

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

COMPILATION OF EXISTING HYDROFRAC IN - SITU STRESS DATA FOR THE RUHR CARBONIFEROUS

Client	Conoco Mineraloel GmbH
Order No.	031 - 94
Date of Order	10.10.94
MeSy Quotation No.	119.07.94 dated 20.07.94
Report prepared by	Prof. Dr. F. Rummel Dipl. Geophys. U. Weber
Report Date	09.12.94
Report No.	28.94

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APPENDIX : Data from UK hydrofrac stress tests

SUMMARY

Hydrofrac stress data are important input information for the design and the operation of CBM projects in the Ruhr Carboniferous. Since 1986 app. 370 hydrofrac stress tests have been carried out in 5 mines in the Ruhr coal field covering an EW range of 90 km and a depth between 600 and 1300 m. The tests were conducted in 38 boreholes of about 40 m length, mostly drilled from galleries far away from mine workings in rather undisturbed rock mass.

Although the singular hydrofrac stress data demonstrate considerable scatter and uncertainties, the mean maximum horizontal stress direction is N 146°E which is in agreement with the NW-SE acting tectonic regime in Central Europe (Fig. 9.1).

The principal stress magnitudes $S_h < S_v \leq S_H$ suggest strike - slip and thrust faulting tectonics, respectively. The vertical stress S_v in most cases is greater than the calculated overburden stress assuming an average rock density of 2.5 g/cm³. For some cases the discrepancy could be explained using existing density profiles which yield mean density values of 2.6 to 2.7 g/cm³. The horizontal principal stress anisotropy S_H/S_h is about 2 with $S_H \approx S_v$, a result which is valid for most intraplate crustal regions for a depth of about 1 km.

Both, the in-situ hydrofrac tests and extensive laboratory investigations indicate that the sandstone / claystones of the coal bearing formations in the Ruhr Carboniferous are characterized by high strength (hydraulic fracturing tensile strength P_{co} (in-situ) = 10 ± 4 MPa, p_{co} (laboratory) = 22.6 ± 10 MPa; compressive strength 61 ± 24 MPa; fracture toughness 1.36 ± 0.29 MN^{-3/2}) and by high Young's moduli of 36 ± 11 GPa.

1. INTRODUCTION / OBJECTIVE

Besides intrinsic coal seam permeability in-situ stresses control the flow paths for Coal Bed Methane production from deep - seated coal seams. Stresses determine permeability anisotropy, the orientation of open microcracks, and design parameters for artificial flow path stimulation by large scale hydraulic fracturing operations .

In comparison to numerous hydrofrac operations in coal in the US (e.g. Wise et al. 1979, CBM symposiums 1987 / 1989), in Germany only few stimulations were conducted to produce stored gases from coal (e.g. Internal Report Saarbergwerke, Müller, 1968). Such few experiments also did not consider the tectonic in-situ stress situation due to the lack of such data.

Today, numerous stress data exist for Central Europe and, particularly, for the Carboniferous sediments of the Ruhr coalfield. Since 1987, about 370 hydrofrac stress tests have been carried out in 38 boreholes drilled from mining galleries at various mining levels in 5 mines.

The objective of this report is to summarize the results of these app. 370 hydrofrac tests which are described in various reports prepared for the Eschweiler Bergwerks Verein (EBV), for Bergbau Forschung Essen GmbH and for Deutsche Montan Technologie GmbH (IGH5) Essen.

2. TEST MINE LOCATIONS

The mine locations where hydrofrac tests were conducted range from the mine Friedrich-Heinrich (RAG) near Kamp Lintfort in the west to the mine Westfalen (EBV/RAG) near Ahlen or Hamm - Heesen in the east. The test locations in the 5 mines extend over an east - west distance of about 90 km, and cover a depth interval between 600 and 1260 m (below NN). The nearest mine to the drill site of the Conoco / Ruhrkohle / Ruhrgas CBM project at Drensteinfurt is the mine Westfalen near Ahlen. At this mine hydrofrac experiments were carried out in 13 boreholes at 7 mining locations at the levels 1035 m and 1260 m (below NN).

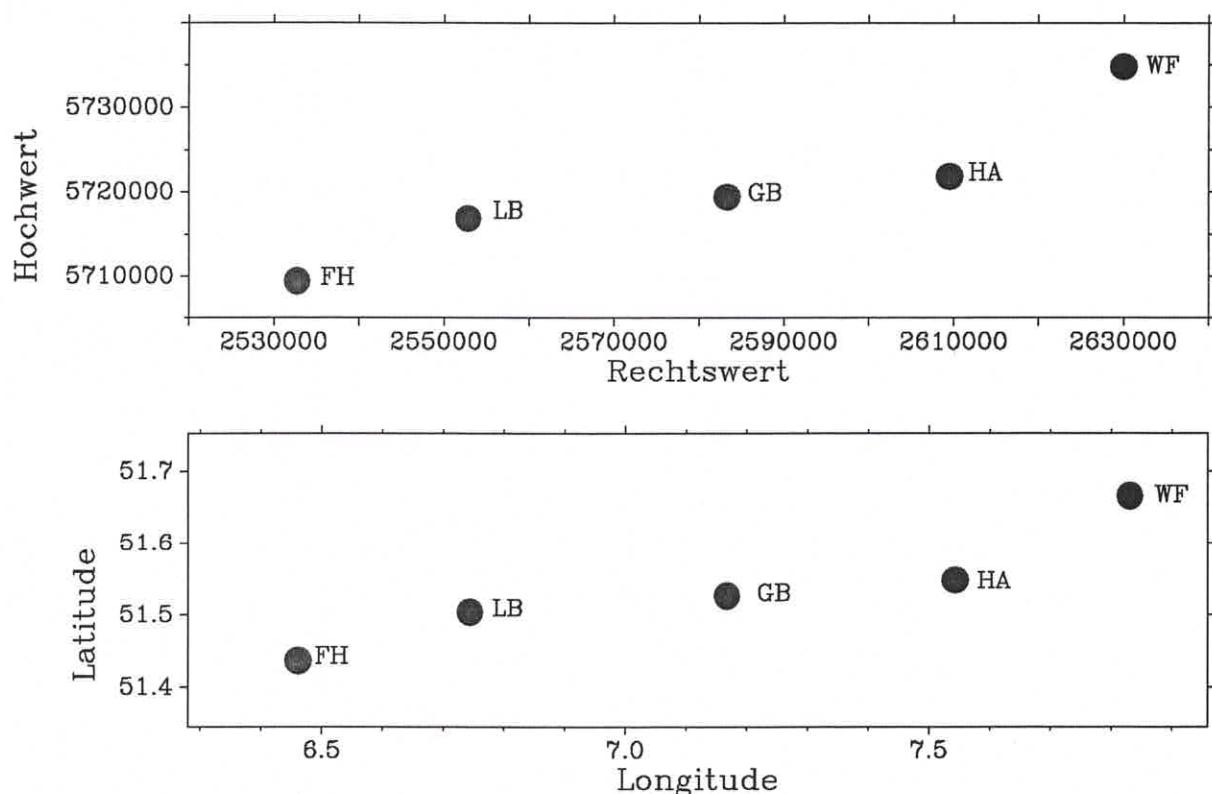
In the following Table 2.1 the location of the mines, the depth levels and the number of boreholes tested at each test site are summarized. Further details on the test sites are given in Section 4.

Table 2.1 : Test Mine Locations, Number of Boreholes Tested / Number of Test Sites

mine	GK-Coordinates	Geograph. Coordinates	depth level m, NN	number of boreholes/ test sites
Friedrich-Heinrich (Kamp-Lintfort)	H 57.093 R 25.328	N 51°26.10 E 6°27.72	- 600	2/1
shaft 4	30 m above NN			
Lohberg (Dinslaken)	H 57.168 R 25.529	N 51°30.17 E 6°44.70	-1270	10/4
shaft 2	45 m above NN			
General Blumenthal (Recklinghausen)	H 57.1935 R 25.83.4	N 51°31.53 E 7°10.13	- 900	3/1
Haus Aden (Bergkamen)	H 57.2175 R 26.09.6	N 51°32.83 E 7°32.62	- 680 - 940	4/2 6/4
shaft 1/2	60 m above NN			
Westfalen (Hamm - Heesen)	H 57.353 R 26.319	N 51°40.17 E 7°51.47	-1035	4/2
shaft 6	80 m above NN			
	H 57.3415 R 26.282	N 51°39.53 E 7°48.33	-1260	9/5
	80 m above NN			

Fig. 2.1 : Mine locations where hydrofrac stress tests have been conducted

- a) Gauss - Krüger Coordinates
- b) geographical coordinates



3. EXISTING HYDROFRAC TEST REPORTS / PUBLICATIONS

3.1 SCHACHTANLAGE FRIEDRICH - HEINRICH

30.03.1990 Abschlußbericht Hydrofrac - Spannungsmessungen Zeche Friedrich-
Heinrich, Bohrungen 0420 / K 617 - T/V, 0420 / K 617 - T/H, 600 m
Sohle, westl. Richtstrecke, 9. - 21.3.1990 (Ru / Kon)

3.2 SCHACHTANLAGE LOHBERG

17.12.1990 Vorabbericht Bohrung B 1 V (Ru / Kon)
21.12.1990 dto. B 2 V (Ru / Kon)
30.01.1991 dto. B 1 H 90° (Ru / Kon)
30.01.1991 dto. B 1 H 45° (Ru / Kon)
20.02.1991 dto. B 2 H 45° (Ru / Kon)
06.03.1991 dto. B 2 H 90° (Ru / Kl)
06.03.1991 dto. B 3 V (Ru / Kl)
06.03.1991 dto. B 3 H 90° (Ru / Kl)
11.03.1991 dto. B 4 V (Ru / Kl)
20.03.1991 dto. B 4 H 80° (Ru / Kon)
02.04.1991 Abschlußbericht Hydrofrac - Spannungsmessungen, Schachtanlage
Lohberg, Dinslaken, Schacht 1 (Ru / Kon / Kl)

3.3 SCHACHTANLAGE GENERAL BLUMENTHAL

12.08.1992 Hydraulic - Fracturing Spannungsmessungen, Schachtanlage General
Blumenthal, Recklinghausen, 9. Sohle, 09.07. - 21.07.92, MeSy Rep.
No. 13.08.92 (Ru / We)

3.4 SCHACHTANLAGE HAUS ADEN

01.08.1986 Abschlußbericht Hydrofrac - Spannungsmessungen in der Schachtan-
lage Haus Aden. RUB Rep. - No. 708 4810 (Ru)

- März 1988 Hydraulic Fracturing Gebirgsspannungsmessungen auf der 940 m Sohle des Ruhrkohle - Bergwerks Haus Aden. Diplomarbeit, Institut für Geophysik, Ruhr - Universität Bochum (J. Kück)
- 14.10.1989 1. Bericht. Bohrungen 1165 - 1166, 745 m Sohle, Hauptquerschlag Nord, (22. - 27.09.1989)
- 05.01.1990 2. Bericht. Bohrungen 1172 und 1173, 1000 m Sohle, Diagonalquerschlag n.N., (13 - 21.12.1989)
- 22.04.1991 Vorabbericht, Bohrung 1229 (Ru/KI)
- 02.05.1991 Vorabbericht, Bohrung 1231 (Ru/KI)
- 15.05.1991 Abschlußbericht, Bohrungen 1229 und 1231, 745 m Sohle, Hauptquerschlag n.N., (16. - 23.04.1991), (Ru / KI)

3.5 SCHACHTANLAGE WESTFALEN

21.11.1987	Kurzbericht Bohrung	1 V	(19.-20.11.87)
27.11.1987	dto.	1 V	(24.-25.11.87)
02.12.1987	dto.	2 H	(30.11.-01.12.87)
07.12.1987	dto.	1 V	(03.12.87)
26.02.1988	dto.	2 H	(17.-18.02.88)
08.02.1988	dto.	laboratory tests on cores of borehole 1 V	
03.03.1988	dto.	laboratory tests on cores of borehole 1 V	
23.03.1988	dto.	Bohrung 3 V	(17.-21.03.88)
30.03.1988	dto.	4 H	(24.-29.03.88)
25.04.1988	Zwischenbericht	Bohrungen 1 V, 2 H, 3 V, 4 H	
17.08.1988	dto.	Bohrungen 5 V, 6 V	(11.-16.08.88)
30.09.1988	Kurzbericht	Bohrungen 7 V, 8 H	(29.08.-02.09.88)
16.01.1989	dto.	9 H	(03.-05.01.89)
03.02.1989	dto.	10 V	(31.01.-01.02.89)
07.09.1989	dto.	11 V, 7 V, 12 H, 8 H	(16.08.-04.09.89)

- 13.10.1989 Kurzbericht Bohrung 8 H (repetition tests)
06.02.1990 Abschlußbericht test period Nov. 87 - Sept. 89
21.08.1990 Kurzbericht (repetition tests) Bohrung H 8 (16.-17.08.90)
21.08.1990 Vorabbericht Bohrung H 13 (15.-20.08.90)
31.08.1990 Abschlußbericht Bohrungen H 13 und H 8 unter Beachtung der Ergebnisse früherer Messungen auf dieser Schachtanlage (Kon / Ru)

3.6 PUBLICATIONS

MÜLLER, W : Messungen der absoluten Gebirgsspannungen im Steinkohlenbergbau. Glückauf - Forschungshefte, 50/2, 105 - 111, 1989

MÜLLER, W. : The stress state in the Ruhr coalfield. Proceedings ISRM - Congress Vol. 3, 1707 - 1711, Aachen 1991

RUMMEL, F., U. WEBER : Stress field in the coal mines of the Ruhr coal district. Proceedings US Rock Mechanics Symposium, Vol. 2, 609 - 611, Madison 1993

KÜCK, J. : Hydraulic Fracturing Gebirgsspannungsmessungen auf der 940 m Sohle des Ruhr - Bergwerks Haus Aden. Diplomarbeit, Institut für Geophysik, Ruhr Universität Bochum, 1988

STELLING, W., F. RUMMEL : Messung von Primärspannungen durch Hydraulic Fracturing auf dem Bergwerk Haus Aden. Mitteilung aus dem Markscheidewesen, Jg. 99, Heft 1, S. 176 - 184, Verlag Glückauf, Essen 1992

4. TEST SITE DESCRIPTION

4.1 FRIEDRICH - HEINRICH

(i) Borehole Location

600 m level, app. 1000 m SW of shaft 4, along the western Richtstrecke (see Fig. 4.1)

depth below NN : - 556 m

depth below surface : - 586 m

R 2532300 $\lambda = 6^{\circ}27.922$

H 5708910 $\varphi = 51^{\circ}30.907$

(ii) Boreholes

- 0420 / K 617 - T / V : 40 m vertical, compact claystone - siltstone series
- 0420 / K 617 - T / H : 37 m horizontal, 155 degrees drilled towards NW,
compact claystone - siltstone series

(iii) Geology at Test Site

Between coal seams Gironnelle 1 and Finefrau, middle Wittener Schichten (Esskohlen), Westfal A.

4.2 LOHBERG

(i) Borehole Locations

4 drilling and test locations on the 5th level (-1270 m NN), near shaft 2, locations 1 and 2 along Eastern Abteilungsquerschlag towards North, locations 3 and 4 along Nullabteilung towards North (see Fig. 4.2), maximum horizontal distance between test locations app. 2.5 km, all locations except no. 2 directly south of Bruckhauser fault.

- mean depth below NN : - 1270 m

mean depth below surface : - 1315 m

- locations 1 and 2 :

mean R : 2554400	mean H : 5718220
mean λ : 6° 47.111	mean ϕ : 51° 35.826

- locations 3 and 4 :

mean R : 2552670	mean H : 5717050
mean λ : 6° 45.602	mean ϕ : 51° 35.205

(ii) Boreholes

- *test location 1*

- B 1 V : 40 m, vertical, sandstone - claystone series with coal layers
- B 1 H 90° : 40 m, horizontal, 77 degrees drilled towards E, compact sandstones with coal layers
- B 1 H 45° : 40 m, horizontal, 31 degrees drilled towards NE, compact sandstones with coal layers

- *test location 2*

- B 2 V : 40 m, vertical, sandstone - claystone series with coal layers
- B 2 H 90 : 40 m, horizontal, 77 degrees drilled towards E, sandstone with coal layers
- B 2 H 45 : 60 m, horizontal, 37 degrees drilled towards NE, sandstone - sandy shale series

- *test location 3*

- B 3 V : 33 m, vertical, sandstone - claystone series with coal layers
- B 3 H 90 : 40 m, horizontal, 77 degrees drilled towards NE, sandstone

- test location 4

- B 4 V : 40 m, vertical, sandstone - claystone series with coal layers
- B 4 H 80 : 41 m, horizontal, 67 degrees drilled towards NE, sandstone - sandy shales.

(iii) General Geology at Test Site

Between coal seams Anna and Matthias, Fettkohlen, upper Bochumer Schichten, Westfal A.

4.3 GENERAL BLUMENTHAL**(i) Borehole Location**

Drilling and test location on the 9th level in the 5th Querschlag towards North (see Fig. 4.3), directly below the coal seam Dickebank.

depth below NN : - 900 m
depth below surface : - 975 m
R : 2582700 H : 5721480
 λ : 7° 11.660 φ : 51° 37.378

(ii) Boreholes

- B 7 V : 40 m, vertical, silty clay - sandstone series, one coal seam at 20 m depth
- B 5 H : 40 m, horizontal, drilled towards 155 degrees, fine - grained compact sandstone with earth layers
- B 6 H : 40 m, horizontal, drilled towards 195 degrees, fine - grained compact sandstone with earth layers.

(iii) Geology at Test Site

Near coal seam Dickebank, lower Fettkohlen, Bochumer Schichten, upper Westfal A.

4.4 HAUS ADEN

(i) Borehole Locations

The drilling and test locations mainly were along the two Hauptquerschläge towards North on the - 680 m and on the - 940 m level (see Fig. 4.4):

• - 680 m level (NN)

- Test series September 1989 and April 1991, see reports dated 14.10.89 and 15.5.91, 2 vertical and 2 horizontal boreholes between Station 5775 and 5865 m along the Hauptquerschlag towards North

mean depth, NN : - 689 m

mean depth below surface : - 749 m

mean R : 2606137 mean λ : $7^\circ 32.049$

mean H : 5726305 mean ϕ : $51^\circ 39.743$

• - 940 m level (NN)

- Test series 1986, see Kück (1988) and RUB report dated 1.8.86, 2 vertical and 2 horizontal boreholes in the area of the Wattenscheider Sattel on both sides of the Cappenberg fault

mean depth, NN : - 938 m

mean depth below surface : - 998 m

mean R : 2607983 mean λ : $7^\circ 35.606$

mean H : 5723988 mean ϕ : $51^\circ 38.473$

- Test series December 1989, see MeSy report dated 5.1.90, 2 vertical boreholes drilled from the Diagonalquerschlag towards North, at Station 2105 and Station 2025

mean depth, NN : - 938 m
mean depth below surface : - 998 m
mean R : 2609661 mean λ : 7° 35.060
mean H : 5723954 mean ϕ : 51° 38.435

(ii) Boreholes

- 680 m level (NN)

- B 1165 V : 38 m, vertical, Station 5785, compact fine - grained sandstone, upper Bochumer Schichten
- B 1166 H : app. 35 m, horizontal, Station 5865, drilled towards N 65 E, sandstone - claystone series, upper Bochumer Schichten
- B 1229 V : 42 m, vertical, Station 5775, medium - grained sandstone, sandy shale, claystone, penetrated coal seams Gustaf 2 / Gretchen 1, upper Bochumer Schichten
- B 1231 H : 40 m, horizontal, normal to Hauptquerschlag direction or towards N 53 E, Station 5860, medium - grained sandstone below coal seams G2 / Gr 1, upper Bochumer Schichten

- 940 m level (NN)

- 1060 V (B 2 V) : 57 m, vertical, 300 m south of the Cappenberg fault, penetrating coal seam Wasserfall, fine - grained sandstone, lower Bochumer Schichten

- 1059 H (B 1 H) : 49 m, horizontal, same locations as B 2 V, drilled towards N 232 E, between coal seams Wasserfall 1/2, fine - grained sandstone, lower Bochumer Schichten
- 1078 V (B 4 V) : 76 m (lower 35 m not stable), vertical, 600 m north of Cappenberg fault on the Cappenberg Sattel, penetrating coal seams Ernestine and Röttgersbank, fine - grained sandstone, middle Bochumer Schichten
- 1061 H (B 2 H) : 40 m, horizontal, 200 m north of Cappenberg fault, drilled towards N 232 E, fine - grained sandstone, middle Bochumer Schichten
- B 1172 V : 47 m, vertical, Station 2105, Diagonalquerschlag towards N, below coal seam Ernestine, compact Röttgers sandstone, middle Bochumer Schichten
- B 1173 V : 47 m, vertical, Station 2025, below coal seam Karl 2, compact Röttgers sandstone, middle Bochumer Schichten.

(iii) Geology

- ***Test site - 680 m level :***

compact medium- to fine - grained sandstone, claystone, coal seams Gustaf 2 / Gretchen 1, upper Bochumer Schichten, Westfal A.

- ***Test site - 940 m level :***

fine - grained sandstone, lower Bochumer Schichten at boreholes 1059 - 1060 and middle Bochumer Schichten at the Cappenberg fault location; compact Röttgers sandstone, middle Bochumer Schichten at boreholes 1172 and 1173.

4.5 WESTFALEN

(i) Borehole Locations

The drilling and test locations were at the 1035 m and the 1260 m level. The test sites are shown in Fig. 4.5. The maximum horizontal distance between the underground test sites is about 2.1 km.

1035 m level

mean depth below NN	: - 950 m
mean depth below surface	: - 1030 m
mean R : 2630368	mean λ : $7^{\circ}53.223$
mean H : 5733898	mean φ : $51^{\circ}43.532$

1260 m level

mean depth below NN	: - 1170 m
mean depth below surface	: - 1250 m
mean R : 2629486	mean λ : $7^{\circ}52.446$
mean H : 5733358	mean φ : $51^{\circ}43.253$

(ii) Boreholes

- test locations at the 1035 m level

- B 3 V : 42 m, vertical, western Richtstrecke 1 / 7, Station 148 m, compact fine - grained sandstone
- B 4 H : 42 m, horizontal, same location as B 3 V, borehole orientation N 144 E, heavily jointed sandstone, partly porous
- B 10 V : 50 m, vertical, western Richtstrecke 3 / 6, compact sandstone, coal seam at 40 m (1 m thickness)

- B 9 H : 40 m, horizontal, same locations as B 10 V, sandstone, partly strongly jointed with coal layers intersected

- test locations at the 1260 m level

- B 1 V : 42 m, vertical, 6. westl. Abteilung, Station 4 / 85, sandstone - claystone series, intersecting coal seam Girondelle at 16 m (0.6 m).
- B 2 H : 39 m, horizontal, same location as B 1 V, borehole direction N 30 E, sandstone with quartz - filled bedding planes
- B 5 V : 41 m, vertical, western Richtstrecke 1 - 7 Süd, Station 650 m, compact sandstone, coal seam at 6 m (0.8 m)
- B 6 V : 41 m, vertical, western Richtstrecke 1 - 7 Süd, Station 1454 m, compact sandstone, coal seam at 33 m (1 m)
- B 7 V : 41 m, vertical, western Richtstrecke 1 - 7 Süd, Station 140 m, sandstone - claystone series, sandstone strongly jointed
- B 8 H : 41 m, horizontal, WR 1 - 7 Süd, Station 650 m, borehole direction N 162 E, compact sandstone
- B 11 V : 42 m, vertical, WR Süd, Station 450 m, compact sandstone, coal seam at 23 m (0.4 m)
- B 12 H : 43 m, horizontal, direction N 162, WR 1 - 7 Süd, Station 450, compact sandstone
- B 13 H : 41 m, horizontal, direction N 161, WR 1 - 7 Süd, Station 1808, compact sandstone with quartz veins (same locations as B 8 H)

(iii) Borehole Coordinates

Level	Borehole No.	RW	HW
1035 m	B 3 V	2628956	5733649
	B 4 H	2628931	5733606
	B 10 V	2631717	5734126
	B 9 H	2631866	5734210
1260 m	B 1 V	2629500	5732082
	B 2 H	2629518	5732078
	B 5 V	2629483	5734011
	B 8 H	dto.	dto.
	B 13 H	dto.	dto.
	B 11 V	2629671	5734117
	B 12 H	dto.	dto.
	B 7 V	2629939	5734272
	B 6 V	2628802	5733590

(iv) Geology**- 1035 m level**

coal seams Karl 2 / Ida, middle Bochumer Schichten, Westfal A.

- 1260 m level

between coal seams Sonnenschein and Plaßhofsbank, middle Bochumer Schichten, Westfal A.

Table 4.1 : Borehole Coordinates (GK) and Depth

mine	borehole	depth below NN	depth below surface	R	H
		m	m		
Friedrich Heinrich	617 V	556	586	2532300	5708910
	617 H	dto.	dto.	dto.	dto.
Lohberg	B 1 V	1270	1315	2554521	5717775
	B 1 H 90	dto.	dto.	dto.	dto.
	B 1 H 45	dto.	dto.	dto.	dto.
	B 2 V	dto.	dto.	2554211	5718859
	B 2 H 90	dto.	dto.	dto.	dto.
	B 2 H 45	dto.	dto.	dto.	dto.
	B 3 V	dto.	dto.	2552633	5717141
	B 3 H 90	dto.	dto.	dto.	dto.
	B 4 V	dto.	dto.	2552704	5716944
	B 4 H 80	dto.	dto.	dto.	dto.
General Blumenthal	B 7 V	900	975	2582700	5721480
	B 5 H	dto.	dto.	dto.	dto.
	B 6 H	dto.	dto.	dto.	dto.
Haus Aden	1165 V	689	749	2606159	5726277
	1166 H	dto.	dto.	2606112	5726340
	1229 V	dto.	dto.	2606166	5726265
	1231 H	dto.	dto.	2606114	5726337
	1060 V (B2V)	938	998	2608208	5723695
	1059H (B1H)	dto.	dto.	2608215	5723684
	1078 V (B4V)	dto.	dto.	2607863	5724143
	1061H (B2H)	dto.	dto.	2607647	5724428
	1172 V	dto.	dto.	2609634	5723984
	1173 V	dto.	dto.	2609688	5723924

Table 4.1 : continued

mine	borehole	depth below NN	depth below surface	R	H
		m	m		
Westfalen	B 3 V	950	1030	2628956	5733649
	B 4 H	dto.	dto.	2628931	5733606
	B 10 B	dto.	dto.	2631717	5734126
	B 9 H	dto.	dto.	2631866	5734210
	B 1 V	1170	1250	2629500	5732082
	B 2 H	dto.	dto.	2629518	5732078
	B 5 V	dto.	dto.	2629483	5734011
	B 8 H	dto.	dto.	dto.	dto.
	B 13 H	dto.	dto.	dto.	dto.
	B 11 V	dto.	dto.	2629671	5734117
	B 12 H	dto.	dto.	dto.	dto.
	B 6 V	dto.	dto.	2628802	5733590
	B 7 V	dto.	dto.	2629939	5734272

Fig. 4 .1 a : Borehole Location at Mine Friedrich - Heinrich (horizontal cross section)

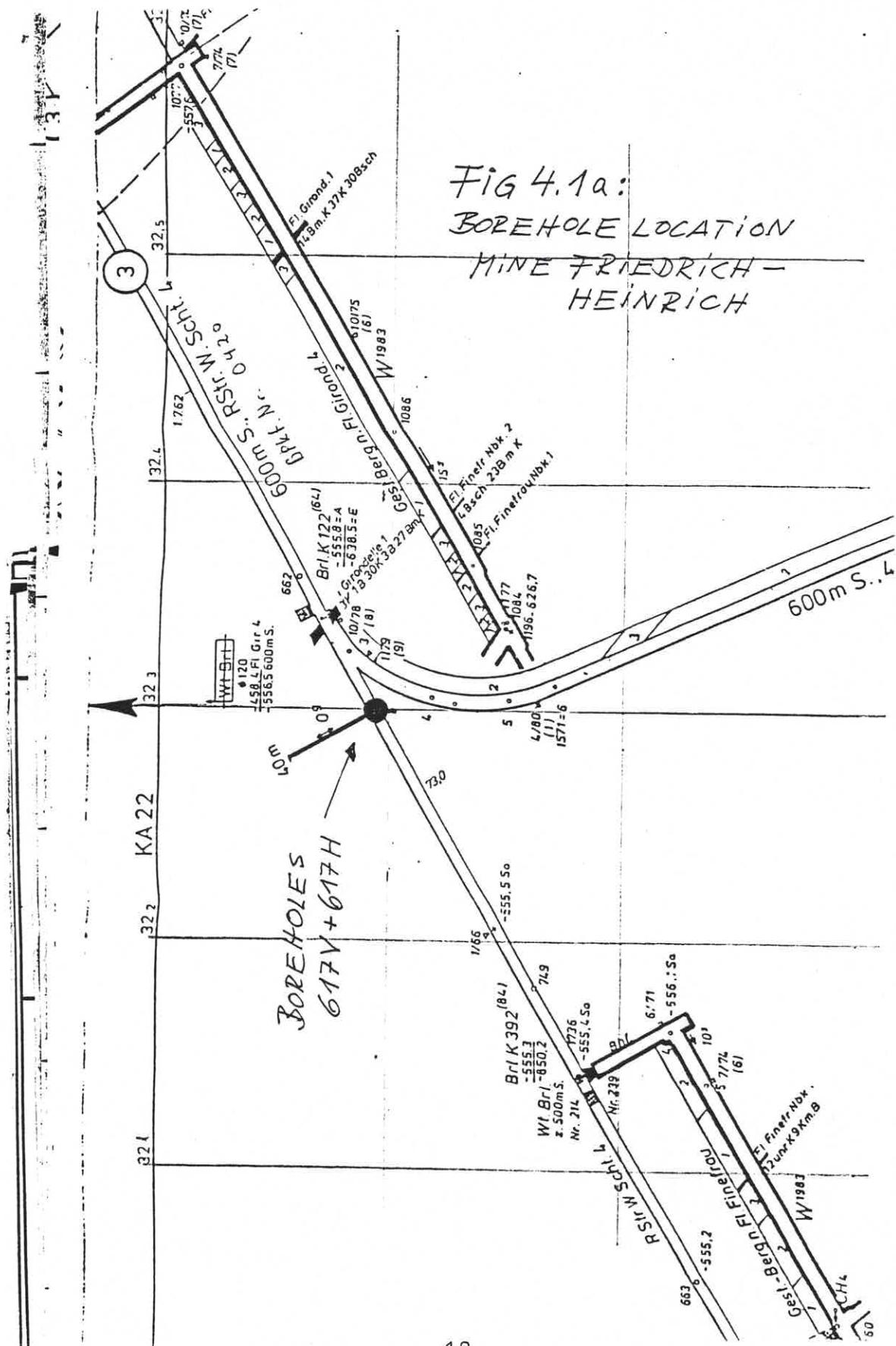


Fig. 4.1 b : Borehole Location at Mine Friedrich Heinrich (vertical cross section)

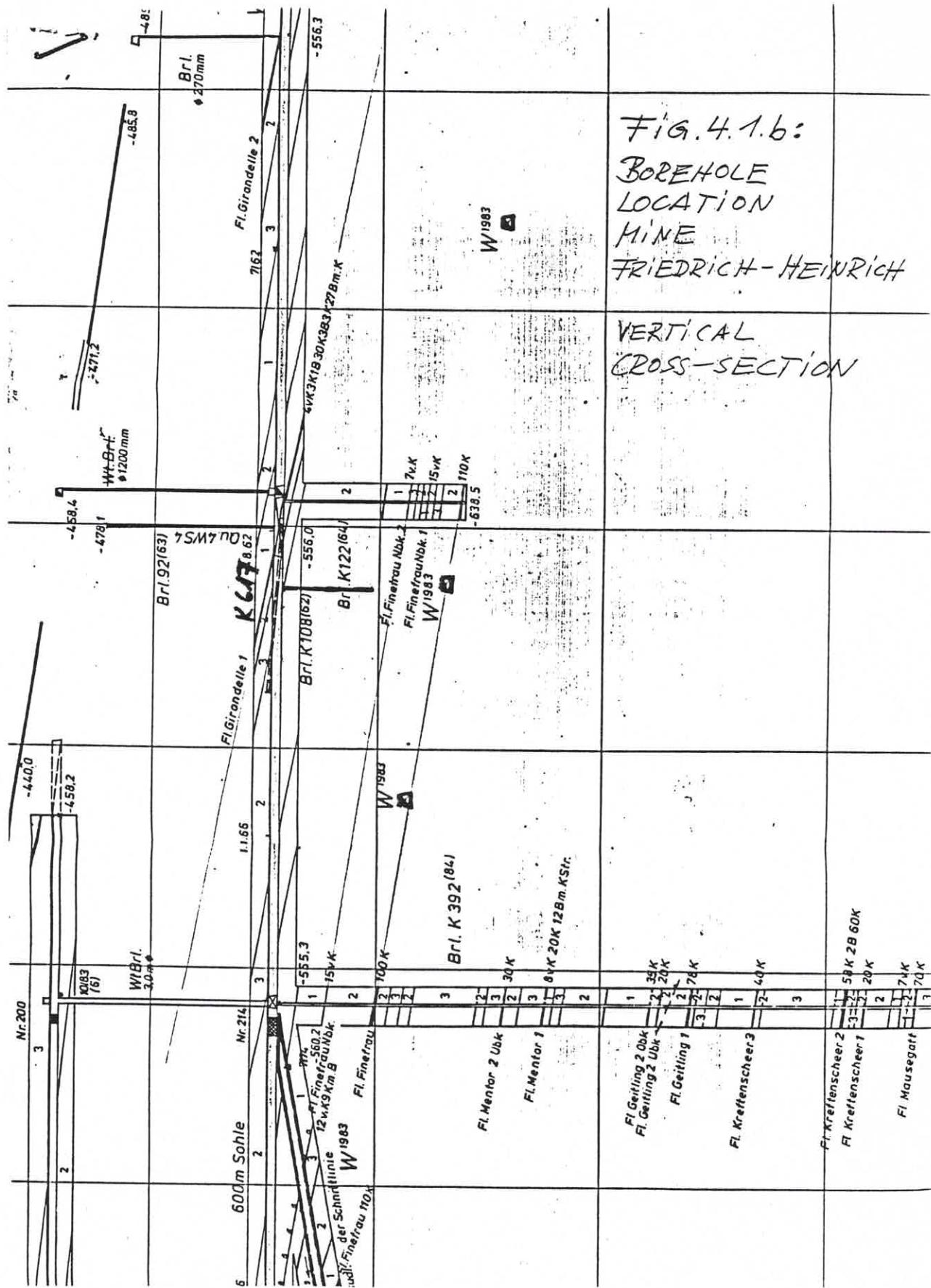


Fig. 4.2 : Test locations at Mine Lohberg (horizontal cross section)

