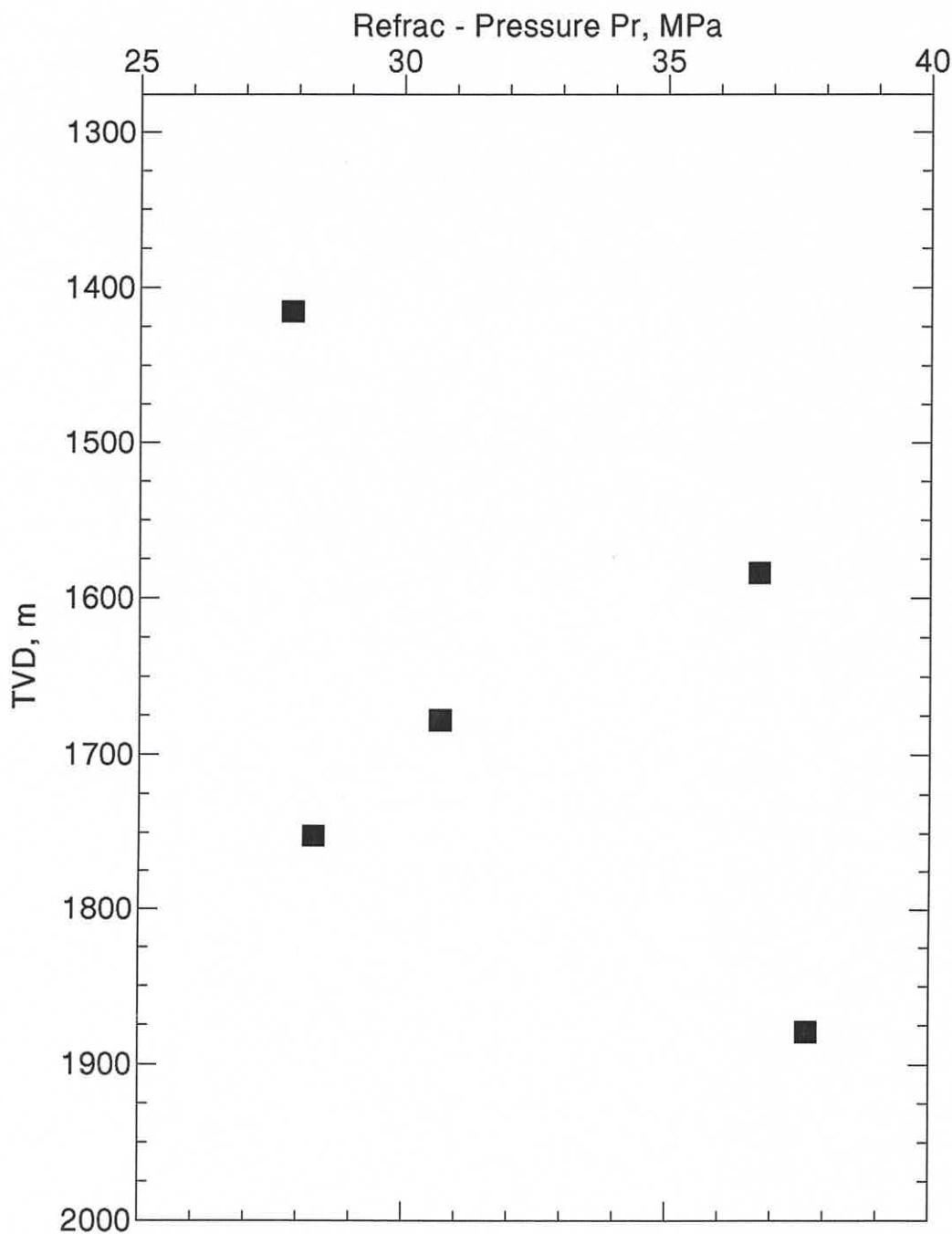
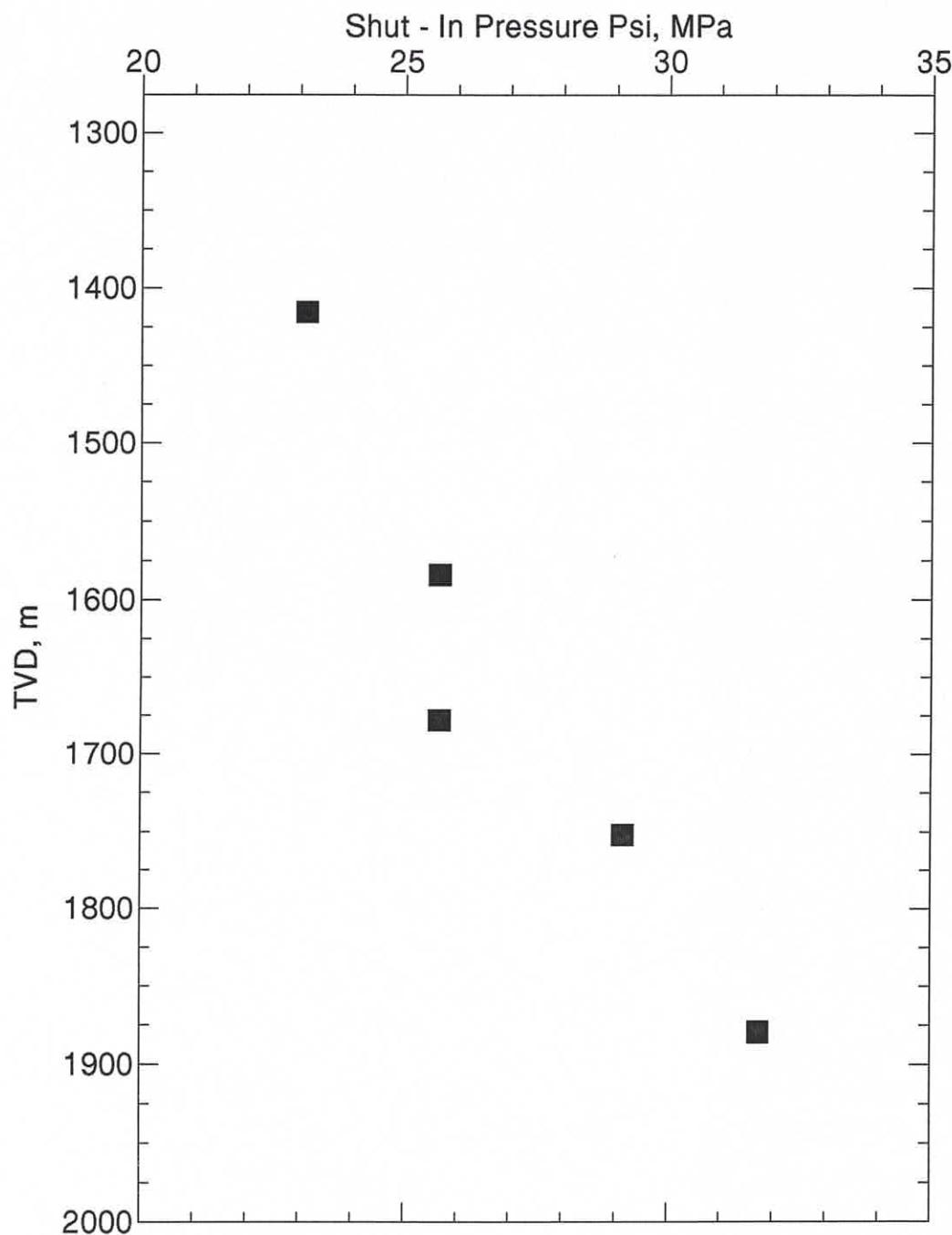


Figure 5.3 : Shut - in pressure P_{si} vs. true vertical depth TVD derived from open - hole hydrofrac testing in borehole Natarp-1.



Neglecting the formation pore pressure P_o , the resulting principle stresses S_h and S_H according to eqs. 5.1 to 5.3 are listed in Table 5.5 and graphically shown in Figure 5.4. The vertical stress is calculated for a mean overburden rock mass density of 2.5 g/cm³.

The stress magnitudes within the depth interval between 1415 m to 1880 m in bore-hole Natarp-1 can be summarized by the following preliminary stress - depth profiles (final relations will be given after the analysis of the cased - hole tests conducted in borehole Natarp-1):

$$S_v, \text{ MPa} = 0.0245 \cdot \text{TVD, m } (\rho = 2.5 \text{ g/cm}^3)$$

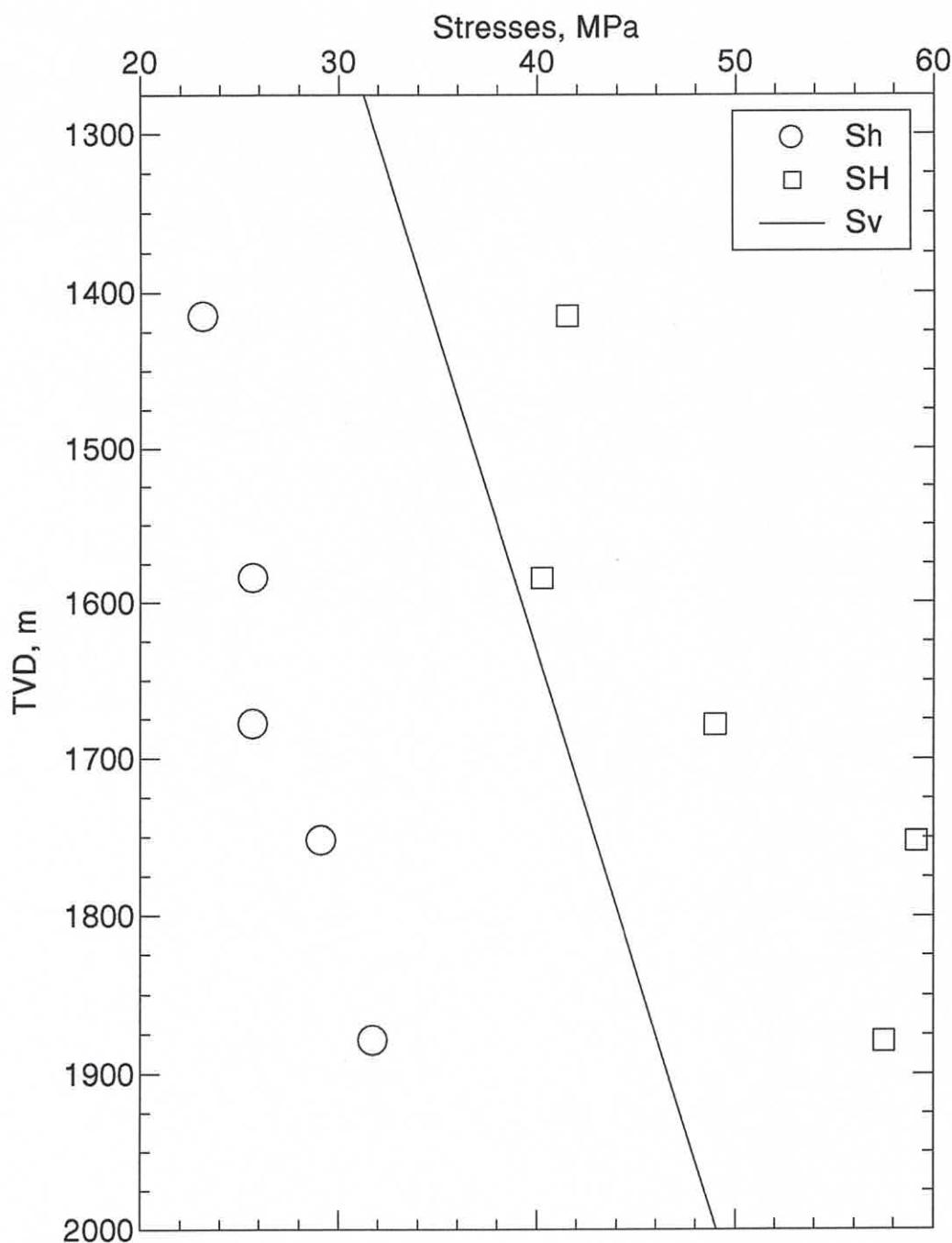
$$S_h, \text{ MPa} = 22.5 + 0.0185 \cdot (\text{TVD, m} - 1415)$$

$$S_H, \text{ MPa} = 38.8 + 0.0433 \cdot (\text{TVD, m} - 1415)$$

Table 5.5 : Result of stress evaluation using the HUBBERT and WILLIS approach.

test no	depth m	depth below surface TVD m	S_v ($\rho = 2.5$ g/cm ³) MPa	S _h		S _H MPa
				MPa	MPa	
10	1418.0	1415.2	34.71	23.13		41.50
9	1587.0	1584.2	38.85	25.67		40.25
8	1681.0	1678.2	41.16	25.67		49.00
7	1707.0	1704.2	41.80	-		-
6	1755.0	1752.2	42.97	29.16		59.16
5	1882.0	1879.2	46.09	31.74		57.54
4	1935.0	1932.2	47.39	-		-

Figure 5.4 : Principal stresses vs. true vertical depth TVD derived from open - hole hydrofrac stress measurements in borehole Natarp-1.



6. DISCUSSION OF RESULTS

- (i) The observed rock mass permeability between 7 μD and 23 μD characterizes the tight sand- and claystones within the coal bearings. Similar permeability values were observed in borehole Rieth-1 [MeSy - REPORT 1995 a, b]. Conoco's analysis of the injection / fall - off tests on the coal seams at 1878.0 m and 1760.3 m depth yield permeabilities of 70 μD to 100 μD . The result of the short pressure pulse test is in agreement to the result of the injection / fall - off test.
- (ii) Formation breakdown required pressures up to the capacity of the packer elements used. The observed high frac - gradients between 0.021 MPa/m and 0.029 MPa/m and the high in - situ tensile strength upto 13.5 MPa characterizes the fracability of the carboniferous coal - bearing rock formation of low permeability.
- (iii) The stress evaluation according to the HUBBERT and WILLIS [1957] concept yields the following preliminary stress profiles for the borehole section between 1415 m and 1880 m:

$$S_v, \text{ MPa} = 0.0245 \cdot \text{TVD, m} (\rho = 2.5 \text{ g/cm}^3)$$

$$S_h, \text{ MPa} = 22.5 + 0.0185 \cdot (\text{TVD, m} - 1415)$$

$$S_H, \text{ MPa} = 38.8 + 0.0433 \cdot (\text{TVD, m} - 1415)$$

- (iv) Final stress - depth profiles as well as a comparison with existing stress data of the Ruhr - Carboniferous will be given after analysis of the cased - hole tests conducted in borehole Natarp-1.

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.

MeSy - REPORT (1995 a) : Open - hole permeability and hydrofrac stress measurements in borehole Rieth-1. *Report - No. 27.95, 11.07.95*.

MeSy - REPORT (1995 b) : Cased - hole permeability and stress measurements in borehole Rieth-1. *Report - No. 29.95, 04.08.95*.

WILSON, P. and R. HINCHCLIFF : Cased - hole injection procedure, borehole Rieth-1. *Internal Conoco Report, 19.05.1995*.

8. ACKNOWLEDGEMENT

MeSy is grateful to Conoco Mineralöl GmbH, Essen for the contract to carry out the hydraulic tests in borehole Natarp-1. We are particularly grateful to Mr. K. Thomas (Conoco) for infrastructural information, his participation during the in - situ tests.

Infrastructural information and assistance during in - situ testing were also provided by Mr. W. Hartog (Conoco). Further help was provided by personal of the drilling company Bohrgesellschaft Rhein - Ruhr.

The in - situ test were conducted by the MeSy personnel P. Hegemann, T. Przybilla, H. Vogt and U. Weber during 24 hour work days.

Table 2.1 : Technical data of borehole Natarp-1.

location	about 1.5 km N of Hoetmar, NRW, Germany	
borehole	Natarp-1	
Gauß-Krüger-coordinates	RW : 3423925.40	HW : 5751505.93
geogr. coordinates	N 51° 53' 37"	E 7° 53' 41"
altitude a.m.s.l.	62.5 m	
borehole depth	1968.9 m	
borehole diameter (open-hole section)	6-1/4" (1378.4 m - 1575.0 m)	6-1/8" (1575.0 m - 1968.9 m)
casing	0 - 1378 m	
casing diameter	OD 7", ID 6.2"	
borehole fluid	Tsst Polymer + Bentonit	
borehole fluid density	1.13 g/cm ³	
drilling contractor	Bohrgesellschaft Rhein -Ruhr	

3. TEST - EQUIPMENT

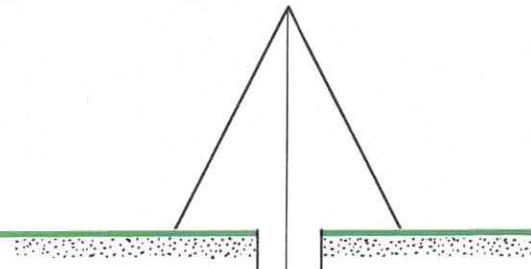
The open - hole tests in borehole Natarp-1 were carried out using the MeSy wireline technology, where a straddle packer tool is moved within the borehole via a 7 - conductor standard logging cable (CAMESA type 7-J 46 RTZ, OD 15/32") by the MeSy winch system MKW 5000. A schematic view of the system is given in Figure 3.1.

According to the open hole diameter of 6-1/8" to 6-1/4" (156 mm to 159 mm), the straddle packer tool was the MeSy PERFRAC VII system equipped with steel - cord reinforced inflatable packer elements (type TAM 5-1/16" I.E.) with a diameter of 131 mm and a sealing length of about 1 m. The test interval length was about 3 m during the injection / fall - off tests and about 1 m during the hydrofrac tests.

The packer elements and the injection interval were pressurized via two separate hydraulic stainless steel tubing pressure lines (OD 10 mm, ID 8 mm for interval pressurization; OD 8 mm, ID 6 mm for packer pressurization). The tubings were fixed to the logging cable by special aluminum clamps in 50 m intervals.

APPENDIX A

OPERATION REPORT DATED 07.08.95



BOREHOLE
HYDROFRACTURING
STRESS MEASUREMENTS
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Dipl.-Geophys. U. Weber

Date: 07.08.1995

Project: CBM project Sigillaria License Area
Location: Natarp / Hoetmar, NRW, Germany
Borehole: Natarp-1
Purpose: open-hole permeability and hydrofrac stress measurements
Test-Period: 02.-05.08.1995
Participants:
 Mr. K. Thomas (Conoco Essen)
 Dipl. Ing. P.Hegemann (MeSy, 02.-04.08.95)
 Dipl. Geophys. T. Przybilla (MeSy, 01.-05.08.95)
 Prof. Dr. F.Rummel (MeSy, 05.08.95)
 Dipl. Ing. H.Vogt (MeSy, 02.-05.08.95)
 Dipl. Geophys. U.Weber (MeSy, 02. -05.08.95)

TIME TABLE OF TESTING

date	time	event
July 95		preparation of equipment
31.07.95	14:00	arrival of winch system MKW-5000 at Natarp-1 drill-site
01.08.95	11:00-15:00	transportation of tubing to test-site
02.08.95	17:45	departure of MeSy engineers P. Hegemann, T.Przybilla, H.Vogt and U. Weber from Bochum
	20.00	arrival at drill-site
	20:00-01:30	set - up of winch, double-packer tool (3 m interval-length) and surface equipment
03.08.95	01:30	tool at zero-mark (middle of test-interval), venting of the hydraulic system
	01:35	start tripping into hole
	01:35-02:20	test of tool in the casing at 20 m depth
	06:00-06:53	tool at 1888.5 m (cable load: 1.7 tons) and cleaning of test section by pumping into interval while moving tool to test-position (cable load: 2.1 tons)
	06:53-10:02	injection-test 1 at 1878.0¹ m
	09:29	interruption of electric power-supply, lost of all digital data recorded so far due to failure of UPS

¹ all depth marks were measured from rig floor (2.80 m above ground level) and corresponds to the middle of the test-interval

date	time	event
03.08.95	09:32	restart of digital data aquisition unit
	10:02-10:52	moving tool upward to next test position at 1760.0 m
	10:52-11:35	tool at 1763.2 m and cleaning of test section by pumping into interval while moving tool to test-position (cable load: 2.2 tons)
	11:35-16:16	injection-test 2 at 1760.3 m
	16:16-17:36	moving tool upward to next test position at 1480.5 m
	17:36-17:55	tool at 1483.0 m and cleaning of test section by pumping into interval while moving tool to test-position (cable load: 1.8 tons)
	17:55	injection-test 3 at 1480.5 m , during setting packers pressure rapidly decreases
	18:52	decission to end test due to pressure decrease
	18:52-21:00	tripping tool out of hole
	21:00-21:28	test of tool in the casing at 20 m depth
	21:30	tool out of hole, tubing between upper and lower packer damaged
	21:30-23:56	repair and set up hydrofrac tool with 1 m interval length
	23:56	start tripping into hole
	00:11-00:42	test of tool in the casing at 20 m depth
04.08.95	03:32	tool at 1935.0 m (cable load: 1.4 tons)
	03:40-05:08	hydrofrac-test 1 at 1935.0 m
	04:05	sudden decrease of packer pressure during frac-test due to failure of safty burst-disk
	05:08-08:20	tripping tool out of hole
	08:20-08:59	change of burst-disk
	08:59	start tripping into hole
	09:06-09:33	test of tool in the casing at 20 m depth
	12:20	tool at 1882.0 m (cable load: 1.4 tons)
	12:23-14:06	hydrofrac-test 2 at 1882.0 m
	14:06-18:26	movement to test position at 1755.0 m (max. cable load: 3.0 tons)
	18:26-20:11	hydrofrac-test 3 at 1755.0 m
	19:00	departure of P. Hegemann
	20:11-21:05	movement to test position at 1707.0 m
	21:05-21:54	hydrofrac-test 4 at 1707.0 m , it was not possible to fracture the rock with max. differential packer pressure of 27.5 MPa

	date	time	event
04.08.95		21:54-22:19	movement to test position at 1681.0 m
05.08.95		22:19-01:45	hydrofrac-test 5 at 1681.0 m
		01:45-03:12	movement to test position at 1587.0 m
		03:12-05:18	hydrofrac-test 6 at 1587.0 m
		05:18-06:34	movement to test position at 1418.0 m
		06:34-08:53	hydrofrac-test 7 at 1418.0 m
		08:53-12:30	tripping tool out of hole
		11:30	arrival of Prof. Rummel at test-site
		13:30	equipment down from drill-rig plattform
		14:00	departure of Prof. Rummel
		16:10	departure of MeSy engineers (T.Przybilla, H.Vogt, U.Weber) from test-site with MeSy LKW and MeSy PKW, Winchsystem and 2 drums with coil-tubing remain at drill-site
		17:30	arrival at Mesy-Bochum, end of open-hole test campaign

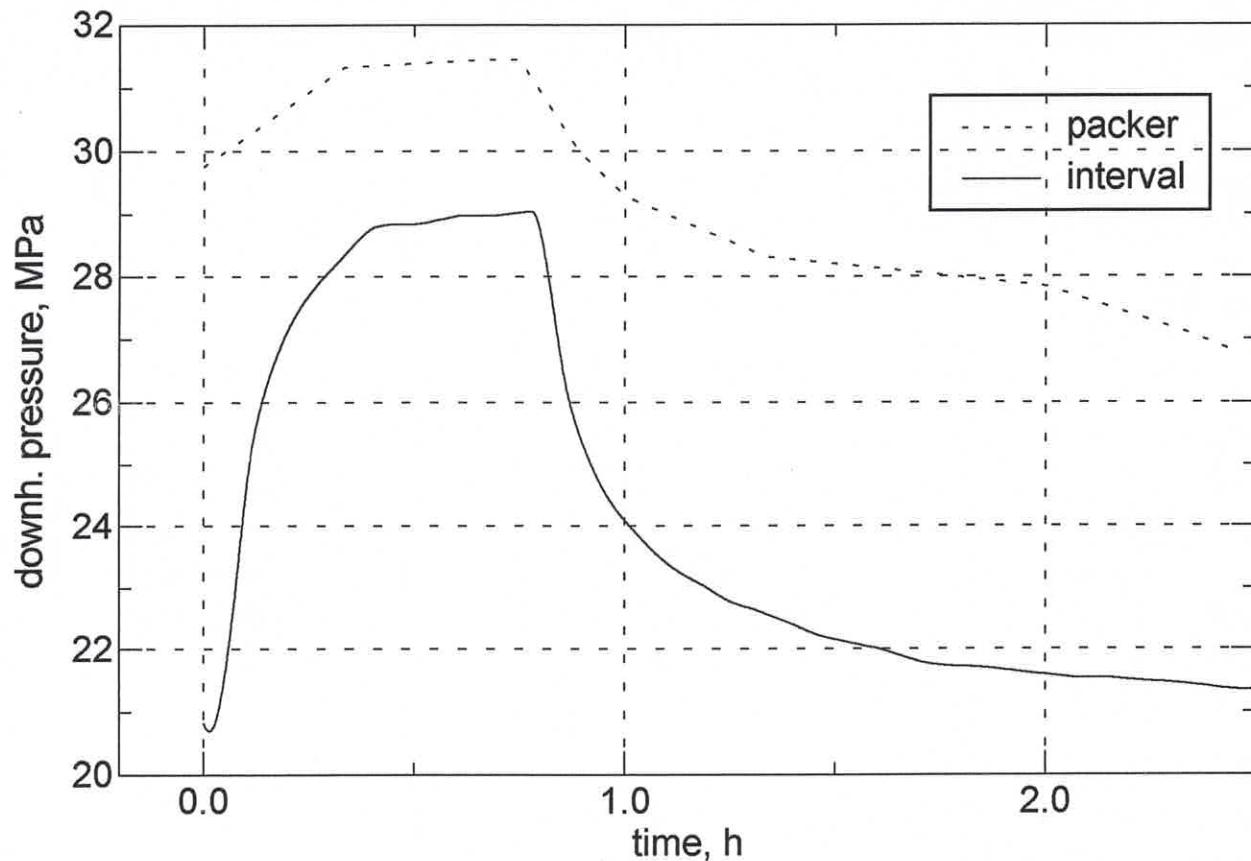
APPENDIX B

OVERVIEW - PLOTS OF INJECTION / PRESSURE FALL - OFF TESTS

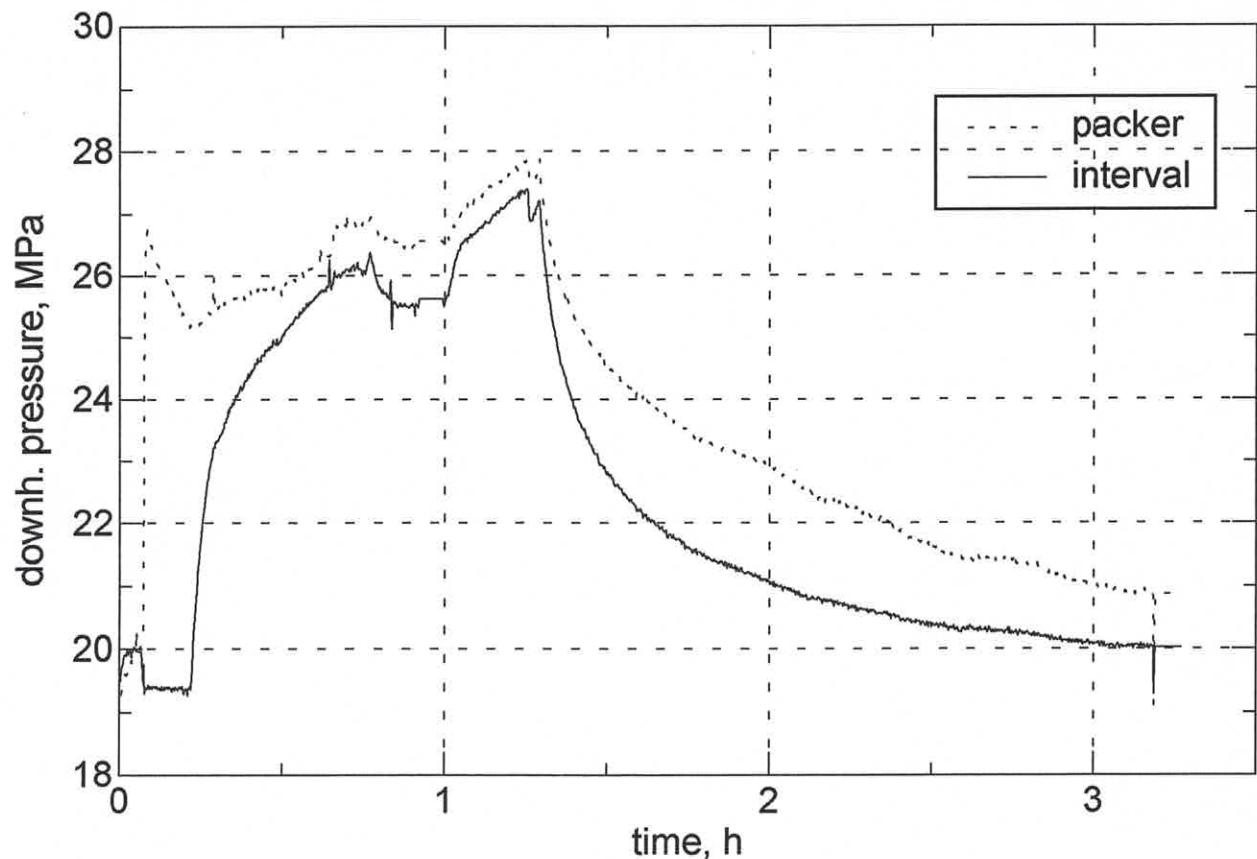
remarks:

solid line: downhole interval pressure
broken line: downhole packer pressure

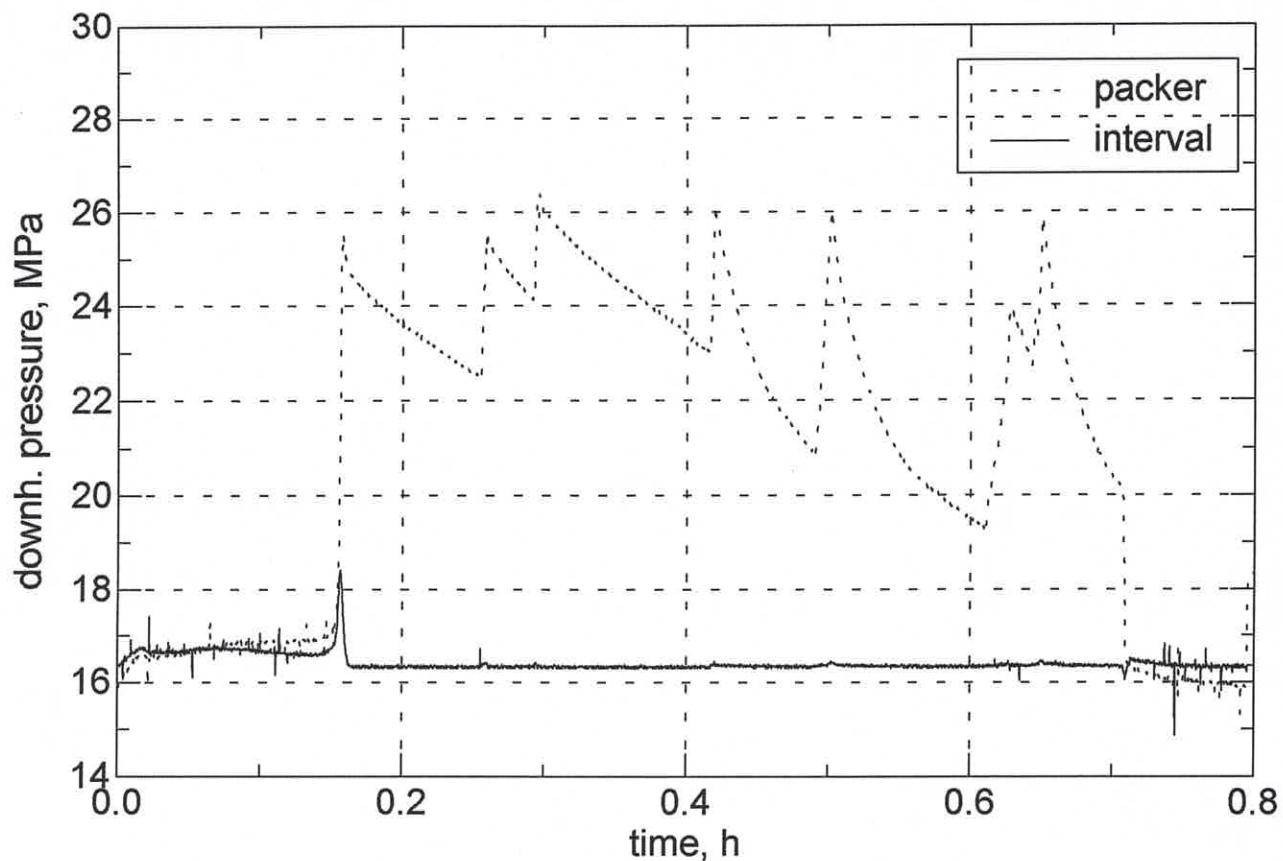
OPEN - HOLE TEST 1 AT 1878.0 m
file: 1878D.DAT
Start: 03.08.95, 06:53 End: 03.08.95, 10:02



OPEN - HOLE TEST 2 AT 1760.3 m
file: 1760OH1.DAT
Start: 03.08.95, 11:35 End: 03.08.95, 16:16



OPEN - HOLE TEST 3 AT 1480.5 m
file: 1480OH1.DAT
Start: 03.08.95, 17:45 End: 03.08.95, 18:52