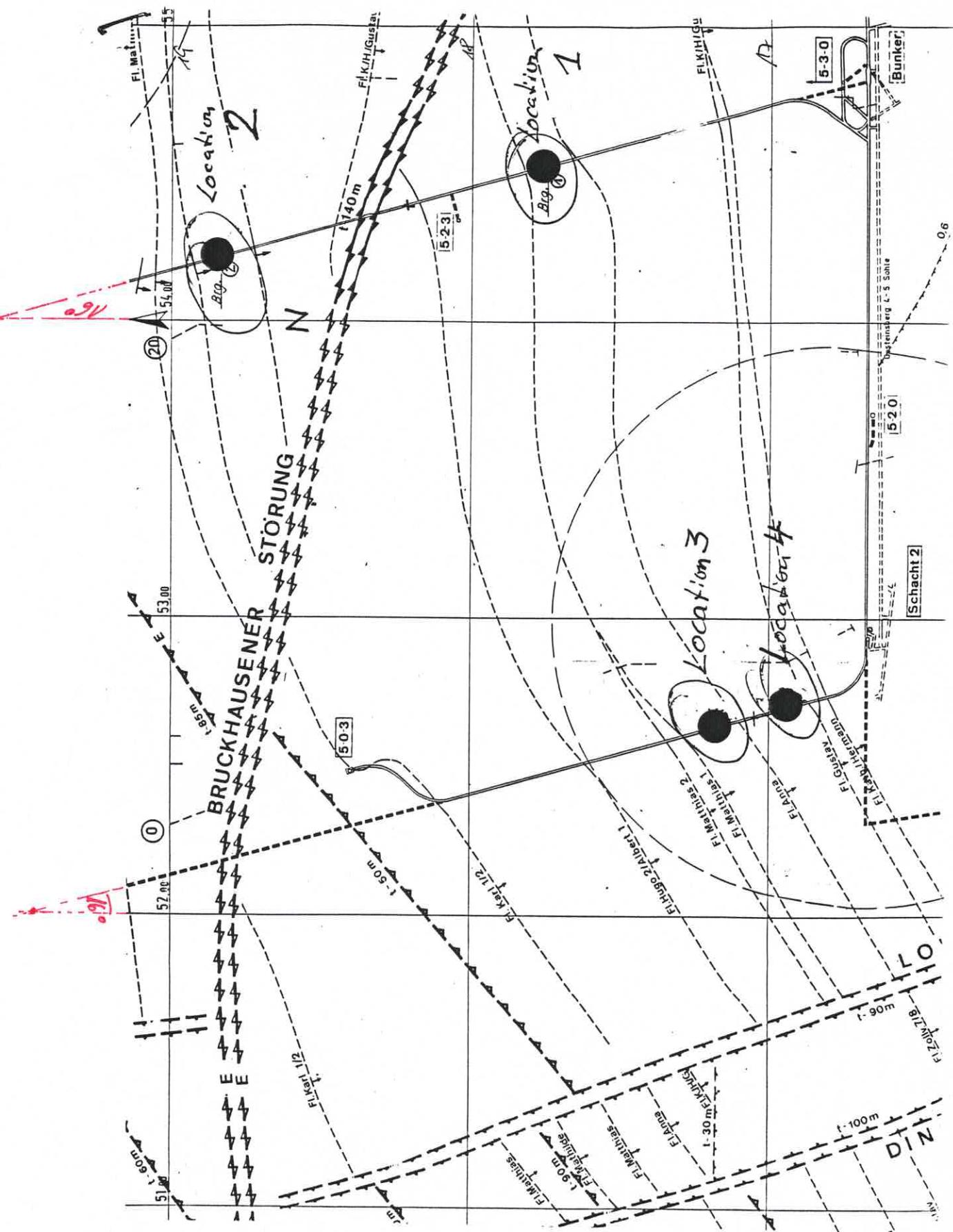


Fig. 4.3 : Test location at Mine General Blumenthal (horizontal cross section)

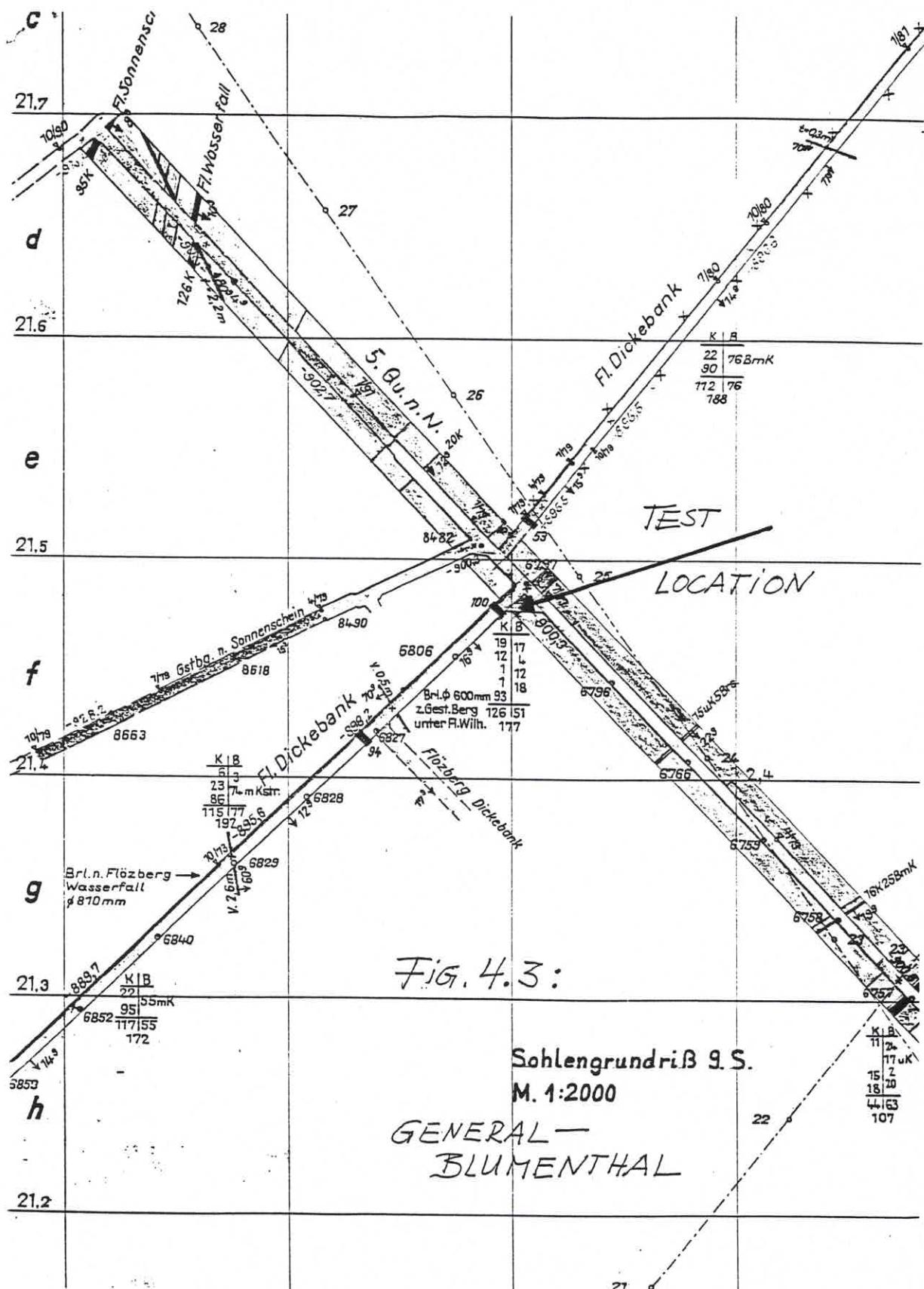


Fig. 4.4 a : Test locations at Mine Haus Aden

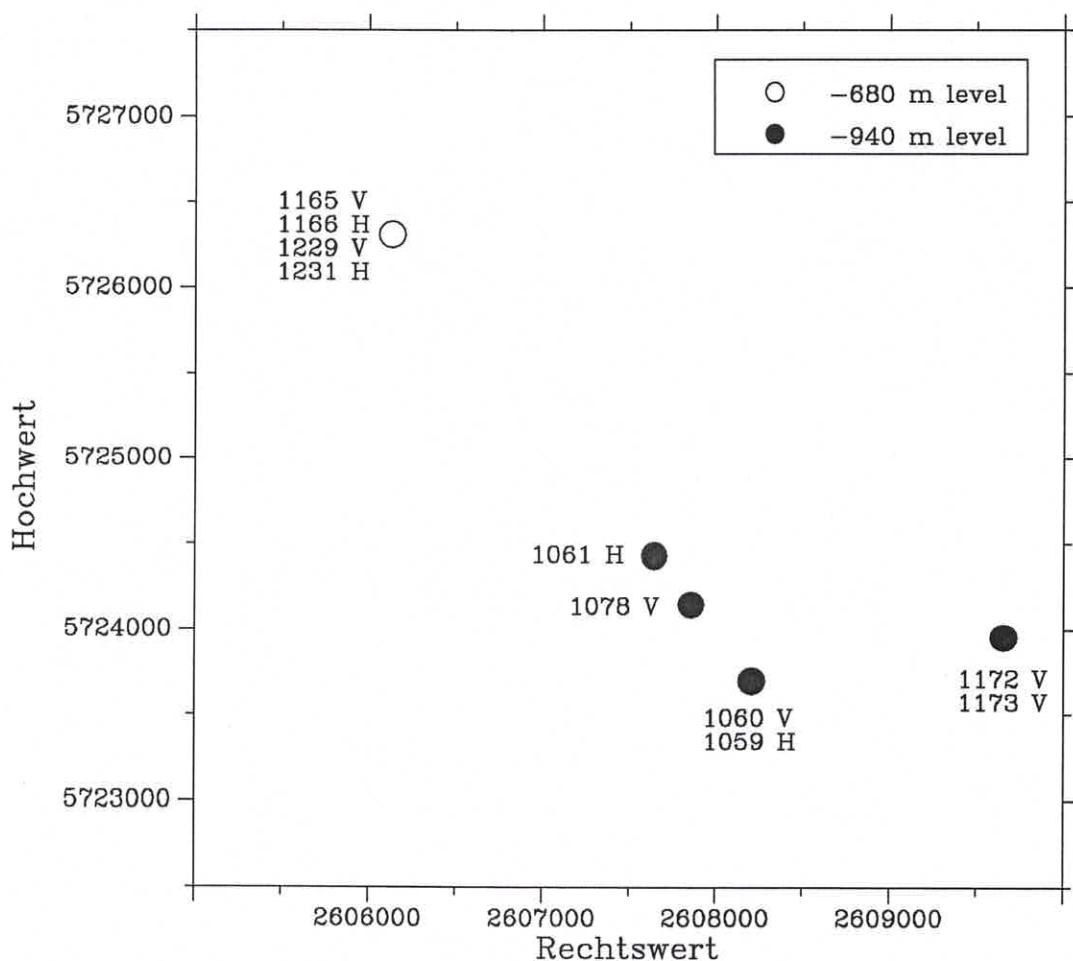


Fig. 4.4 b : Test locations at Mine Haus Aden, 680 m level, horizontal cross section

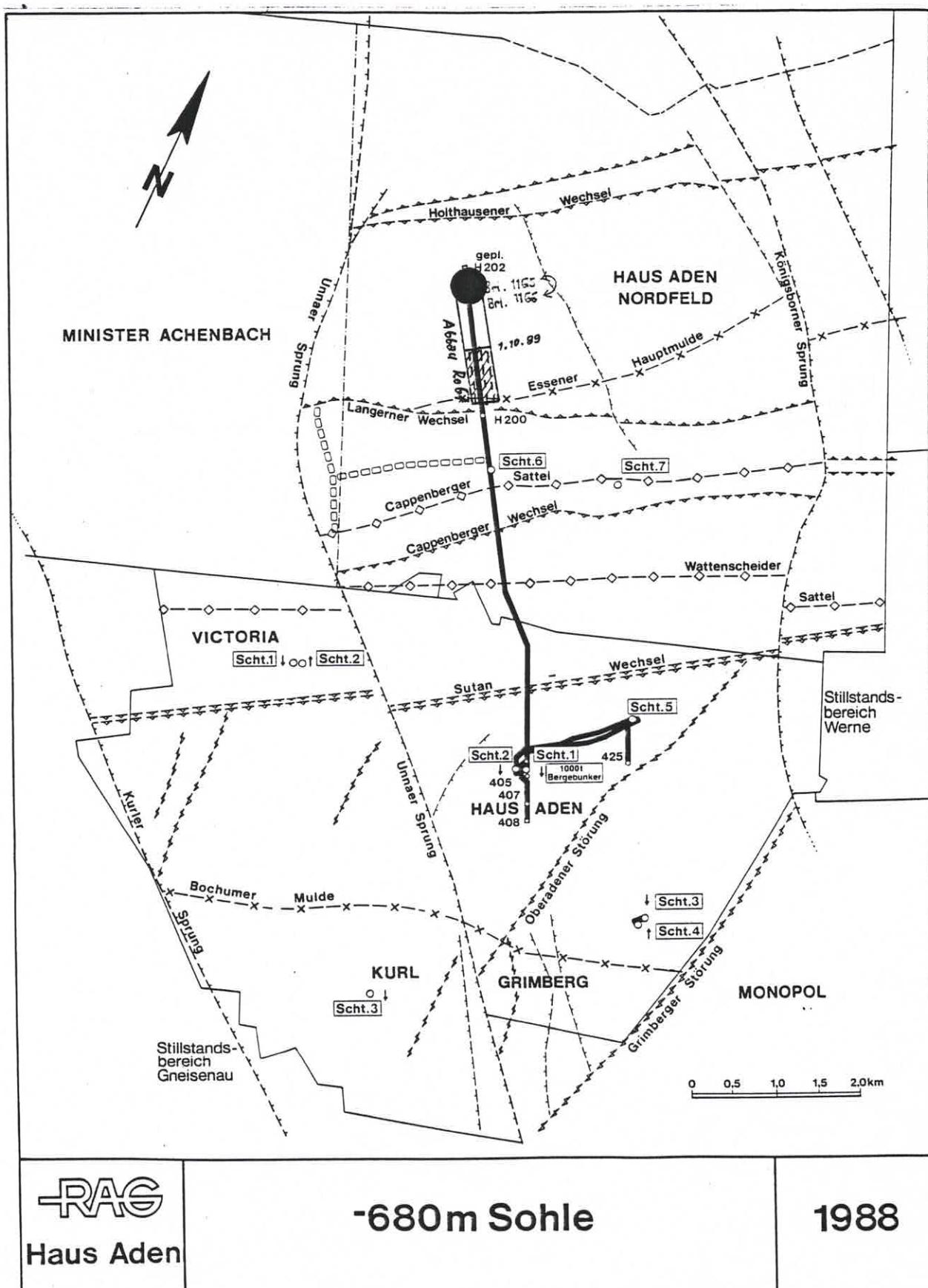


Fig. 4.4 c : Test locations at Mine Haus Aden, 940 m level, horizontal cross section

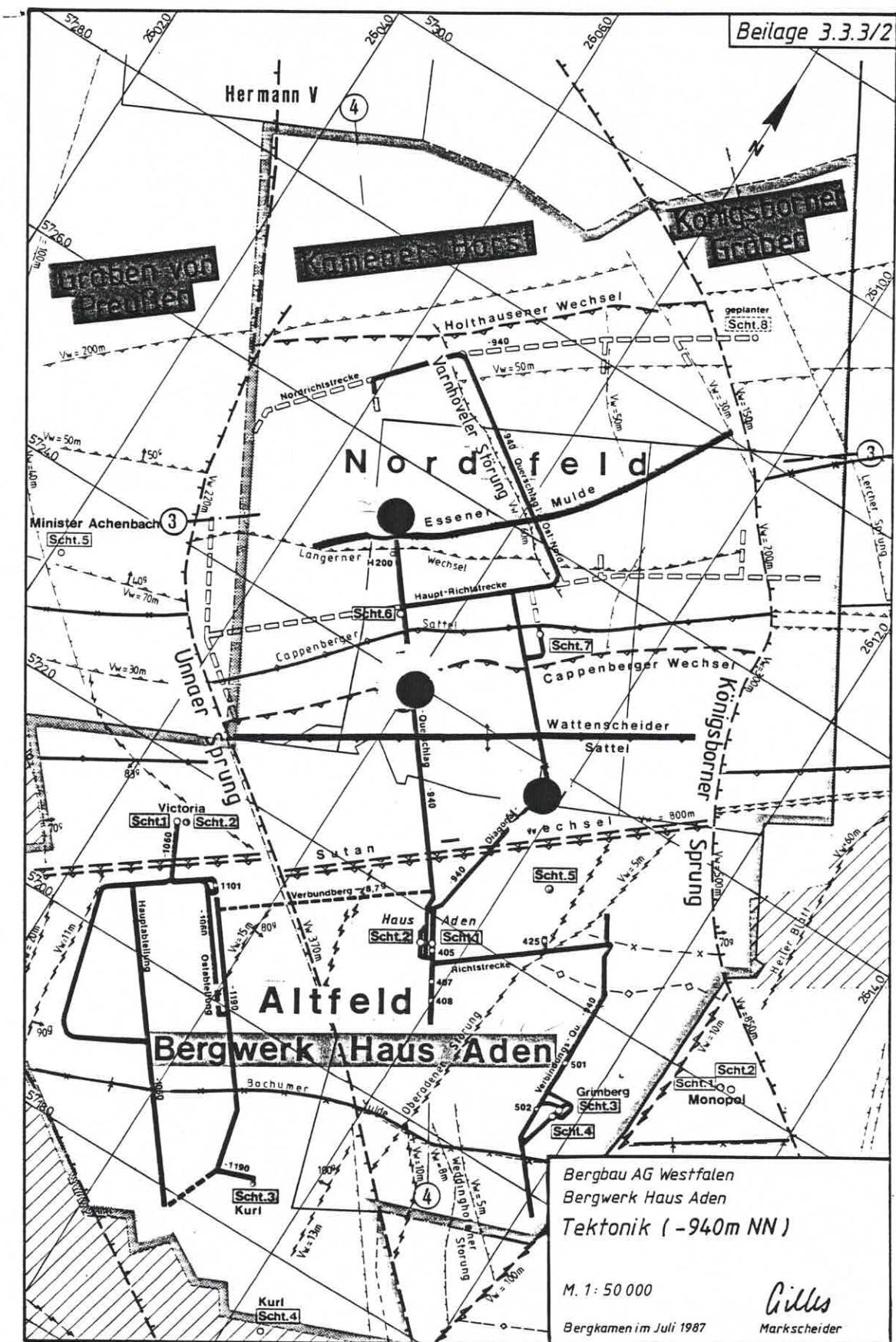
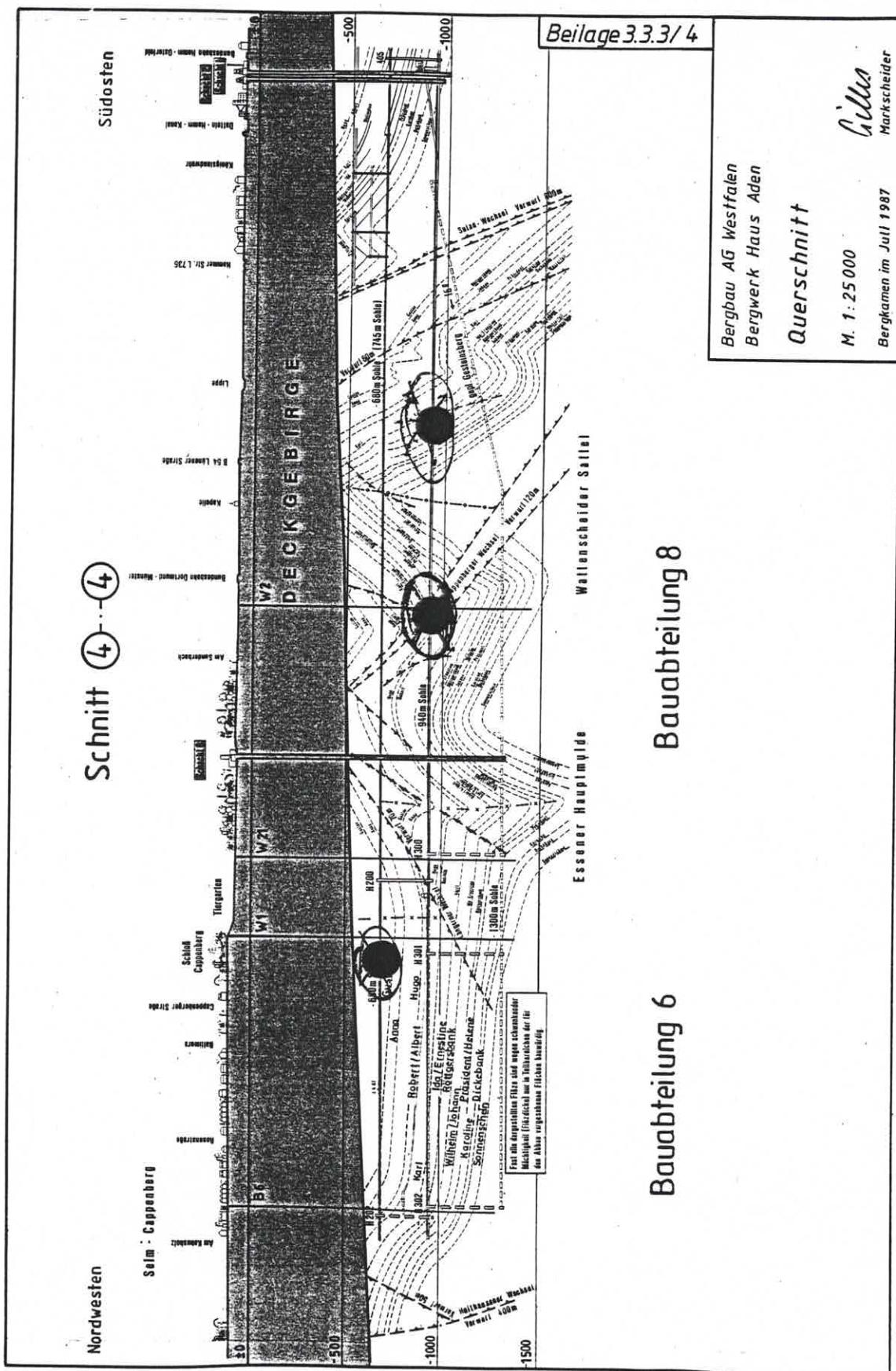


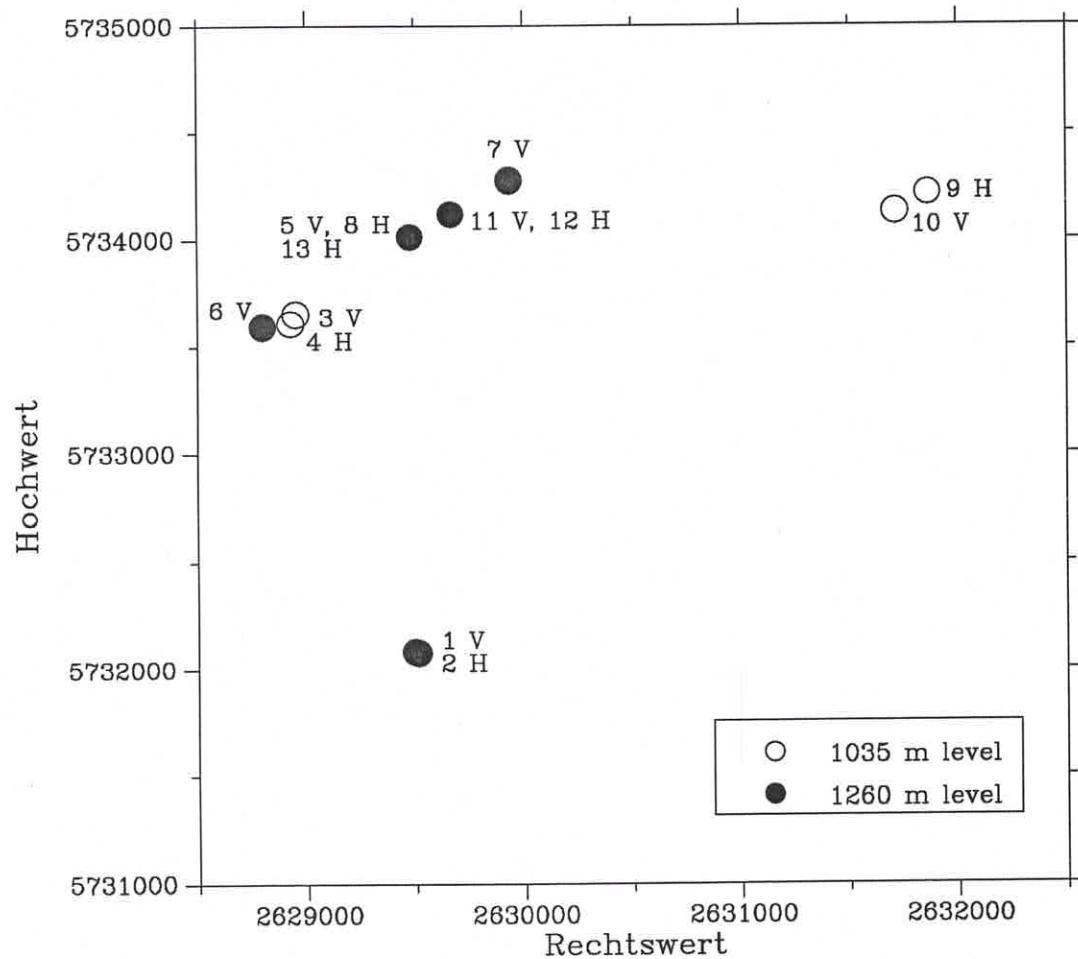
Fig. 4.4 d : Test locations at Mine Haus Aden, 680 and 940 m level, vertical cross section



Bauabteilung 6

Bauabteilung 8

Fig. 4.5 a : Test locations at Mine Westfalen



5. HYDROFRAC TESTING SYSTEM, TEST PROCEDURES AND DATA INTERPRETATION METHOD

5.1 HYDROFRAC TESTING SYSTEM

Since 1980 RUB and MeSy have developed a special hydrofrac testing system to be used in deep mines where hydrofracturing requires extremely high differential pressures in the order of 30 to 40 MPa. Conventional packer elements cannot sustain such pressures. The straddle packer tools are designed for 48 mm or 57 to 60 mm diameter boreholes. The rubber packer elements are supported by spring - steel friction sleeves at their end parts which take - up acting axial forces and guarantee high differential pressure capacity.

The straddle packer tool PERFRAC I is tripped into vertical boreholes on a steel cable together with 2 hydraulic lines of 8 to 10 mm ID for packer and interval pressurization. In the case of horizontal boreholes the tool is moved via the 2 pressure steel tubings of 16 mm OD, together with a steel cable for safety.

Both, pressure and flow rate data are recorded at the wellhead via mechanical data acquisition with respect to explosion safety requirements in coal mining. Since the required pumping rate to induce and propagate hydrofractures is small (some liters per minute) this data monitoring is fully sufficient, particularly for the exact determination of the shut - in (equilibrium) pressures.

A schematic test set - up is shown in Fig. 5.1.

5.2 TESTING PROCEDURE

In each borehole of about 40 m length 5 to 16 interval sections were tested (interval length about 1 m) starting from the bottom and moving towards the wellhead. At each test interval the following test program was conducted:

- set packers;

- pressurize interval to a differential pressure of 3 to 5 MPa to measure rock in - situ permeability and to ensure that test section is suited for hydrofrac testing (no significant open fractures);
- pressurize interval until breakdown (frac initiation at p_c) with a pumping rate of some l/min;
- deflate interval and repressurize interval during subsequent refrac pressure cycles to determine the refrac pressure p_r and the shut - in pressure p_{si} ;
- deflate packers and move to the next test section.

After completion of all hydrofrac tests in one borehole, the hydrofrac straddle packer tool was replaced by the impression packer tool, which consisted of a packer element with a soft rubber membrane and a magnetic single shot unit for frac orientation measurement.

5.3 PRESSURE DATA INTERPRETATION AND STRESS EVALUATION

Generally, MeSy uses inversion techniques for the interpretation of hydrofrac tests conducted in anisotropic and fractured rock. Here, the hydrofrac data analysis was conducted on the basis of the classical Hubbert & Willis concept which contains the following assumptions:

- The borehole is aligned to a principal stress axis. This assumption can be accepted for vertical boreholes in most cases, particularly in deep mines away from the mine workings. Since prior to testing the direction of horizontal principal stresses is unknown and drilling directions are limited by the mine geometry, horizontal boreholes generally are not aligned with a principal stress direction. In some cases it was possible to drill the horizontal holes according on the results from tests in the vertical hole with restriction according to mine geometry.
- The rock is homogeneous and isotropic. Neglecting the existence of coal seams in the Ruhr Carboniferous, the compact sandstone and siltstone layers are in close agreement to this assumption, i.e. fracture propagation direction is not affected by the rock properties.

- The fracturing fluid (water) does not penetrate into the rock prior to fracture initiation. Since the rocks have extremely low permeability in the micro - Darcy range, this assumption also may be accepted.
- Once the fracture is initiated it propagates in the direction normal to the minimum stress, i.e. the fracture traces observed on the borehole wall by the impression packer method yield the stress direction. This can be accepted for the vertical boreholes, but may not always be true for the horizontal boreholes if the borehole axis is not aligned to a principal stress axis. Therefore, stress directions, here, were generally derived from tests in the vertical boreholes. For cases where the boreholes are not aligned with a principal stress axis, the fracture trace orientation is not used for interpretation.

The classical Hubbert & Willis approach leads to the following simple hydrofrac relation by neglecting the pore pressure term (pore pressure is assumed to be zero for the compact impermeable rock):

(i) Vertical Boreholes with Vertical Fractures

$$P_c = 3 P_{si} - S_h + P_{co}$$

$$P_{si} = S_h$$

$$P_{co} = P_c - P_r$$

with

P_c breakdown pressure at frac initiation

P_r fracture reopening pressure

P_{si} shut - in pressure during fracture closure

P_{co} rock mass hydrofrac tensile strength

S_h, S_h major and minor principal horizontal stresses

S_v vertical principal stress (overburden stress)

(ii) Horizontal Boreholes aligned with the Major Horizontal Stress Axis and Vertical Fractures induced:

$$P_c = 3 P_{si} - S_v + P_{co} \text{ or } S_v = 3 P_{si} - P_r$$

$$P_{si} = S_h$$

(iii) Horizontal Boreholes aligned with the Least Principal Stress axis (in general S_h) with

- radial fractures:

$$P_{si} = S_h$$

- vertical fractures ($S_v > S_h$):

$$P_c = 3 P_{si} - S_v + P_{co} \text{ or } S_v = 3 P_{si} - P_r$$

$$P_{si} = S_h$$

- horizontal fractures ($S_h > S_v$):

$$P_c = 3 P_{si} - S_v + P_{co} \text{ or } S_h = 3 P_{si} - P_r$$

$$P_{si} = S_v$$

In practice, not every single hydrofrac test was evaluated but rather the averaged test results for each borehole were used for the stress evaluation, i.e.:

P_r mean reopening pressure

P_{si} mean shut - in pressure

θ mean fracture azimuth

The test results from the vertical boreholes were assumed to yield better data on S_h , S_h and θ compared to the test results from the horizontal boreholes with uncertainty on their alignment with a principal stress axis.

The averaging method is justified if sufficient data are available (say 10 tests at a depth of app. 10 m away from the well head). The variation of refrac and shut - in pressures per borehole generally was in the range of 1 to 2 MPa, the scatter in fracture orientation θ was in the order of ± 30 degrees.

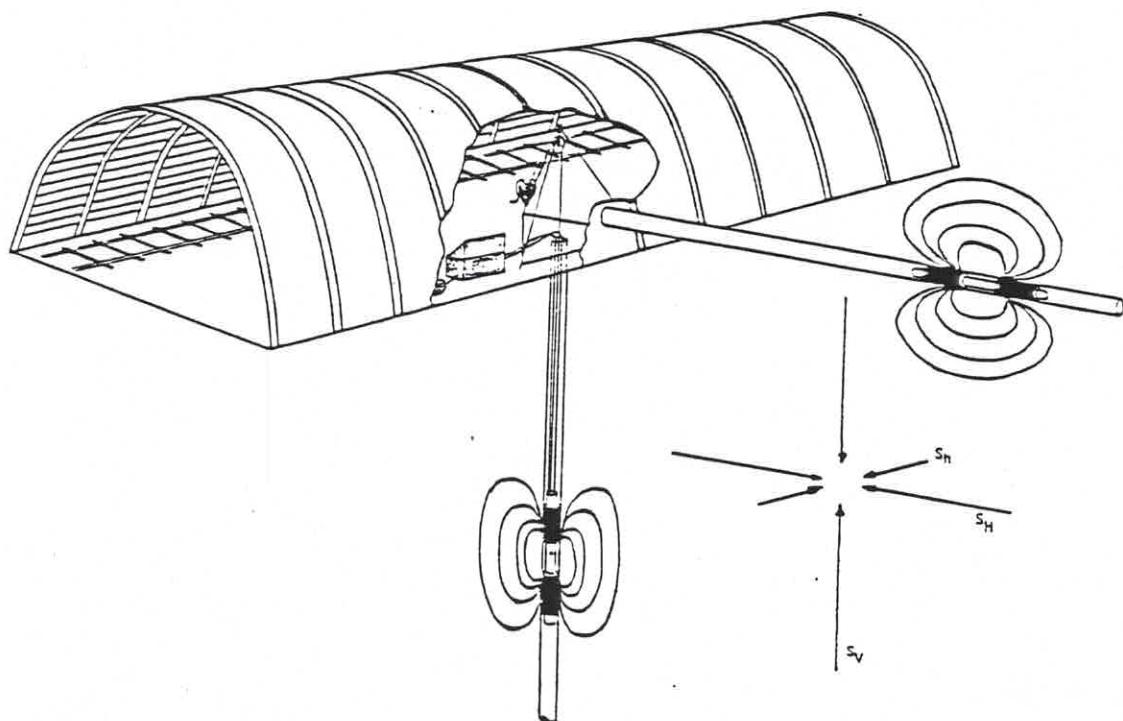
In case the pore pressure cannot be neglected the above relations for the breakdown pressure P_c can be stated as:

$$P_c = 3 P_{si} - S^* + P_{co} - P_o$$

where P_o is the pore pressure and S^* is the corresponding maximum principal stress (S_H or S_V). If the pore pressure is assumed to be hydrostatic ($P_o = \rho_{H2O} \cdot g \cdot z$). Solving for S^* this means to reduce its value by 10 MPa (100 bars) for a mean depth of 1000 m below surface.

As shown in Section 6 no pore pressures were observed. As seen in Section 7 and 8 the assumption of hydrostatic pore pressure in the Ruhr Carboniferous would reduce measured S_V values considerable below the overburden stress values, and would significantly reduce the horizontal principal stress anisotropy.

Fig. 5.1 : Hydrofrac testing set - up under coal mining conditions



6. HYDROFRAC PRESSURE RECORDS

Approximately 370 hydrofrac tests have been carried out in 38 boreholes in the 5 mines (Table 6.1) each test consisting of

- a permeability test prior to fracturing (pressure pulse of about 5 MPa and subsequent observation of the pressure decay over a period of some minutes);
- the fracture initiation test by increasing the interval pressure with a pumping rate of some liters per minute;
- several refrac pressure cycles to determine the fracture reopening pressure P_r and the shut - in pressure P_{si} .

Some typical examples of hydrofrac test records are given in Fig. 6.1. The pressure - time records generally are characterized by the following:

- extremely small pressure decay during the permeability test;
- extremely high (app. 30 to 40 MPa) breakdown pressure values P_c and subsequent sudden pressure decrease;
- characteristic pressure peaks for pressure reopening during subsequent slow pumping rates;
- constant pressure levels during subsequent pumping;
- characteristic and easy to identify shut - in pressures, the pressure only slightly decreased during the shut - in period, again an indication for extremely low rock mass permeability.