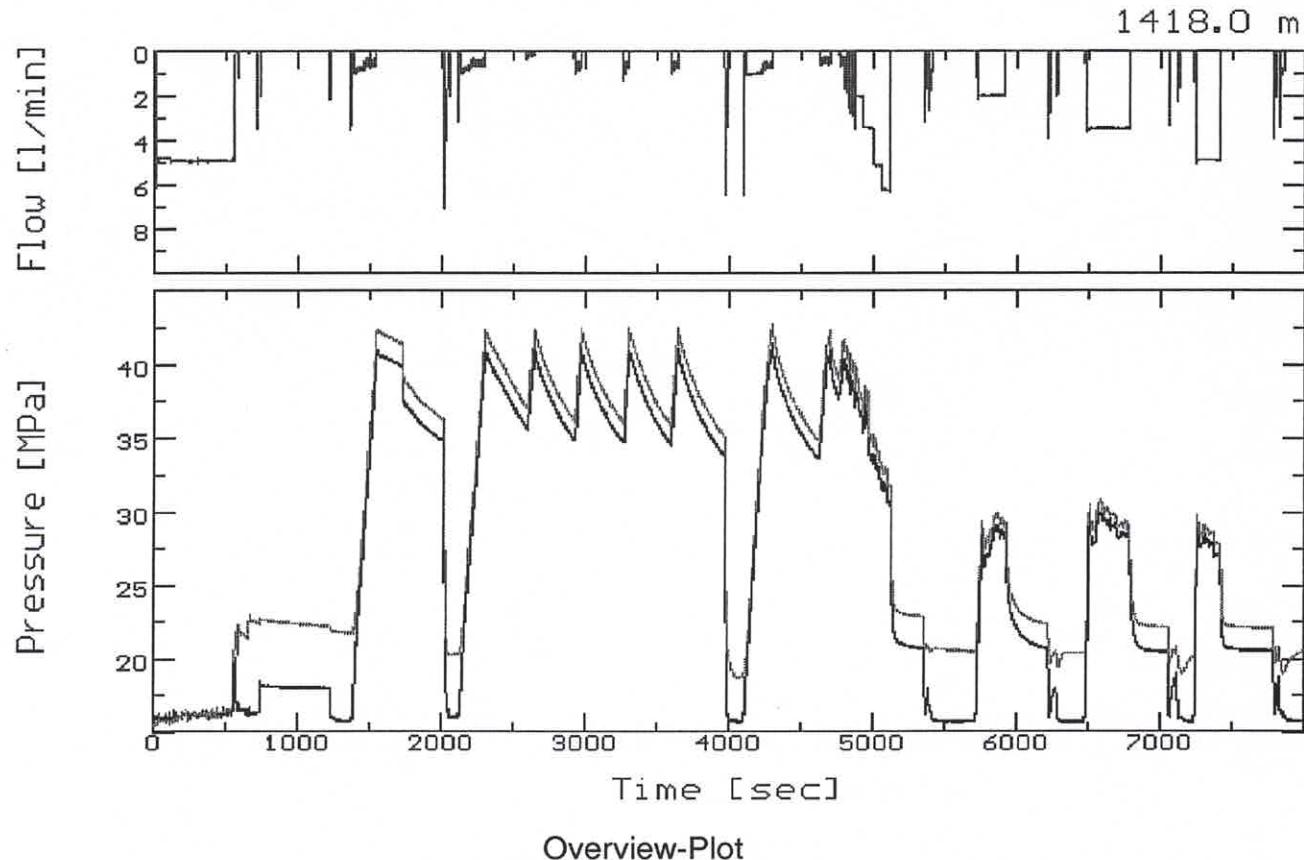
APPENDIX C

OVERVIEW PLOTS OF HYDROFRAC STRESS TESTS AND PRESSURE RECORD ANALYSIS FOR STRESS ESTIMATION

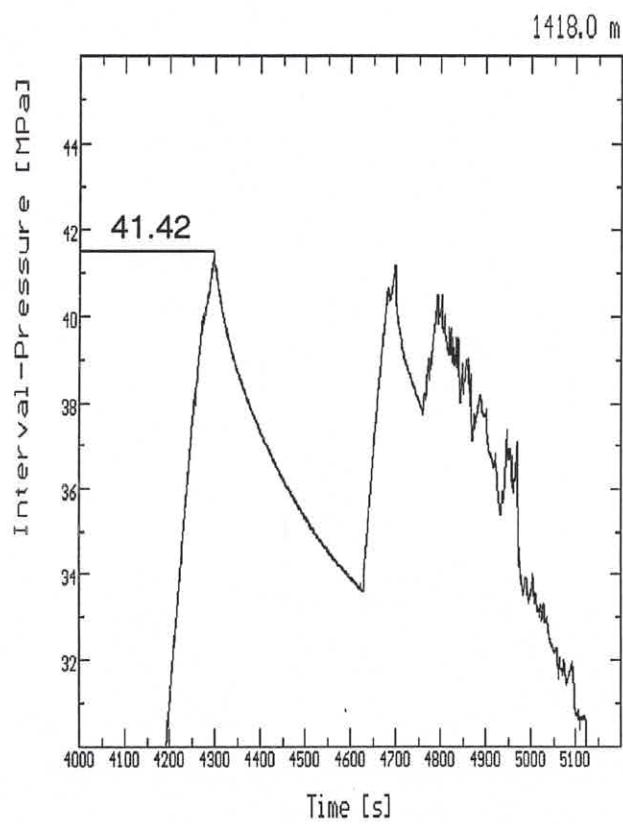
For each test section, the analysis contains:

- overview - plots of downhole injection- and packer pressure and surface flow - rate records of conducted frac - tests
- a detailed pressure vs. time plot for the determination of the frac - pressure P_c
- a pressure vs. volume plot for the determination of the refrac - pressure P_r
- several plots for the determination of the shut - in pressure P_{si}

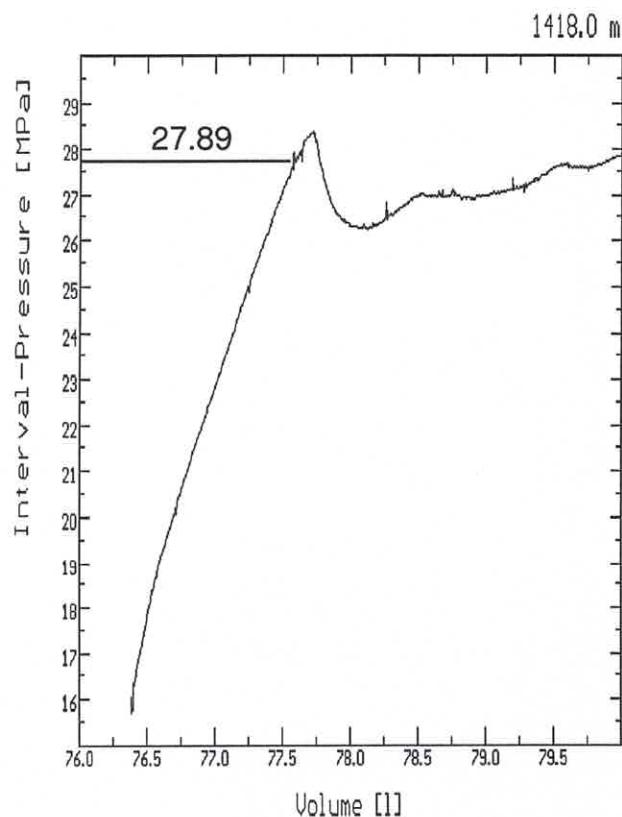
open - hole hydrofrac test at 1418.0 m



Overview-Plot

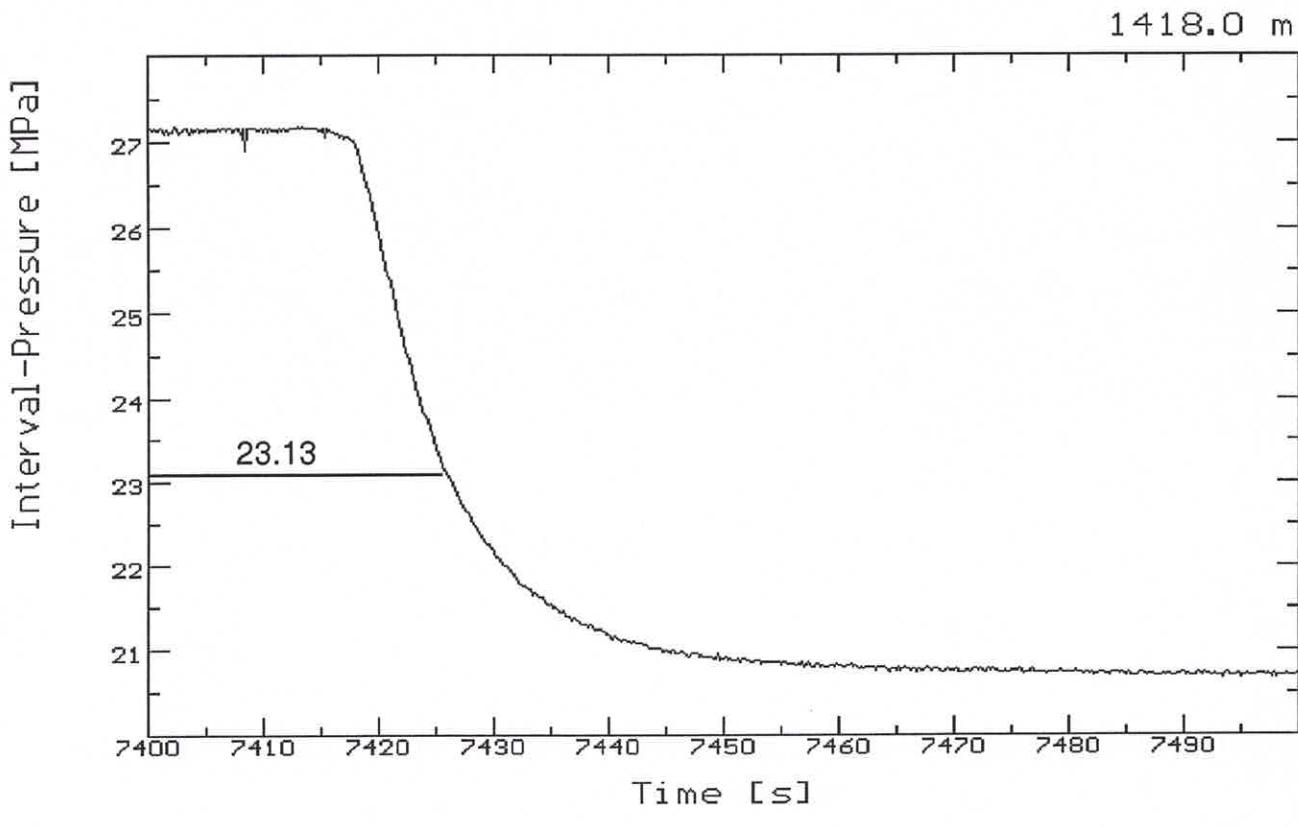


Estimation of P_c

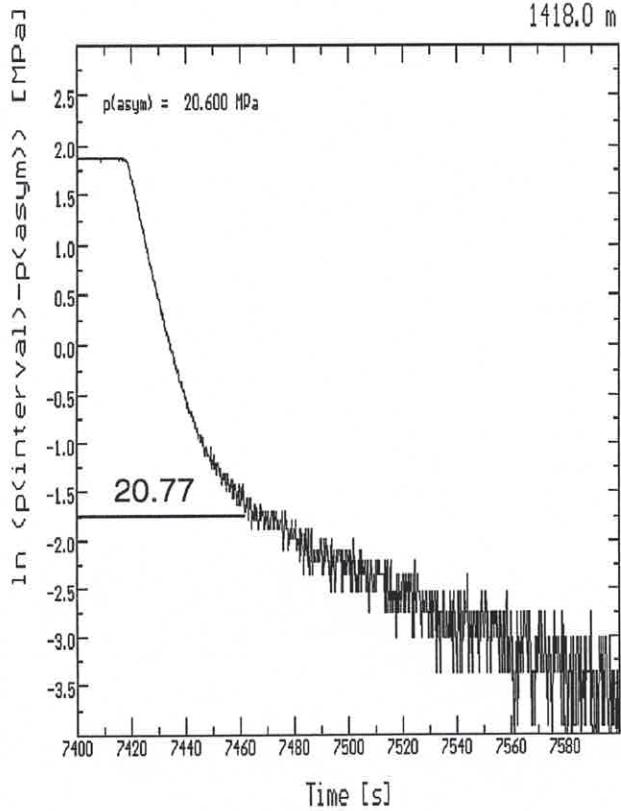


Estimation of P_r

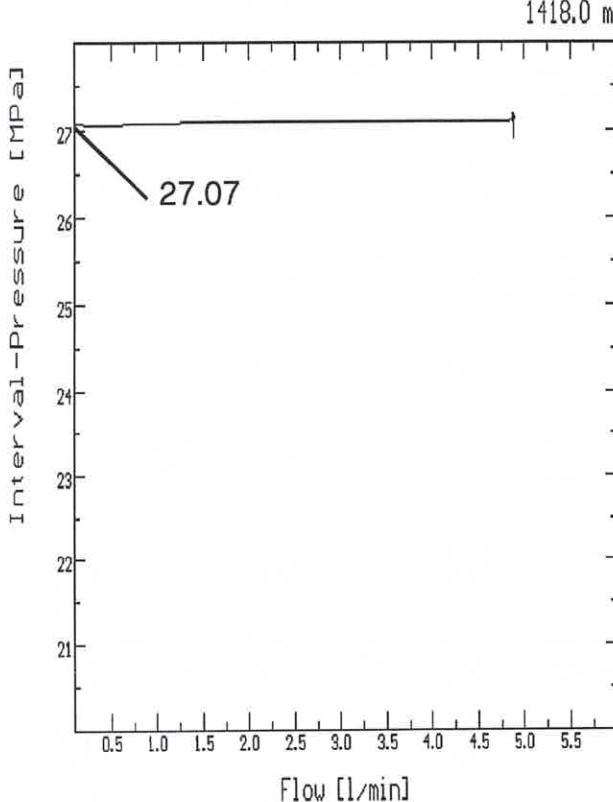
open - hole hydrofrac test at 1418.0 m



Estimation of P_{si}

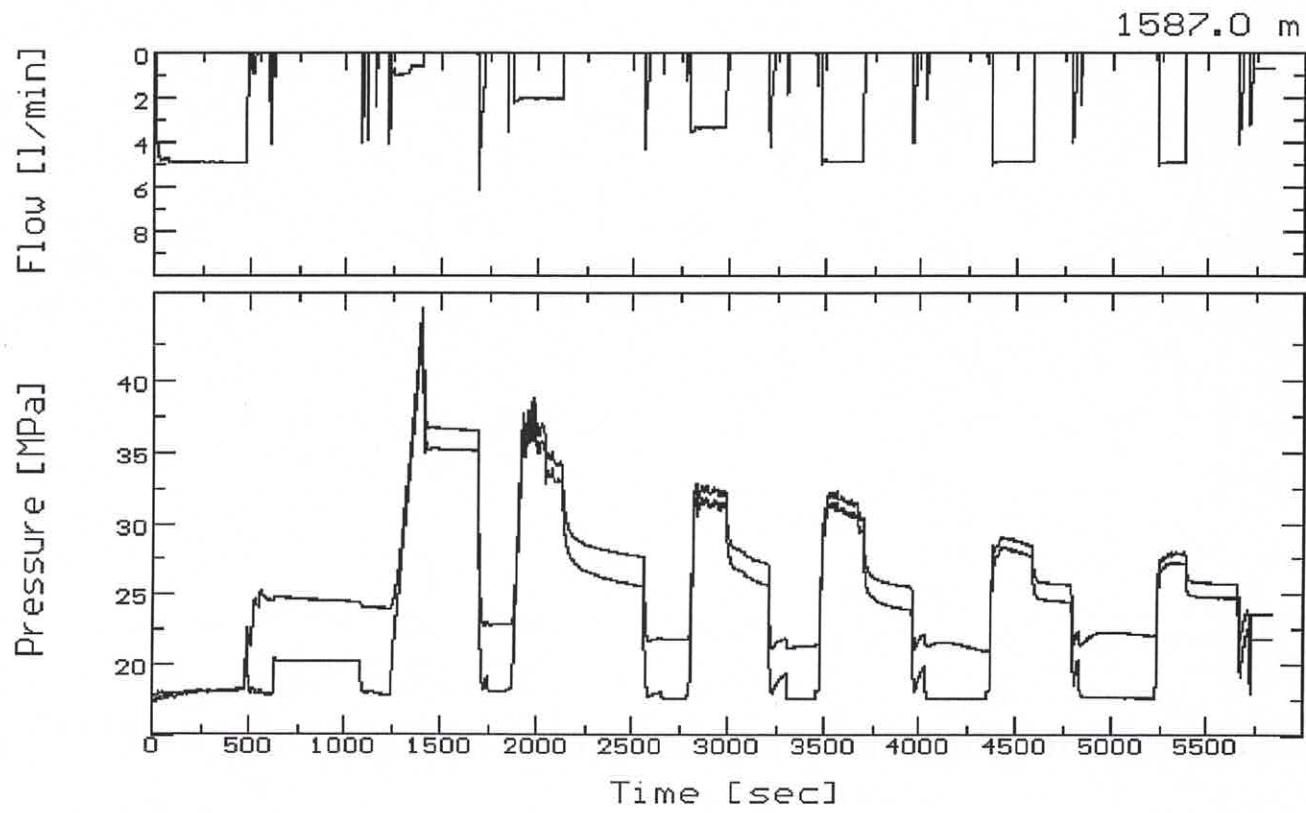


Estimation of $P_{si, \text{min}}$

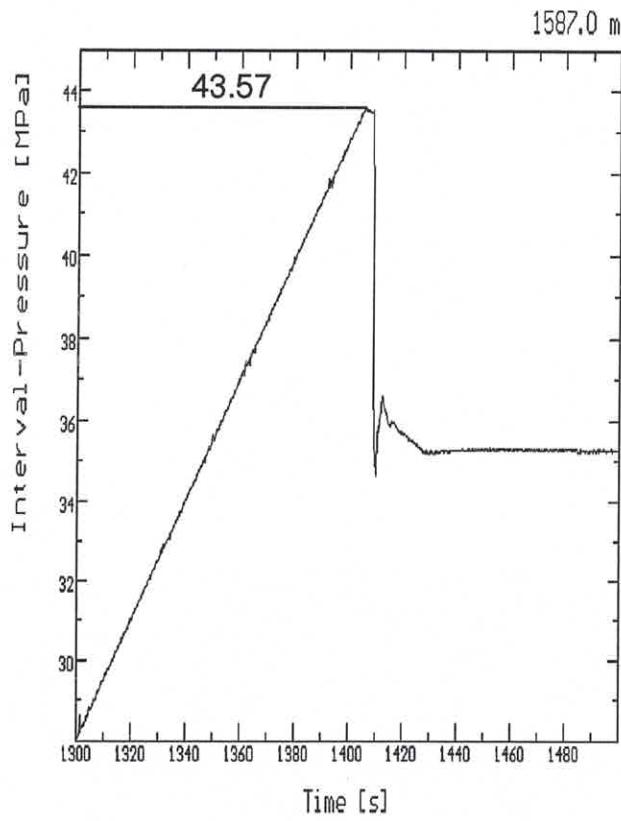


Estimation of $P_{si, \text{max}}$

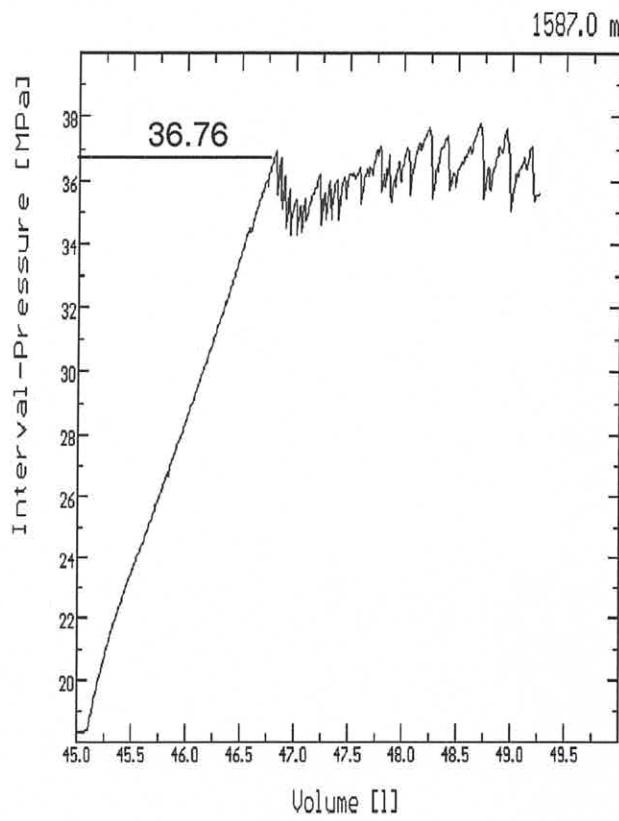
open - hole hydrofrac test at 1587.0 m



Overview-Plot

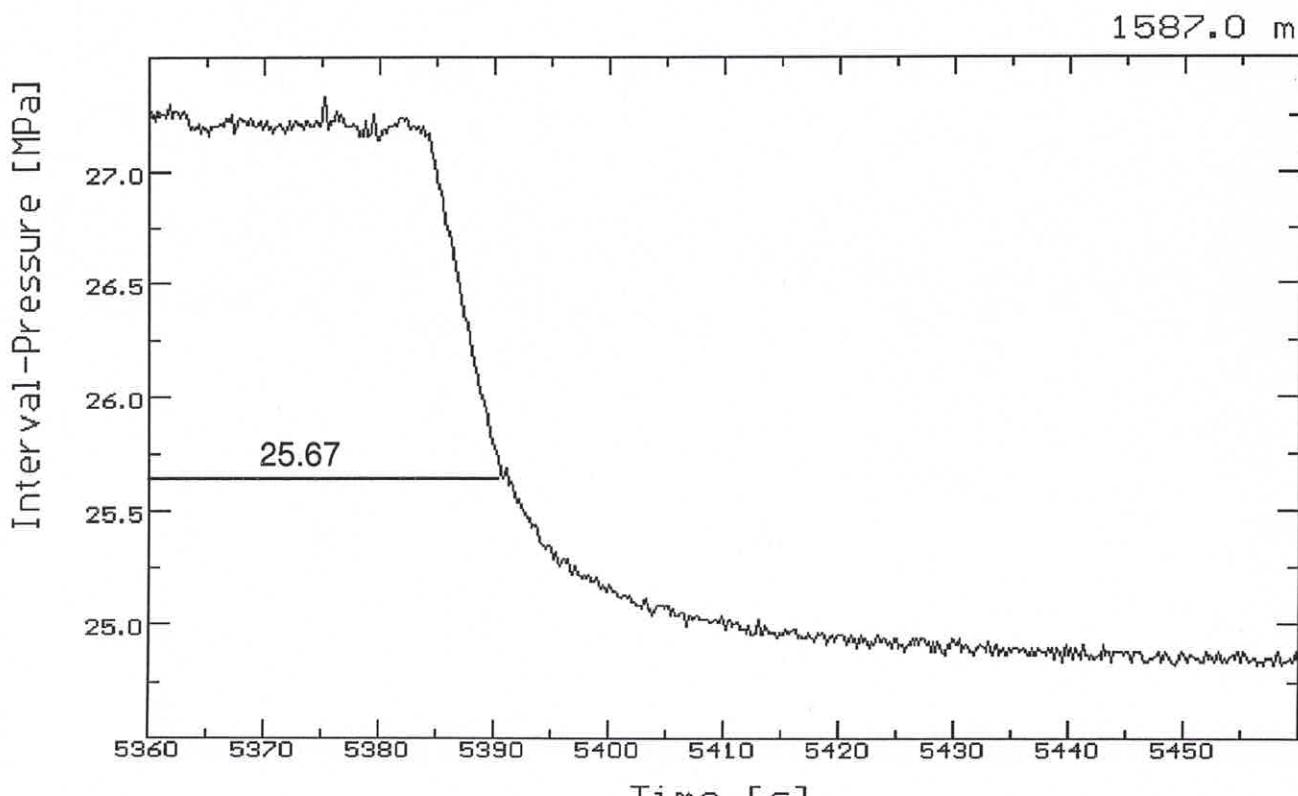


Estimation of P_c

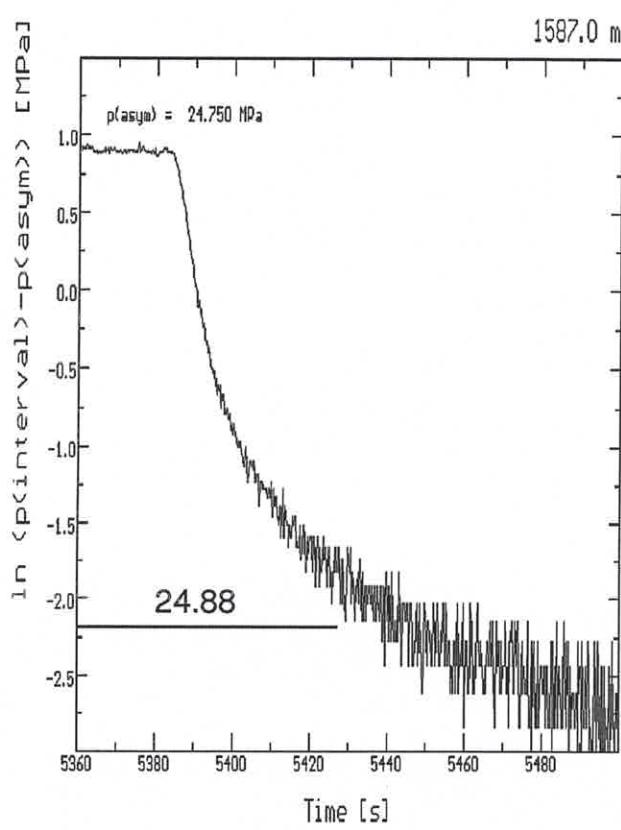