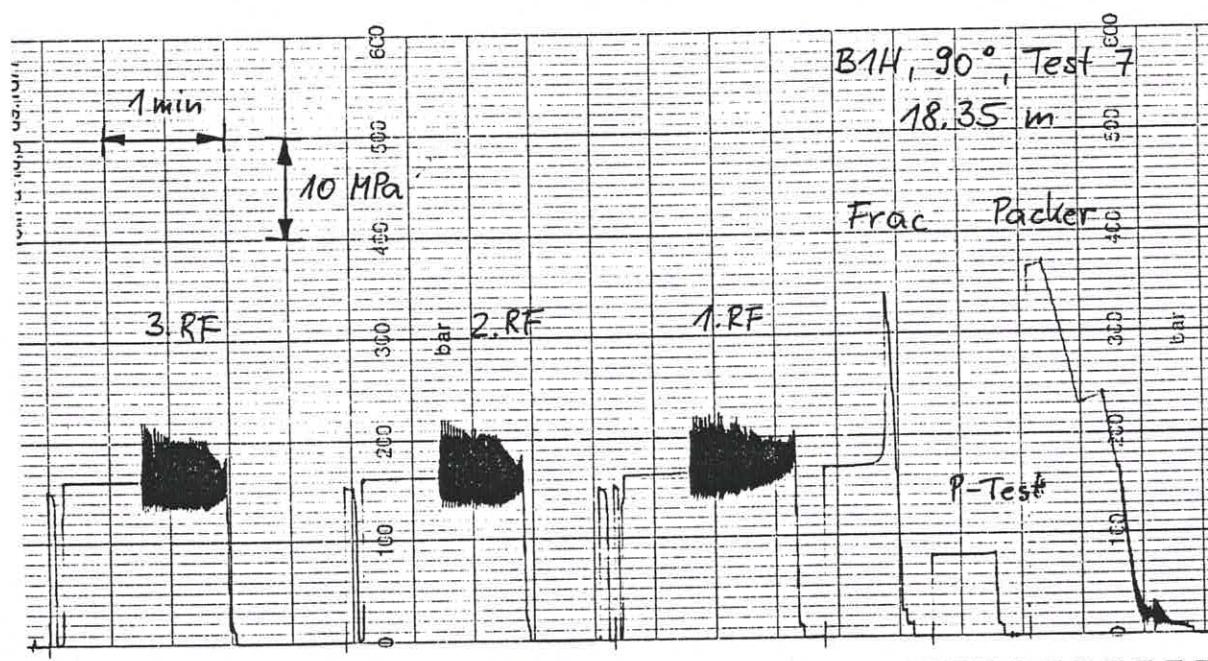
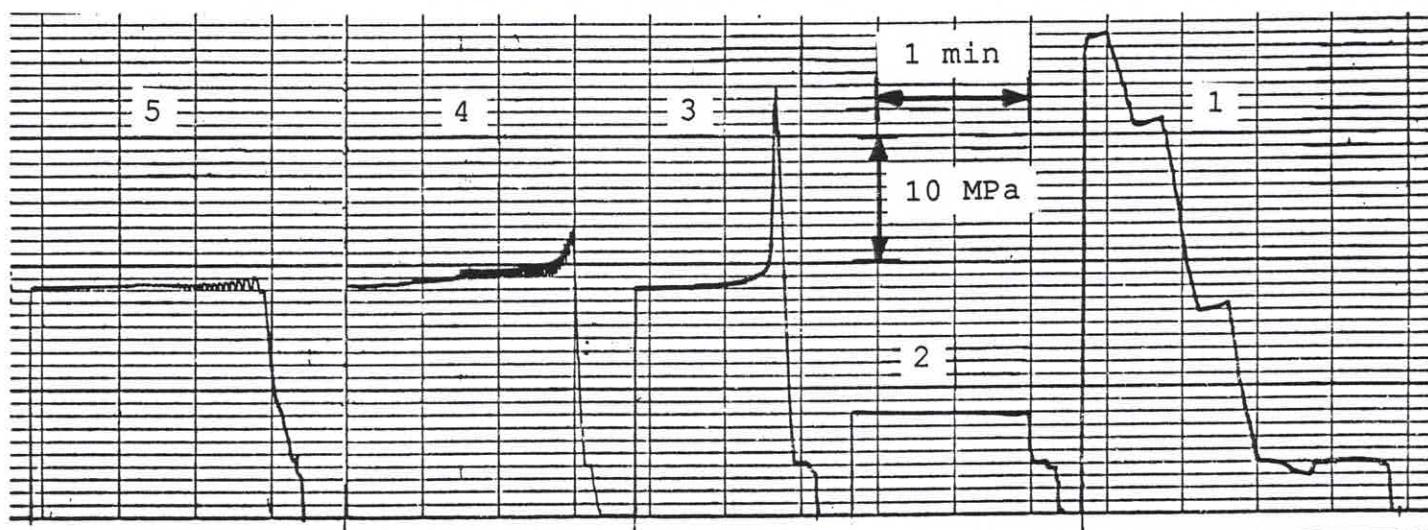
Table 6.1 : Hydrofrac Experiments in Ruhr Coal Mines (Nov. 94)

Mine	borehole	test interval	number of hydrofrac tests
Friedrich Heinrich	617 - T/V	9.6 - 37.6	15
	617 - T/H	6.2 - 34.2	15
Lohberg	B 1 V	3.2 - 25.0	7
	B 1 H 90	3.4 - 36.4	12
	B 1 H 45	3.8 - 36.8	12
	B 2 V	3.5 - 19.4	4
	B 2 H 90	9.5 - 30.5	7
	B 2 H 45	3.8 - 42.8	14
	B 3 V	3.5 - 12.5	4
	B 3 H 90	3.5 - 36.5	12
	B 4 V	25.0 - 37.0	5
General Blumenthal	B 4 H 80	10.5 - 13.5	2
	B 7 V	7.1 - 37.1	11
	B 5 H	6.1 - 34.6	11
Haus Aden	B 6 H	7.5 - 28.1	12
	B 1165 V	22.2 - 34.2	6
	B 1166 H	5.0 - 38.3	8
	B 1229 V	27.5 - 39.0	4
	B 1231 H	4.0 - 37.0	12
	B 2 V	8.0 - 27.7	6
	B 1 H	6.2 - 28.8	8
	B 4 V	17.2 - 37.3	3
	B 2 H	8.1 - 26.8	6
	B 1172 V	4.3 - 44.3	14
	B 1173 H	22.4 - 43.3	8

Table 6.1 : continued

Mine	borehole	test interval	number of hydrofrac tests
Westfalen	B 3 V	11.0 - 39.6	11
	B 4 H	12.0 - 38.3	12
	B 10 V	24.0 - 46.0	9
	B 9 H	5.0 - 37.0	12
	B 1 V	4.0 - 39.0	13
	B 2 H	10.0 - 37.0	10
	B 5 V	4.0 - 37.0	12
	B 6 V	4.0 - 31.0	10
	B 7 V	6.0 - 34.0	9
	B 8 H	7.0 - 37.0	24
	B 11 V	4.0 - 20.0	7
	B 12 H	6.0 - 39.0	11
	B 13 H	2.9 - 38.9	13

Fig. 6.1 : Typical pressure records observed during hydrofrac tests in German coal mines



7. HYDROFRAC PRESSURE DATA

The hydrofrac pressure values P_c (frac initiation), P_r (fracture reopening), and P_{si} (fracture closure) are listed in Tables 7.1 to 7.3. The data presented are mean values for each borehole mostly for the borehole sections app. 10 m away from the well head.. Of course, the P_c - data show significant variation due to local rock strength (± 5 MPa). The variation in P_r and P_{si} is in the order of ± 2 MPa, if we consider only data observed away from the mine gallery.

In Figures 7.1 to 7.6 the mean characteristic pressure data are plotted as a function of depth below surface for both vertical and horizontal boreholes. Stratigraphic heights are not available. Figure 7.7 shows the variation of the characteristic pressure values for borehole H 8, at the - 1250 m level (below surface) in the mine Westfalen, the most thoroughly investigated borehole.

Table 7.1 : Mean breakdown Pressure P_c , mean reopening pressure P_r , and mean shut - in pressure P_{si} values for each borehole at all locations

mine	borehole	depth below surface	P_c	P_r	P_{si}	θ
		m	MPa	MPa	MPa	N ° E
Friedrich Heinrich	617 V	586	20.9 ± 2.4	15.3 ± 1.8	13.1 ± 1.4	123 ± 12
	617 H	586	21.8 ± 1.0	17.4 ± 2.0	11.3 ± 0.8	140 ± 26
Lohberg	1 V	1315	23.4 ± 2.0	20.3 ± 0.6	18.5 ± 0.9	153 ± 14
	1 H 90	1315	28.5 ± 3.9	19.8 ± 3.2	16.2 ± 0.7	160 ± 8
	1 H 45	1315	26.5 ± 4.8	21.6 ± 2.5	15.8 ± 2.0	155 ± 14
	2 V	1315	34.8 ± 5.8	27.1 ± 3.5	25.0 ± 3.8	150 ± 12
	2 H 90	1315	31.8 ± 2.6	20.0 ± 2.5	16.0 ± 2.1	--
	2 H 45	1315	25.8 ± 4.0	23.2 ± 3.7	18.0 ± 3.5	--
	3 V	1315	20	19.5	15.5	170
	3 H 90	1315	33.0 ± 4.2	15.9 ± 2.6	12.1 ± 0.6	171 ± 6
	4 V	1315	18.9 ± 2.9	16.9 ± 2.8	13.7 ± 1.7	161 ± 17
	4 H 80	1315	25.5	14	6.5	--

Table 7.1 : continued

mine	borehole	depth below surface	P _c	P _r	P _{si}	θ
		m	MPa	MPa	MPa	N ° E
General Blumenthal	7 V	975	34.0±6.4	22.6±6.3	23.2±5.3	170±40
	5 H	975	30.2±4.8	23.5±5.4	25.8±3.8	--
	6 H	975	31.3±3.1	26.6±1.8	25.8±2.1	--
Haus Aden	1165 V	750	22.7±4.8	17.5±3.8	14.5±2.9	100±19
	1166 H	750	23.4±3.6	15.1±1.2	12.3±1.9	--
	1229 V	750	15.3±1.0	10.0±2.2	7.8±1.5	133±21
	1231 H	750	14.4±4.0	11.6±3.6	8.4±3.0	130±26
	1060 V (2V)	998	20.0±6.2	16.2±4.7	15.2±2.7	(40±20)
	1059 H (1 H)	998	23.2±3.6	17.8±2.3	17.5±0.8	--
	1078 V (4 V)	998	17.3±7.4	11.4±3.1	10.4±2.0	(40±20)
	1061 H (2H)	998	19.5±2.5	16.3±2.5	12.8±3.2	--
	1172 V	998	25.7±3.7	21.1±3.6	18.4±3.3	163±30
Westfalen	1173 V	998	28.6±8.2	19.1±2.8	15.0±1.8	174±20
	3 V	1030	20.8±2.8	13.6±3.3	12.6±1.7	180±16
	4 H	1030	17.8±1.5	11.4±1.5	9.2±1.0	188±21
	10 V	1030	21.2±4.4	13.4±2.1	9.1±2.1	--
	9 H	1030	29.9±6.2	21.8±6.0	17.7±3.5	--
	1 V	1250	32 ±10	27 ±3	25 ±3	158± 1
	2 H	1250	26.2±2.8	20.8±1.9	19.6±1.8	--
	5 V	1250	26.5±3.7	18.3±2.5	16.6±2.3	162±47
	8 H	1250	36.3±3.3	27.7±2.6	24.4±3.1	160± 3
	13 H	1250	33.6±3.4	20.9±1.4	18.4±0.7	155±17
	11 V	1250	19.1±5.0	9.7±1.1	8.8±1.1	156± 8
	12 H	1250	33.5±3.7	25.2±2.0	18.9±1.4	166±21
	6 V	1250	25.0±3.5	17.0±2.0	13.8±1.2	158±22
	7 V	1250	17.8±2.7	13.3±4.4	10.8±2.6	--

Table 7.2 a : Hydrofrac pressure values in Vertical Boreholes

mine	borehole	depth below surface	P_c	P_r	P_{si}
			m	MPa	MPa
Friedrich Heinrich	617 V	586	20.9 ± 2.4	15.3 ± 1.8	13.1 ± 1.4
General Blumenthal	7 V	975	34.0 ± 6.4	22.6 ± 6.3	23.2 ± 5.3
Haus Aden	1165 V	750	22.7 ± 4.8	17.5 ± 3.8	14.5 ± 2.9
	1229 V	750	15.3 ± 1.0	10.0 ± 2.2	7.8 ± 1.5
	1060 V (2 V)	998	20.0 ± 6.2	16.2 ± 4.7	15.2 ± 2.7
	1078 V (4 V)	998	17.3 ± 7.4	11.4 ± 3.1	10.4 ± 2.0
	1172 V	998	25.7 ± 3.7	21.1 ± 3.6	18.4 ± 3.3
	1173 V	998	28.6 ± 8.2	19.1 ± 2.8	15.0 ± 1.8
Westfalen	3 V	1030	20.8 ± 2.6	13.6 ± 3.3	12.6 ± 1.7
	10 V	1030	21.2 ± 4.4	13.4 ± 2.1	9.1 ± 2.1
	1 V	1250	32.0 ± 10.5	27.0 ± 3.0	25.0 ± 3.0
	5 V	1250	26.5 ± 3.7	18.3 ± 2.5	16.6 ± 2.3
	11 V	1250	19.1 ± 5.0	9.7 ± 1.1	8.8 ± 1.1
	6 V	1250	25.0 ± 3.5	17.0 ± 2.0	13.8 ± 1.2
	7 V	1250	17.8 ± 2.7	13.3 ± 4.4	10.8 ± 2.6
Lohberg	1 V	1315	23.4 ± 2.0	20.3 ± 0.6	18.5 ± 0.9
	2 V	1315	34.8 ± 5.8	27.1 ± 3.5	25.0 ± 3.8
	3 V	1315	20	19.5	15.5
	4 V	1315	18.9 ± 2.9	16.9 ± 2.8	13.7 ± 1.7

Table 7.2 b : Hydrofrac pressure values in Horizontal Boreholes

mine	borehole	depth below surface	P_c	P_r	P_{si}
			m	MPa	MPa
Friedrich Heinrich	617 H	586	21.8 ± 1.0	17.4 ± 2.0	11.3 ± 0.8
General Blumenthal	5 H	975	30.2 ± 4.8	23.5 ± 5.4	25.8 ± 3.8
	6 H	975	31.3 ± 3.1	26.6 ± 1.8	25.8 ± 2.1
Haus Aden	1166 H	750	23.4 ± 3.6	15.1 ± 1.2	12.3 ± 1.9
	1231 H	750	14.4 ± 4.0	11.6 ± 3.8	8.4 ± 3.0
	1059 H (1 H)	998	23.3 ± 3.6	17.8 ± 2.3	17.5 ± 0.8
	1061 H (2 H)	998	19.5 ± 2.5	16.3 ± 2.5	12.8 ± 3.2
Westfalen	4 H	1030	17.8 ± 1.5	11.4 ± 1.5	9.2 ± 1.0
	9 H	1030	29.9 ± 6.2	21.8 ± 6.0	17.7 ± 3.5
	2 H	1250	26.2 ± 2.8	20.8 ± 1.9	19.6 ± 1.8
	8 H	1250	36.3 ± 9.3	27.7 ± 2.6	24.4 ± 3.1
	13 H	1250	33.6 ± 3.4	20.9 ± 1.4	18.4 ± 0.7
	12 H	1250	33.5 ± 3.7	25.2 ± 2.0	18.9 ± 1.4
Lohberg	1 H 90	1315	28.5 ± 3.9	19.8 ± 3.2	16.2 ± 0.7
	1 H 45	1315	26.5 ± 4.8	21.6 ± 2.5	15.8 ± 2.0
	2 H 90	1315	31.8 ± 2.6	20.0 ± 2.5	16.0 ± 2.1
	2 H 45	1315	25.8 ± 4.0	23.2 ± 3.7	18.0 ± 3.5
	3 H 90	1315	33.0 ± 4.2	15.9 ± 2.6	12.1 ± 0.6
	4 H 80	1315	25.5	14	6.5

Table 7.3 : Hydrofrac pressure values, borehole B H 8, - 1250 m level, Westfalen

z,m	year	P_c, MPa	P_r, MPa	P_{sl}, MPa
7.0	88	30.5	25.0	21.0
10.0	88 / 90	36.0	25 / 25	21 / 20
11.5	89	34.0	26.0	20.5
13.0	89	37.5	26.0	21.0
14.5	89	36.0	26.0	21.0
16.0	88	40.0	25.0	22.5
17.5	89 / 90	37.5	26 / 26	23.5 / 22.5
19.0	88	36.0	26.0	24.0
20.5	89	32.0	26.0	24.0
22.0	88 / 90	35.5	28 / 27	25 / 24
23.5	89	33.0	27.0	24.0
25.0	88	37.0	28.0	25.0
28.0	88 / 90	36.0	28.5 / 27	26 / 24
29.5	89	33.5	28.0	25.0
31.0	88	37.5	30.0	27.0
32.5	89 / 90	35.0	30 / 30	27 / 27
34.0	88 / 90	42.5	34 / 32	31.5 / 30
37.0	88	43.5	33.0	29.5
mean		36.3 ± 3.3	27.7 ± 2.6	24.4 ± 3.1

Fig. 7.1 : P_c versus depth below surface for vertical boreholes

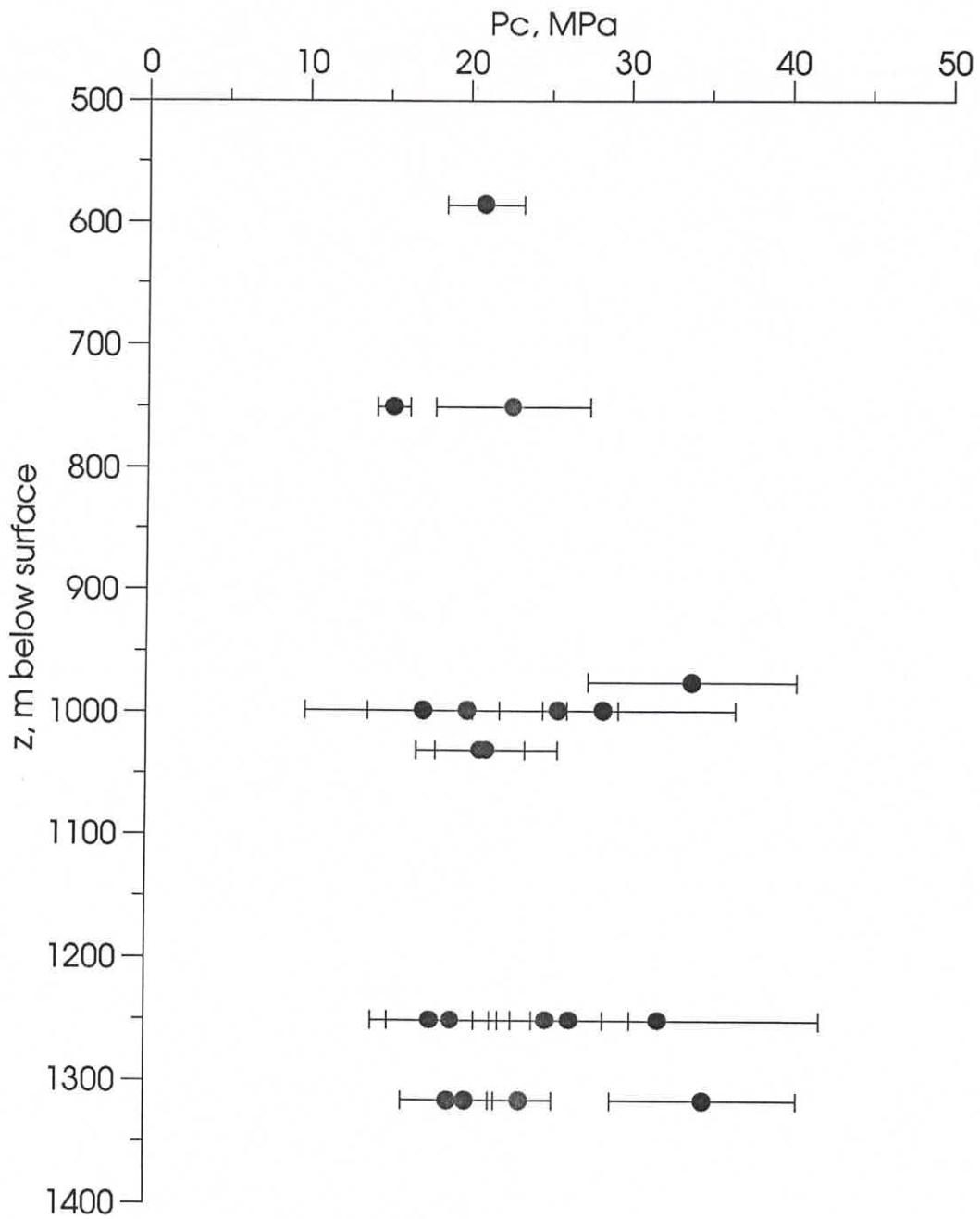


Fig. 7.2 : P_r versus depth below surface for vertical boreholes

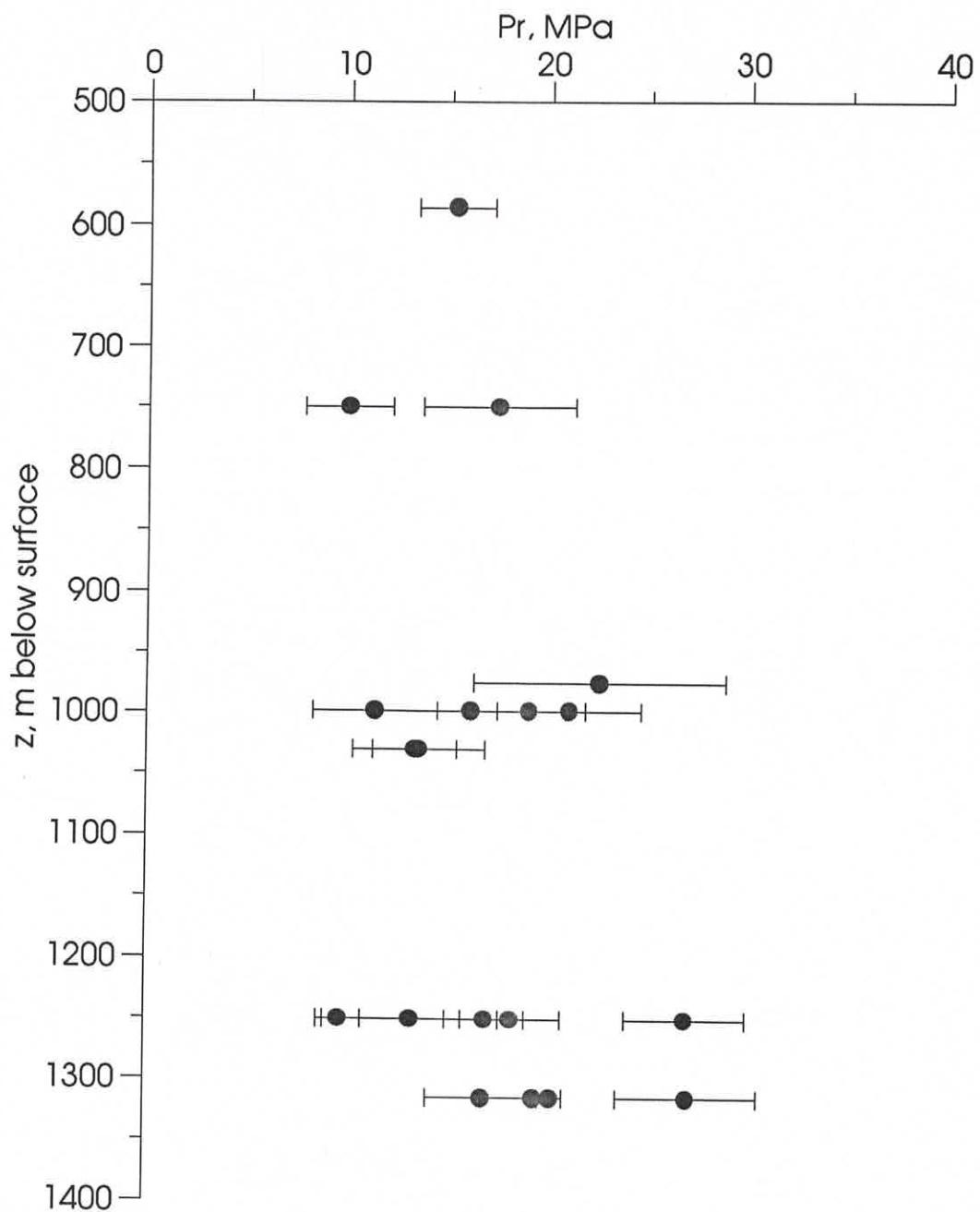


Fig. 7.3 : P_{si} versus depth below surface for vertical boreholes

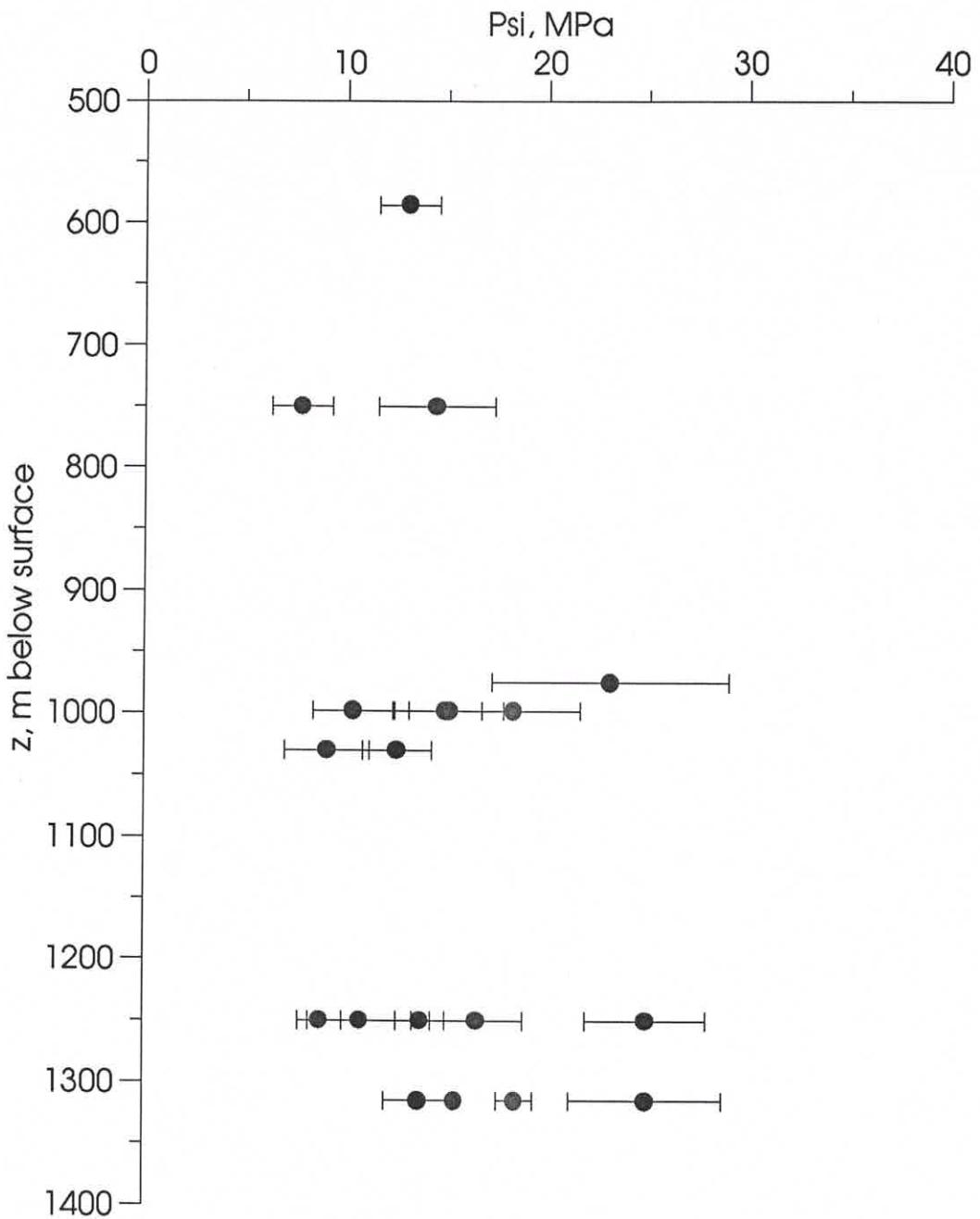


Fig. 7.4 : P_c versus depth below surface for horizontal boreholes

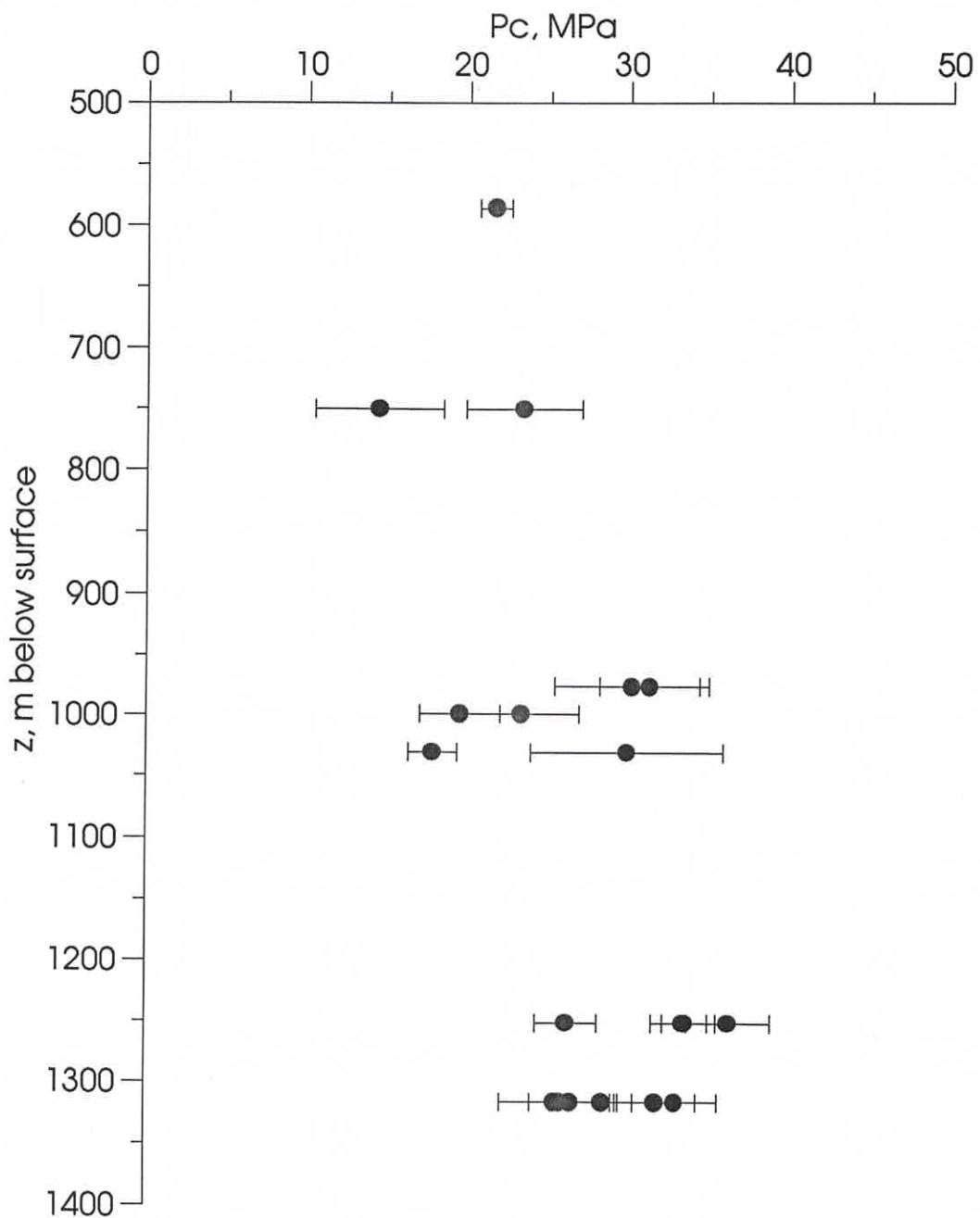


Fig. 7.5 : P_r versus depth below surface for horizontal boreholes

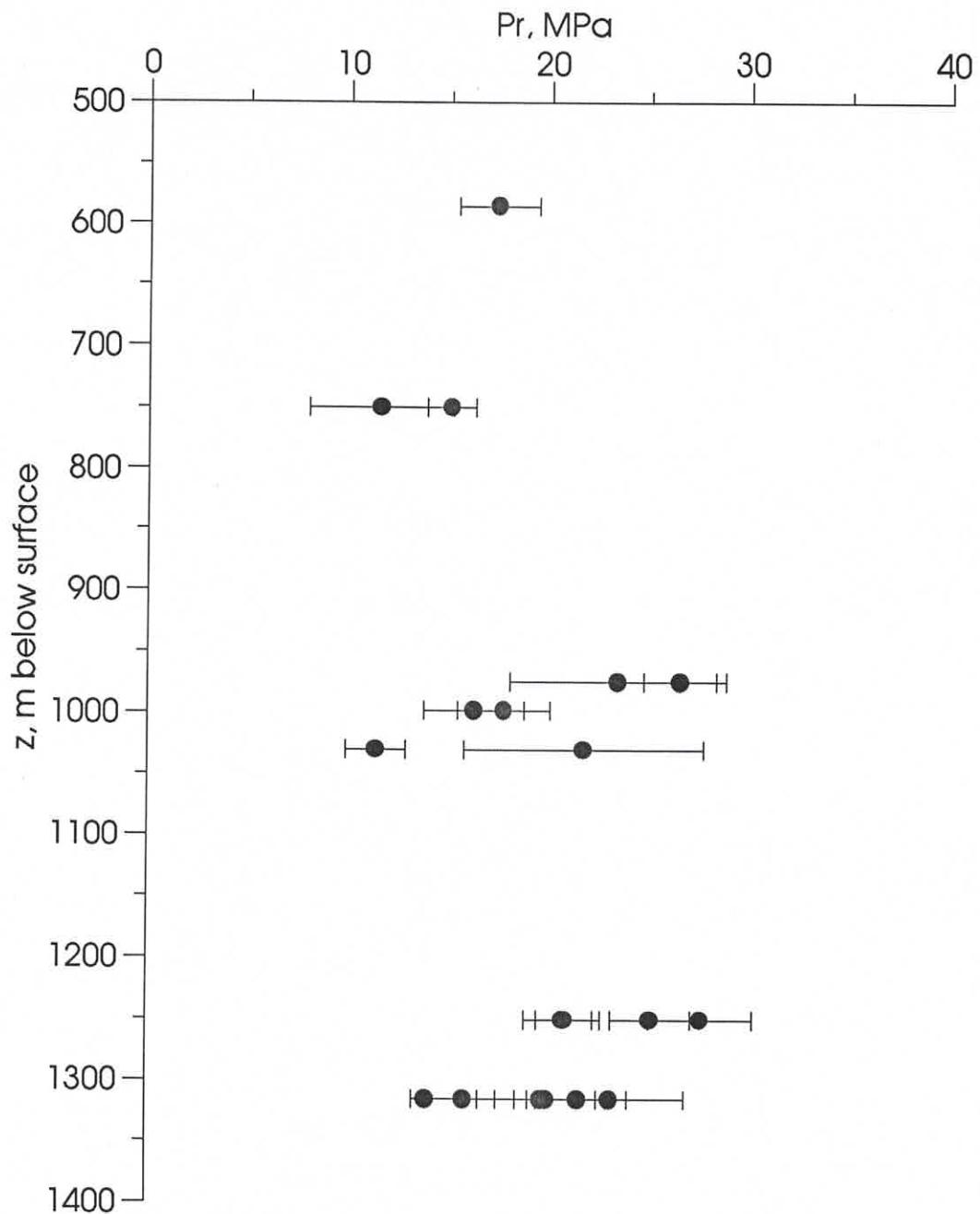


Fig. 7.6 : P_{si} versus depth below surface for horizontal boreholes

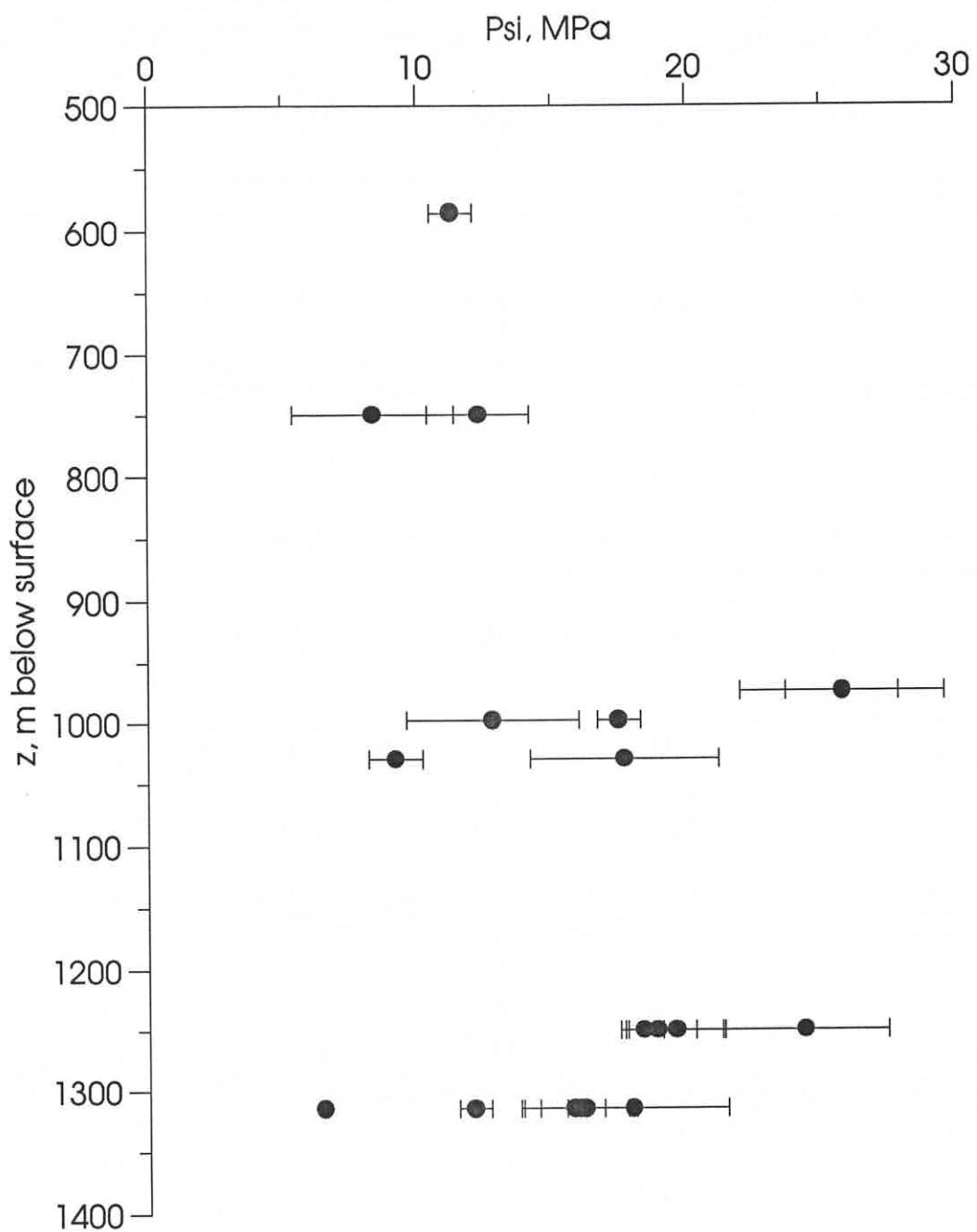
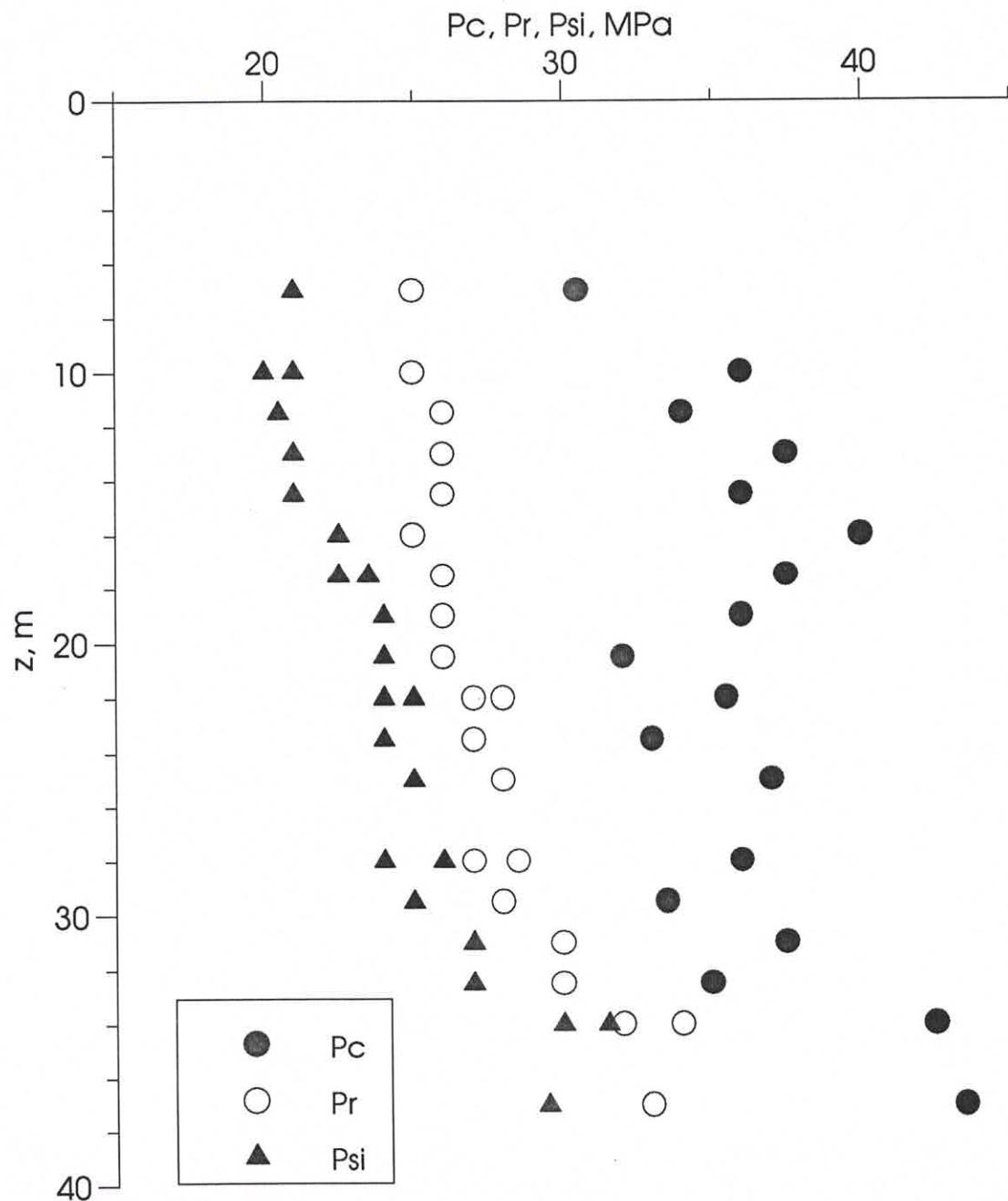


Fig. 7.7 : Hydrofrac pressure values P_c , P_r and P_{si} for borehole B H 8, 1250 m below surface, Westfalen. Data obtained in 3 test series 1988 / 89 /90. Compare Table 7.3.



8. HYDROFRAC STRESS DATA

The hydrofrac mean pressure data presented in Table 7.1 are used for the principal stress evaluation by assuming the overburden stress is a principal stress. Otherwise, the stress evaluation follows the procedures described in Section 5.3.

The results of the stress estimate are listed in Table 8.1 and are shown graphically in Figures 8.1 to 8.6. Table 8.1 also contains the value of the overburden stress S_v^* assuming a constant overburden mean rock density of 2.5 g/cm³ for all test locations in the 5 different mines. In the calculation of S_v^* the elevation of the mine above sea level is considered. θ indicates the direction of maximum horizontal stress S_H derived from the tests, mainly in the vertical boreholes.

In order to follow the estimate of stresses given in Table 8.1 one example is shown for the case of mine Friedrich - Heinrich.

- (i) For the vertical borehole 617 V where vertical fractures were induced we obtained the following mean pressure values (Table 7.1):

$$P_{si} = 13.1 \text{ MPa}$$

$$P_r = 15.3 \text{ MPa}$$

Then, the H & W equation yields the value for S_h and S_H :

$$S_h = P_{si} \rightarrow 13.1 \text{ MPa}$$

$$S_H = 3 \cdot S_h - P_r \rightarrow 24 \text{ MPa}$$

- (ii) For the horizontal borehole 617 V where also vertical fractures were induced we observed the following mean pressure values (Table 7.1):

$$P_{si} = 11.3 \text{ MPa}$$

$$P_r = 17.4 \text{ MPa}$$

The H & W equation yields the values for S_h and S_v :

$$S_h = P_{si} \rightarrow 11,3 \text{ MPa}$$

$$S_v = 3 \cdot S_v - P_r \rightarrow 16.5 \text{ MPa}$$

- (iii) From (i) and (ii) the following stress values are shown in Table 8.1 :

$$S_v = 16.5 \text{ MPa}$$

$$S_H = 24.5 \text{ MPa}$$

$$S_h = \frac{1}{2} (S_{h(i)} + S_{h(ii)}) = 12.2 \text{ MPa}$$

- (iv) Similar procedures were used for the stress estimates at other locations.

Table 8.1 : Principal stresses S_v , S_H and S_h , and the direction of S_H , θ . For comparison the overburden stress S_v^* , for an average density of 2.5 g/cm³.

mine	location coordinates	depth below surface	S_v^*	S_v	S_H	S_h	θ
	R, H	m	MPa	MPa	MPa	MPa	degrees
Friedrich Heinrich	2532300 5708910	586	14.4	16.5	24.0	12.2±0.9	130±21
Lohberg	1/2 2554400 5718220 3/4 2552670 5717050	1315	32.2	28.4	41.6	18.3±3.5	152±14
General Blumenthal	2582700 5721480	975	23.9	26.2	49.8	23.2	170±40
Haus Aden	2606137 5726305 2608346 5724054	750 18.6 13.6 13.4 8.1	21.9 18.6 25.0 26.5 28.0	27.5 13.7 14.4	13.7 100 130±26 168±30		
Westfalen	2630368 5733898 2629486 5733358	1120 1250	27.7 30.7	23.8 37.7	19.1 27.1	12.2 17.6	156±30 154±47
mean direction S_H							147±23

Fig. 8.1 : S_v and S_v^* as a function of depth

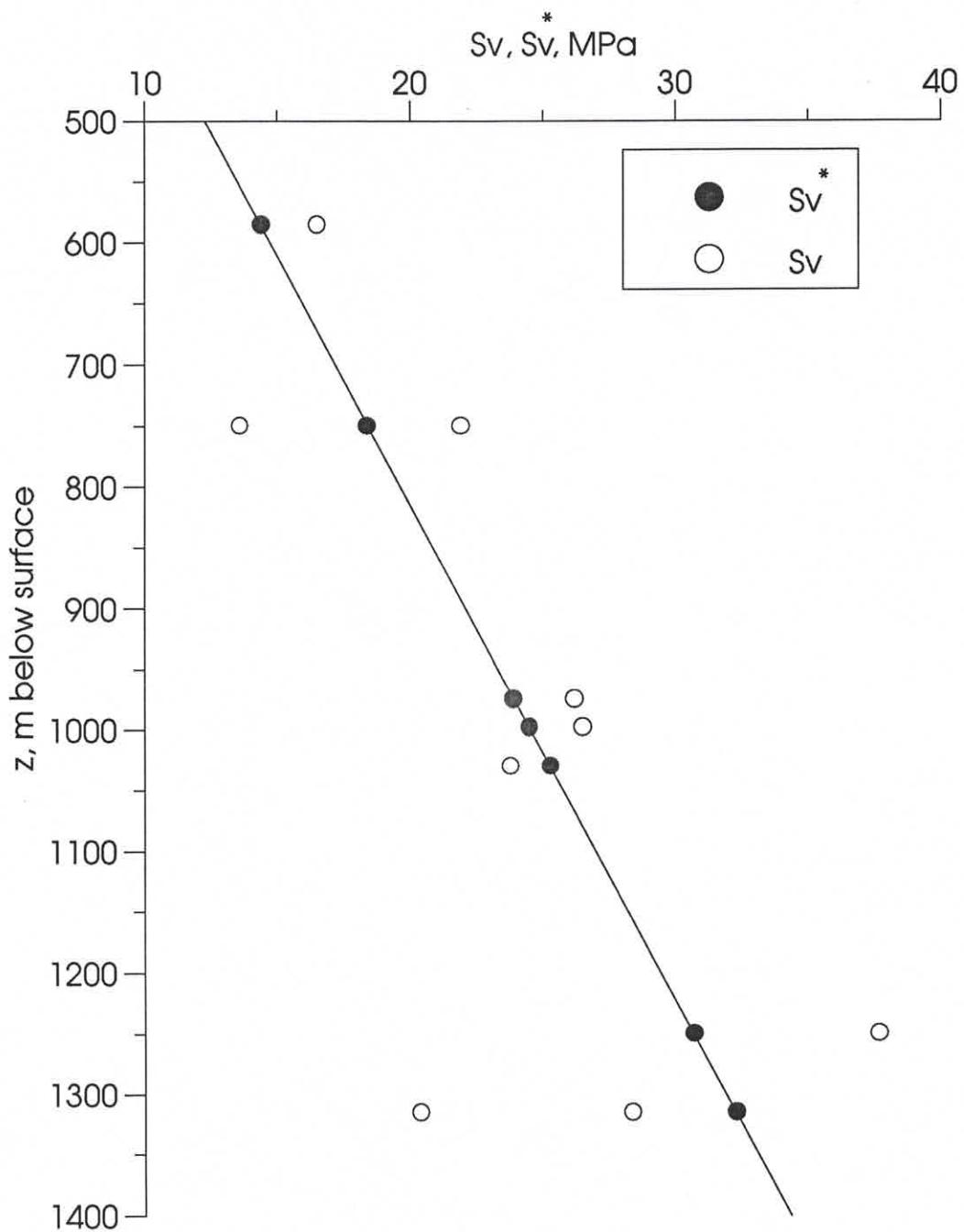


Fig. 8.2 : Normalized stresses S_h/S_v and S_h/S_v^* as a function of depth

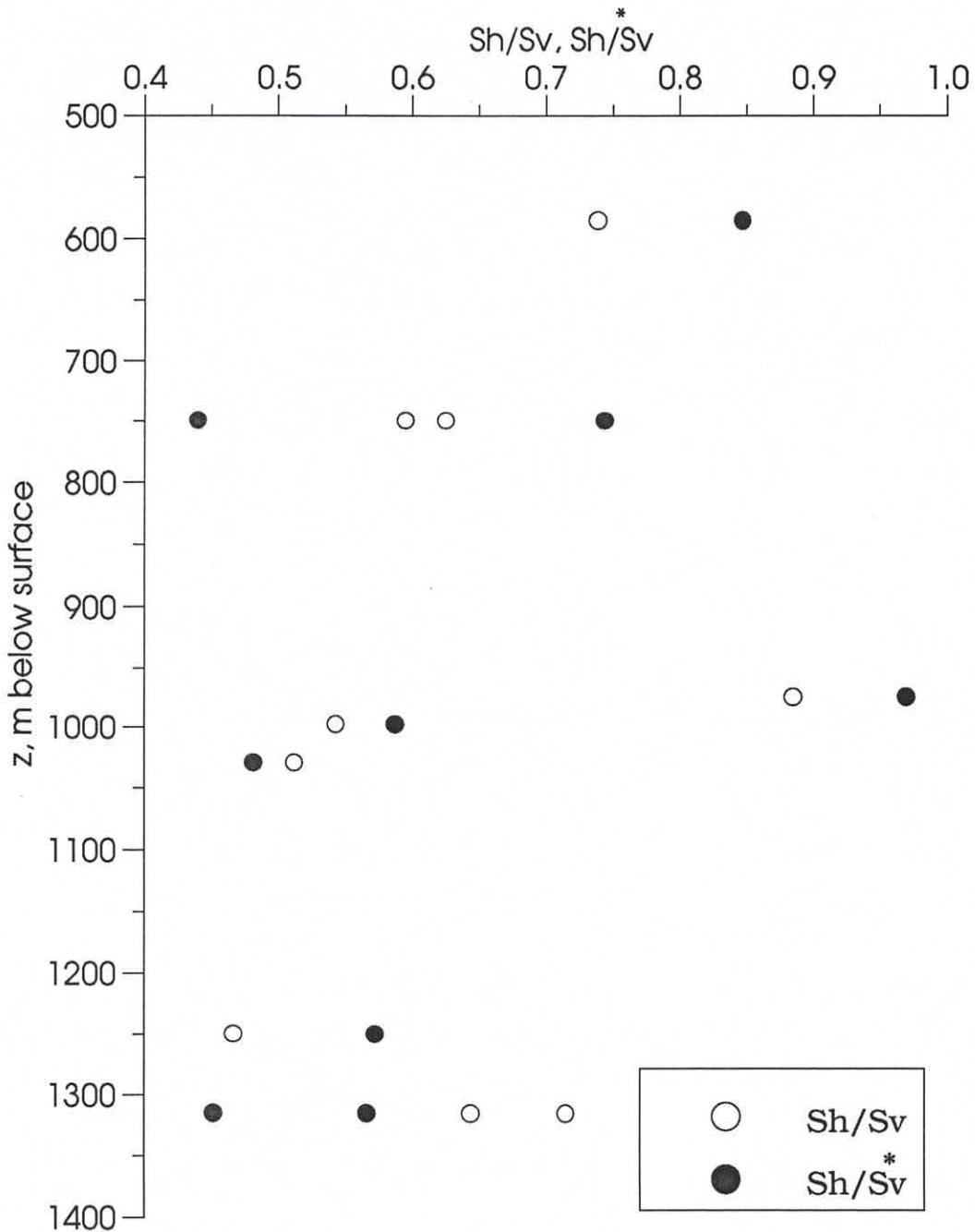


Fig. 8.3 : Normalized stresses S_H/S_v and S_H/S_v^* as a function of depth

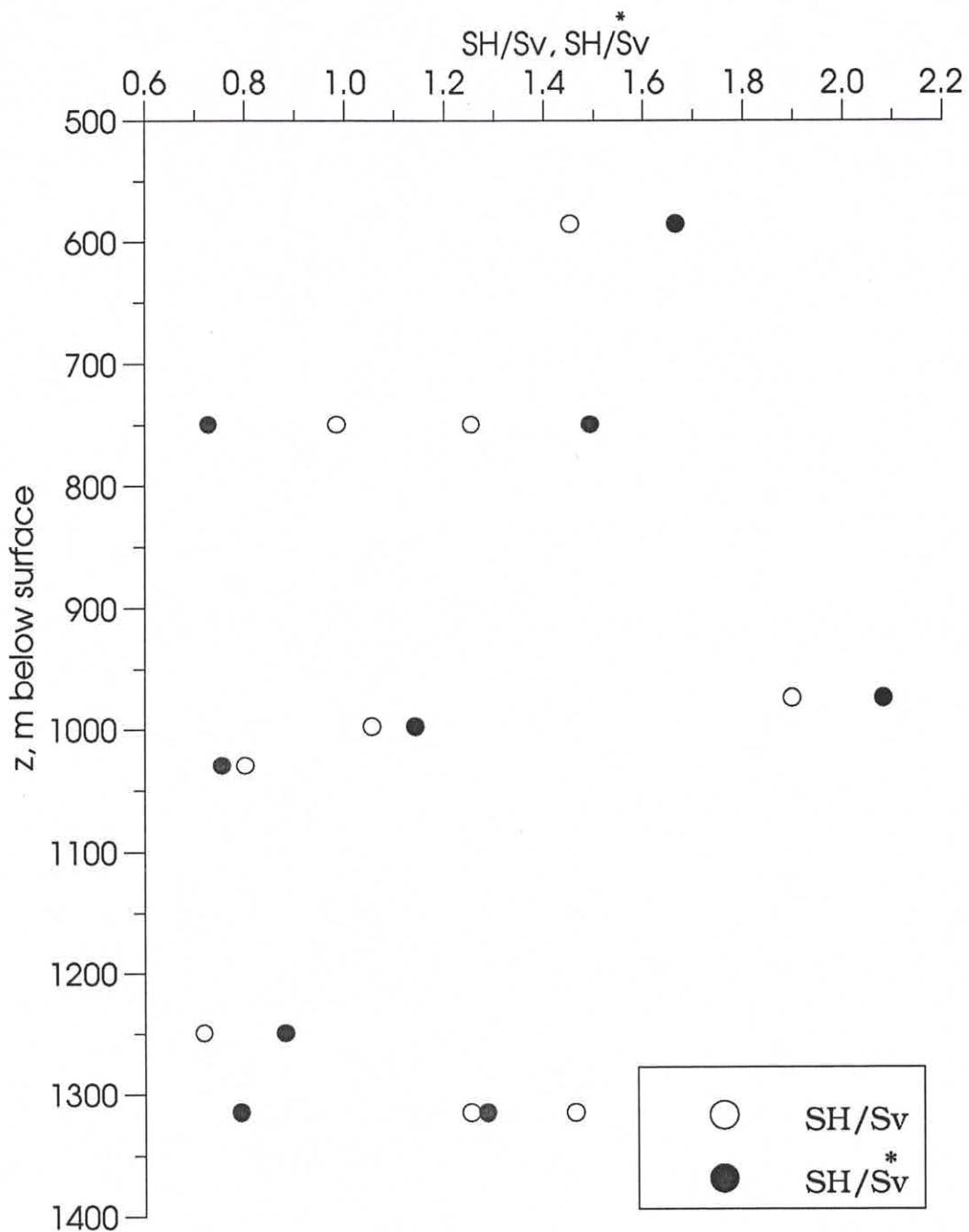


Fig. 8.4 : Maximum horizontal principal stress direction θ (S_H) as a function of depth

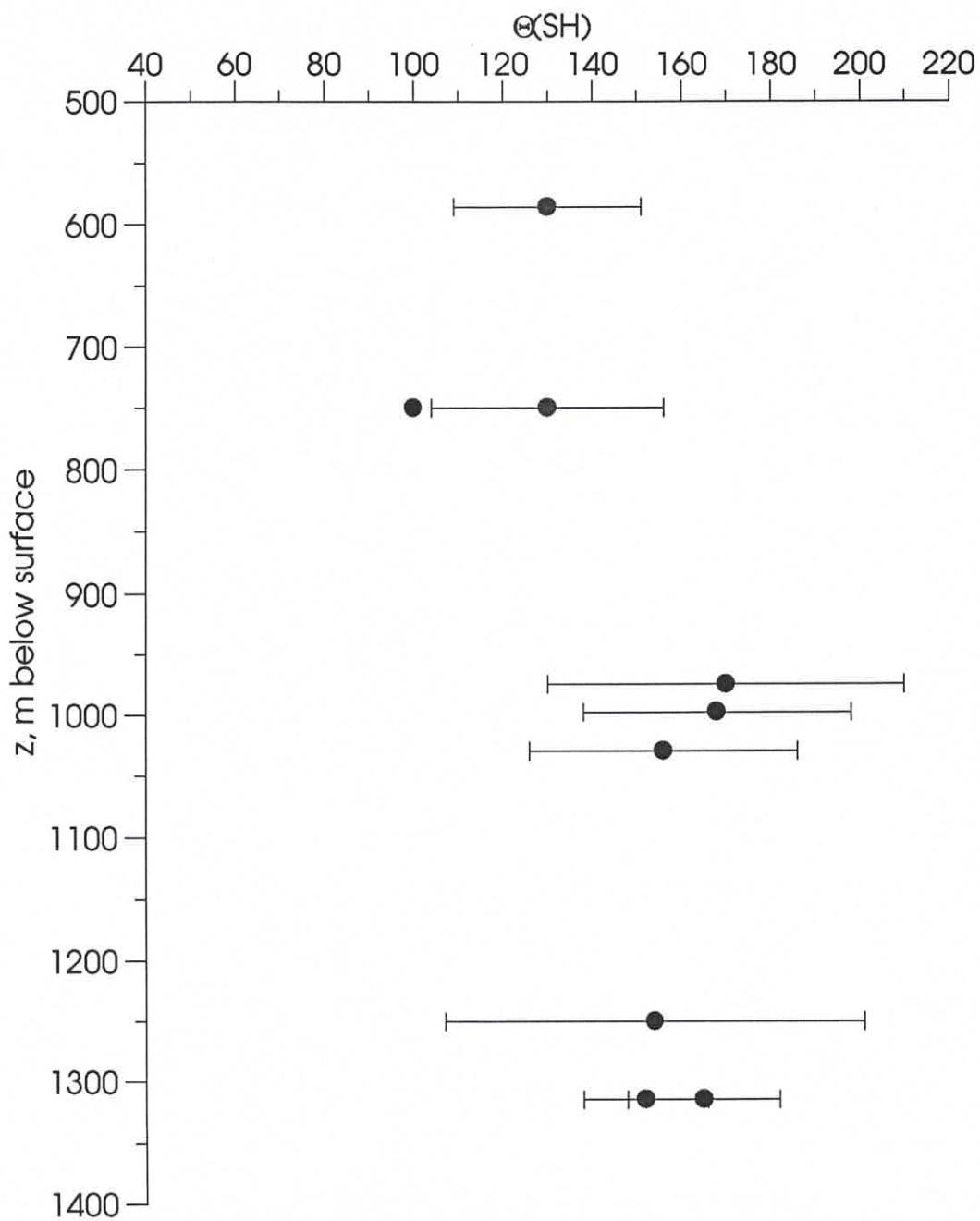


Fig. 8.5 : Maximum stress direction (S_H) for the different mines

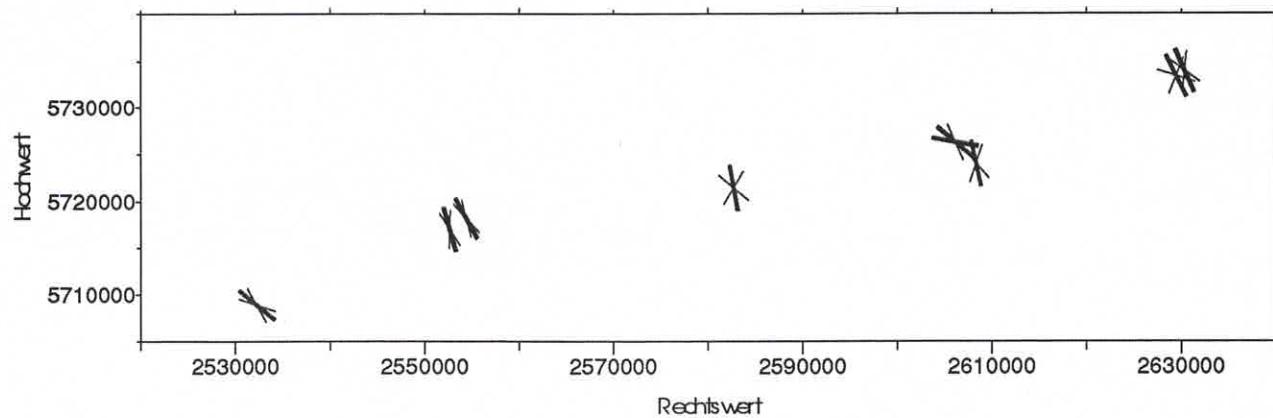
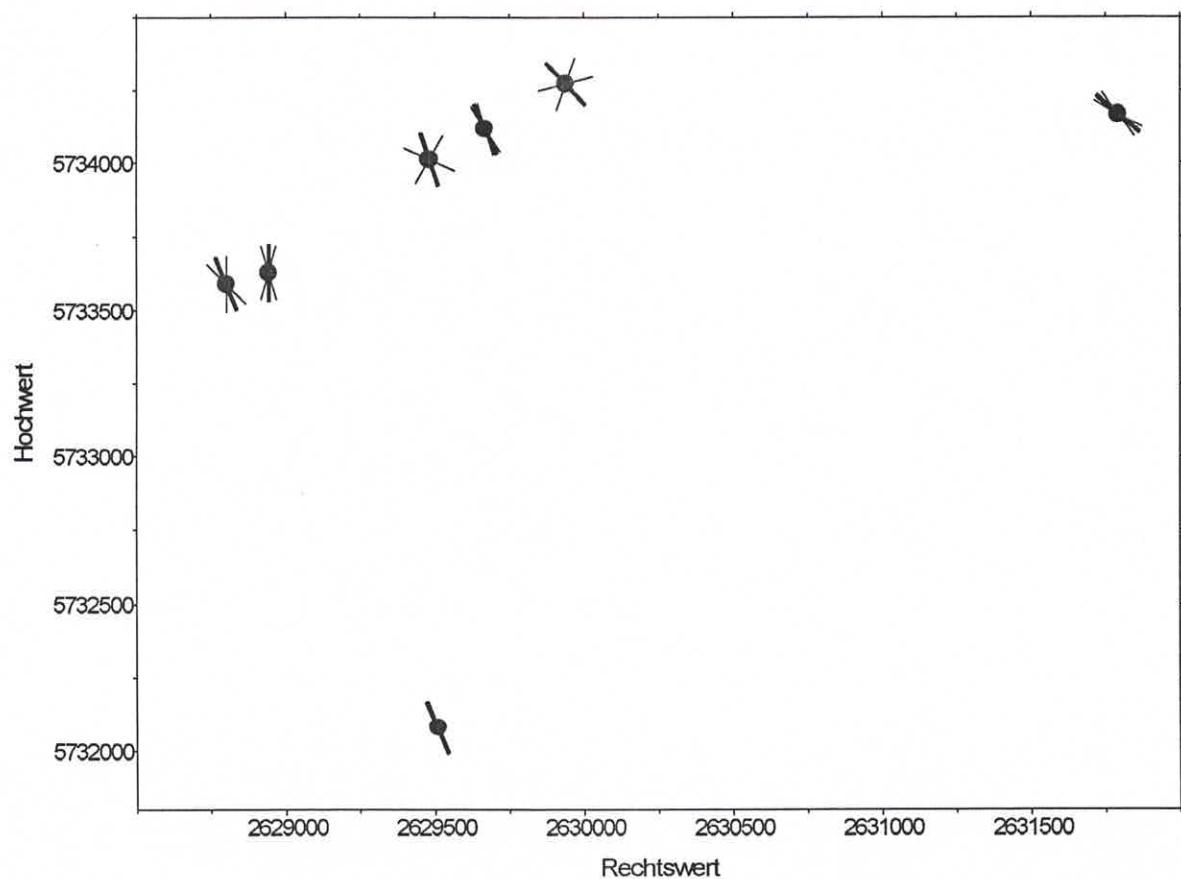


Fig. 8.6 : Stress direction (S_H) for test locations at the mine Westfalen, derived from tests in vertical boreholes



9. DISCUSSION OF STRESS DATA

9.1 STRESS FIELD ORIENTATION

At all mine locations the direction of S_H is NW - SE (mean value 147 ± 23) in agreement with the tectonic stress regime in Central and Western Europe. This means that the mine itself does not strongly influence the stress field at least at test locations not in the vicinity of the workings. Neglecting the value $\theta = 100^\circ$ at the 680 m level at Haus Aden, the scatter of orientation from $\theta = 130^\circ$ at Friedrich Heinrich to $\theta = 170^\circ$ at General Blumenthal or at Haus Aden (940 m level) is acceptable in the view of uncertainties on local homogeneity, isotropy and the finite data base. The mean value of N 147° E fits into the hydrofrac stress map for Central Europe (Fig. 9.1). Variations of tectonic induced variations of stress directions within the Ruhr - area cannot be accepted.

9.2 VERTICAL STRESS

The vertical stress S_v can only be derived from tests in horizontal boreholes. The best opportunity to obtain a reliable value for S_v is to observe horizontal fractures in a horizontal borehole drilled in the direction of the S_h - axis where $P_{si} = S_v$ (assuming $S_h > S_v$). In most of the cases, vertical fractures were observed in the horizontal boreholes indicating, at least, $S_v > S_h$. The derivation of S_v from vertical fractures in horizontal boreholes is not very sensitive to slight variations of S_v^* due to variation in the density profiles and the uncertainty of the test data. However, the derived S_v - values are, in most cases in the order of the overburden stress assuming an overburden density of 2.5 g/cm^3 . In most cases, $S_v > S_v^*$ which suggests a higher overburden density. This is also suggested by density profiles derived from gravity measurements (Fig. 9.2 a, b). A mean overburden density of 2.6 could be discussed which could explain some of the differences in S_v and S_v^* .

9.3 HORIZONTAL STRESSES

In general, we observe the stress situation

$$S_H \geq S_v > S_h$$

with

$$S_H \approx 2 \cdot S_h.$$

This anisotropy in horizontal stresses is also observed for other locations in Central and Western Europe and world - wide. It suggests strike - slip tectonics and thrust faulting in the uppermost crust assuming friction coefficients of about 0.6 to 1.0.

The horizontal stress data, here, are mainly derived from tests in vertical boreholes. In such cases the value of $S_h = P_{si}$ is the more reliable parameter compared to S_H . However, accepting the Hubbert & Willis approach the S_H - values are also reasonable if compared to other test locations in deep boreholes at areas undisturbed by mining.