Estimation of P_r

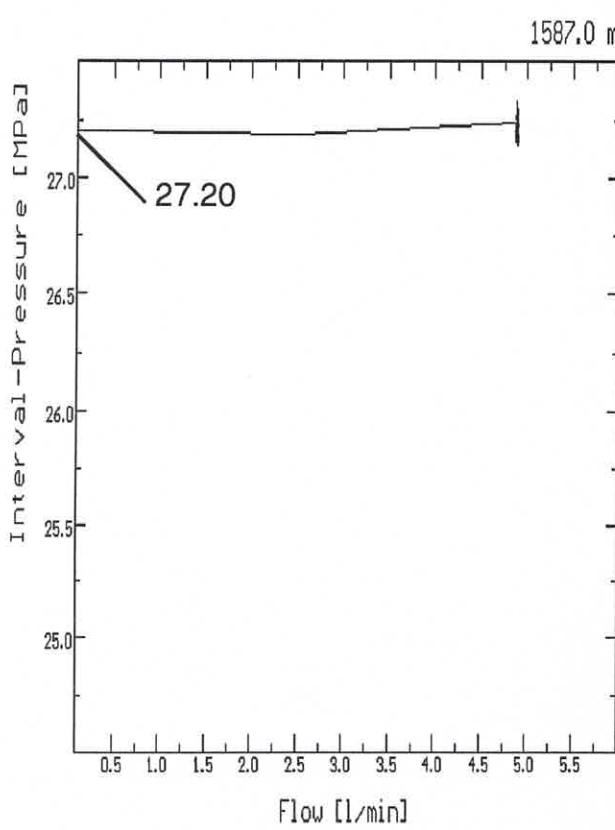
open - hole hydrofrac test at 1587.0 m



Estimation of P_{si}

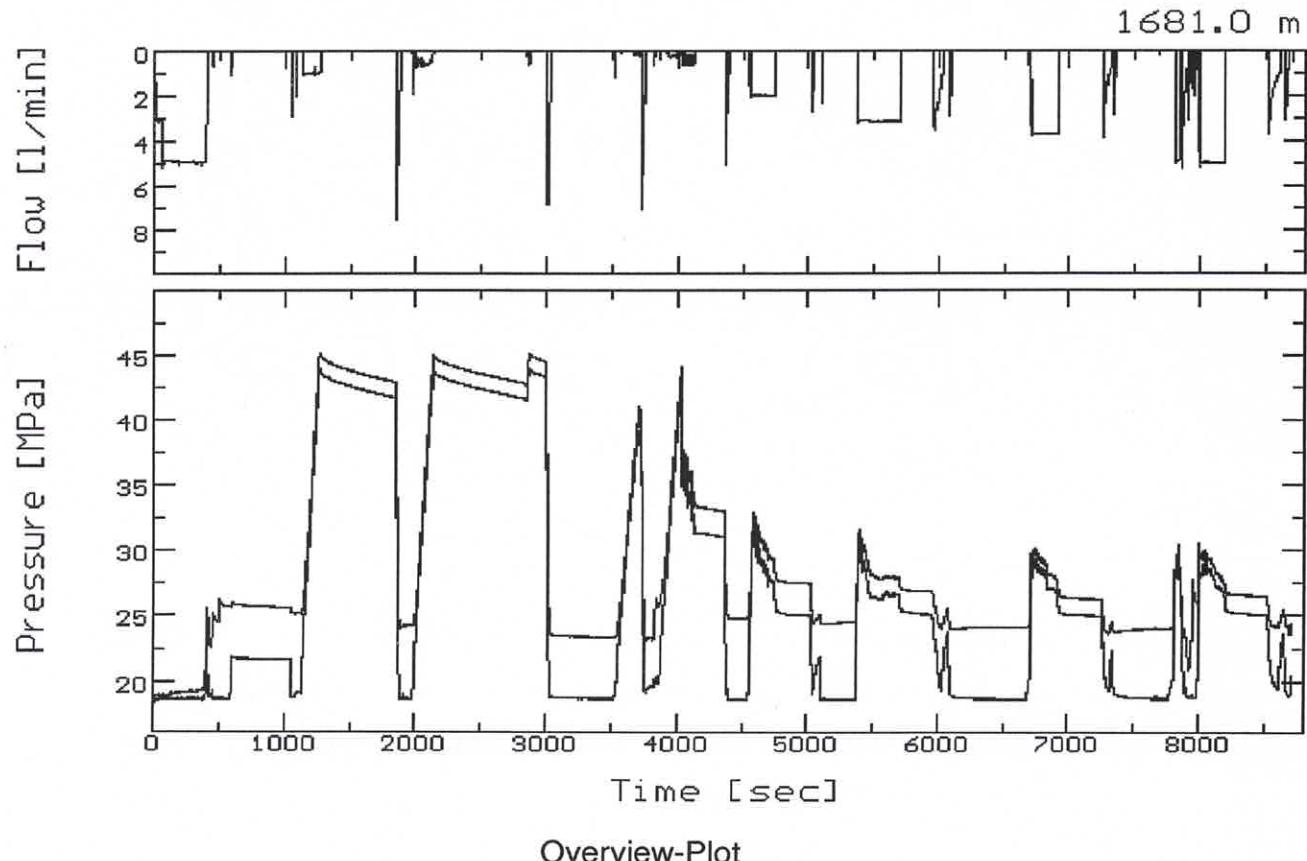


Estimation of $P_{si, min}$

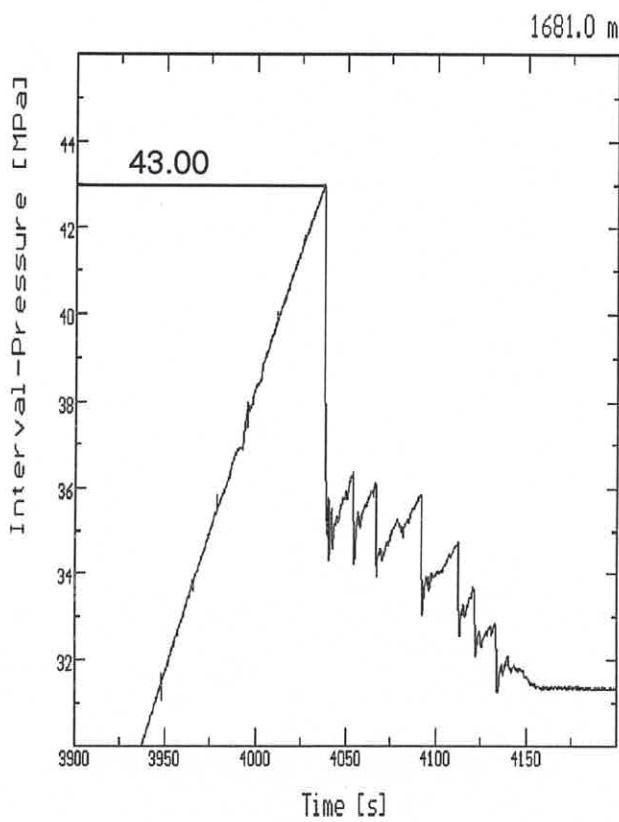


Estimation of $P_{si, max}$

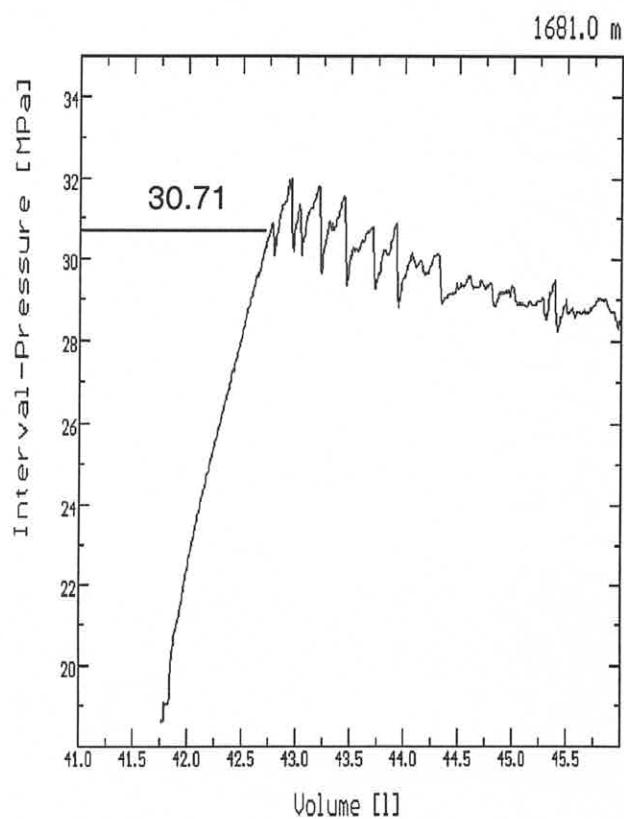
open - hole hydrofrac test at 1681.0 m



Overview-Plot

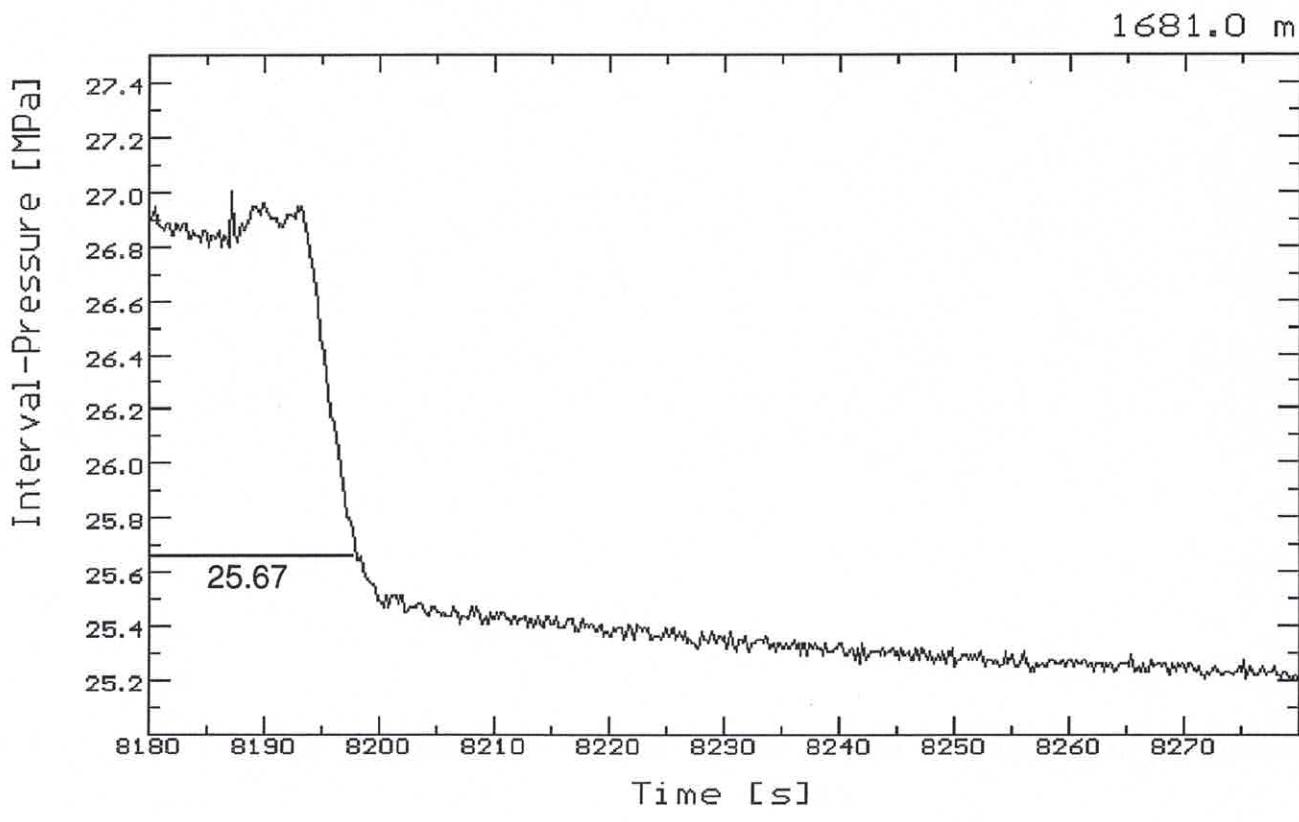


Estimation of P_c

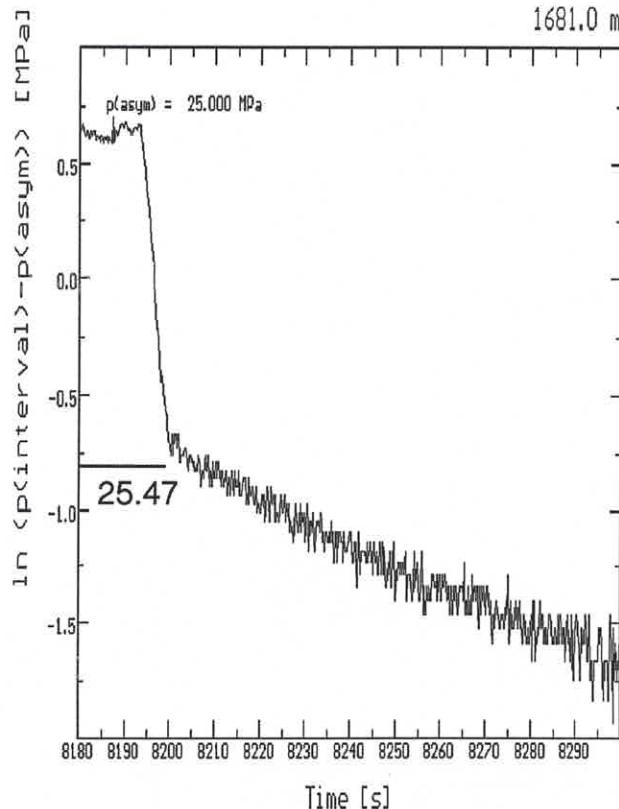


Estimation of P_r

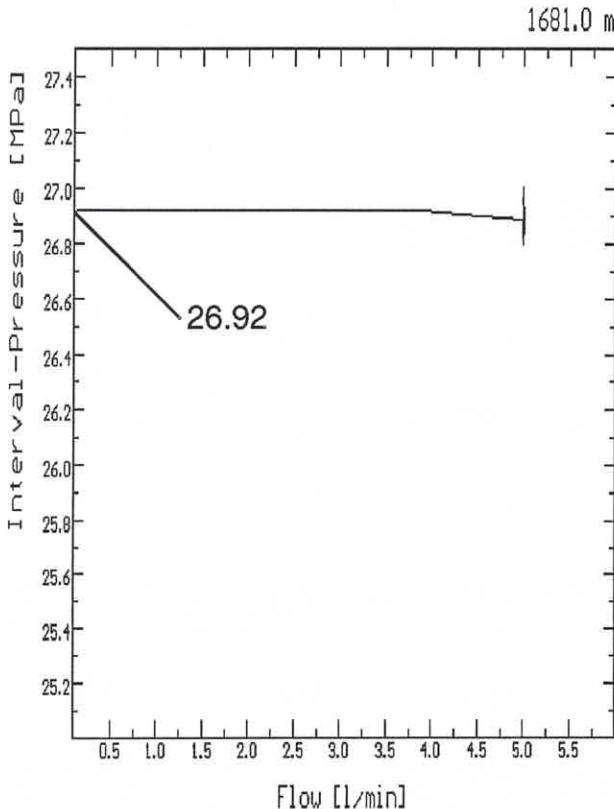
open - hole hydrofrac test at 1681.0 m



Estimation of P_{si}

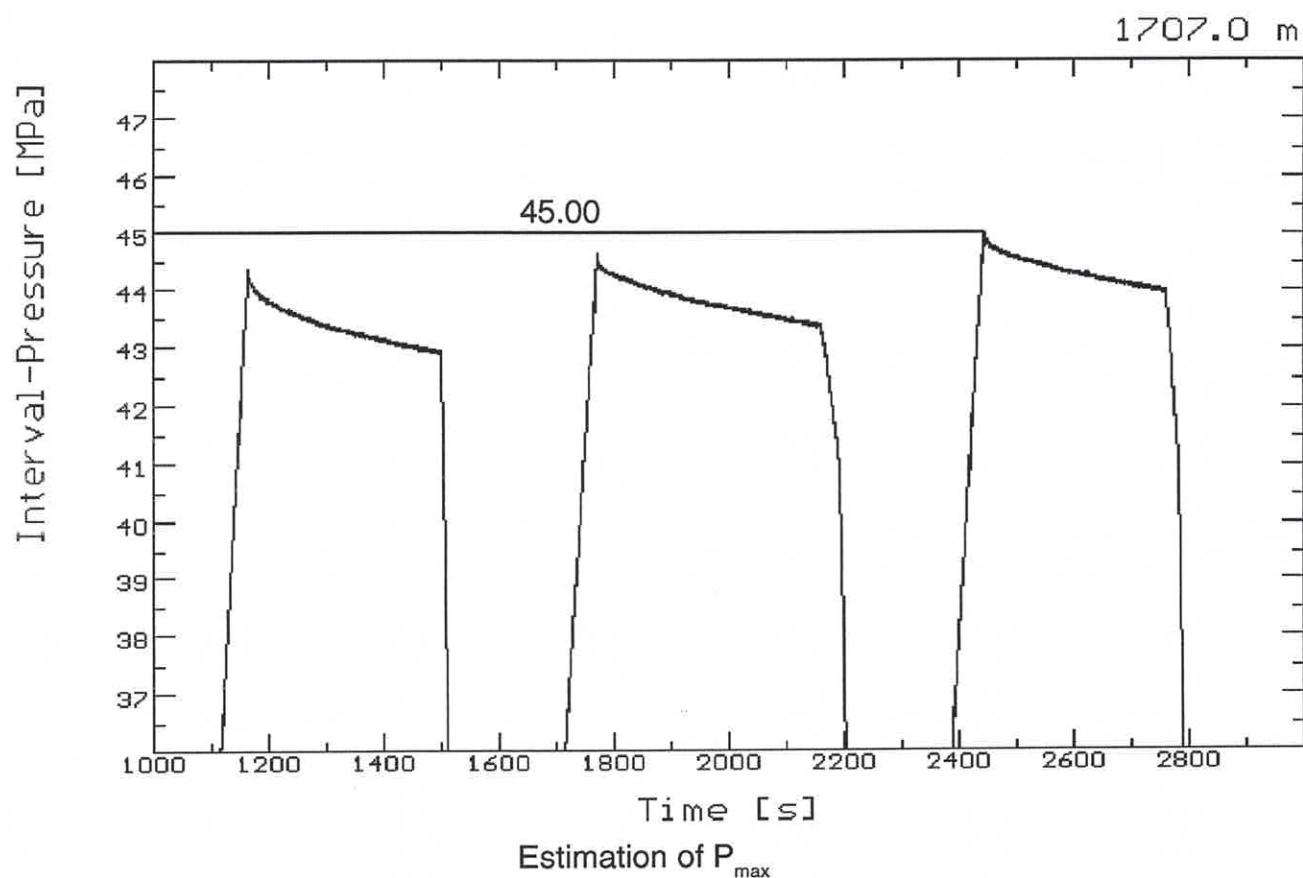
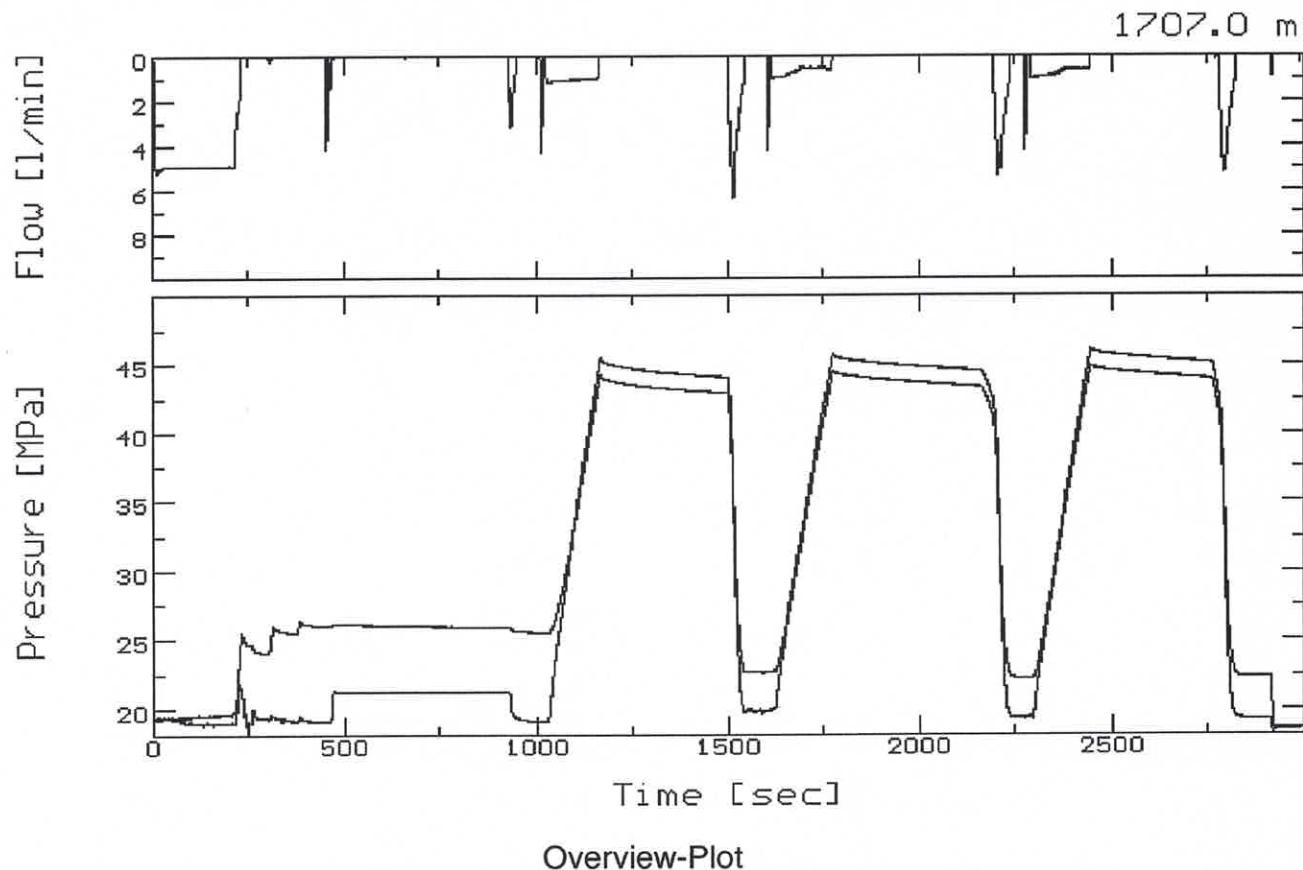