Fig. 9.1 : Stress direction (S_H) within Central Europe derived from hydrofrac bore-hole testing during the period 1973 to 1994

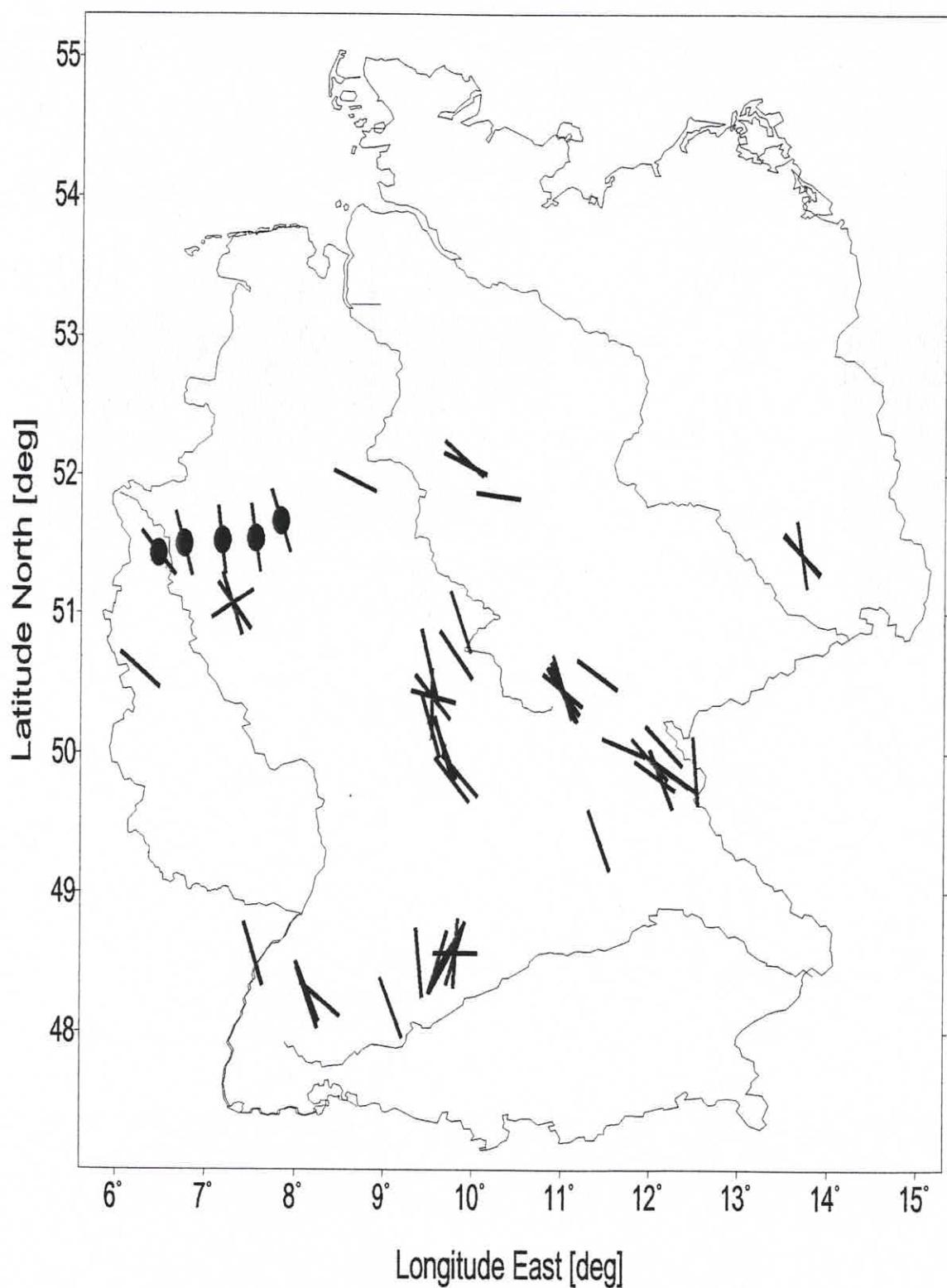


Fig. 9.2 a, b : Density profiles at shafts Königsborn 4 (b) and Carolinenglück derived from gravimetric density logs (courtesy of U. Casten, RUB, 1994)

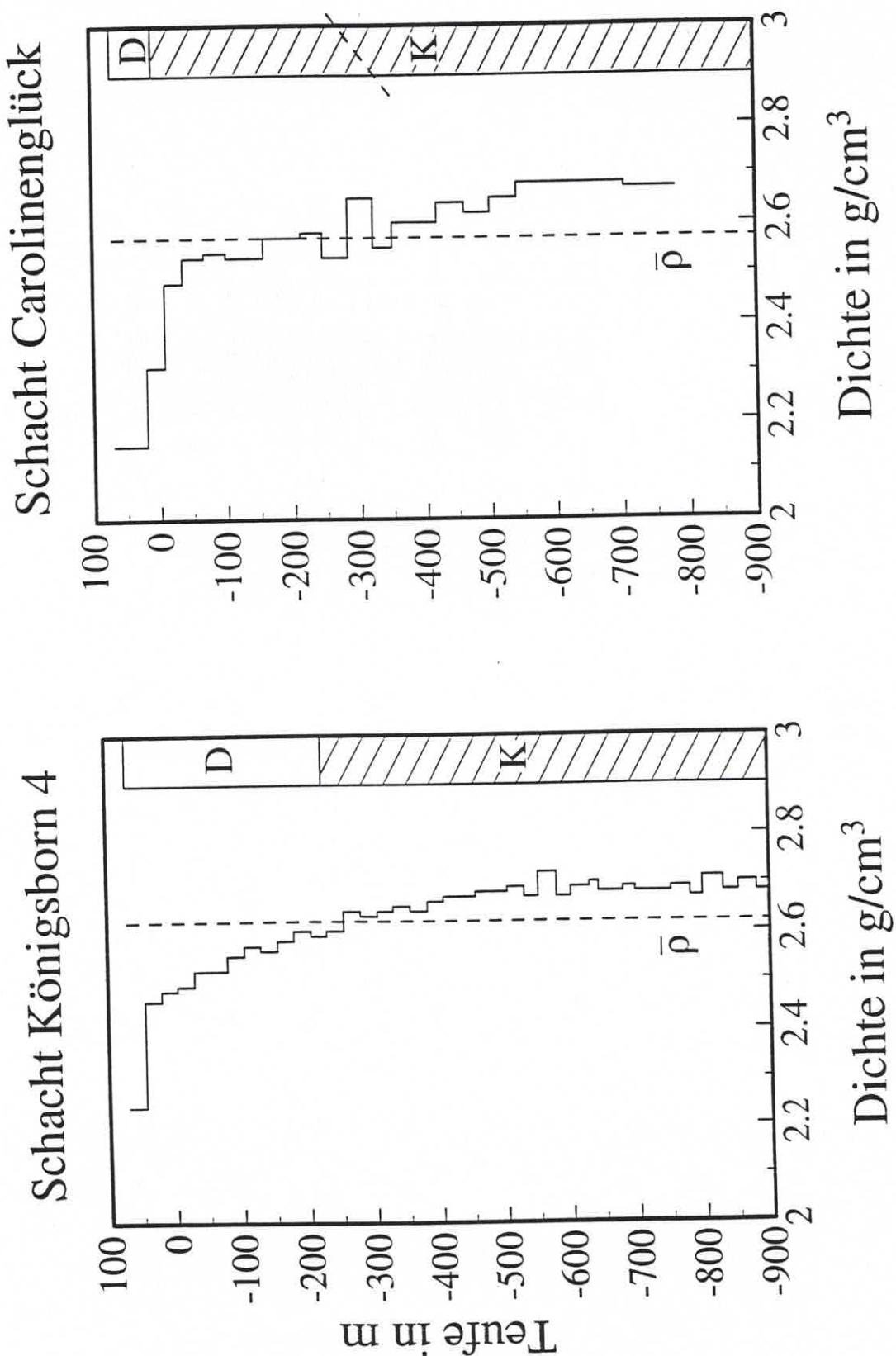


Fig. 9.3 : Normalized stress S_H / S_v as a function of depth below surface for Central Europe

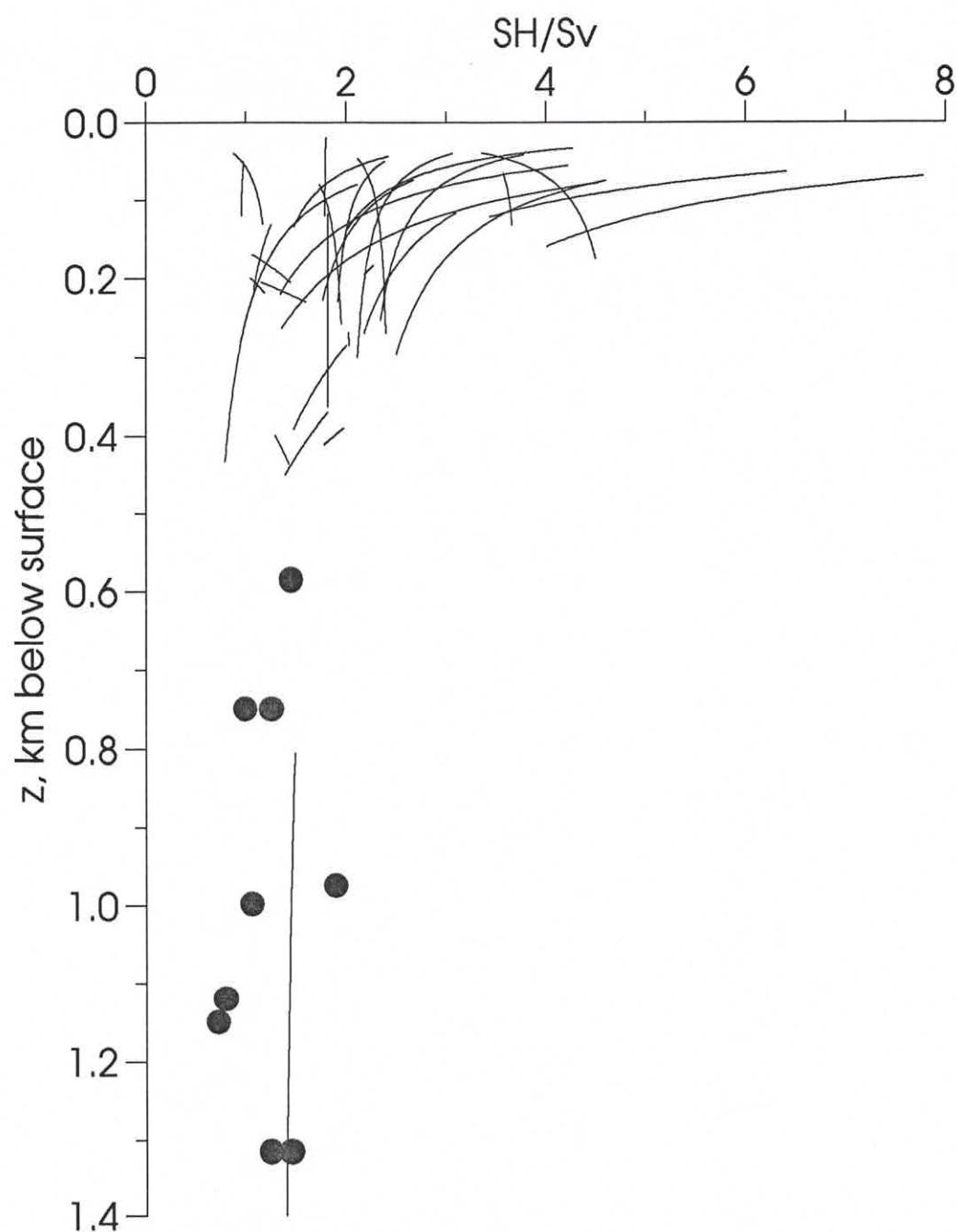
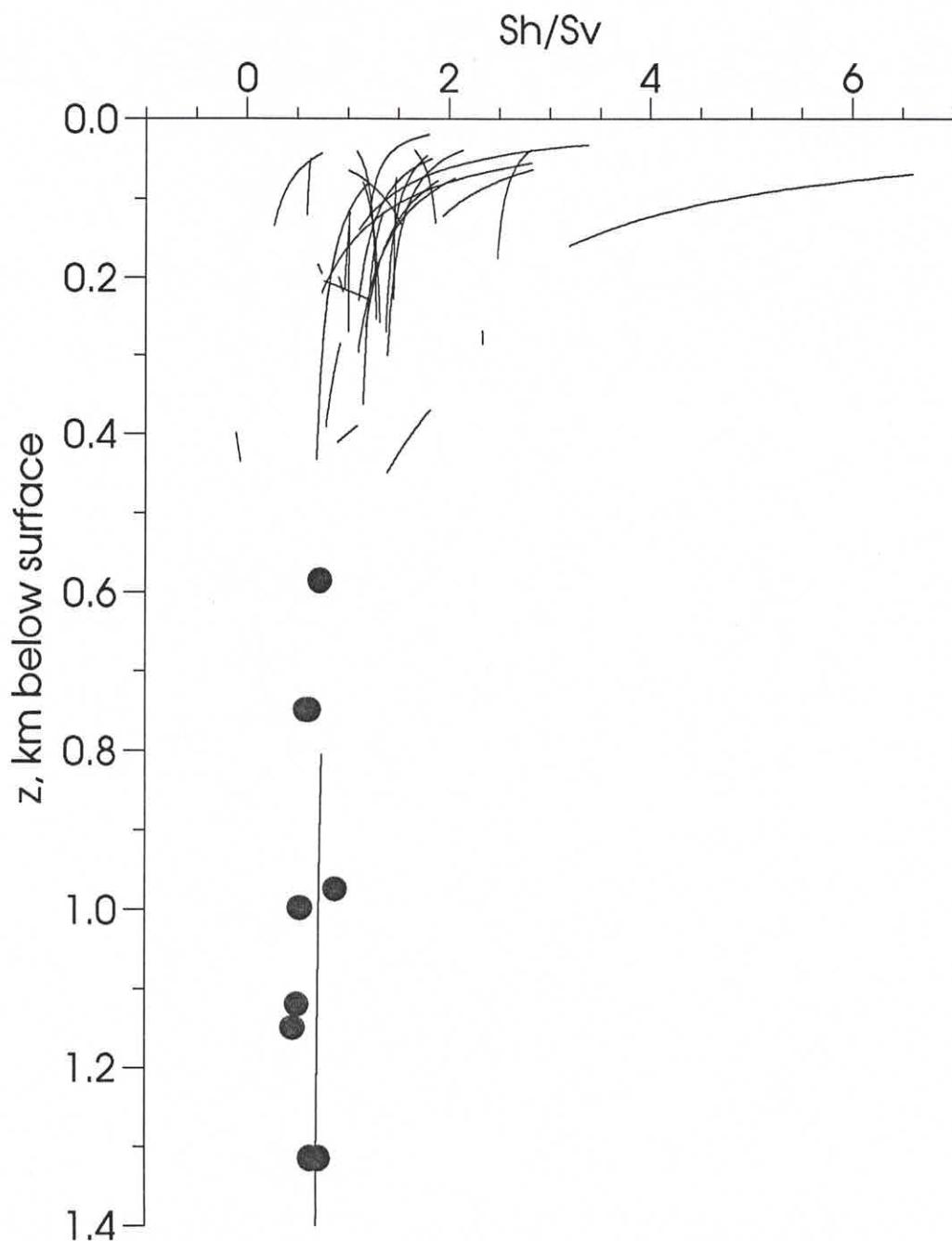


Fig. 9.4 : Normalized stress S_h / S_v as a function of depth below surface for Central Europe



10. PHYSICAL ROCK PROPERTIES

Rock physical properties affect hydraulic fracturing stimulation operation, borehole stability and the occurrence of borehole breakouts (which again can be a stress indicator), as well as frictional behaviour within the rock mass along weakness planes (joints, bedding planes, faults) during long - term CBM operation.

Relevant physical properties for the Ruhr Carboniferous rocks (sandstones, siltstones) are:

(i) Rock Density

Literature data yield a mean value $\rho = 2.65 \text{ g/cm}^3$.

(ii) Young's Modulus E and Poisson's Ratio

29 Young's modulus measurements (static) on the fine - grained sandstone cores from borehole H 13 (mine Westfalen, 1250 m level) yield a mean Young's modulus $E = 35.7 \pm 11 \text{ GPa}$ (strain rate 10^{-5} s^{-1}), a value which also could be valid for the dense and compact siltstones (see MeSy Rep. 12.12.90).

(iii) Uniaxial Compressive Strength σ_{\max}

39 specimens from borehole H 13 (mine Westfalen) yield uniaxial compressive strength values ranging from 20 to 125 MPa with a mean value of $61 \pm 24 \text{ MPa}$ (see MeSy Rep. 12.1290).

(iv) Hydrofrac Tensile Strength P_{co} / p_{co}

The observed mean hydrofrac tensile strength in - situ data (rockmass) P_{co}^* are listed in Table 10.1. The data range from 0.5 MPa to 16.1 MPa with an overall mean value of $6.72 \pm 3.26 \text{ MPa}$. As shown by the mean values for each mine (or each location) in Table 10.1(P_{co}^{**}) the mean values and the scatter is al-

most identical for each test site. Thus, no direct dependence of P_{co} on lithology is obvious.

In comparison, the laboratory hydrofrac tensile strength p_{co} determined on 3 cm diameter cores with a 3 mm injection borehole, subjected to confining pressure p_m is considerable higher (MeSy Rep. 12.12.90). The mean laboratory hydrofrac tensile strength value measured on 36 mini - cores from borehole H 8, Westfalen, yield a mean strength of 22.6 MPa (P_{co} (H 8) = 8.6 ± 3.3 MPa). (See Table 10.1).

(v) Fracture Toughness K_{IC}

Fracture toughness K_{IC} was measured on 24 core samples, again from borehole H 8, Westfalen. Neglecting test arrangement with respect to bedding planes, the laboratory tests yield a mean fracture toughness $K_{IC} = 1.36 \pm 0.29$ $\text{MNm}^{-3/2}$.

Using the fracture mechanics relation

$$P_{co} = \frac{K_{IC}}{(h_o + h_a)\sqrt{r}}$$

(Rummel, Fracture Mechanics of Rock, 217 - 239, Acad. Press Geol. Series, 1987). Yield an intrinsic micro - crack length of 0.5 mm, which is in the order of the grain size of the rocks. For the in - situ case for a borehole with 60 mm diameter, the same relation yields an in - situ rock mass crack length of 3 mm, a reasonable result.

Table 10.1 : In -situ hydrofrac tensile strength $P_{co} = P_c - P_r$. Compare Table 7.1.
 P_{co}^* mean per borehole, P_{co}^{**} mean per mine location

mine	borehole	depth below surface	P_{co}^*	P_{co}^{**}
		m	MPa	MPa
Friedrich Heinrich	617 V	586	5.6	
	617 H	586	4.4	5.0 ± .8
Lohberg	1 V	1315	3.1	
	1 H 90	1315	8.7	
	1 H 45	1315	4.9	
	2 V	1315	7.7	
	2 H 90	1315	11.8	
	2 H 45	1315	2.6	
	3 V	1315	0.5	
	3 H 90	1315	16.1	
	4 V	1315	2.0	
	4 H 80	1315	11.5	6.9 ± 5.1
General Blumenthal	7 V	975	11.4	
	5 H	975	6.7	
	6 H	975	4.7	7.6 ± 3.4
Haus Aden	1165 V	750	5.2	
	1166 H	750	8.3	
	1229 V	750	5.3	
	1231 H	750	2.8	
	1060 V	998	3.6	
	1059 H	998	5.4	
	1078 V	998	5.9	
	1061 H	998	3.2	
	1172 V	998	4.6	
	1173 V	998	9.5	5.4 ± 2.1

Table 10.1 : continued

mine	borehole	depth below surface	P_{co}^*	P_{co}^{**}
		m	MPa	MPa
Westfalen	3 V	1030	7.2	
	4 H	1030	6.4	
	10 V	1030	7.8	
	9 H	1030	8.1	
	1 V	1250	5.0	
	2 H	1250	5.4	
	5 V	1250	8.2	
	8 H	1250	8.6 ± 3.3	
	13 H	1250	12.7	
	11 V	1250	9.4	
	12 H	1250	8.3	
	6 H	1250	8.0	
	7 V	1250	4.5	7.7 ± 2.1
mean				6.72 ± 3.26

11. LITERATURE

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RUMMEL F. : Fracture mechanics approach to hydraulic fracturing stress measurements. In: Fracture Mechanics of Rock, ed. B. K. Atkinson, 217 - 239, Acad. Geol. Ser., London, 1987.

Whitworth, K.R. (ed.) : Investigation into the effects of lithology on the magnitude and ratio of in - situ stress in coal measures. CEC Report, B.C. Corp., Operation Dept., Eastwood, UK

12. ACKNOWLEDGEMENT

MeSy is grateful to Conoco Mineraloel GmbH Essen to provide the opportunity to review and summarise the vast amount of hydrofrac stress data obtained during the period 1986 to 1991 in the Ruhr coal mines. Particularly, MeSy is grateful to the Ruhr - Kohle AG organisations (EBV, Bergbauforschung Essen GmbH and DMT GmbH (IGH5) Essen) to have initiated the measurement program and for the support of the program over the period 1986 to 1991. Many persons of these institutions were involved, scientists, mining personnel and drillers. Test site coordinates and information on test site geology were provided by the Markscheiders from each mine.

Numerous MeSy co-workers participated in the in - situ underground tests in the mines : I. Befeld, O. Befeld, J. Grotkopp, J. Hansen, P. Hegemann, G. Klee, H. Konietzky, J. Renner, H. Vogt, U. Weber, R. Weckheuer.

The present review was sent to Conoco Mineraloel GmbH (Mr. K. Thomas) for review. Its constructive comments were appreciated.

The Appendix presents the present data from hydrofrac stress testing in the UK coal fields conducted by MeSy for British Coal. MeSy is grateful for B.C. co-workers M D North, K R Onions and K R Withworth.

**HYDROFRAC - DATA FROM
MINE BLUMENTHAL**

Tabelle 1a: Charakteristische Druckwerte im Teufenbereich 0 - 18.1 m
 (Vertikalbohrung B 7)

Teufe m	P_c MPa	P_r MPa	P_{si} MPa
7.1	15.0	10.0	6.5
10.1	12.0	8.0	4.5
13.1		8.5	7.5
15.1		10.0	8.8
18.1	20.0	6.0	8.0
Mittelwert:		8.5 ± 1.7	7.1 ± 1.7

Tabelle 1b: Charakteristische Druckwerte im Teufenbereich 22.1 - 37.1 m

Teufe m	P_c MPa	P_r MPa	P_{si} MPa
22.1		12.0	15.5
25.1	27.0	20.0	19.5
28.1	35.5	27.0	27.5
31.1	39.5	30.0	30.0
34.1		25.0	25.0
37.1		21.5	21.8
Mittelwert:		22.6 ± 6.3	23.2 ± 5.3

Tabelle 2: Rißorientierungen (Vertikalbohrung B 7)

Teufe m		Streichen degree	Einfallsrichtung degree	Einfallen degree
7.1	A	174.0	264	90 #
	B	136.6	224	90
10.1		159.0	249	79 #
13.1		184.7	275	78 #
15.1	A	254.4	164	77 #
	B	124.9	215	14
18.1	A	135	45	83 #
	B	123.6	34	90
22.1	A	152.7	243	80
	B	133.6	44	90 #
	C	131.6	222	84
25.1	A	204.7	115	69
	B	193.3	103	76 #
28.1	A	181.3	91	73 #
	B	236.2	146	90
31.1		142.6	53	69 #
34.1		129.3	219	90 #
37.1		222.8	313	90 #
Mittelwerte				81.4 ± 7.7
(# wurde verwendet)		170 ± 40		

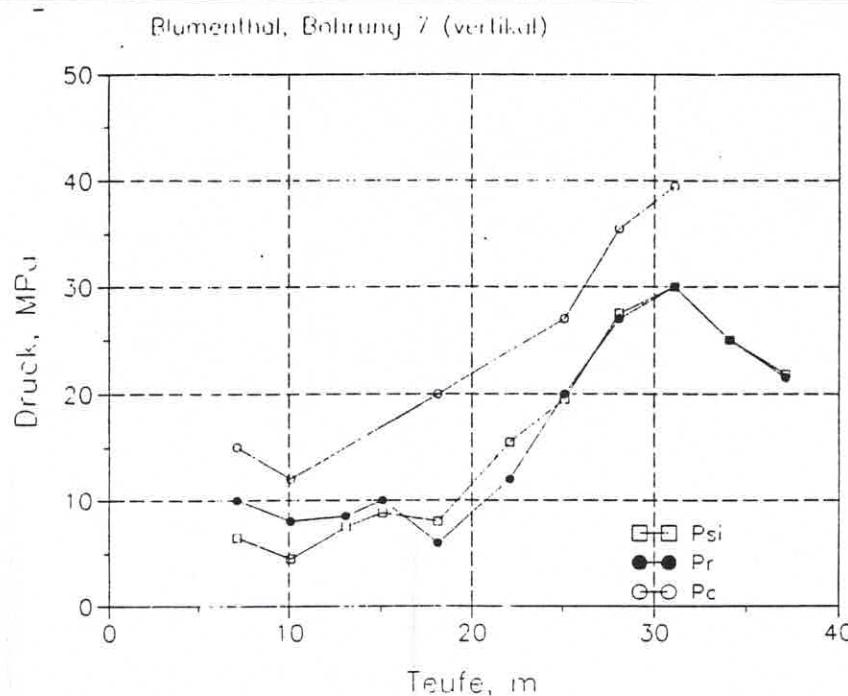


Abbildung 2: Charakteristische Drücke, die in der Bohrung B 7 gemessen wurden

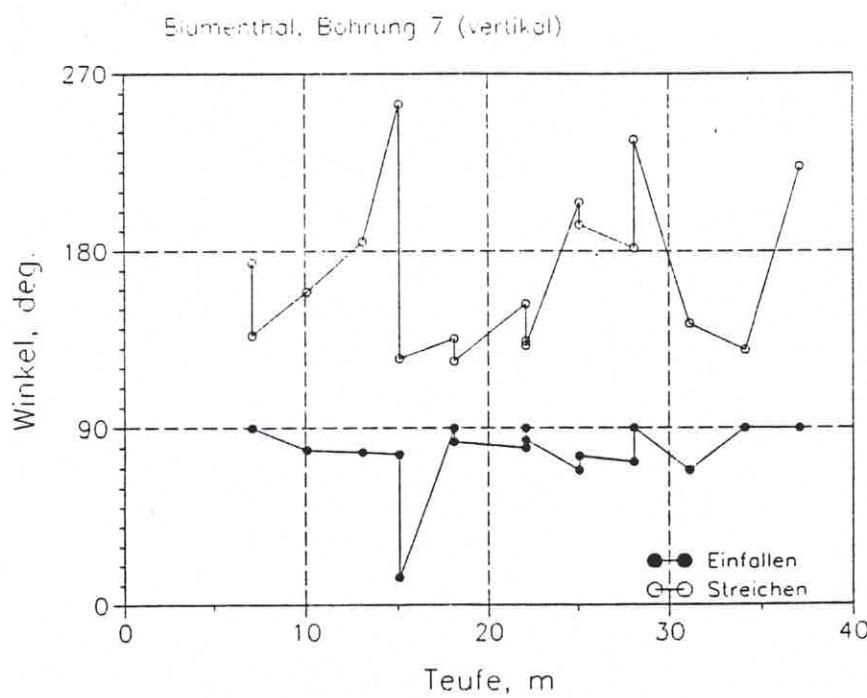


Abbildung 3: Raumwinkel der induzierten Risse in Bohrung B7

5.2.2. Horizontalbohrung B 5

In der Bohrung B 5 konnten bis in eine Tiefe von 34.6 m 11 Frac-Versuche durchgeführt werden. In der Tabelle 3 sind die charakteristischen Druckwerte aufgeführt. Die Tabelle 4 beinhaltet die Rißorientierungen der induzierten Risse.

Tabelle 3: Charakteristische Druckwerte für die Horizontalbohrung B 5

Teufe m	P_c MPa	P_r MPa	P_{si} MPa	
6.1	15.5	7.0	4.0	
7.6	18.0	14.5	9.5	
10.6	21.2	18.0	14.0	
13.6	28.0	23.0	17.0	
16.6	28.5	23.0	18.2	
19.6	365	30.0	29.0	*
22.6	31.0	22.0	25.5	*
25.6	33.0	25.0	27.5	*
28.6	33.0	28.0	27.5	+
31.6		17.0	21.2	*
34.6		23.0	21.5	*
Mittelwerte (horizontale Risse (*)):		23.5 ± 5.4	25.8 ± 3.4	

Tabelle 4: Rißorientierungen (Horizontalbohrung B 5)

Teufe m		Streichen degree	Streichrichtung degree	Einfallen degree
6.1	A	155.2	65	29
	B	175.6	86	76
7.6		155.6	65	13
10.6	A	155.1	65	6
	B	242.8	153	83
13.6	A	155.0	65	68
	B	238.0	148	88
16.6		222.0	132	54
19.6	A	90.8	181	25 *
	B	194.7	285	87
	C	218.4	128	76
22.6	A	155.0	245	37 *
	B	114.7	25	43
25.6		155.0	65	28 *
28.6	A	155.0	65	40
	B	155.0	243	83 +
31.6	A	102.0	192	25 *
	B	216.8	127	43
	C	113.5	24	69
34.6		201.5	112	86 +

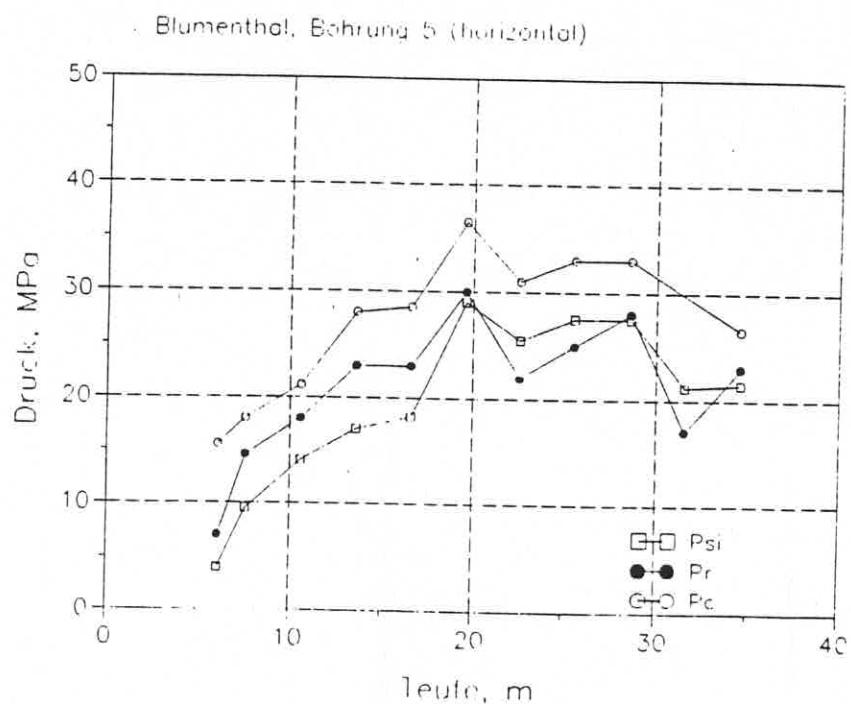


Abbildung 4: Charakteristische Drücke, die in der Bohrung B 5 gemessen wurden

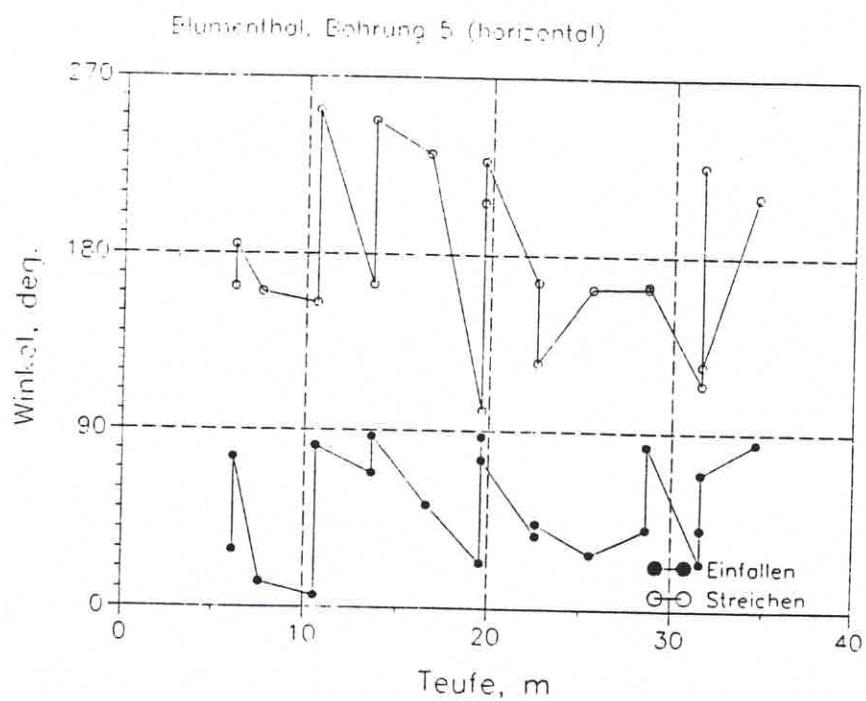


Abbildung 5: Raumwinkel der induzierten Risse in Bohrung B 5

5.2.3. Horizontalbohrung B 6

In der Bohrung B 6 konnten bis in eine Tiefe von 28.1 m 12 Frac-Versuche erfolgreich durchgeführt werden. In einer Tiefe von 4.5 m war kein Druckaufbau im Intervall möglich. In Tabelle 5 sind die charakteristischen Druckwerte aufgeführt. Die Tabelle 6 beinhaltet die Rißorientierungen der induzierten Risse.

Tabelle 5: Charakteristische Druckwerte für die Horizontalbohrung B 6

Teufe m	P_c MPa	P_r MPa	P_{si} MPa	
7.5	26.0	23.0	19.0	*
10.5	33.0	25.0	30.0	*
13.5	31.0	26.5	25.5	*
16.5	31.5	28.0	26.5	+
18.0	30.0	27.0	26.0	*
19.5	32.0	28.5	27.0	*
21.0	35.5	29.0	28.0	*
22.5	30.2	28.5	26.0	*
24.0	36.5	24.5	25.5	+
25.5	31.0	27.0	23.0	+
27.0		26.0	23.5	+
28.1	27.2	26.0	23.0	+

Tabelle 6: Rißorientierungen (Horizontalbohrung B 6)

Teufe m		Streichen degree	Streichrichtung degree	Einfallen degree	
7.5		197.2	107	24	*
10.5	A	196.0	106	45	*
	B	181.8	272	83	
	C	195.6	106	61	
13.5		168.4	258	44	*
16.5		194.1	284	47	+
18.0	A	182.4	272	40	
	B	202.8	113	7	*
19.5		200.7	110	10	*
21.0	A	99.9	190	22	
	B	155.1	245	2	*
22.5		196.9	107	27	*
24.0	A	263	335	69	
	B	253.7	344	58	
	C	254.5	345	71	
	D	260.5	350	81	+
25.5		102.9	193	60	+
27.0		248.9	339	81	+
28.1	A	194.4	284	58	
	B	248.2	339	79	
	C	237.9	328	77	
	D	251.4	341	86	+

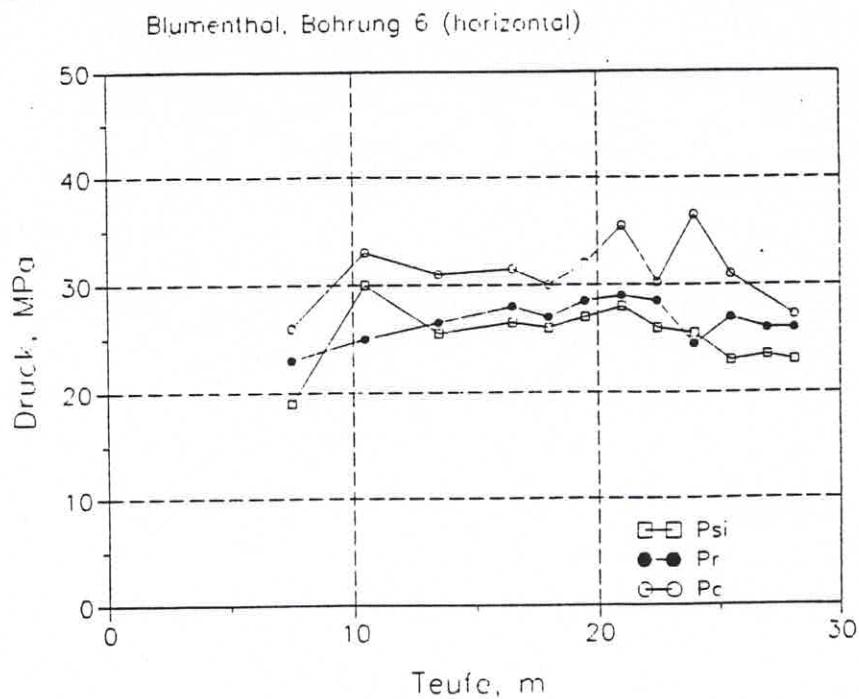


Abbildung 6: Charakteristische Drücke, die in der Bohrung B 6 gemessen wurden

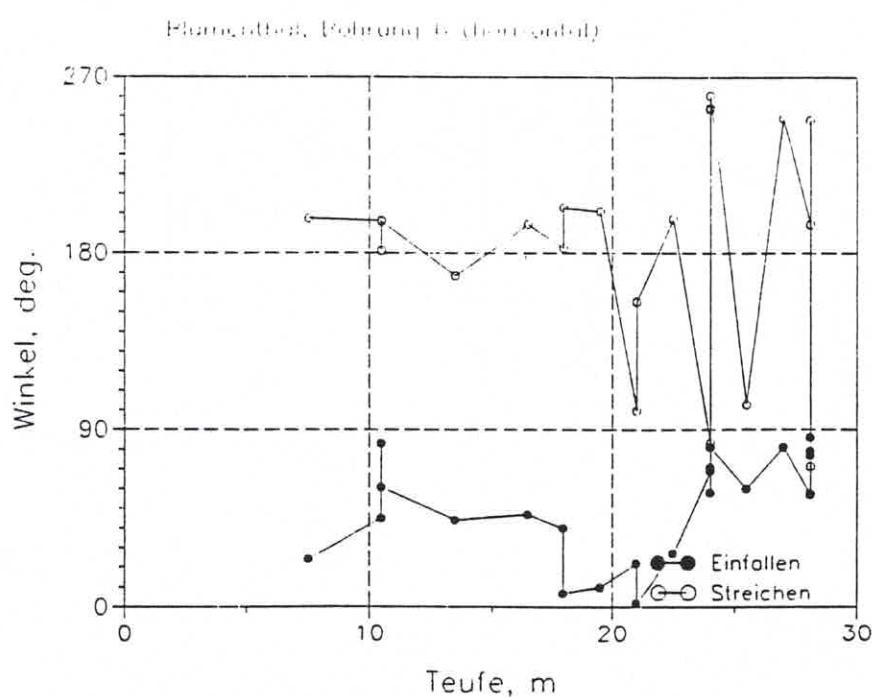


Abbildung 7: Raumwinkel der induzierten Risse in Bohrung B 6

**HYDROFRAC - DATA FROM
MINE HAUS ADEN**

Tab.1: Druckwerte Frac-Versuche in Vertikalbohrung Nr.1165

Test	z m	Pc MPa	PR MPa	Psi/Sh MPa	SH MPa	Θ/α Grad	β Grad
1	22.2	27	20/23	18.5/17	32.5/29	128/88	38
2	25.2	19	14	11	19	--/--	--
3	36.2	29	22	17.5/16.5	30.5/27.5	--/--	--
4	34.2	24	18.5	15	26.5	97/88	7
5	31.2	17	16	15	29	88/88	358
						47/45	316
						23/38	112
6	28.2	18/22	13	11	20	89/87	178

Tab.2: Druckwerte Frac-Versuche in Horizontalbohrung Nr.1166

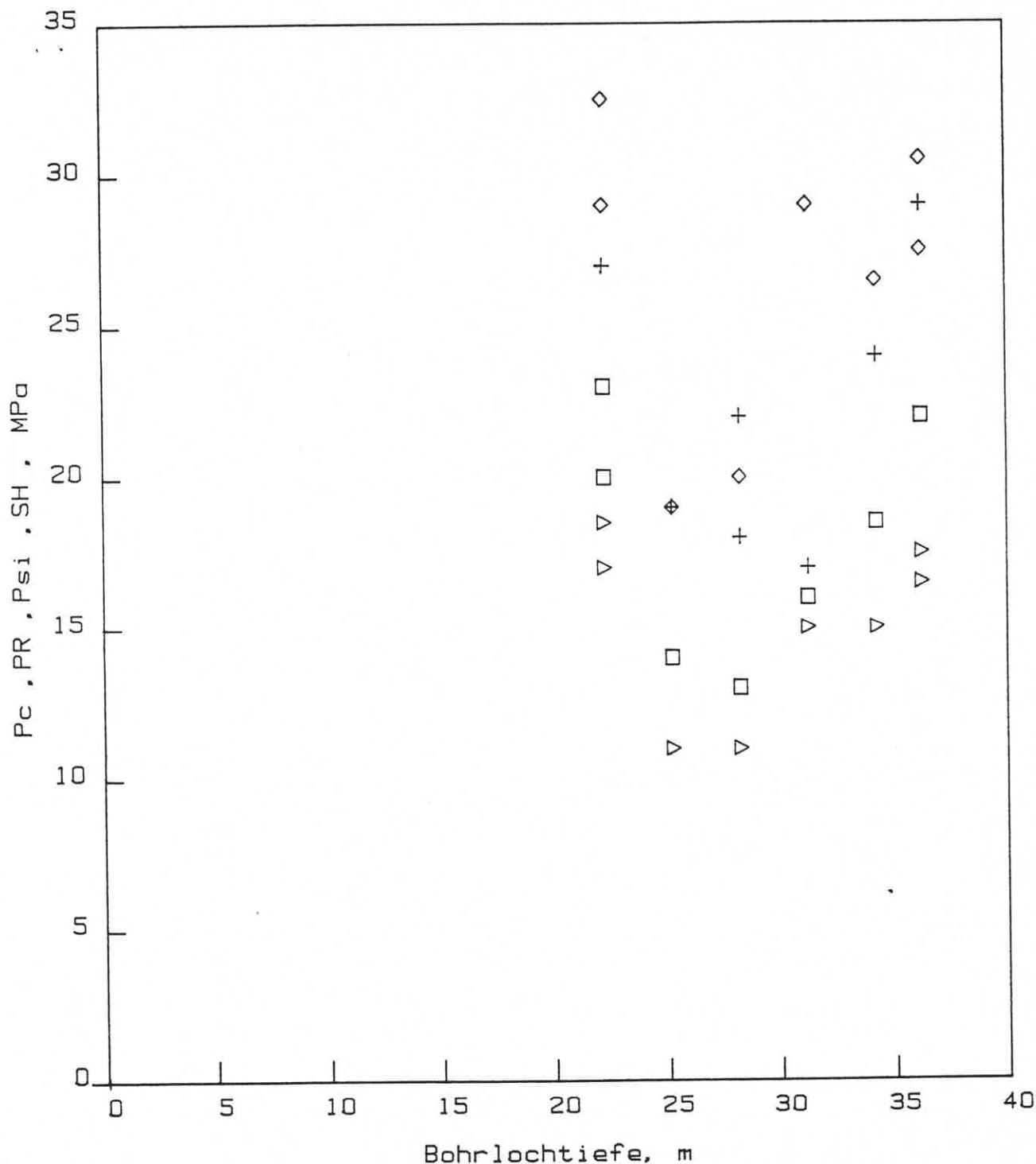
Test	z m	Pc MPa	PR MPa	Psi/Sh MPa	Sv MPa	Θ/α Grad	β Grad
1	38.3	19	16	11/10.5	17/16.5	--/--	---
2	32	28	14/15	11.5	20.5/19.5	25/87	115
3	24.5	24.5	17	14/12	25/19	72/51	161
4	30	27.5	15	13/12	24/21	178/43	88
						65/40	335
						43/52	133
5	21	20	14	10.5	17.5	56/84	326
6	17	--	14/15	12.5	23.5/22.5	--/--	---
7	12	21	16	16.5	33.5/32.5	--/--	---
8	5	24	13.5	11.5	21	155/40	64
						50/61	320
						36/60	126

β : Einfallsrichtung

α : Einfallswinkel

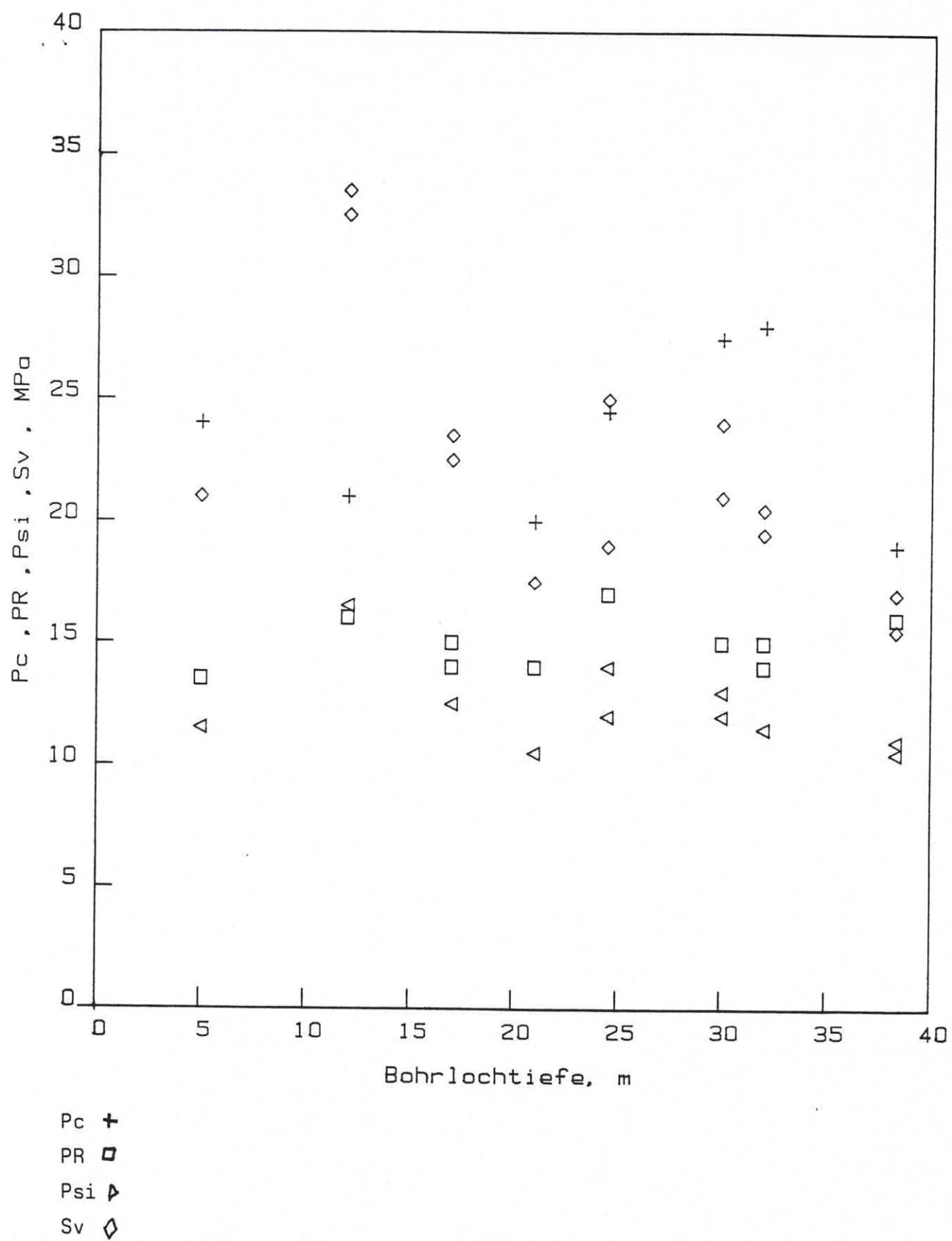
Θ : Streichrichtung

Abb. 1: Druckwerte und Spannungsdaten Bohrung 1165 (vertikal)



P_c +
 PR □
 Ψ_i ▽
 SH ◊

Abb. 2: Druckwerte und Spannungsdaten Bohrung 1166 (horizontal)



Tiefe m	P_c MPa	P_r MPa	$P_{si} = S_h$ MPa	S_h MPa
27.5	kein Druckaufbau möglich			
30.0	--	7.0	5.5	9.5
33.0	14.5	10.3	7.3	11.6
36.0	14.6	13.2	9.5	15.3
39.0	16.7	9.5	8.8	16.9
	15.3 ± 1.0	10.0 ± 2.2	7.8 ± 1.5	13.3 ± 2.9

Tab. 1: Druck - und Hauptspannungswerte in der Bohrung Nr. 1229 (vertikal).

Tiefe m		Θ °	α °	β °	Bemerkung
30.0	A	108.3	90	18	vertik. Frac
33.0	A	106.5	90	197	vertik. Frac
	B	(106.5)	(35)	(197)	
	C	159.6	71	70	steil
	D	(155.8)	(61)	(66)	stehender Frac
36.0	A	130.2	90	40	vertik. Frac
	B	156.4	90	66	vertik. Frac
39.0	A	135.2	90	45	vertik. Frac
		133 ± 21	87 ± 7		

Tab. 2: Lage der Rißflächen in der Bohrung Nr. 1229 (vertikal).
(Θ : Streichen der Rißfläche, α : Einfallswinkel, β : Einfallsrichtung).

Haus Aden, Bohrung 1229 (vertikal)

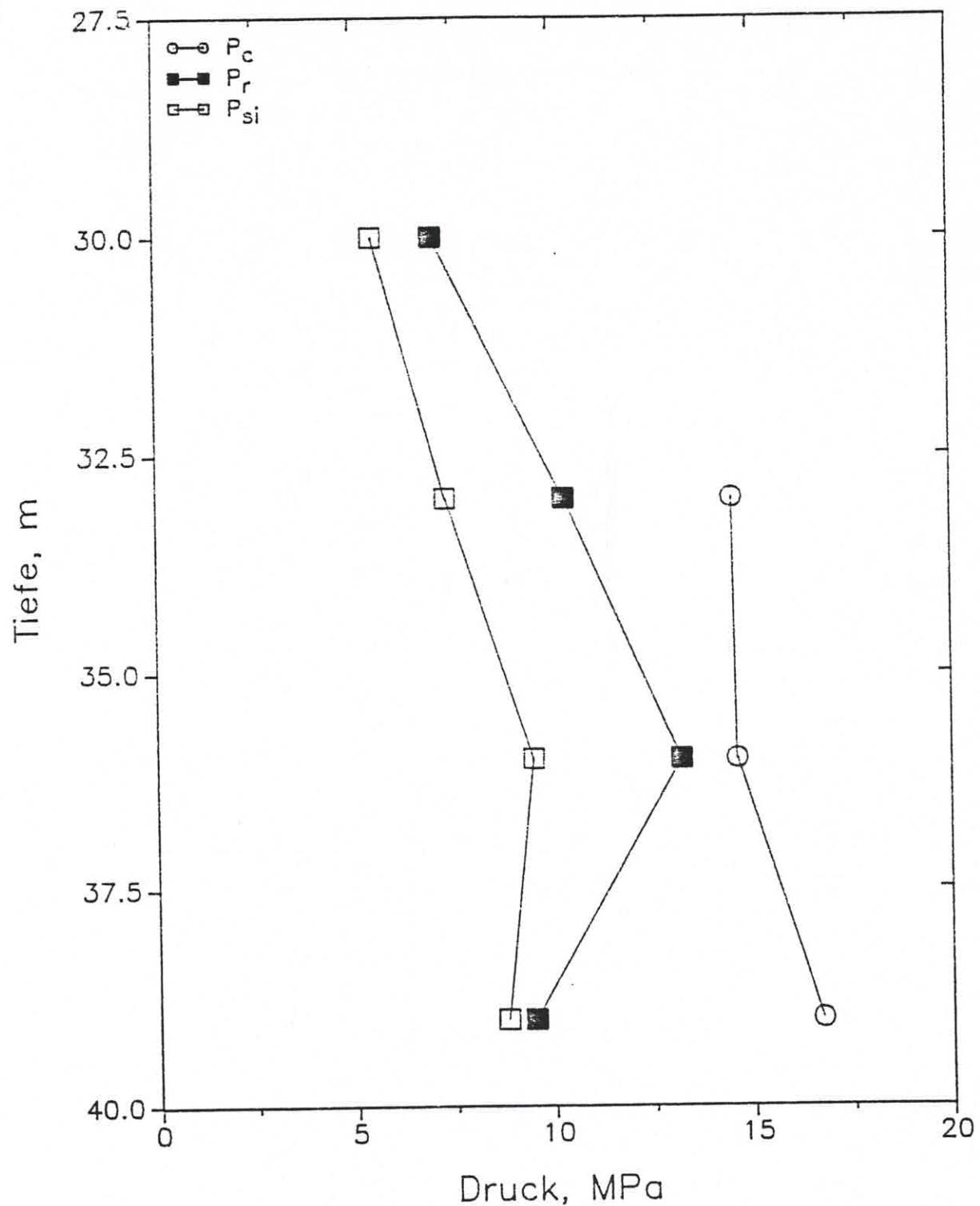


Abb.2: Frac - Druck P_c , Refrac - Druck P_r und Shut - in - Druck P_{si} als Funktion der Tiefe in der Bohrung 1229 (vertikal).

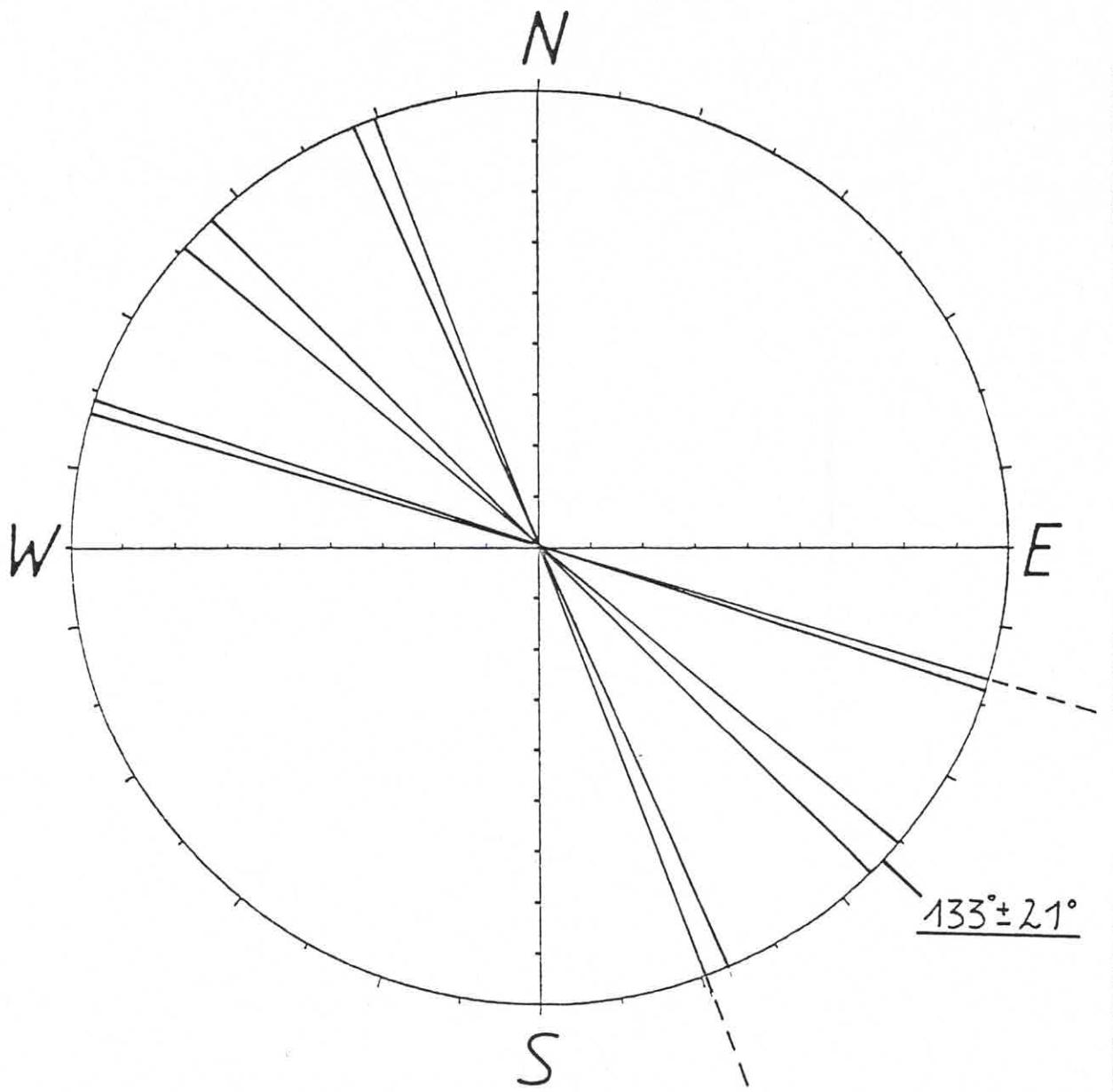


Abb.4: Streichen Θ der Rißflächen in der Bohrung 1229 (vertikal).

Tiefe m	P_c MPa	P_r MPa	$P_{si} = S_h$ MPa
4.0	--	13.7	10.1
7.0	19.0	15.0	11.7
10.0	15.1	12.1	10.0
13.0	9.3	6.5	6.2
16.0	12.5	9.2	4.6
19.0	10.7	7.7	7.0
22.0	9.0	6.5	3.5
25.0	12.2	9.0	4.8
28.0	22.5	19.8	14.0
31.0	14.0	13.0	9.9
33.9	16.8	13.8	9.5
37.0	17.2	13.0	8.9
		14.4 ± 4.0	11.6 ± 3.8
			8.4 ± 3.0

Tab.3: Druck - und Hauptspannungswerte in der Bohrung Nr. 1231 (horizontal).

Tiefe m		Θ °	α °	β °	Bemerkung
4.0	A	147.6	45	58	radialer Frac
	B	(28.6)	(41)	(119)	
	C	(130.1)	(40)	(78)	n. eindeutig
	D	(126.2)	(36)	(56)	n. eindeutig
7.0	A	(19.1)	(55)	(289)	
	B	145.0	61	235	radialer Frac
	C	(111.5)	(79)	(22)	n. eindeutig
10.0	A	131.1	88	41	radialer Frac
	B	171.2	85	261	radialer Frac
	C	(55.0)	(57)	(325)	
	D	129.3	84	39	radialer Frac
13.0	A	170.9	77	261	radialer Frac
	B	(66.5)	(72)	(337)	
16.0	A	(55.0)	(47)	(325)	
	B	103.9	56	14	radialer Frac
19.0	A	166.9	75	257	radialer Frac
	B	(55.0)	(72)	(325)	
	C	(178.4)	(18)	(88)	
	D	(55.0)	(73)	(325)	
22.0	A	(55.0)	(59)	(325)	
	B	132.6	83	43	radialer Frac
25.0	A	(55.0)	(28)	(325)	
	B	116.7	37	27	radialer Frac
	C	126.6	89	37	radialer Frac
28.0	A	85.7	46	356	radialer Frac
	B	98.4	78	8	radialer Frac
31.0	A	(55.0)	(40)	(325)	
	B	(55.0)	(32)	(325)	
	C	(112.8)	(37)	(23)	n. eindeutig
33.9	A	94.5	71	4	
	B	(178.7)	(51)	(89)	n. eindeutig
37.0	A	(40.2)	(27)	(130)	
	B	(55.0)	(29)	(145)	
	C	123.2	84	213	radialer Frac
		130±26	71±17		

Tab.4: Lage der Rißflächen in der Bohrung Nr. 1231 (horizontal).
 (Θ : Streichen der Rißfläche, α : Einfallsinkel, β : Einfallsrichtung).

Haus Aden, Bohrung 1231 (horizontal)

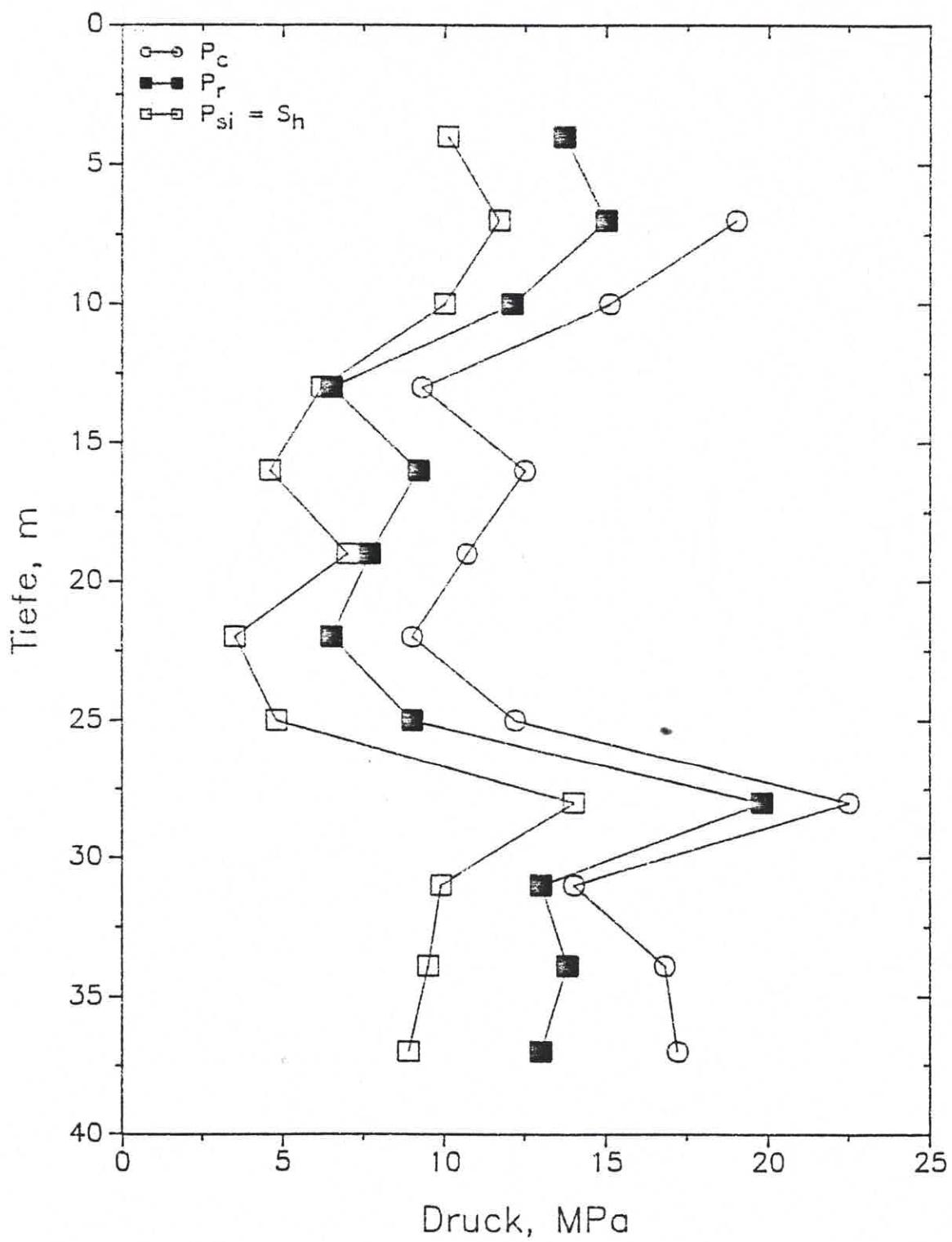


Abb.5: Frac - Druck P_c , Refrac - Druck P_r und Shut - in - Druck P_{si} als Funktion der Tiefe in der Bohrung 1231 (horizontal).

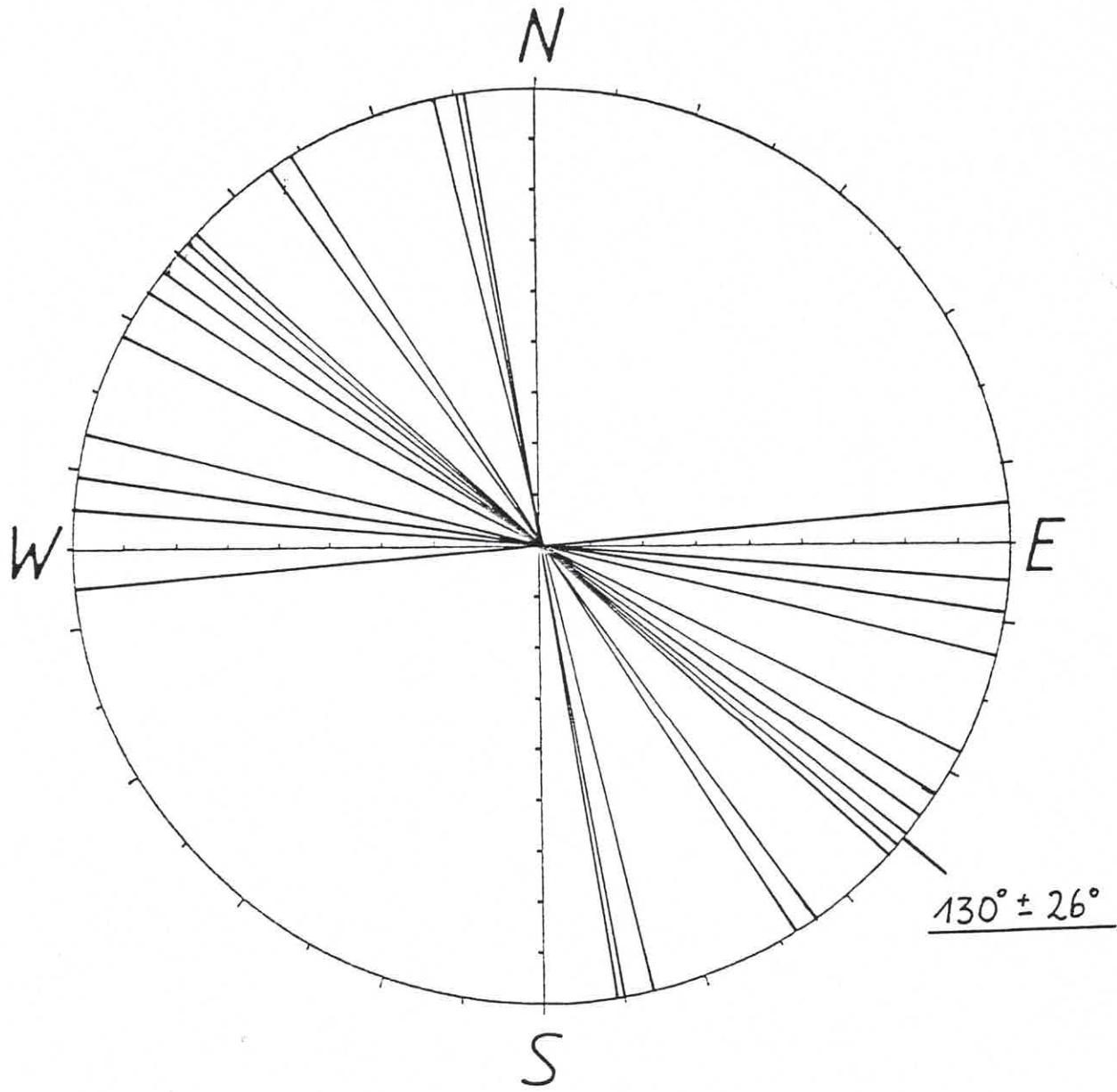


Abb.6: Streichen Θ der Rißflächen in der Bohrung 1231 (horizontal).

$P_c = \frac{P_{c,d,e}}{P_{r,d,e}}$
 $P_r = \frac{P_{r,d,e}}{P_{c,d,e}}$
 $T = \frac{T_{c,r,d,e}}{T_{c,r,d,e}}$
 $\theta = \frac{\theta_{c,r,d,e}}{\theta_{c,r,d,e}}$

Tabelle 1: Messwerte P_c , P_r , P_{si} , horizontale Hauptnormalspannungen SH und Sh , hydraulische Zugfestigkeit $T = P_c - P_r$, Richtung θ von SH (N ueber E).

Bohrung	B 2/V	Test / Meßtiefe, m	P_c /bar	P_r /bar	P_{si} /bar	SH /bar	Sh /bar	T /bar	θ°
6	7.95	160	90-110	90	(68)-88	90	-	50-70	51
5	11.85	190	160	115	(93)	115	-	30	46
4	17.65	260	200-235	170	183-218	170	-	25-60	20
3	21.65	300	200-270	180	178-248	180	-	30-100	40
2	25.65	200	160-170	155	203-213	155	-	30-40	-
1	27.65	120	140-160	140	168-188	140	-	-20-(-40)	-

Tabelle 2: Messwerte P_c , P_r , P_{si} , vertikale und horizontale Hauptnormalspannungen S_v bzw. S_h , hydraulische Zugfestigkeit $T = P_c - P_r$, Richtung θ von SH (N ueber E).

Bohrung B 1/H

Test / Meßtiefe, m	P_c /bar	P_r /bar	P_{si} /bar	S_v /bar	S_h /bar	T /bar	θ°
10 6.15	(290)	200-210	135	103-113	135	80-90	-
1 9.65	175	140-170	140	153-188	140	5-35	-
2 10.65	(270)	175-195	140	133-153	140	75-95	41
3 14.75	200	140-180	140	148-188	140	20-60	49
4 17.75	220	200-220	160	168-188	160	0-20	41
5 20.75	230	160-190	175	243-273	175	10-70	-
6 22.75	240	210-220	190	258-268	190	20-30	31
9 28.75	240	160-200	175	233-273	175	10-80	-

Tabelle 3: Messwerte P_c , P_r , P_{si} , horizontale Hauptnormalspannungen S_H und S_h , hydraulische Zugfestigkeit $T = P_c - P_r$, Richtung θ von S_h (N ueber E).

Bohrung	$B \cdot l_i/V$	Test / Meßtiefe, m	P_c /bar	P_r /bar	P_{si} /bar	S_H /bar	S_h /bar	T /bar	θ°
l_4	17.20	155	100-150	115	103-153	115	5-55	48	16
1	19.65	250	140-170	125	113-143	125	80-110	-	-
2	37.30	80	75-100	95	93-118	95	5-(-20)	3	

Tabelle 4: Messwerte P_c , P_r , P_{si} , vertikale und horizontale Hauptnormalspannungen S_v bzw. S_h , hydraulische Zugfestigkeit $T = P_c - P_r$, Richtung θ von SH (N ueber E).