Estimation of $P_{si, \text{min}}$

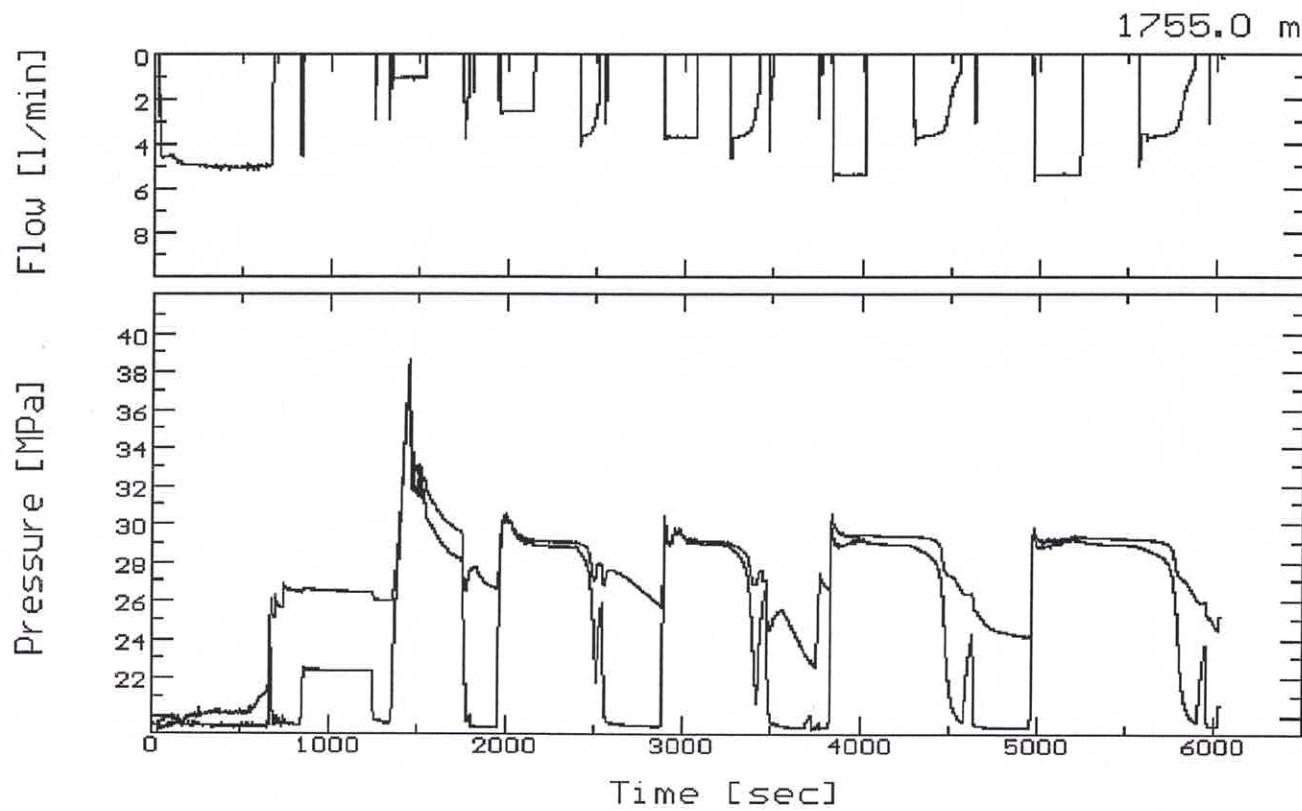


Estimation of $P_{si, \text{max}}$

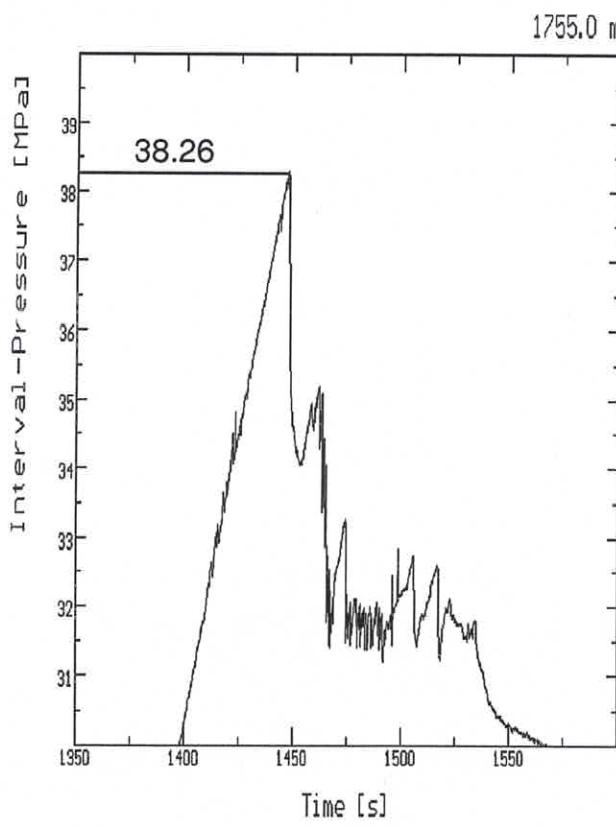
open - hole hydrofrac test at 1707.0 m



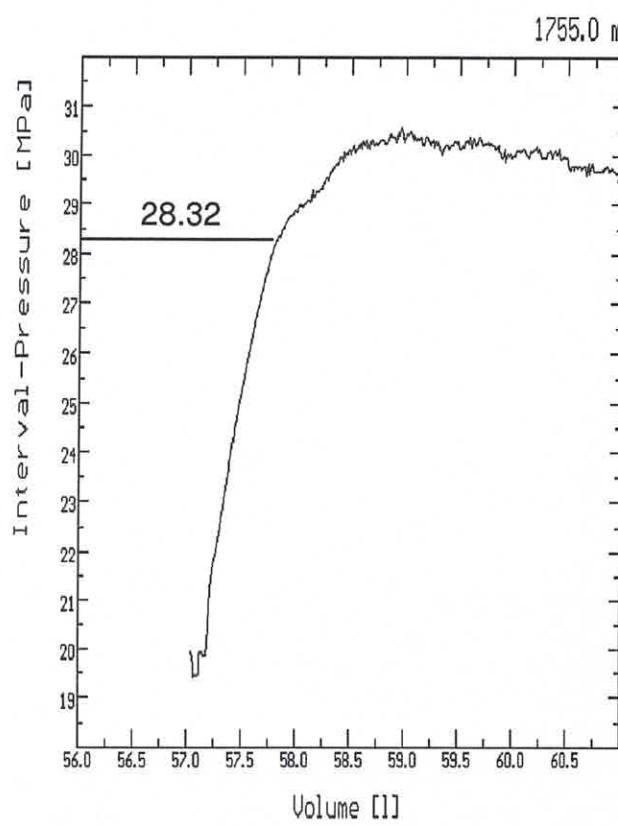
open - hole hydrofrac test at 1755.0 m



Overview-Plot



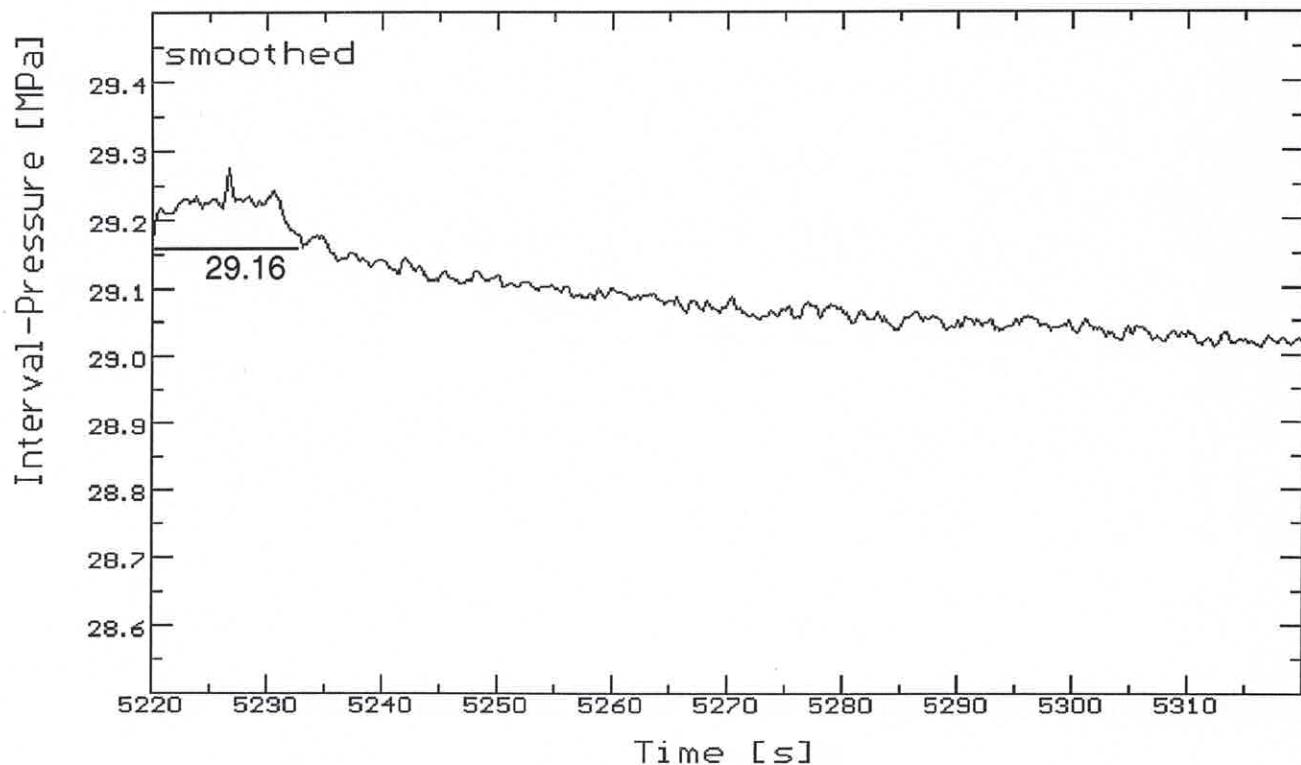
Estimation of P_c



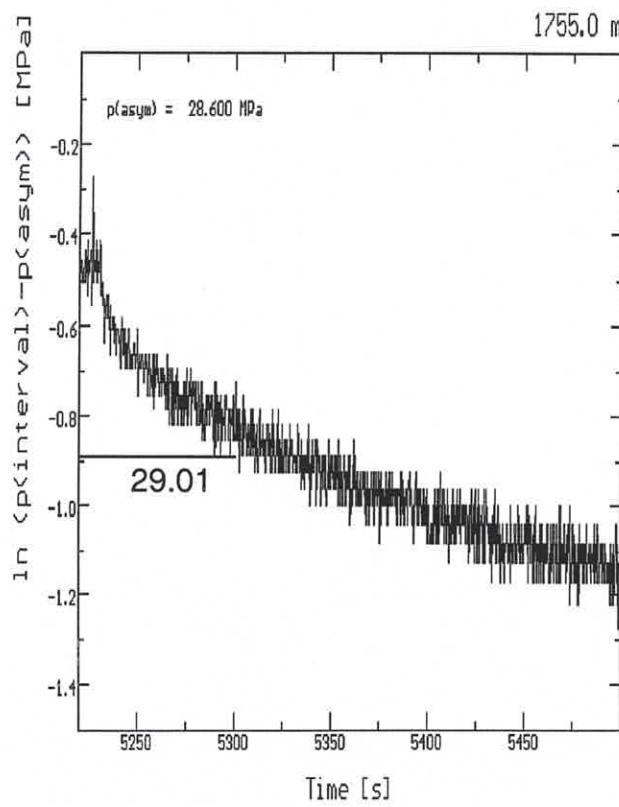
Estimation of P_r

open - hole hydrofrac test at 1755.0 m

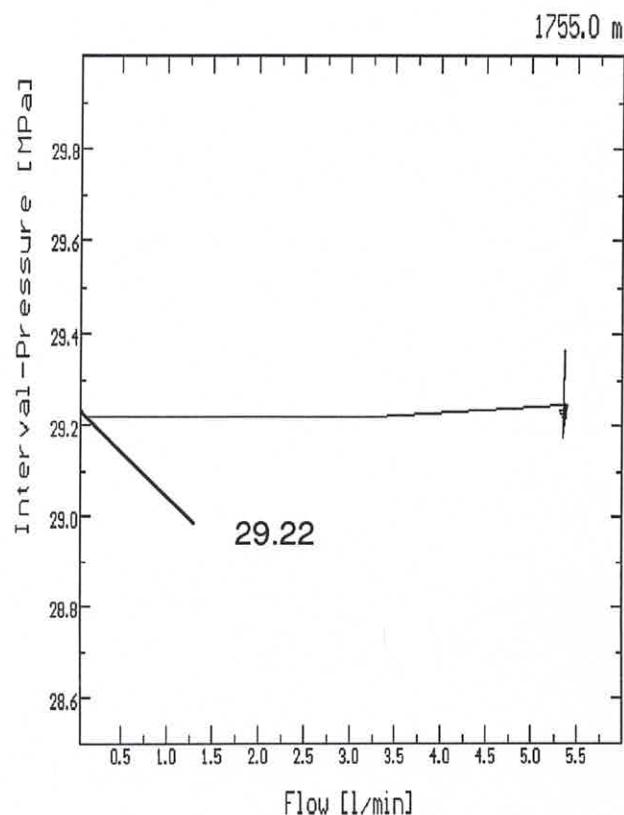
1755.0 m



Estimation of P_{si}

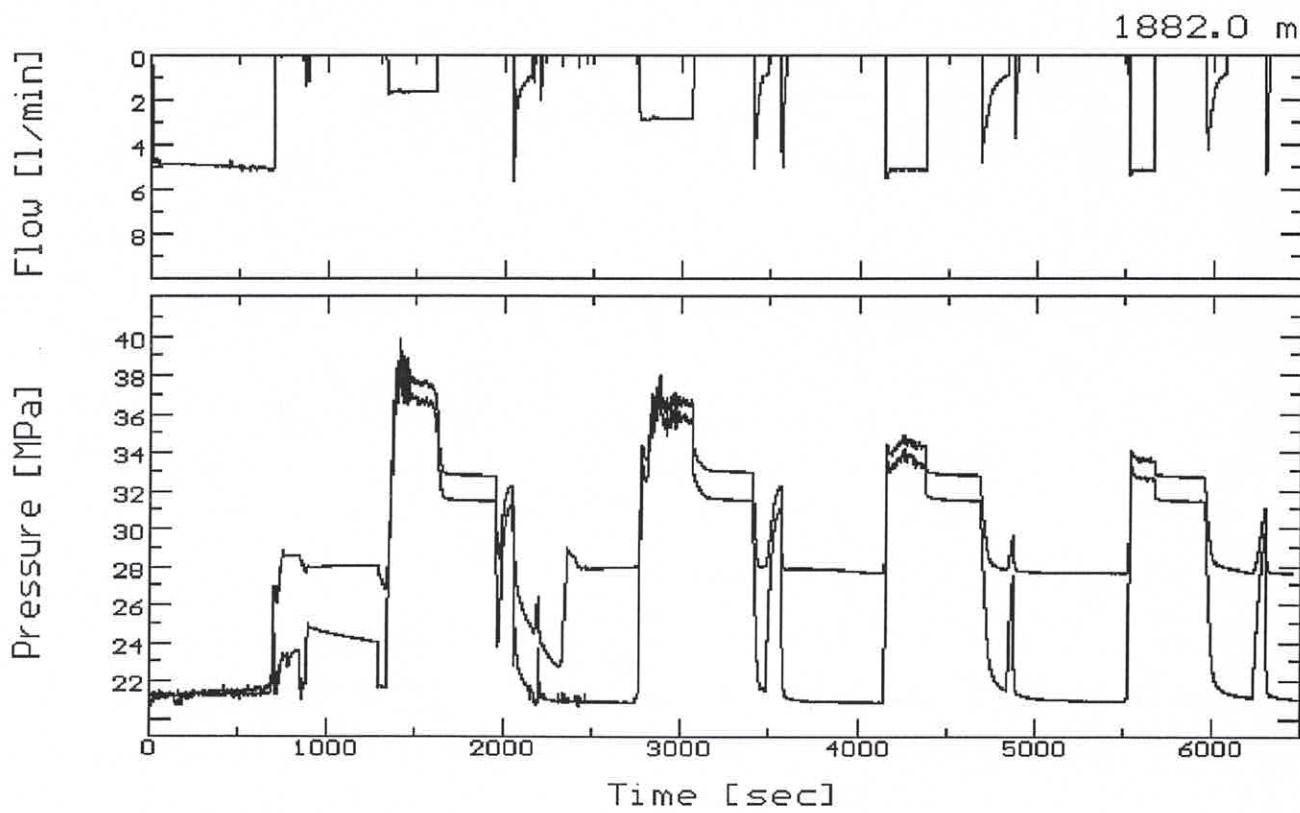


Estimation of $P_{si, min}$

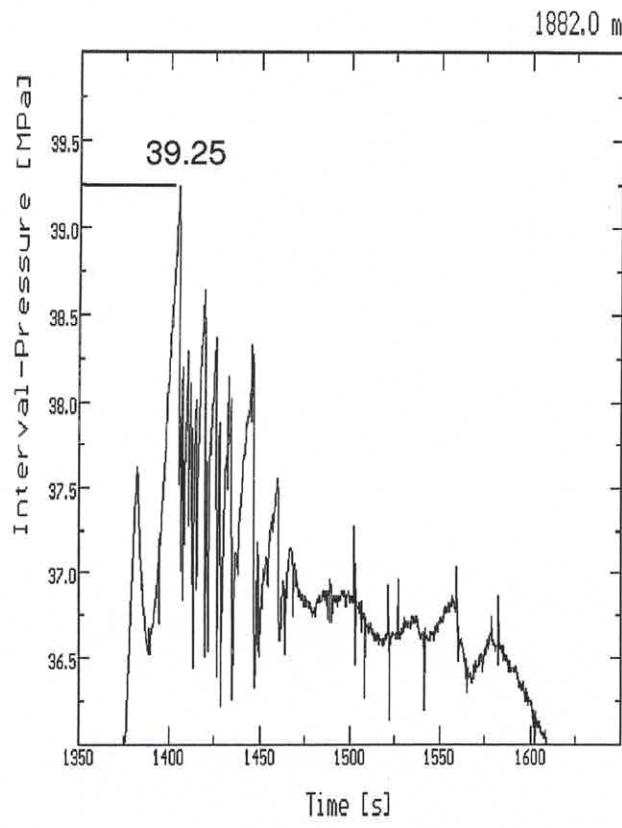


Estimation of $P_{si, max}$

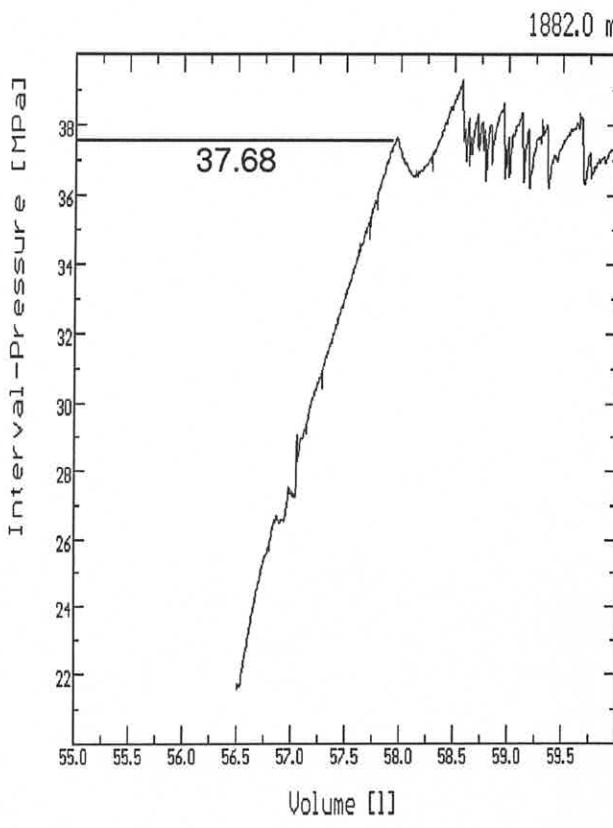
open - hole hydrofrac test at 1882.0 m