Bohrung B 2/H

Test. / Meßtiefe, m	P_c /bar	P_r /bar	P_{si} /bar	S_v /bar	S_h /bar	T /bar	θ°
7.a	8.10	90	60- 80	90	98-118	90	10-30
6	11.70	130	90-115	85	48- 73	85	15-40
5	15.50	120	100	88	100	0	55
4	15.90	180	120-150	115	103-133	115	30-60
3	18.90	230	180-210	175	220-253	175	20-50
1	26.80	210	170-185	110	53- 68	110	25-40

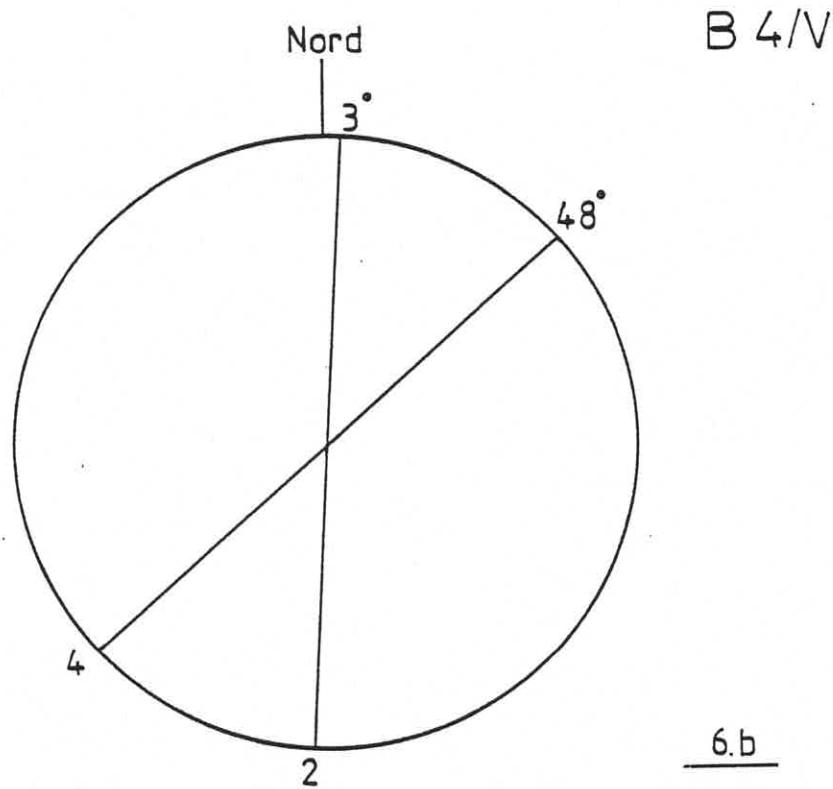
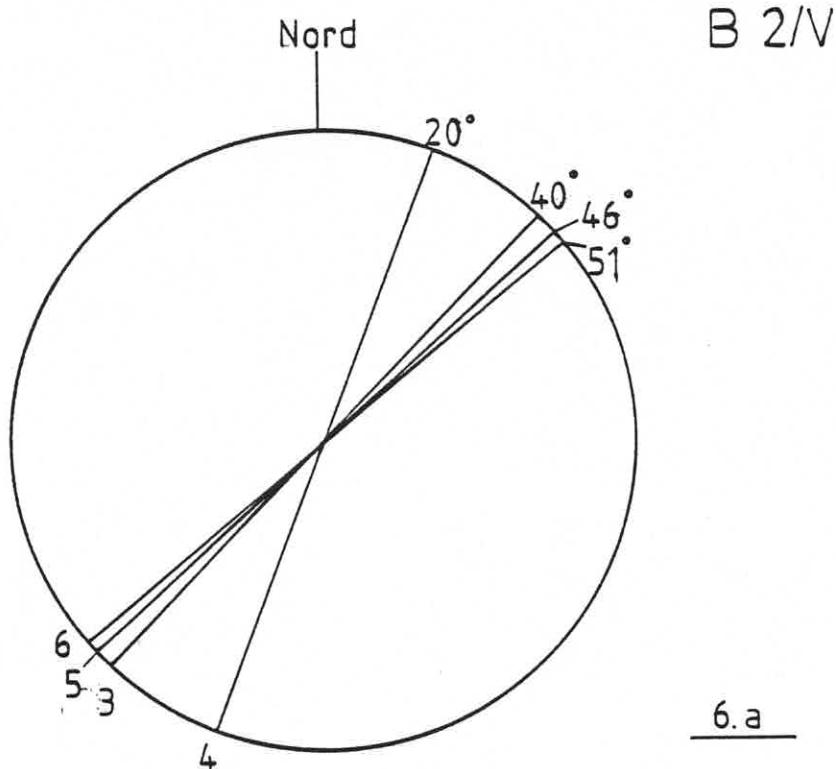


Abb. 6: Frac-Orientierung θ bzw. Richtung von S_H in den beiden vertikalen Bohrungen, in Grad (N über E), Versuch-Nummer.

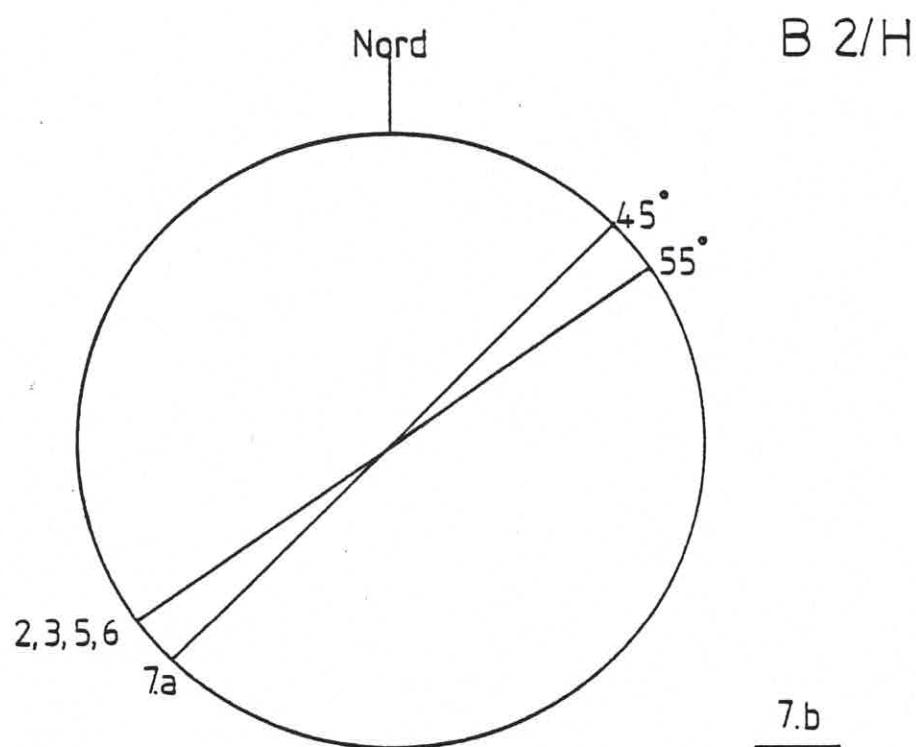
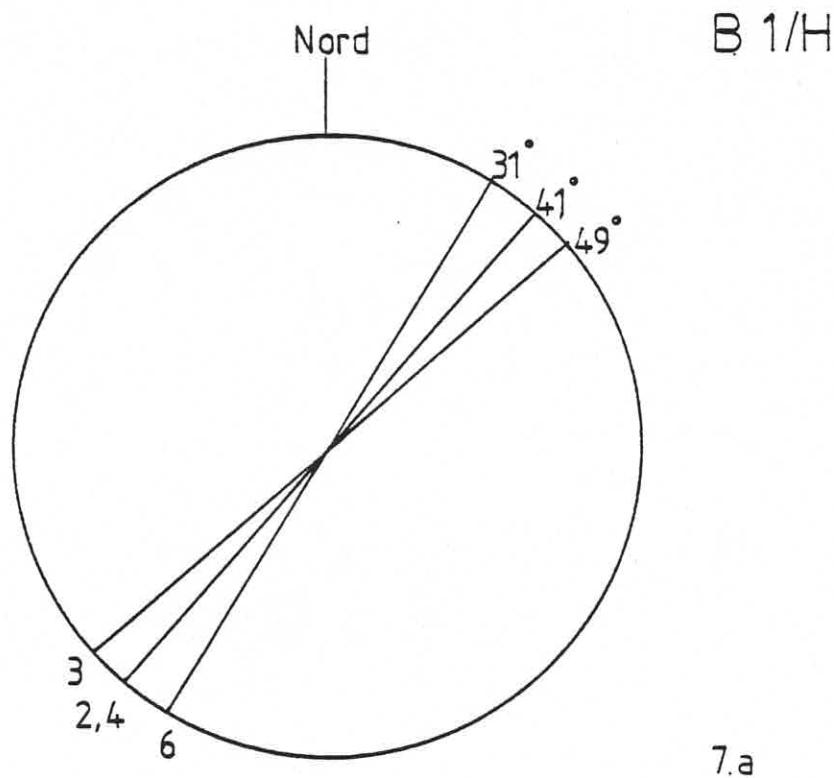


Abb. 7: Frac-Orientierung θ bzw. Richtung von S_H in den beiden horizontalen Bohrungen, in Grad (N über E), Versuchs-Nummer.

Tab. 1 : Charakteristische Frac-Druckdaten, Bohrung Nr. 1172

Test Nr.	Tiefe m	P _a , max MPa	P _c MPa	P _r MPa	P _{co} MPa	P _{si} MPa
14	4.3	25.2	19	14	5.0	7.5
13	7.3	25.2	25.3	19	6.3	14
12	10.3	30	23.5	19	4.5	16 15.5
11	13.3	35.5	22.5	20	2.2	15 <u>+</u>
10	16.3	30.2	29	20	9.0	17 1.1
9	19.3	26	24.5	22	2.5	20.5
8	22.3	25.2	27	22	5.0	20
7	25.3	31	18	16	2.0	14 19.7
6	28.3	27.2	26.5	21	5.5	20 <u>+</u>
5	31.3	30	--	15	--	15.5 2.9
4	34.3	30.5	32	22	10.0	20.5
3	37.3	36	30	28	2.0	23
2	40.3	28	25	24	1.0	21
1	44.3	40	(55)	26	29.0	23
Mittel Test 1 - 14					6.0 <u>±</u> 7	
Mittel Test 1 - 13		25.7 <u>±</u> 3.7	21 <u>±</u> 3.5	4.7 <u>±</u> 3.5	18.4 <u>±</u> 3.1	
Mittel Test 1 - 9			21.8 <u>±</u> 4.0	6.3 <u>±</u> 8.5	19.7 <u>±</u> 2.9	

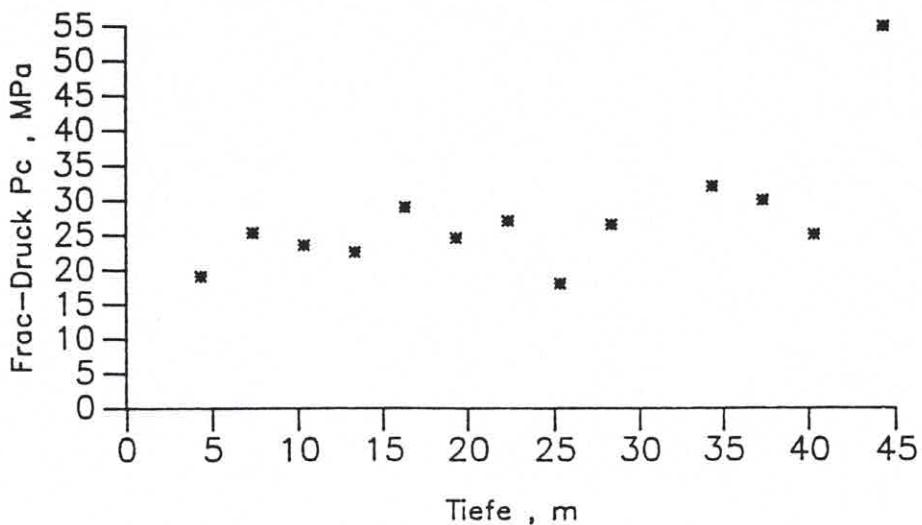


Abb.4 Bohrung 1172 , Frac-Druck P_c

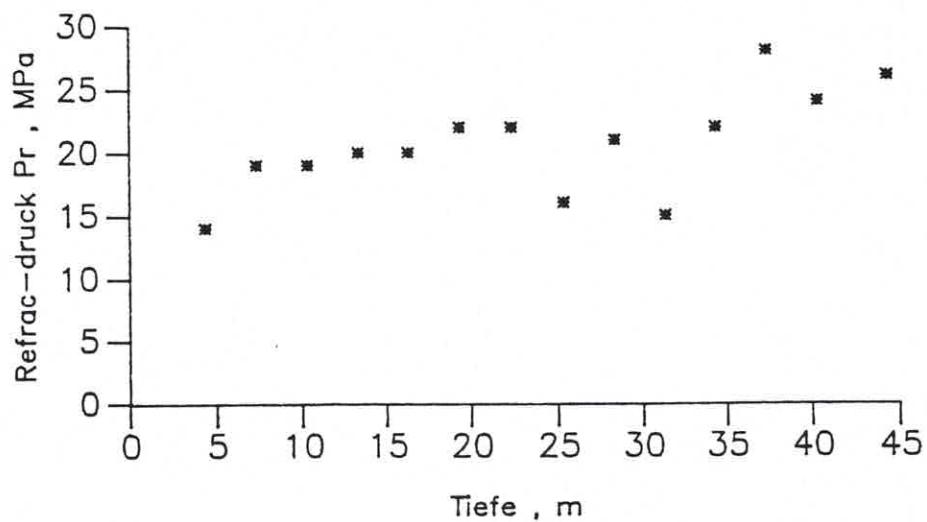


Abb.5 Bohrung 1172 , Refrac-Druck P_r

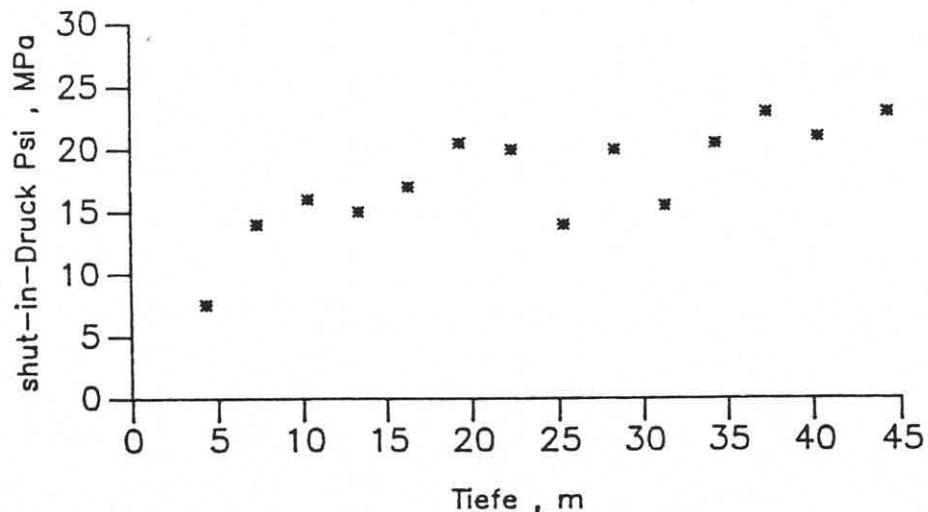


Abb.6 Bohrung 1172 , shut-in-Druck Ψ

Tab. 3 : Bohrung Nr. 1172, Frac-Orientierungen

θ Streichen der Frac-Flächen bezügl. magn. Nord
 α Einfallswinkel der Frac-Flächen (vertikal 90°)
 β Richtung des Einfallens der Frac-Flächen bezügl. magn. Nord
 P_{si} Shut-in-Druck

Test-Nr.	Tiefe	θ	α	β	P_{si}	Bem.
	m	Grad	Grad	Grad	MPa	
1					23	kein Abdruck
2 a	40.3	164	90	--	21	vert. Frac
b		(92)	(68)	(2)		Schichtfläche
3	37.3	137	90		23	vert. Frac
4	34.3	122	90	--	20.5	vert. Frac
5	31.3	205	90	--	15.5	vert. Frac
6 a	28.3	187	90	--	20	vert. Frac
b		209	82	119		steil stehend
c		(54)	(60)	(324)		Schichtfläche
7	25.3	169	104	79	14	steil stehend
8 a	22.3	(72)	(67)	(341)	20	Schichtflächen
b		(56)	(63)	(326)		
9	19.3	152	90	--	20.5	vert. Frac
10	16.3	154	73	64	17	steil stehend
		181	81	91	17	steil stehend
11 a	13.3	(95)	(83)	(5)	15	Schichtflächen
b		(114)	(81)	(24)		
c		(32)	(72)	(302)		
12 a	10.3	(32)	(72)	(302)	16	Schichtflächen
b		(42)	(73)	(312)		
13 a	7.3	122	90	--	14	vert. Frac
b		(27.6)	(65)	(298)		Schichtfläche
14 a	4.3	(20)	(67)	(290)	7.5	Schichtflächen
b		(6)	(56)	(276)		
c		(173)	(68)	(263)		
Mittel (ohne ()) . 163 ± 30 88 ± 7						
Mittel ()		52 ± 44				

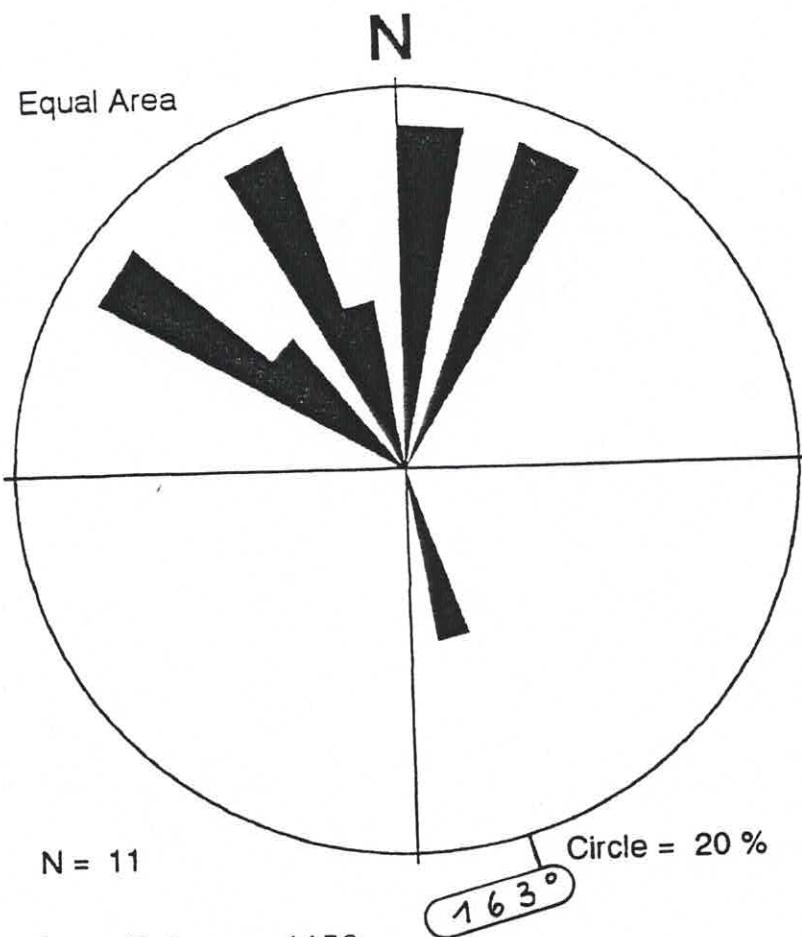
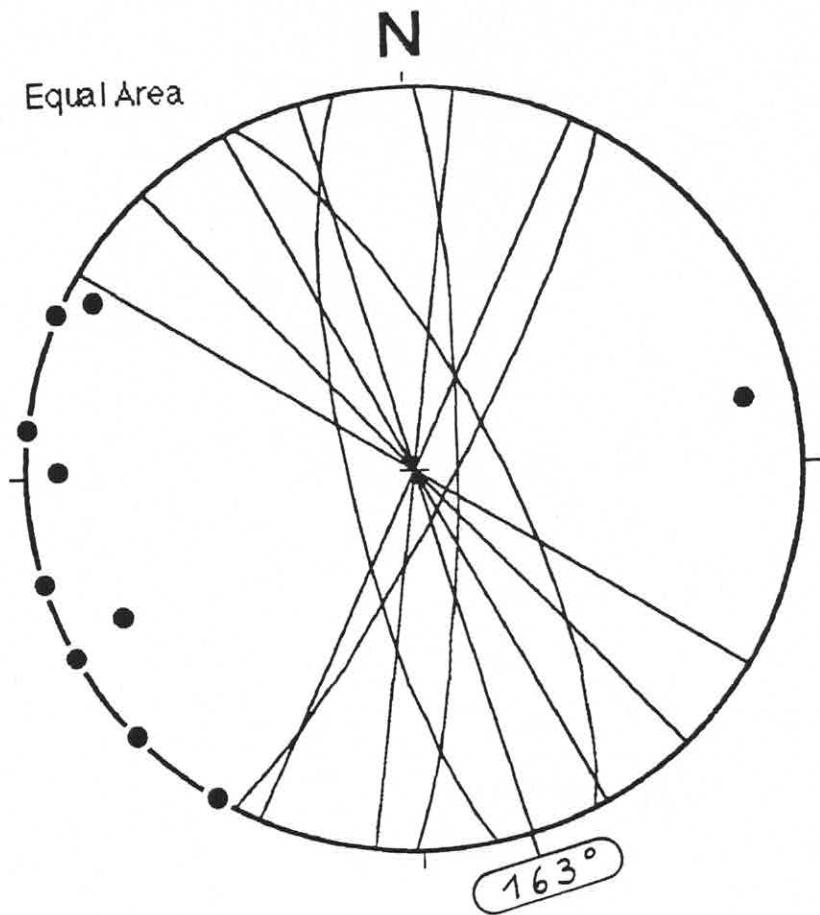


Abb. 10 Bohrung 1172
oben: Lagekugeldarstellung (Pollagen, Großkreise)
unten: Rosettenhistogramm
(bezogen auf Streichen der Frac-Flächen)

Tab. 2 : Charakteristische Frac-Druckwerte Bohrung Nr. 1173

Test Nr.	Tiefe	P _a , max	P _C	P _r	P _{co}	P _{si}
	m	MPa	MPa	MPa	MPa	MPa
8	22.35	25	25.5	20	5.5	16
7	25.35	27	22	16	6.0	12.5
6	28.35	27	22	16	6.0	13.5
5	31.35	32	21	17	3.0	14
4	34.35	35	23.5	18	5.5	14.5
3	37.35	35	36	20	16.0	15
2	40.35	35	34	21	13.0	15.5
1	43.3	39	45	25	20.0	19
Mittel		28.6 ± 8.2	19.1 ± 2.8	9.4 ± 5.7	15 ± 1.8	

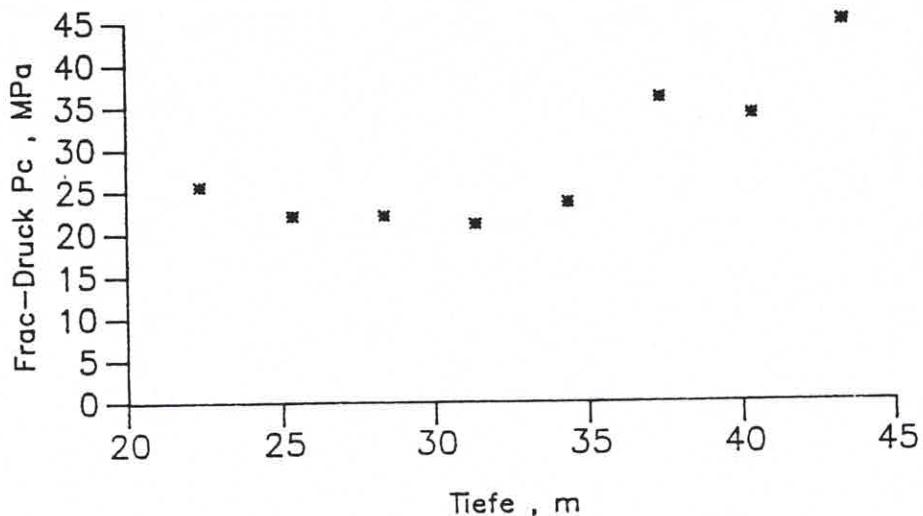


Abb.7 Bohrung 1173 , Frac-Druck P_c

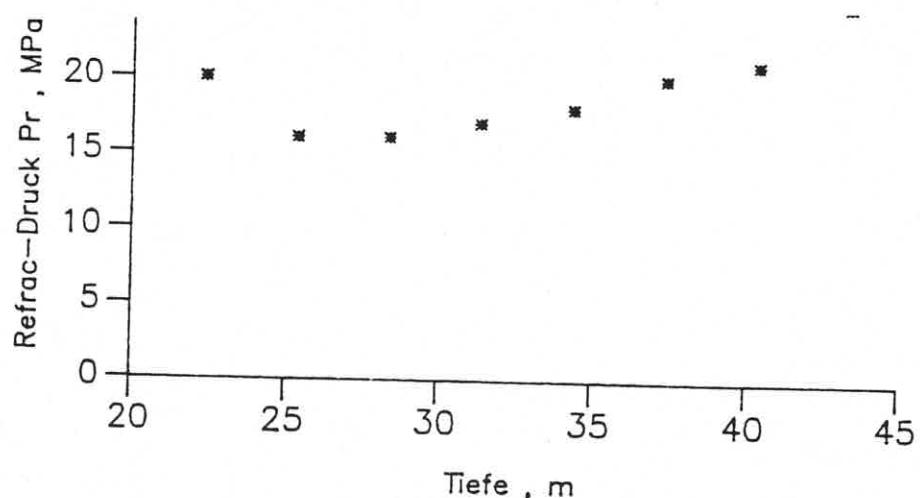


Abb.8 Bohrung 1173 , Refrac-Druck P_r

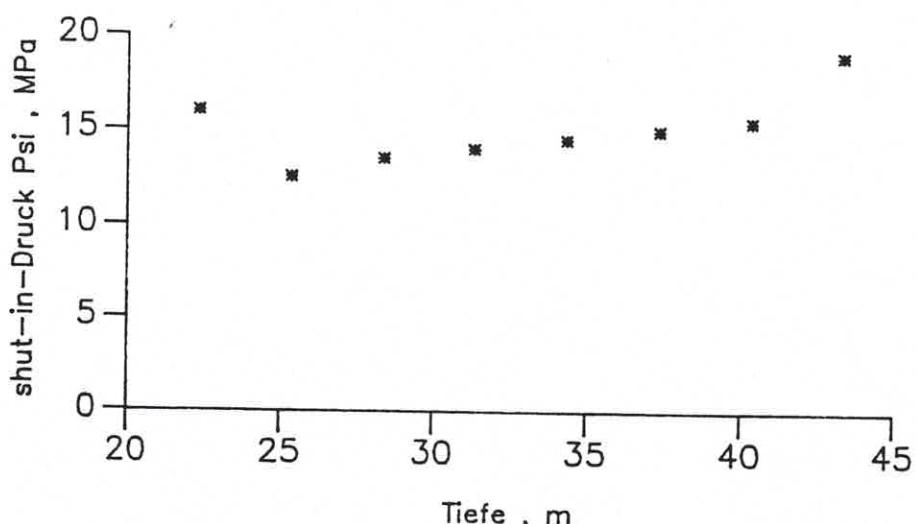


Abb.9 Bohrung 1173 , shut-in-Druck Ψ

Tab. 4 : Bohrung Nr. 1173, Frac-Orientierungen

Θ Streichen der Frac-Flächen bezügl. magn. Nord
 α Einfallswinkel der Frac-Flächen (vertikal 90°)
 β Richtung des Einfallens der Frac-Flächen bezügl. magn. Nord
 P_{si} Shut-in-Druck

Test-Nr.	Tiefe	Θ	α	β	P_{si}	Bem.
		m	Grad	Grad	Grad	MPa
1	43.35	170 (46)	90 (56)	-- 316		b) vert. Frac a) Schichtfl.
2	40.35	171	79	81	15.5	
3	37.35	187 (55)	90 (79)	-- (145)	15	a) vert. Frac b) Schichtfl.
4	34.35	192	90	--	14.5	
5	31.35	128	78	38	14	
6	28.35	180	84	90	13.5	
7	25.35	158 185	81 82	68 95		b) steilstehend a) "
8	22.35	205 165	79 65	115 75	16	a) " b) "
Mittel ohne ()		174 ± 20	82 ± 8		15 ± 2	

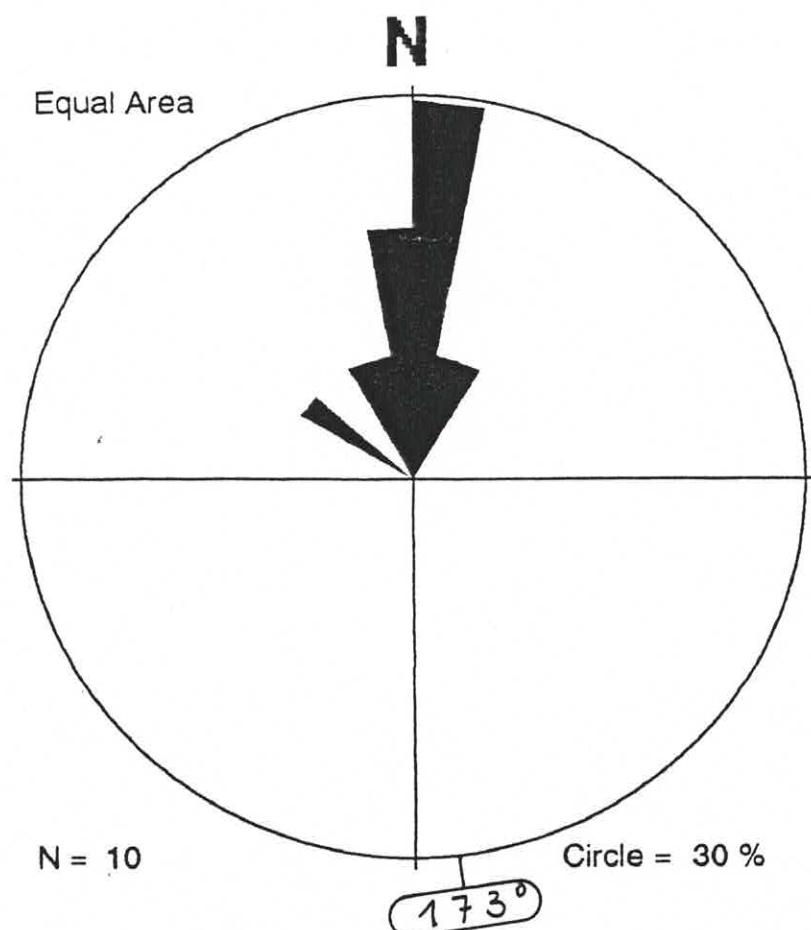
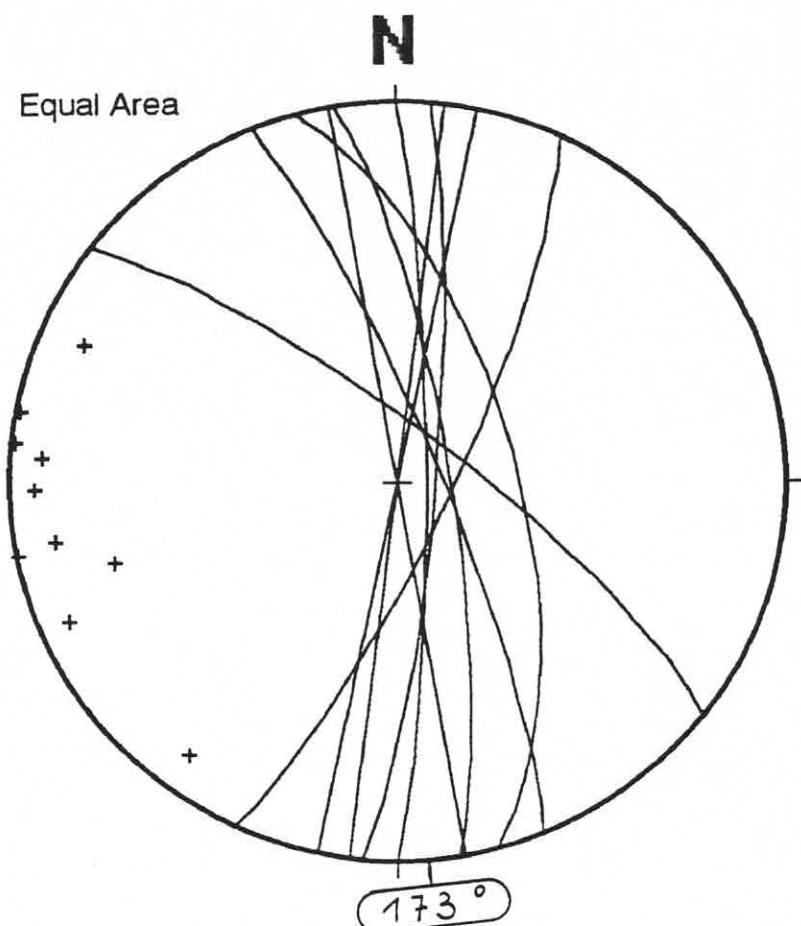


Abb. 11 Bohrung 1173
oben:Lagekugeldarstellung (Pollen, Großkreise)
unten:Rosettenhistogramm
(bezogen auf Streichen der Frac-Flächen)

**HYDROFRAC - DATA FROM
MINE WESTFALEN**

Tab. 5.1 : Bohrung 1/V

Tiefe m	Test Nr.	P _C MPa	P _r MPa	P _{si} MPa	θ Grad	α Grad	Bem.*
4	6	18	7.5	6	52	90	
6	5	14	9.5	9.5	30	90	S
8	4	13	10	10	44	90	
10	3/10	22/22 (16)/33)	18/20 -/25	12/17 -/22	159	90	
12	7/11				157	90	T
14	12	28	25	25			
14.8	13	38	27	26			
19.1	1	23	11	9			T
25.1	2	20	10	11			S
36	9	48	26	25.5			T
39	8	44	28	25			
Mittelwerte							
4 - 8 m		15.0 ± 2.2	9.0 ± 1.9	8.5 ± 1.8	42 ± 9		
10 - 15 m		30.2 ± 5.9	23 ± 3.4	20.4 ± 5.2	158 ± 1		
19 - 25 m		21.5 ± 1.5	10.5 ± 0.5	10.0 ± 1.0	--		
36 - 39 m		46 ± 2	27 ± 1	25.8 ± 1.0	--		

*) S Sandstein
T Tonstein

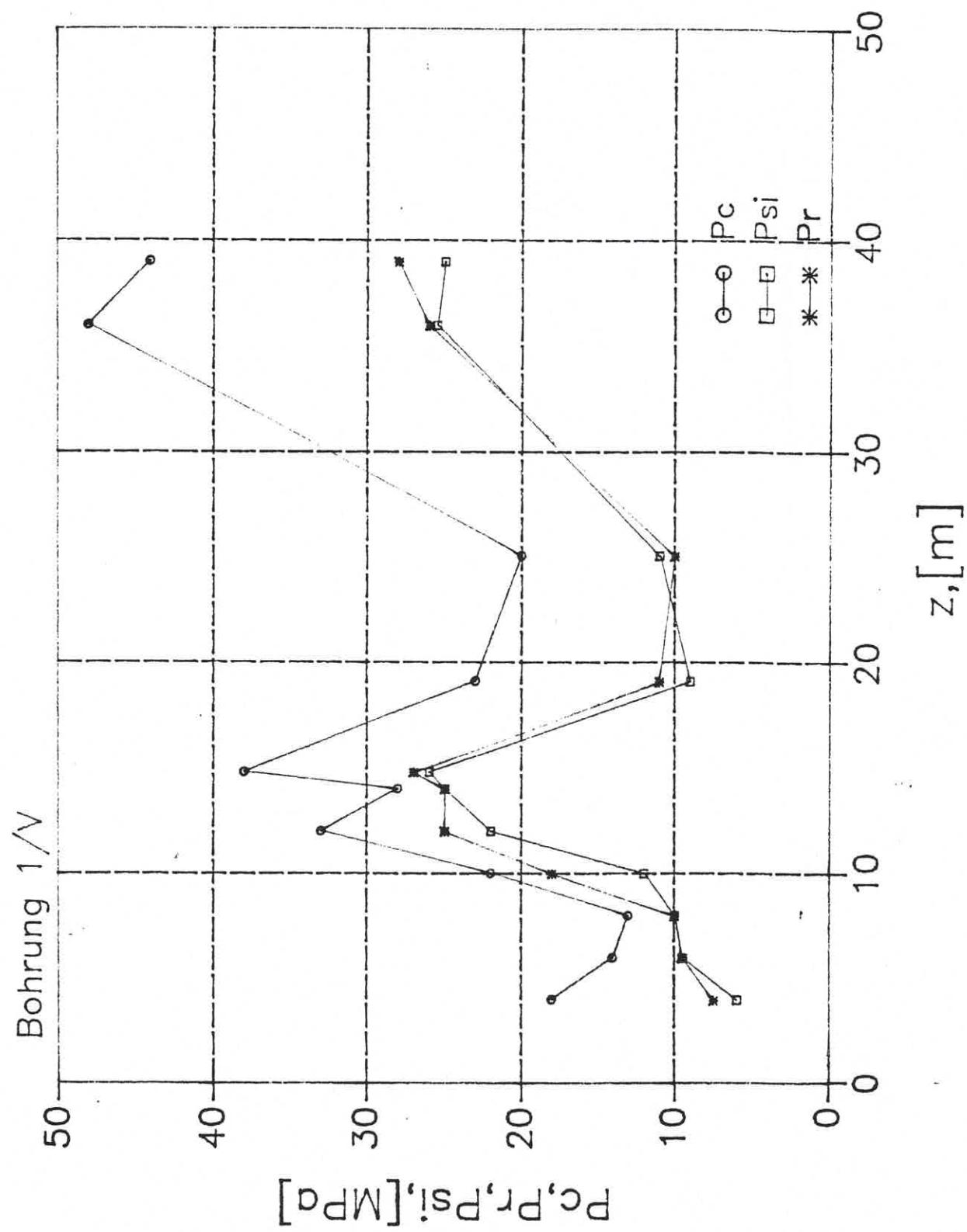


Abb. 5.1

Tab. 5.2 : Bohrung 3/V

Tiefe m	Test Nr.	P _C MPa	P _r MPa	P _{si} MPa	θ Grad	α Grad
11	1	20	8	11	---	---
13.5	2	16.5	10	11.5	203	90
16.5	3	21.5	14	11.5	---	---
19.5	4	19.5	16	13	186	90
22.5	5	18	11	10	---	---
25.5	6	22	11	11	172	90
28.5	7	20	14	14	---	---
31.5	8	20	14	13	154	90
34.5	9	27	20	15	---	---
37.5	10	22	16	14	186	90
39.6	11	22	16	15	---	---
Mittelwerte		20.8 ± 2.6	13.6 ± 3.3	12.6 ± 1.7	180 ± 16	