Overview-Plot

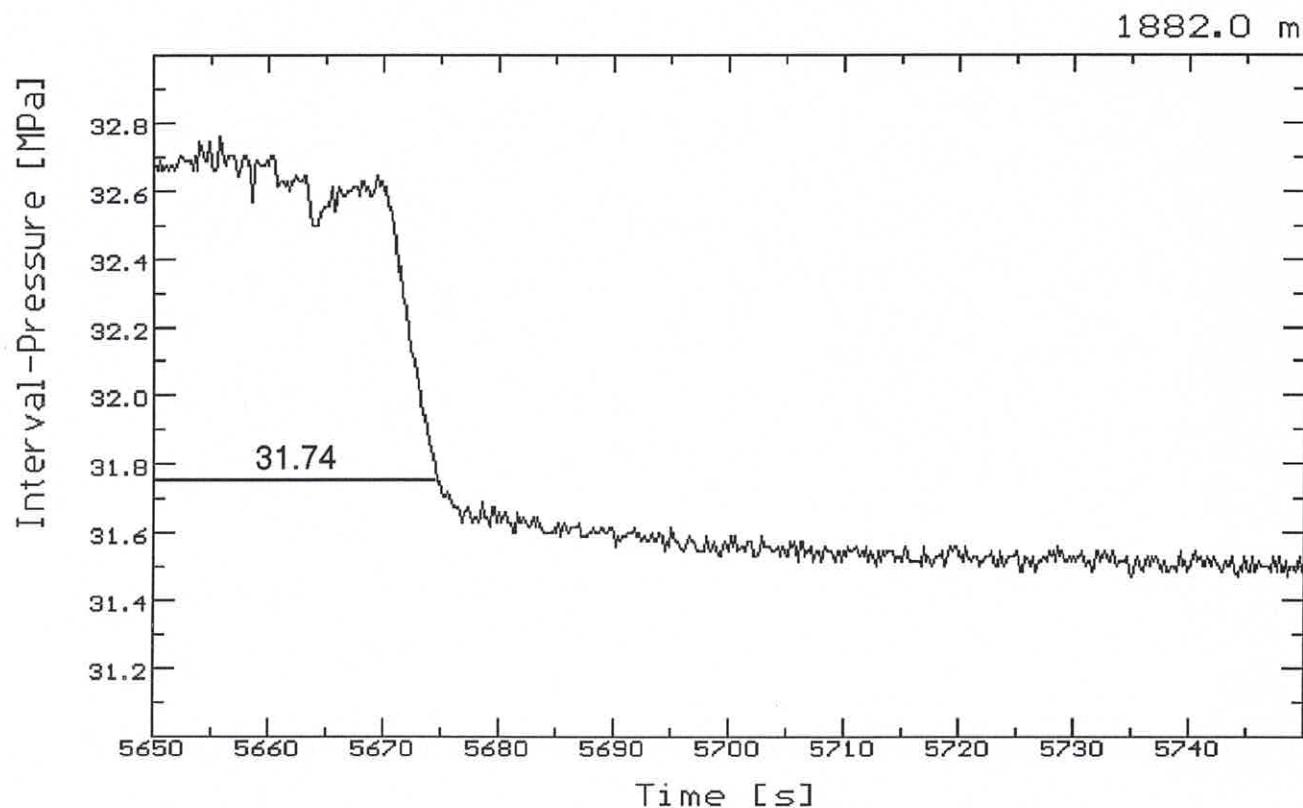


Estimation of P_c

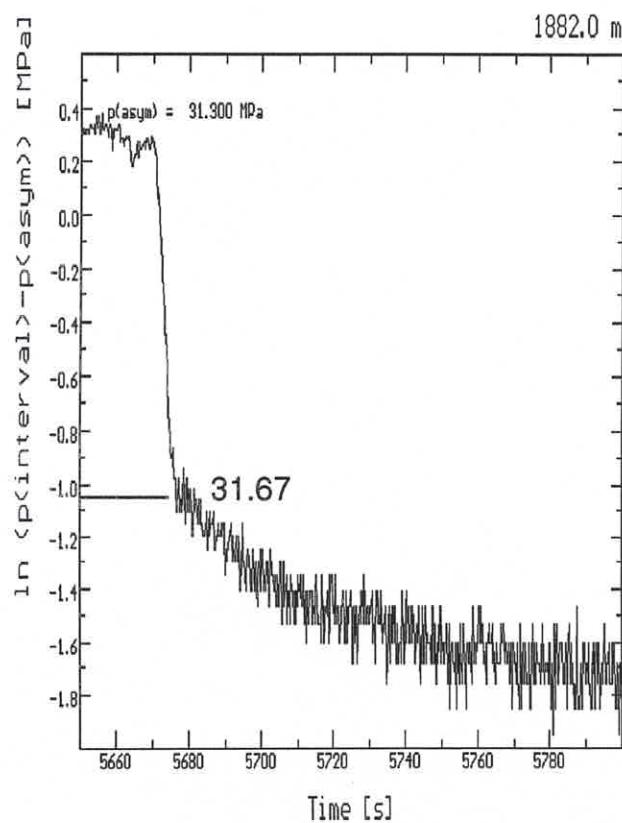


Estimation of P_r

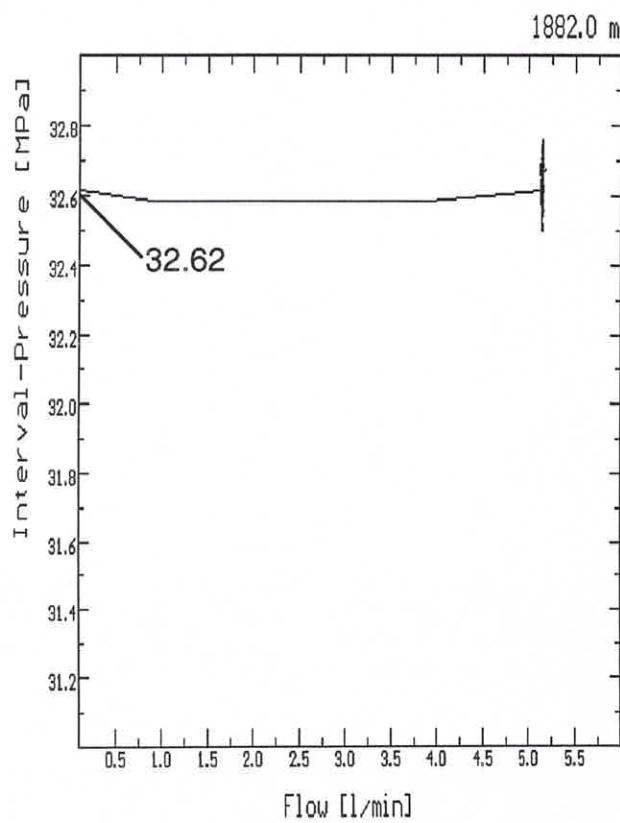
open - hole hydrofrac test at 1882.0 m



Estimation of P_{si}

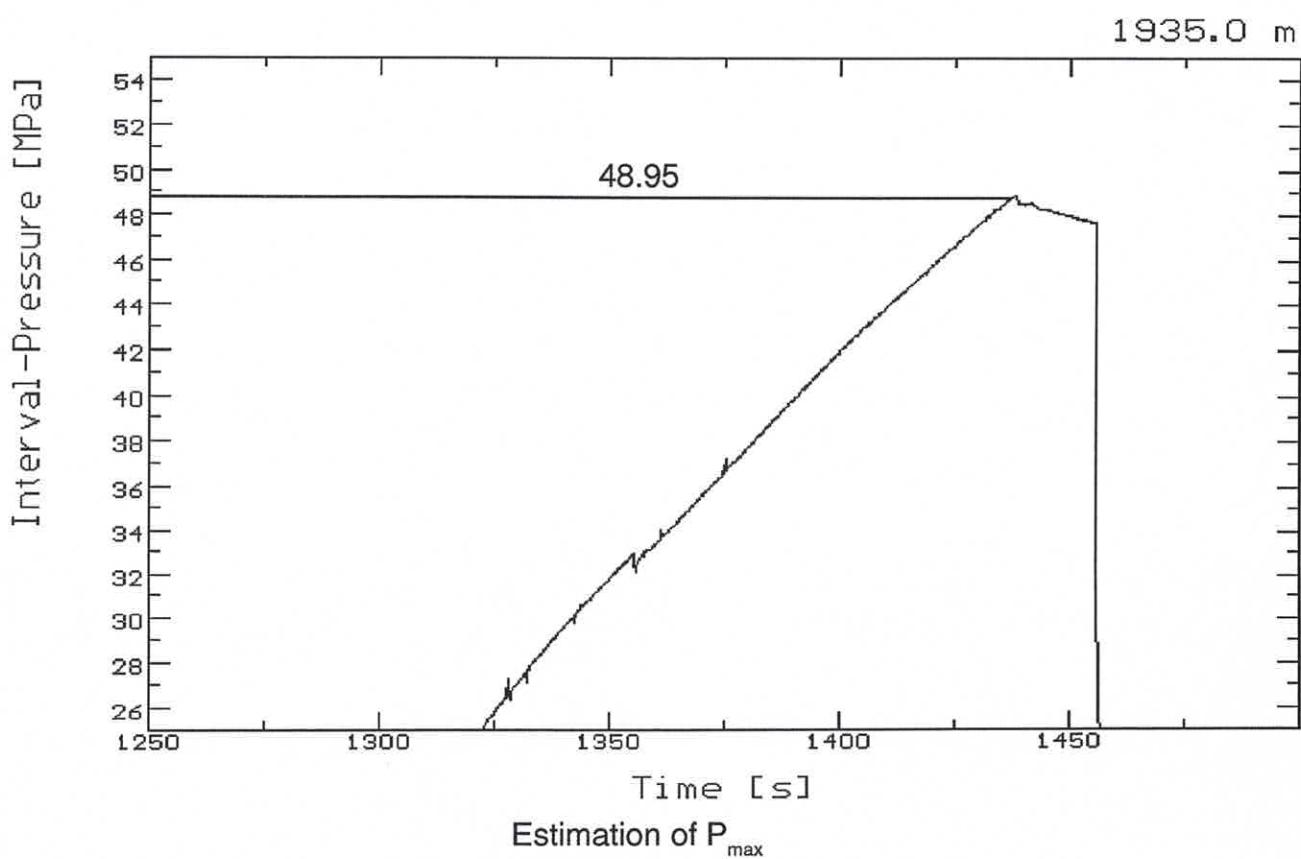
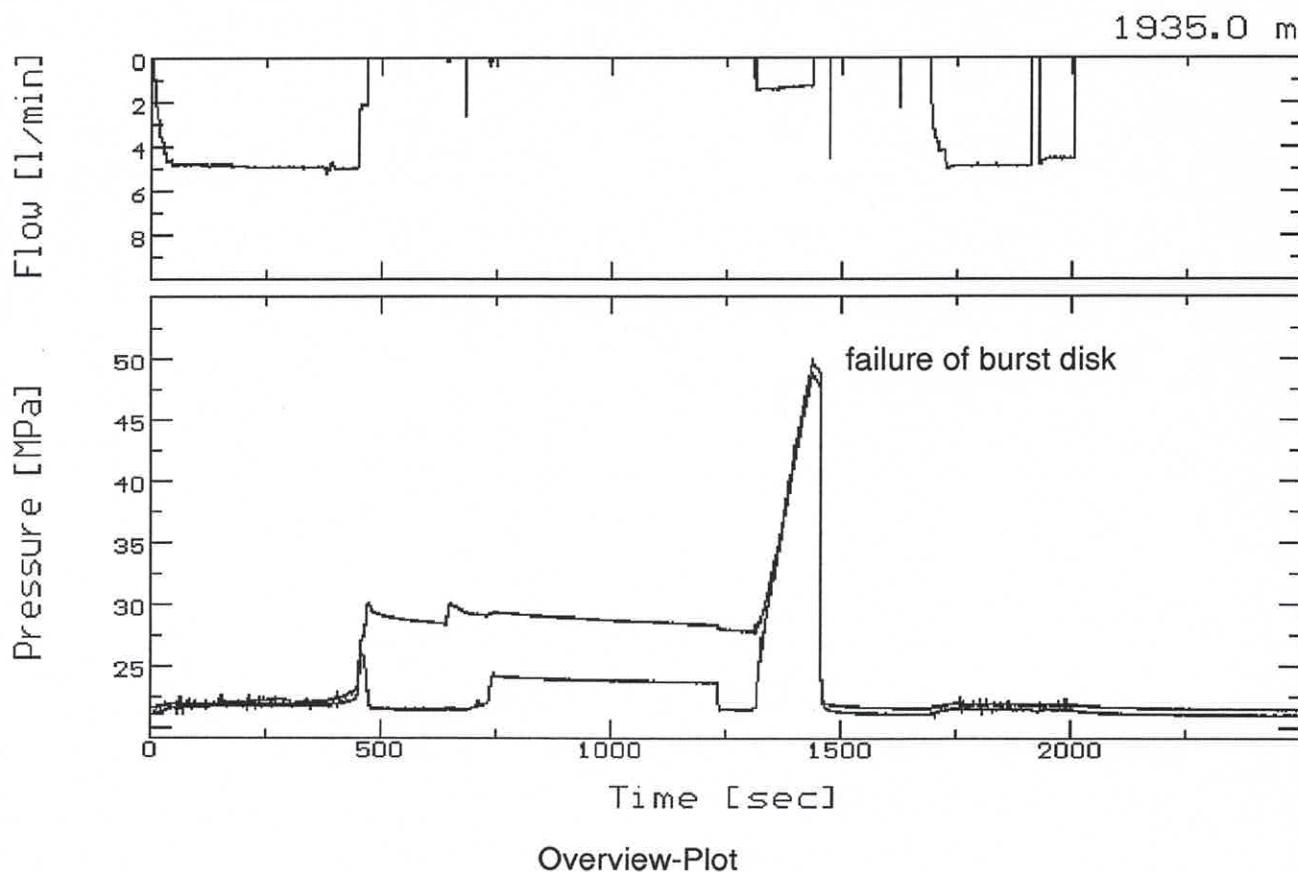


Estimation of $P_{si, \min}$



Estimation of $P_{si, \max}$

open - hole hydrofrac test at 1935.0 m



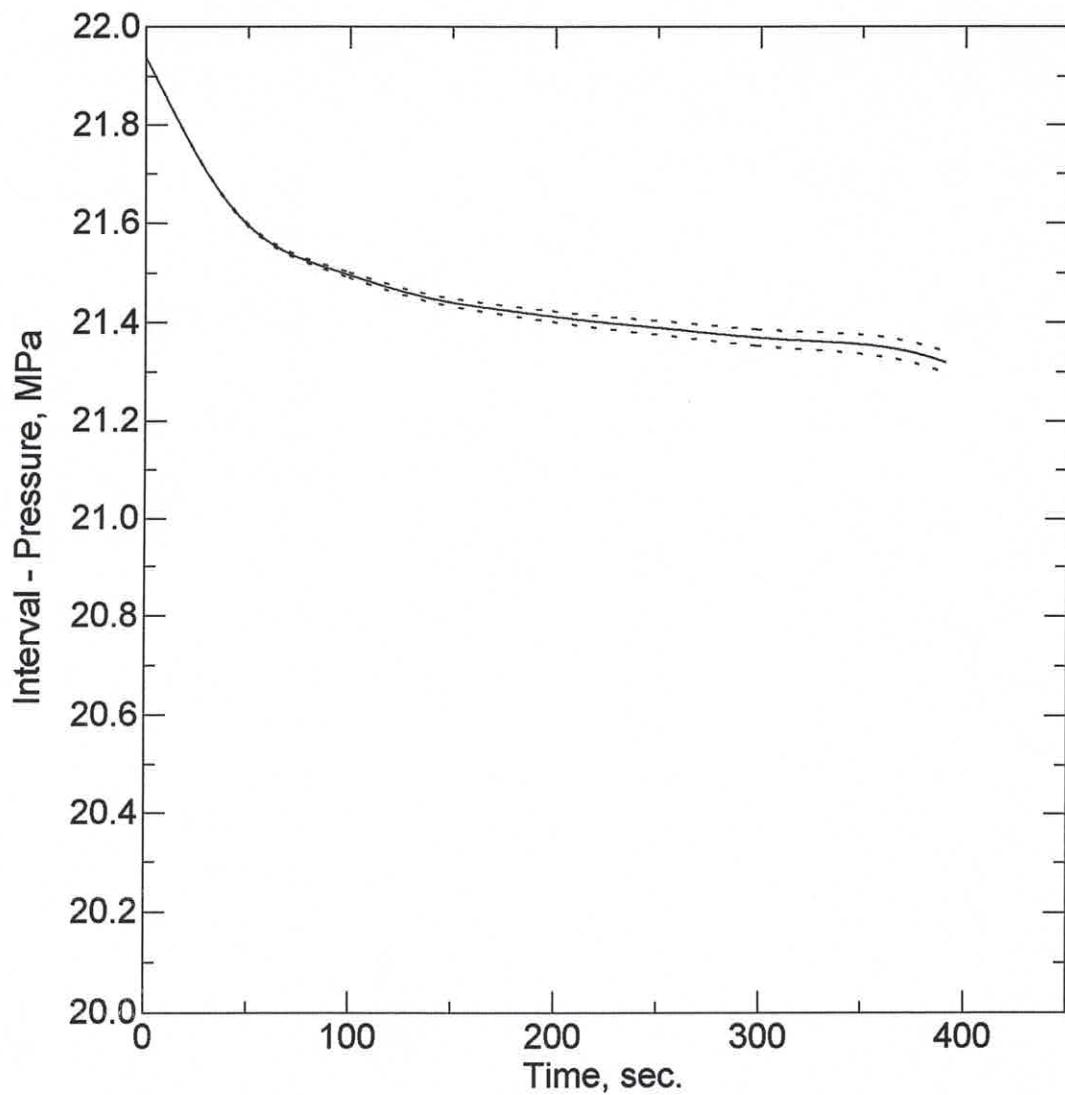
APPENDIX D

ANALYSIS OF PRESSURE PULSE TESTS FOR PERMEABILITY / TRANSMISSIVITY EVALUATION

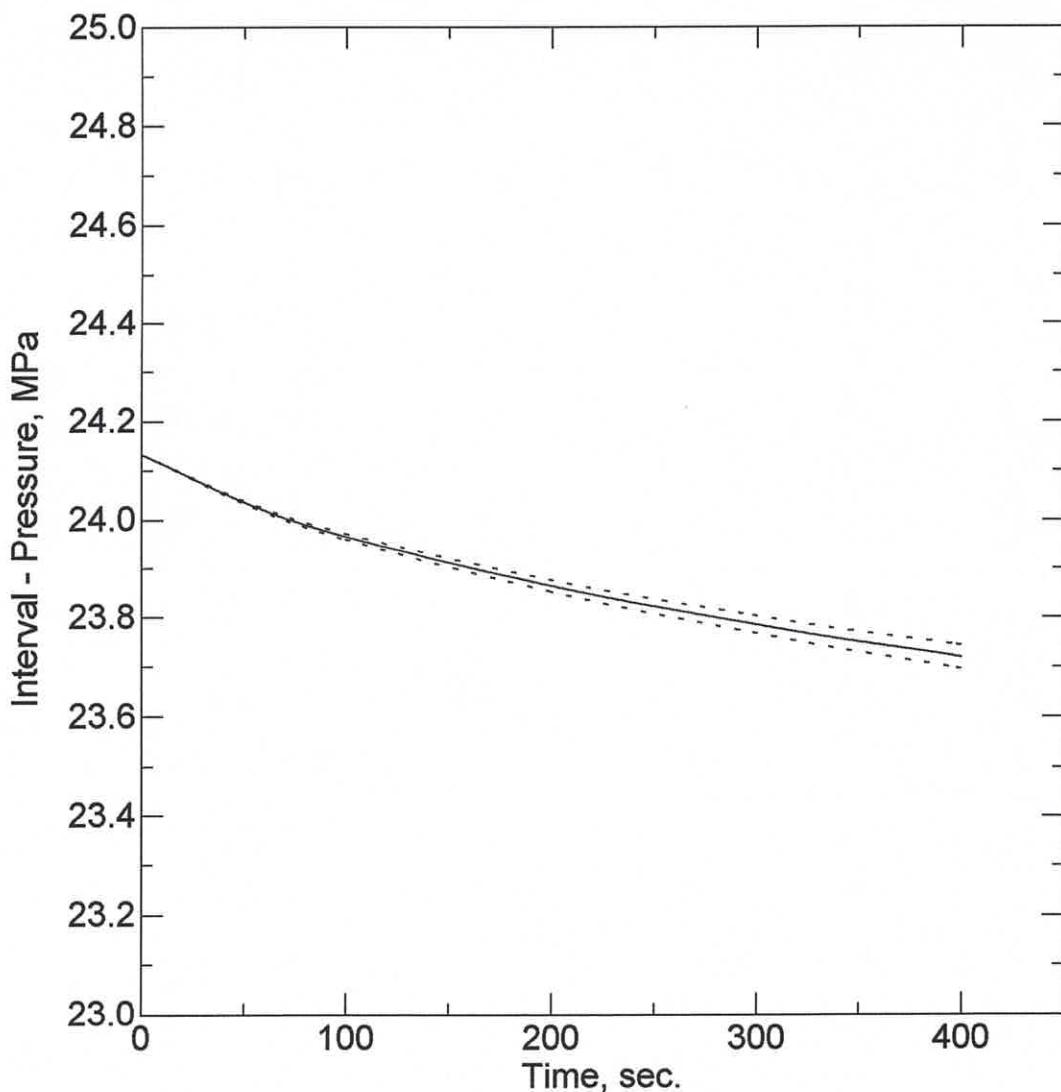
remarks :

- solid line: measured data
- broken lines: maximal difference between measured and theoretically calculated pressure decline curves

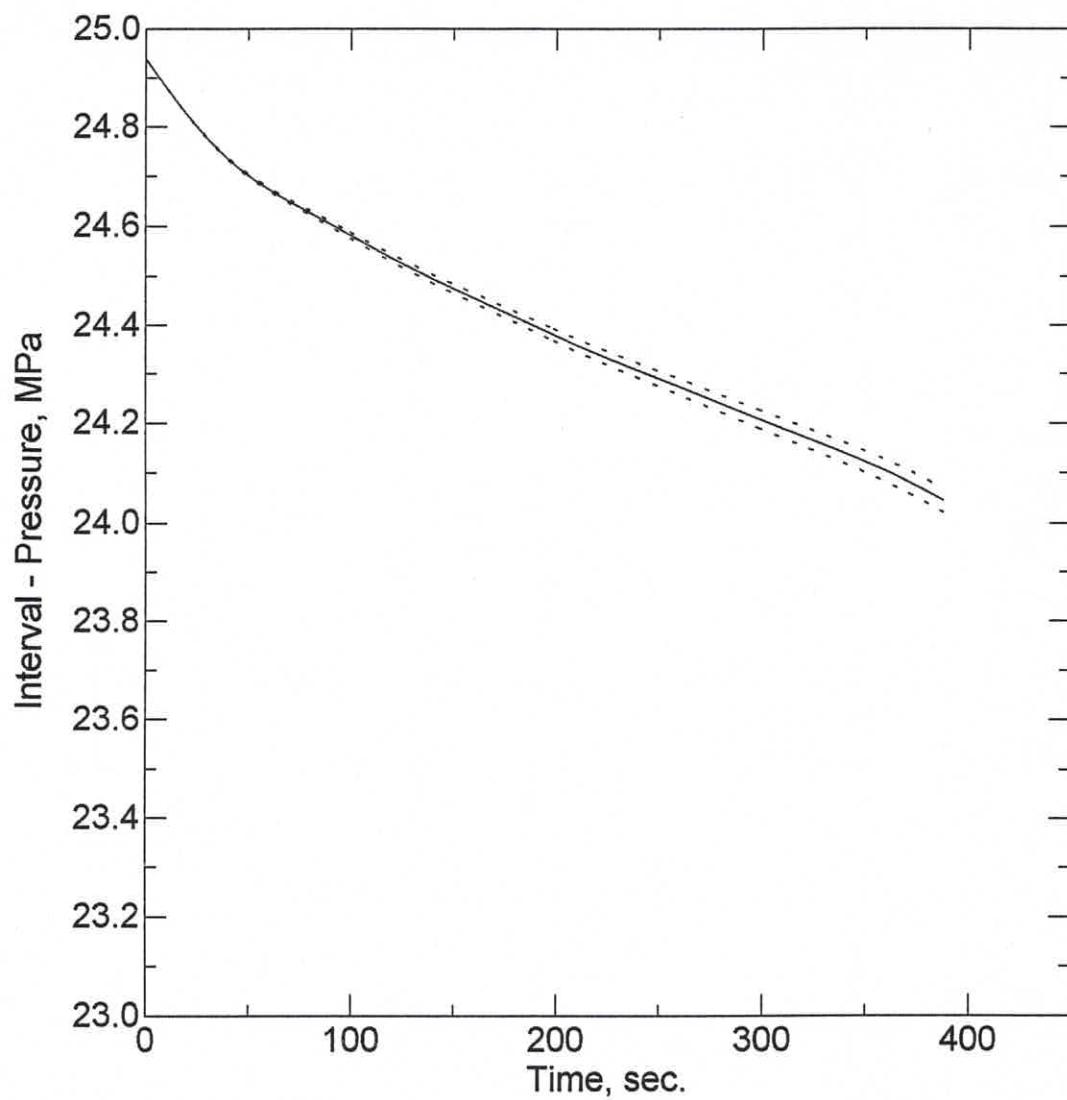
Test 2: 1760.3 m



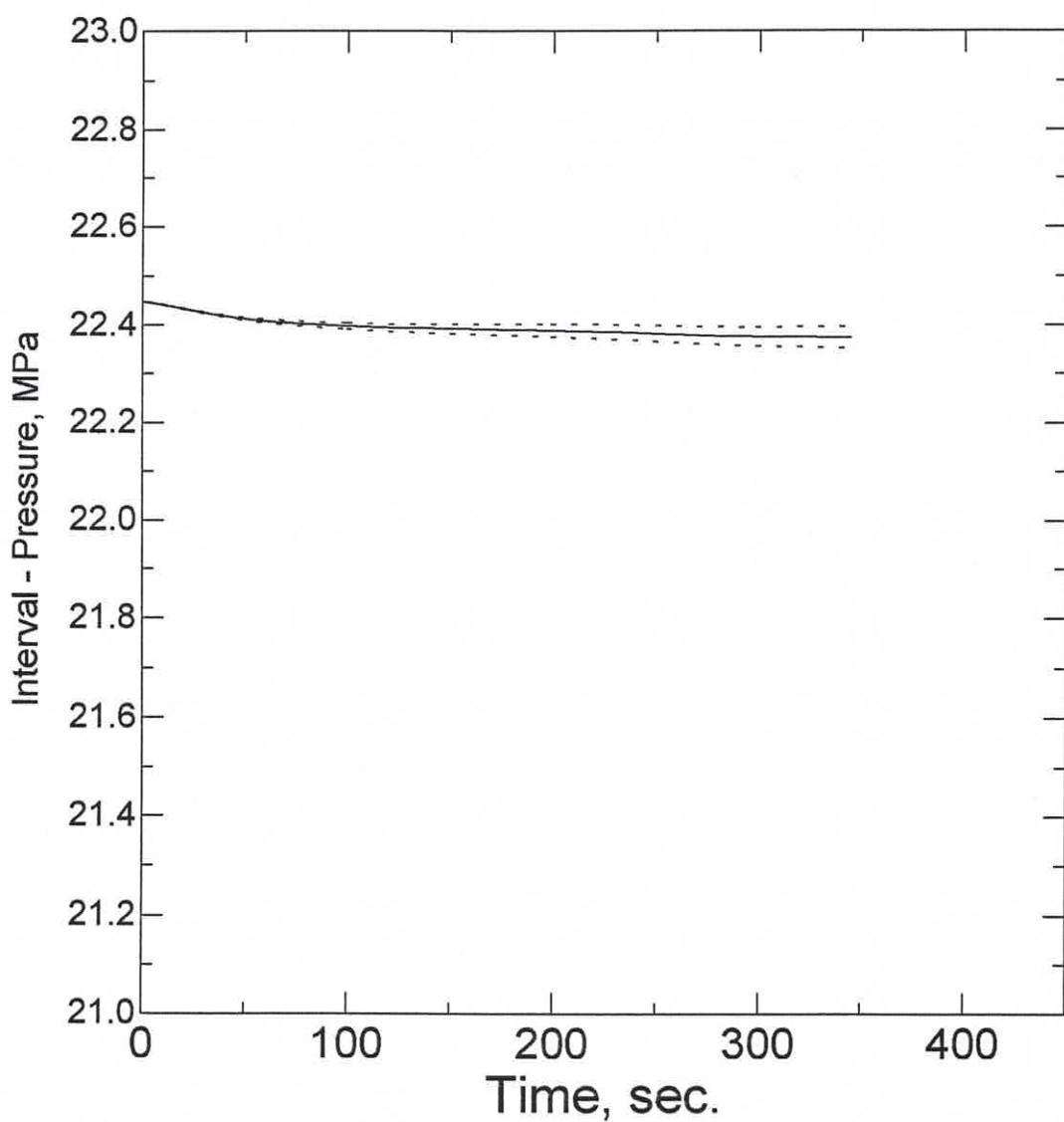
Test 4: 1935.0 m



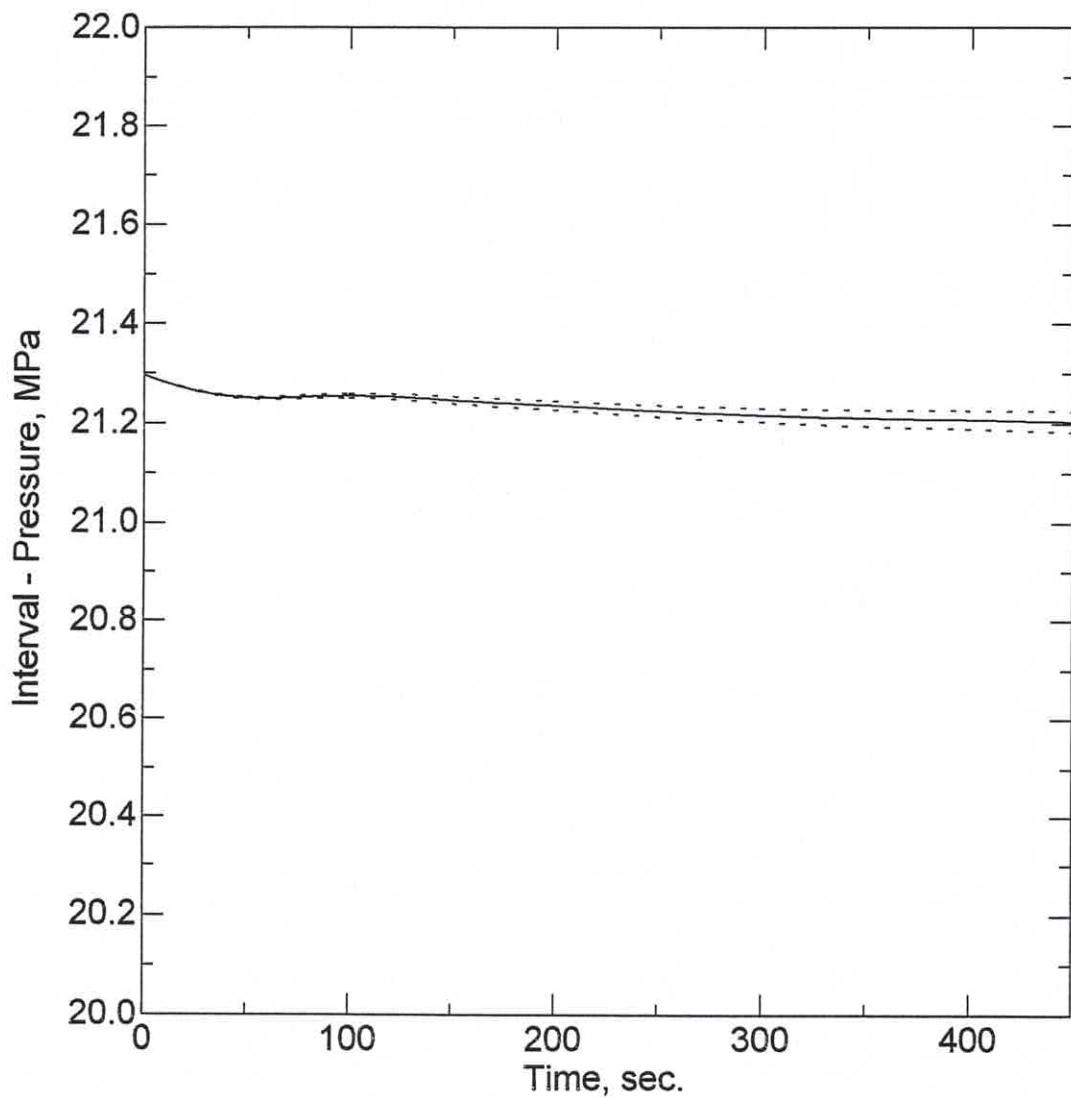
Test 5: 1882.0 m



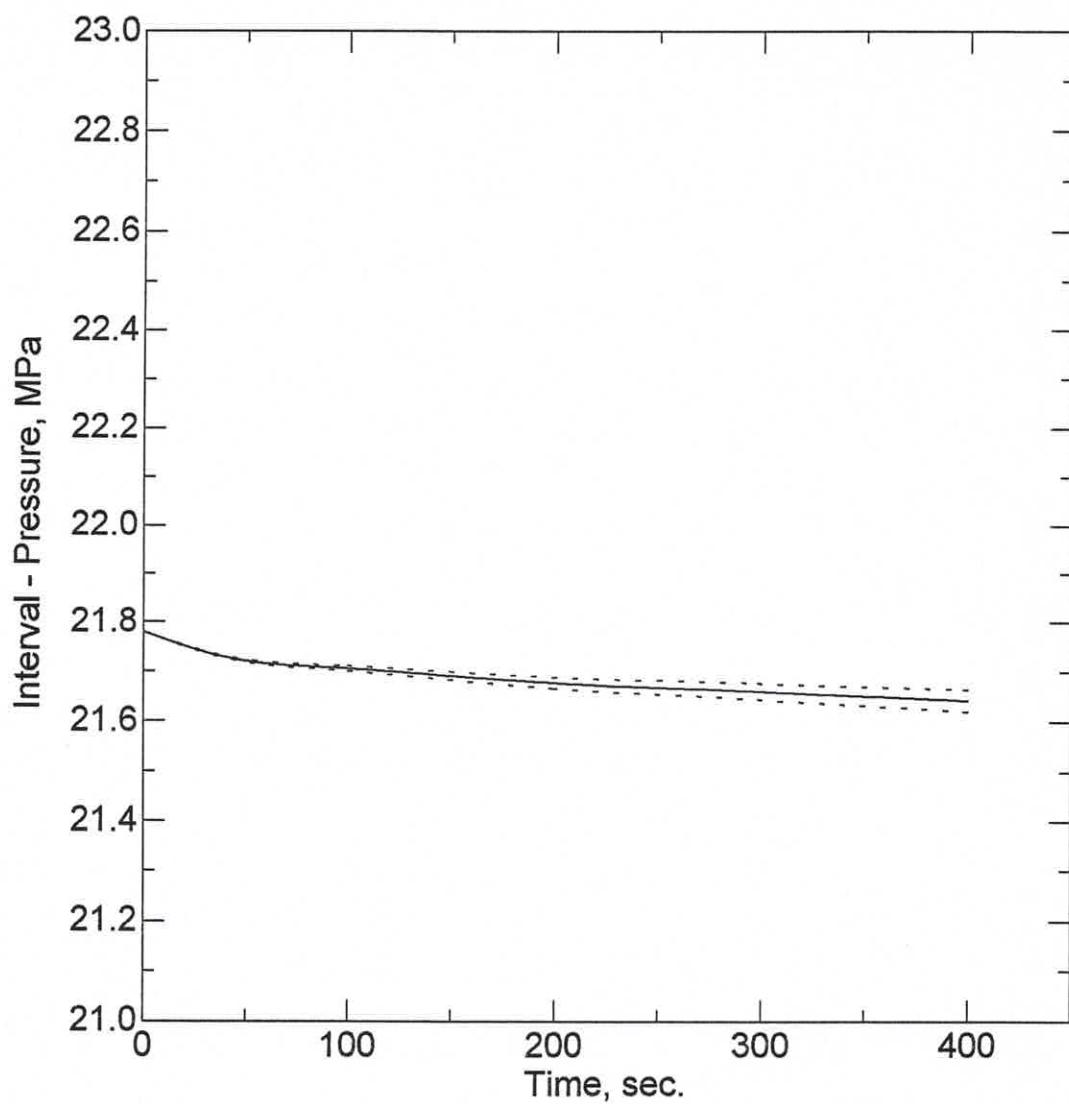
Test 6: 1755.0 m



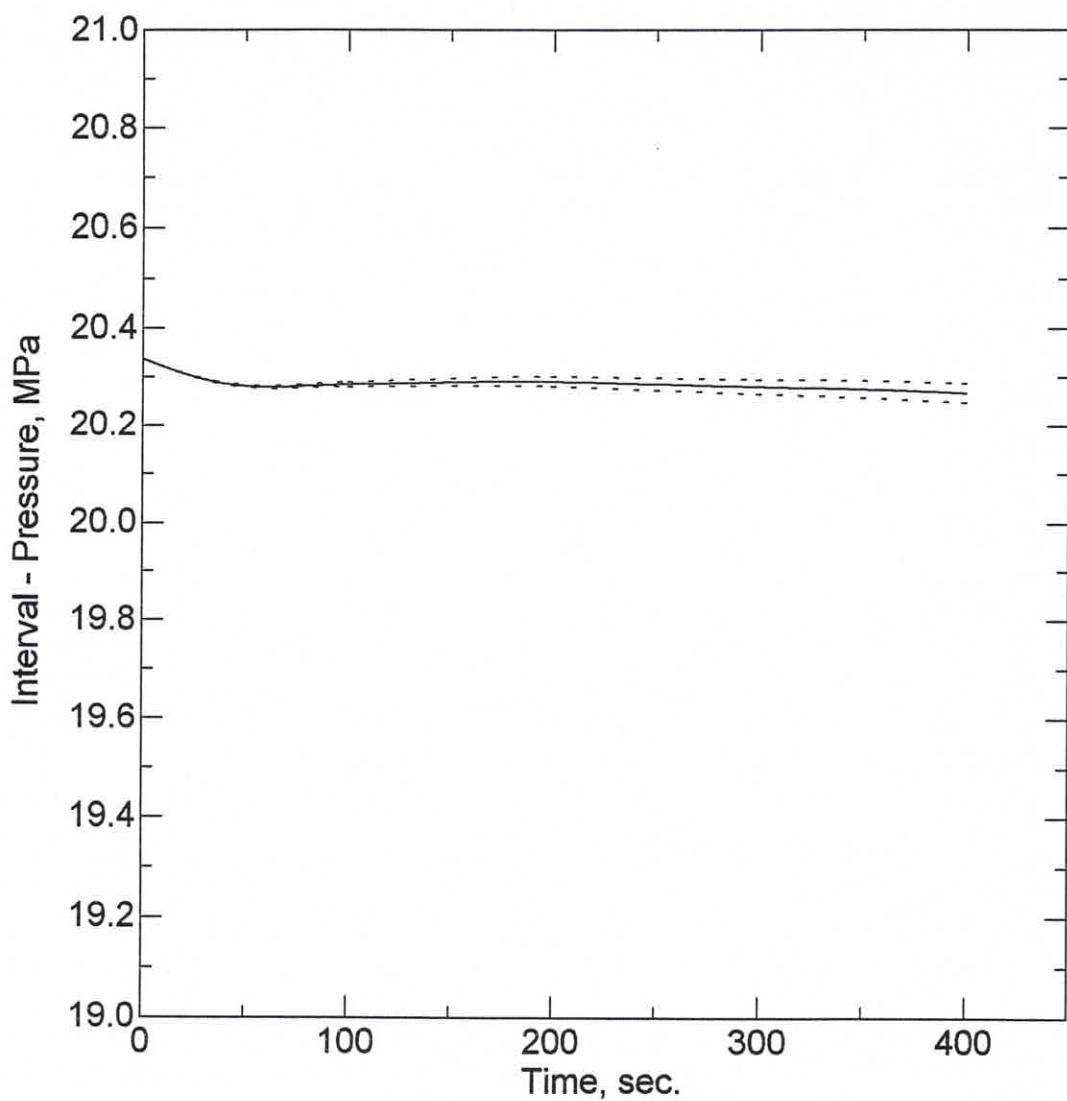
Test 7: 1707.0 m



Test 8: 1681.0 m



Test 9: 1587.0 m



Test 10: 1418.0 m