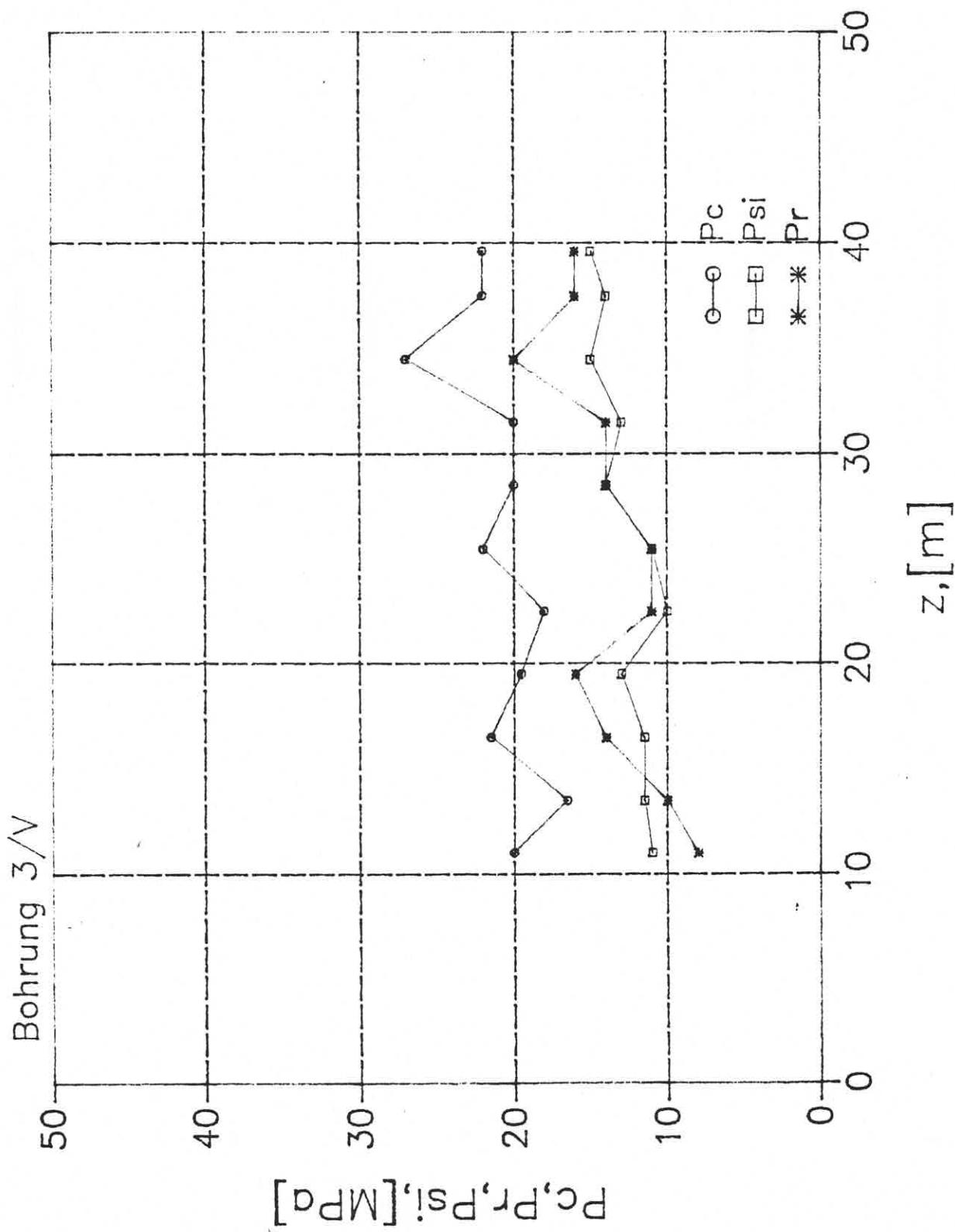


Abb. 5.2

Tab. 5.3 : Bohrung 5/V

Tiefe m	Test Nr.	P_c MPa	P_r MPa	P_{si} Grad	Θ Grad	α Grad	β Grad
4	1	23	15	12	143	90	--
9	2	25	15	15	235	90	--
11	12	26.5	19	17	--	--	--
13	3	32	19	18	118	(28)	28
16	4	29	23.5	19.5	208	90	--
19	5	34	21	20.5	91	81	1
22	6	26	20	17.5	--	--	--
25	7	30.5	19	17.5	--	--	--
28	8	28	19	17.5	--	--	--
31	9	26	18	16	142	82	52
34	10	26.5	16	15	154	90	--
37	11	20	15	14	--	--	--
Mittelwerte		26.5 ± 3.7	18.3 ± 2.5	16.6 ± 2.3	162 ± 47		

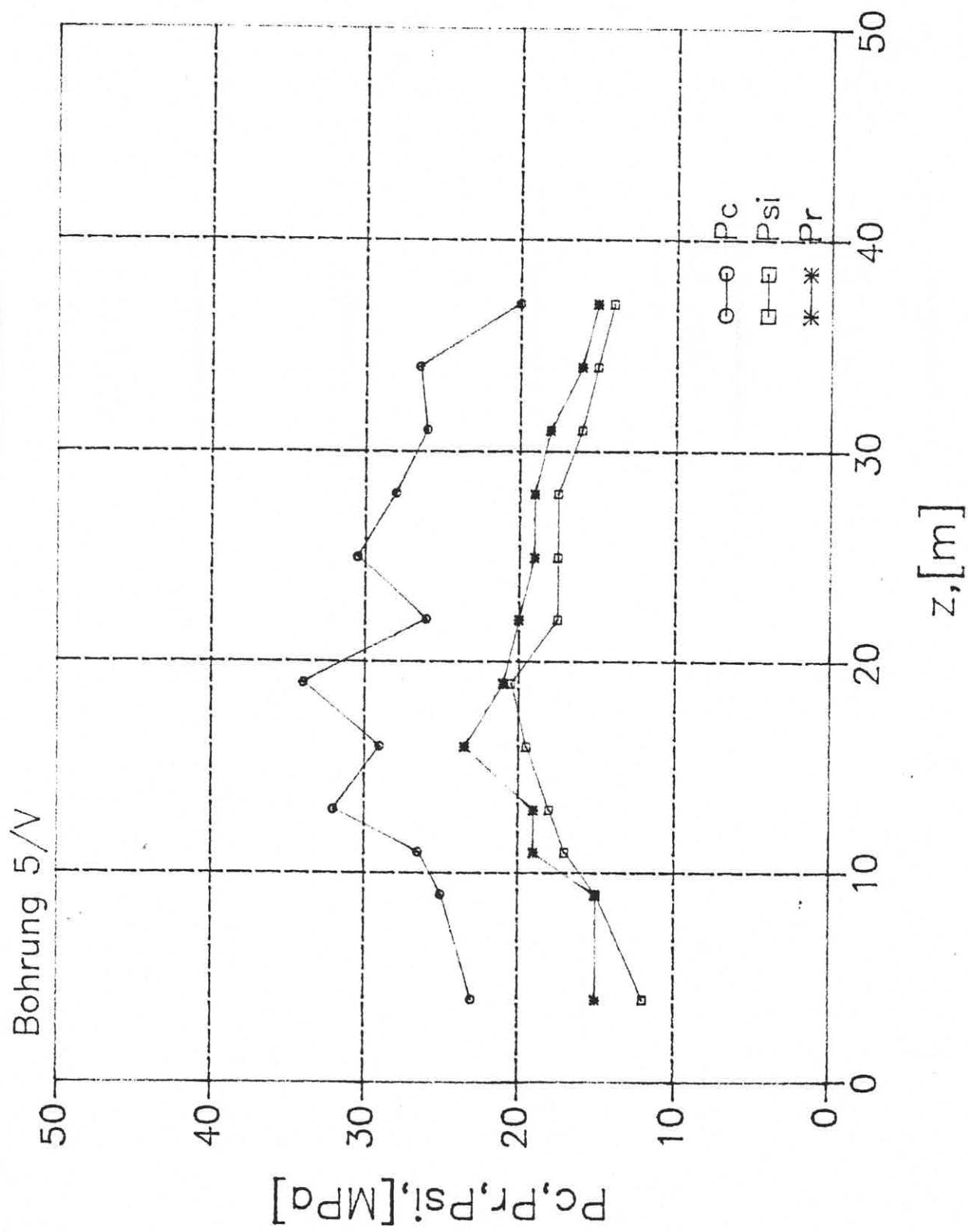


Abb. 5.3

Tab. 5.4: Bohrung 6/V

Tiefe m	Test Nr.	P _C MPa	P _r MPa	P _{si} MPa	θ Grad	α Grad	β Grad
4	1	20	(6)	(4)	---	---	---
7	10	19	13	11	143	90	---
10	2	23	17.5	13	131	90	---
13	9	26	17.5	14	---	---	---
16	3	25	16	14	180	28	270
19	4	27.5	18	14	---	---	---
22	5	25	16	14	171	79	261
25	6	30.5	18	14.5	---	---	---
28	7	24.5	20	15.5	188	90	---
31	8	29.5	(27)	(24)	---	---	---
Mittelwerte (alle)		25.0 ± 3.5	17 ± 2	13.8 ± 1.2	158 ± 22		

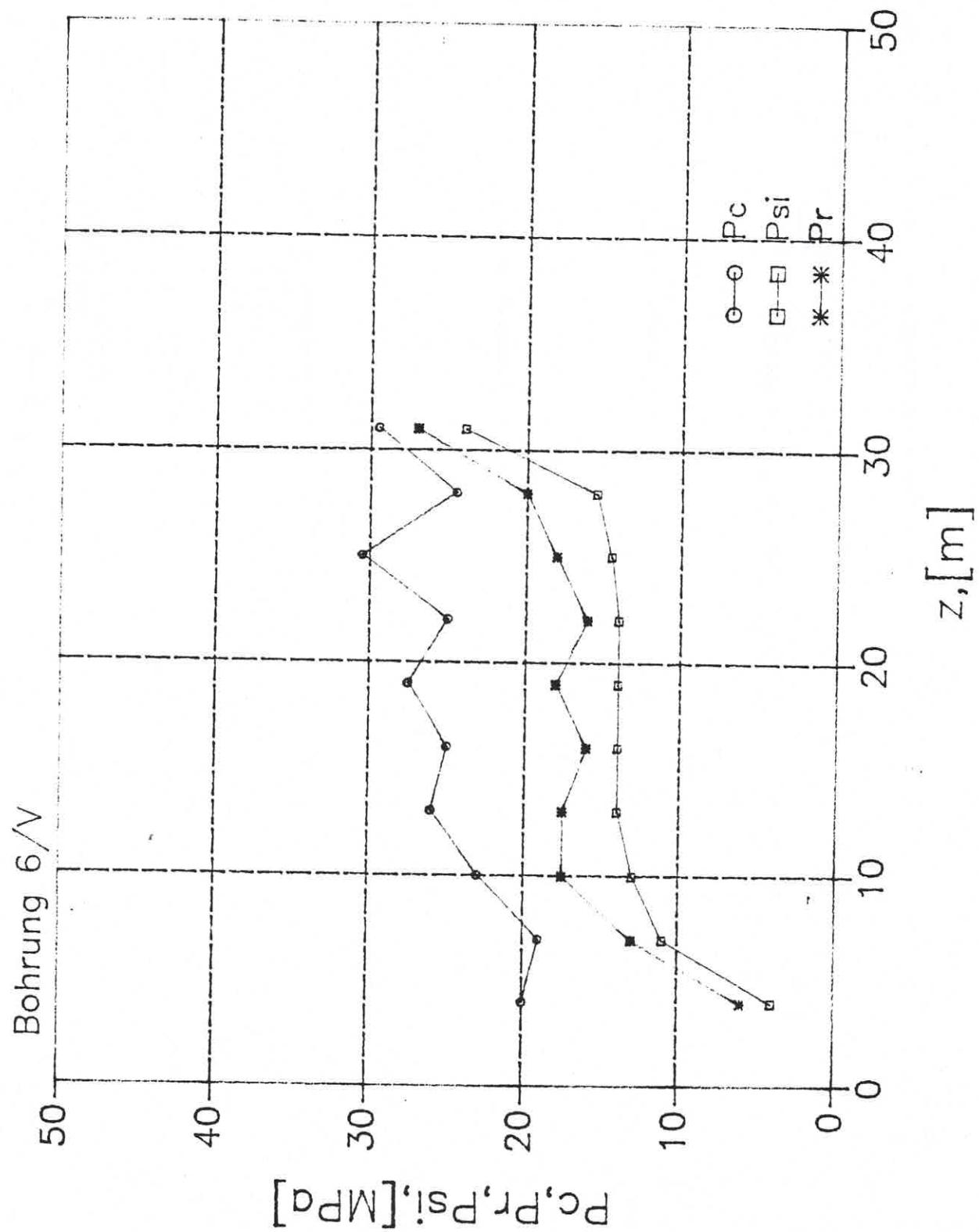


Abb. 5.4

Tab. 5.5: Bohrung 7/V

Tiefe m	Test Nr.	P _c MPa	P _r MPa	P _{si} MPa	θ Grad	α Grad	β Grad
6	2	16	10	9.0	99 104 208	90	---
10	3	21.5	12	10	---	---	---
16	4	14	6	6	---	---	---
19	5	22	20	14	---	---	---
22	6	18	14	11	---	---	---
25	7	20	18	14	---	---	---
28	8	18	16	12	---	---	---
31	9	16	15	13	---	---	---
34	10	15	8	8	---	---	---
Mittelwerte		17.8 ± 2.7	13.3 ± 4.4	10.8 2.6			

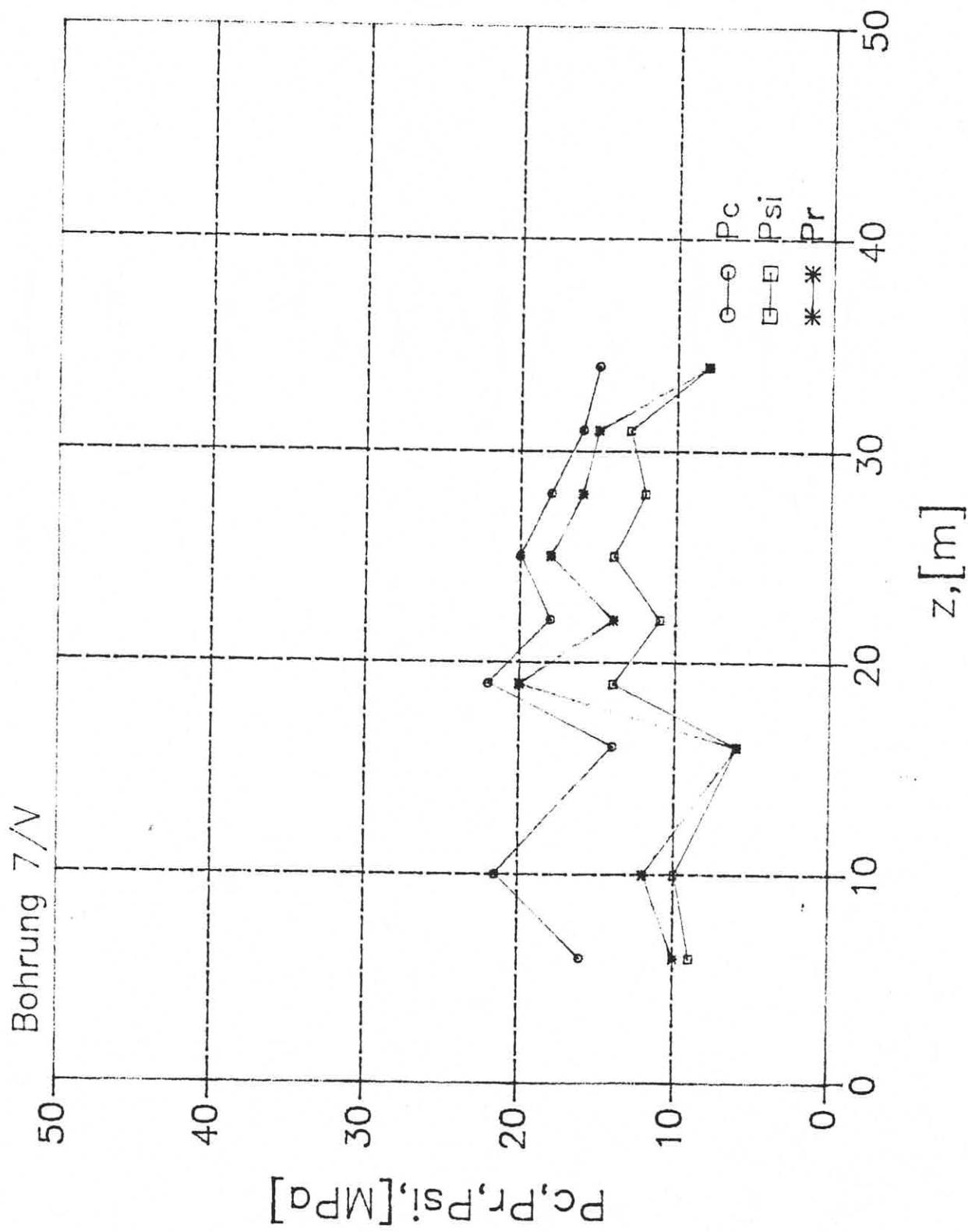


Abb. 5.5

Tab. 5.6: Bohrung 10/V

Tiefe m	Test Nr.	P _c MPa	P _r MPa	P _{si} MPa	θ Grad	φ Grad	β Grad
24	1	17	10	6.5	151	90	---
26	2	18	12	8	---	---	---
28	3	23	13	9	126	90	---
30	4	18	13	8	---	---	---
32	5	19	14	9	---	---	---
34	6	19	13	10.5	150	90	---
36	7	21	13	7	---	---	---
44	8	24	15	10	137	90	---
46	9	31	18	14	---	---	---

Mittelwerte

24 - 46 m	21.2 ± 4.4	13.4 ± 2.1	9.1 ± 2.1	132 ± 12
24 - 44 m	19.9 ± 2.4	12.9 ± 1.4	8.5 ± 1.3	132 ± 12

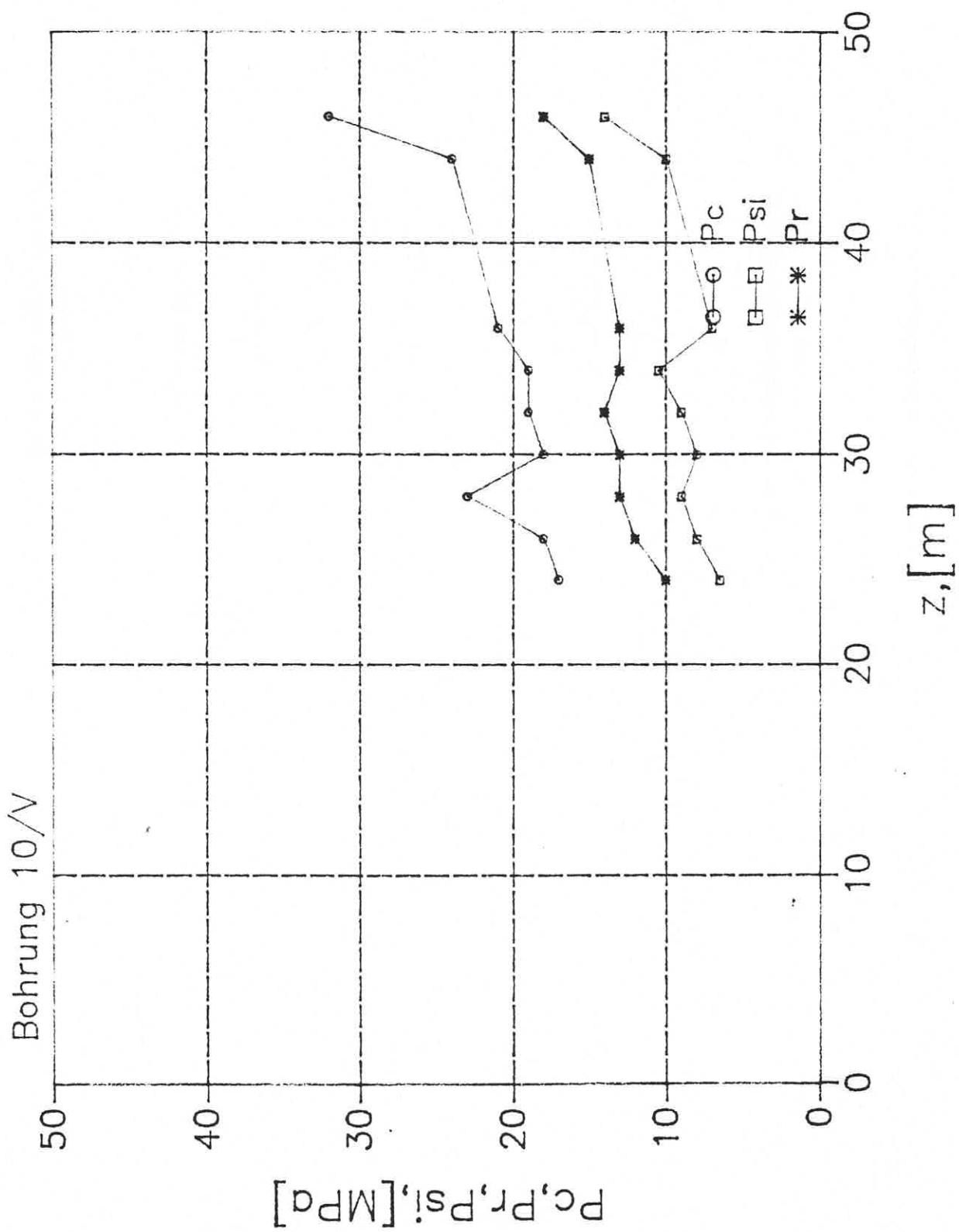


Abb. 5.6

Tab. 5.7: Bohrung 11/V

Tiefe m	Test Nr.	P _c MPa	P _r MPa	P _{si} MPa	θ	α	β
					Grad	Grad	Grad
4	7	(--)	(4)	(3.5)	156	90	---
7.3	6	13.5	8	7	146 187	90 68	---
10	5	14	9	8	164 168	90 82	---
13.2	4	18.5	10	8.5	---	---	---
16	3	17	9	9	---	---	---
19	2	25.5	11	10	---	---	---
20	1	26	11	10	---	---	---

Mittelwerte ohne () 19.1 9.7 8.8 156
 ± 5.0 ± 1.1 ± 1.1 ± 8

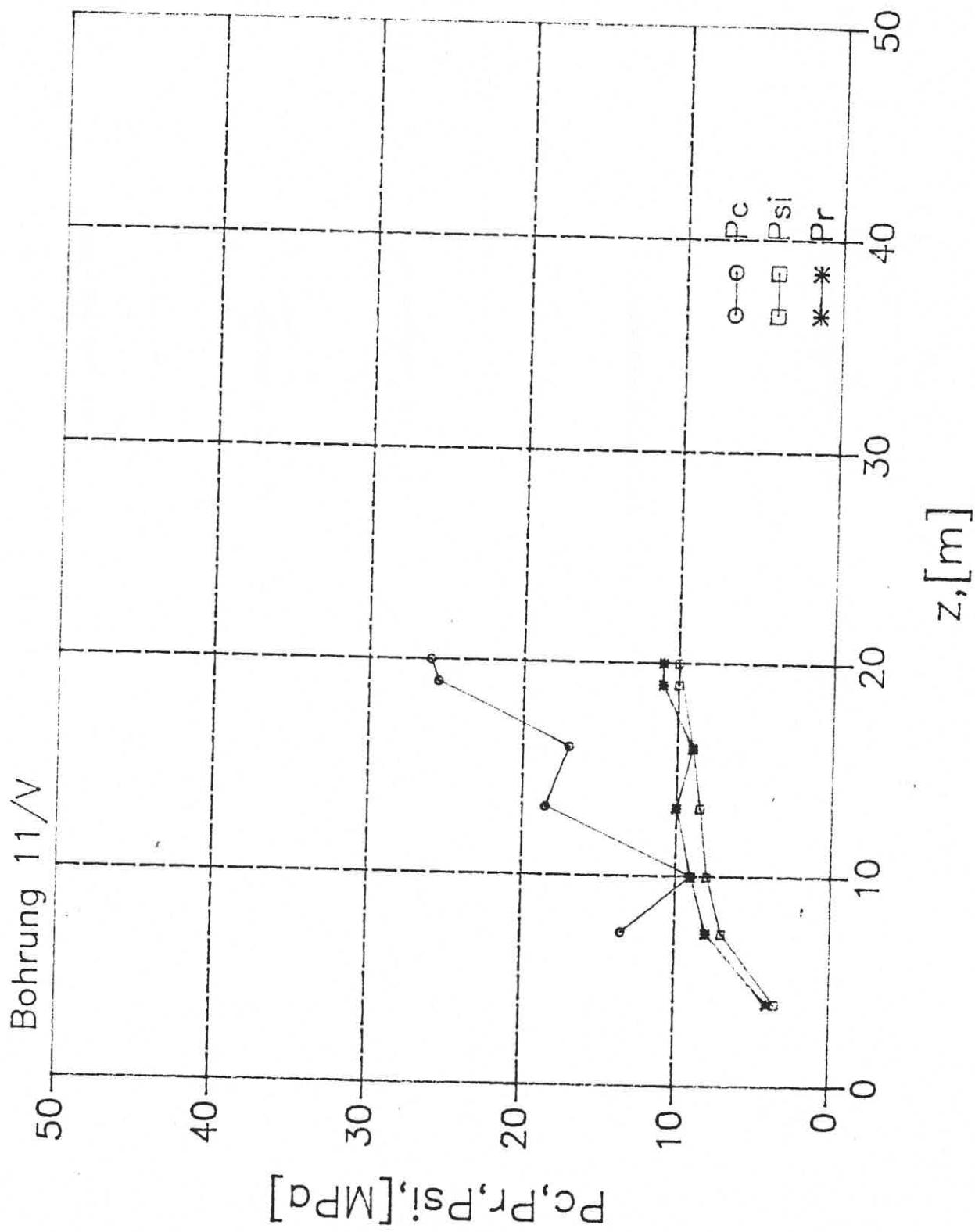


Abb. 5.7

Tab. 5.9 : Bohrung 2/H

Tiefe m	Test Nr.	P _c MPa	P _r MPa	P _{s i} MPa	θ Grad	α Grad	β Grad
10	1	19.0	17.0	14.0	32	154	302
13	2	25.0	21.0	18.0	38	176	308
16	3	23.0	18.0	17.0	42	69	132
19	4	25.0	20.0	18.0	30	92	300
22	5	22.0	18.0	18.0	36	175	306
25	6	26.0	21.0	20.0	30	123	300
28	7	28.0	21.0	20.0	29	31	119
31	8	27.0	22.0	21.5	--	--	--
34	9	28.0	22.5	21.5	25	11	115
37	10	32.0	24.0	22.0	--	--	--

Mittelwerte, alle 25.5

ohne T1	\pm 3.4	\pm 3.4	\pm 2.8	\pm 1.9	\pm 1.8	\pm 6	(104)
	26.2	20.8	19.6	33			(\pm 64)

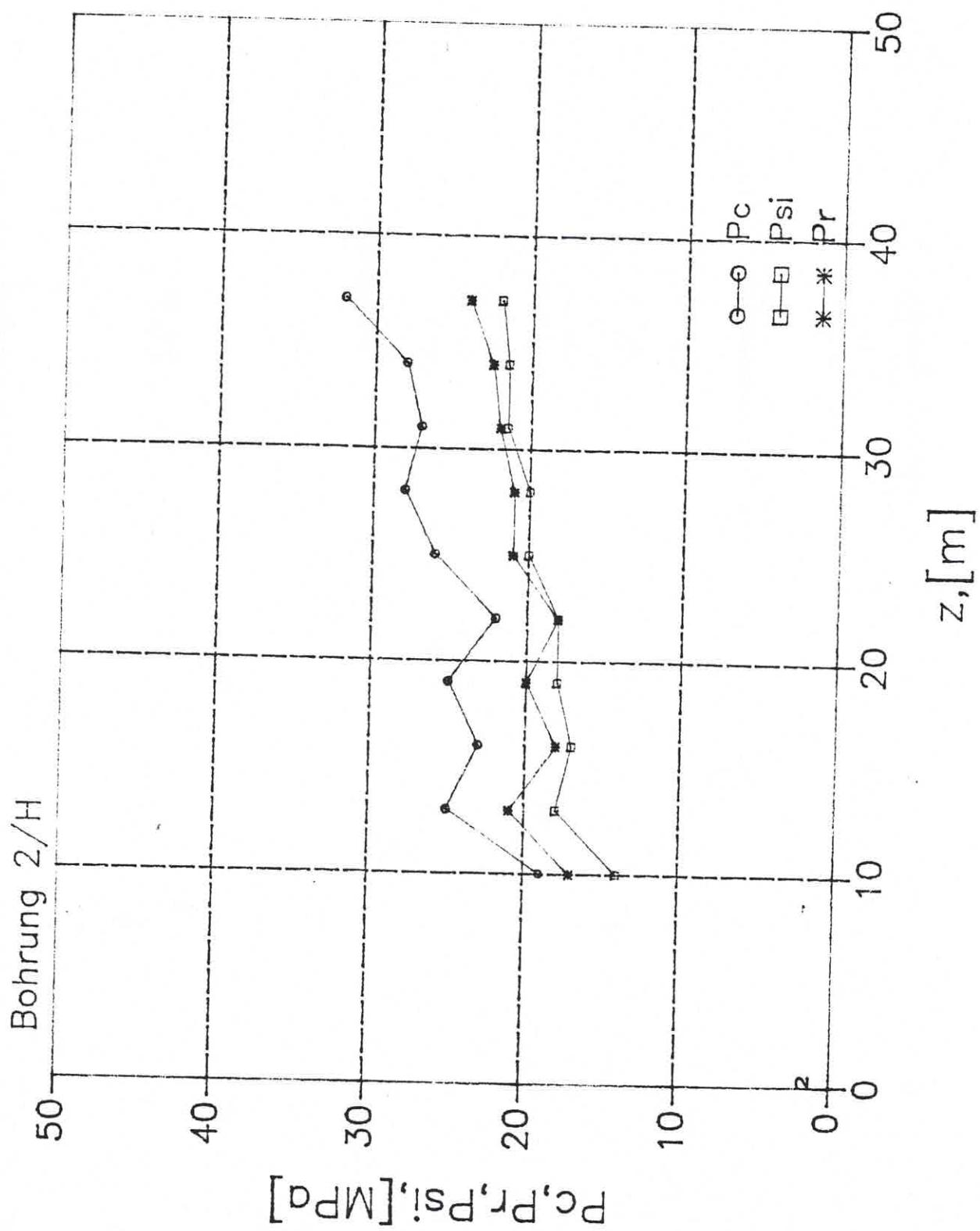


Abb. 5.8

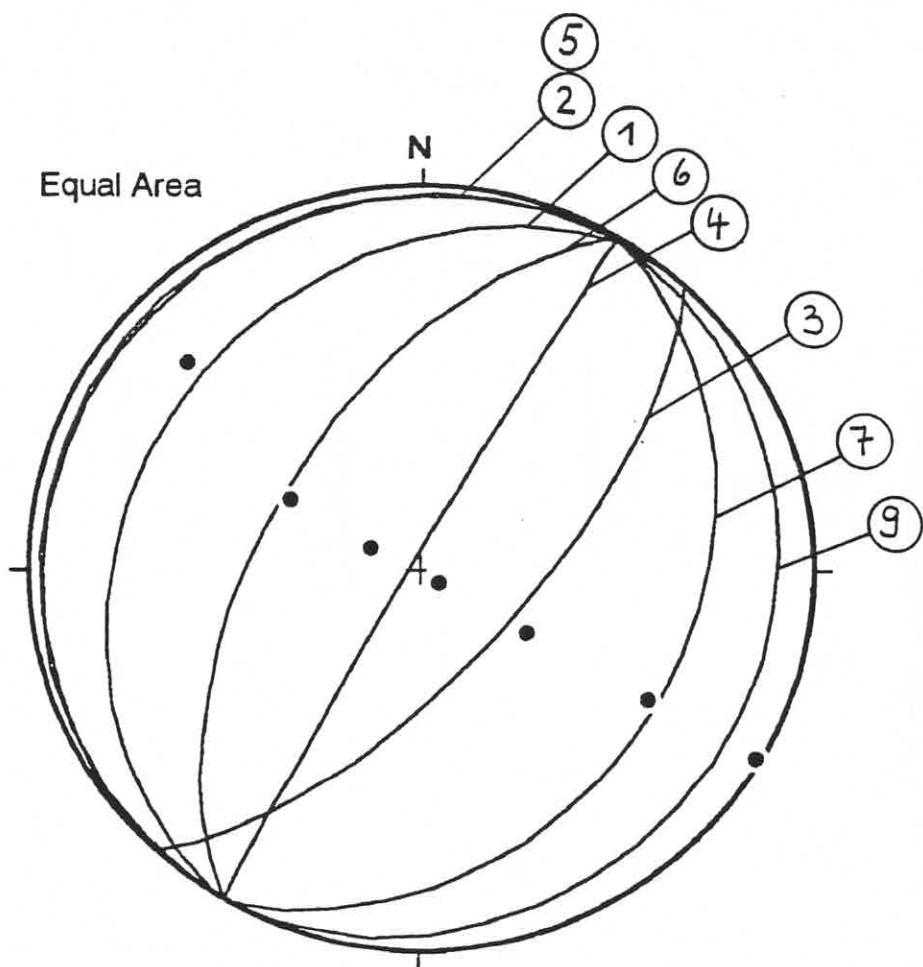


Abb. 5.9: Frac-Richtungen Bohrung 2/H (Pollagen und Großkreise der Frac-Flächen)

Tab. 5.10 : Bohrung 4/H

Tiefe m	Test Nr.	P _c MPa	P _r MPa	P _{s i} MPa	θ Grad	α Grad	β Grad
12	1	18	11	9	164	120	254
15.3	2 a	19	14	11	197	70	107
	2 b				203	37	113
19.8	3	15	10	7.5	(165)	(158)	(225)
21.4	4	19	10	9			
24.1	5	--	--	9			
24.4	6	--	--	8			
24.7	7	--	--	9			
26.8	12	--	--	--			
28.2	9	--	--	--			
30	8	--	--	10			
34.7	11	--	--	--			
38.3	10	18	12	10			
Mittelwerte		17.8 ± 1.5	11.4 ± 1.5	9.2 ± 1.0	188 ± 21	76 ± 41	

Bemerkung: 19.8 m stark verzweigtes Rißsystem /
unklare Bestimmung der Eingabedaten für Rechenprogramm!

21.4 m kein Abdruck vorhanden

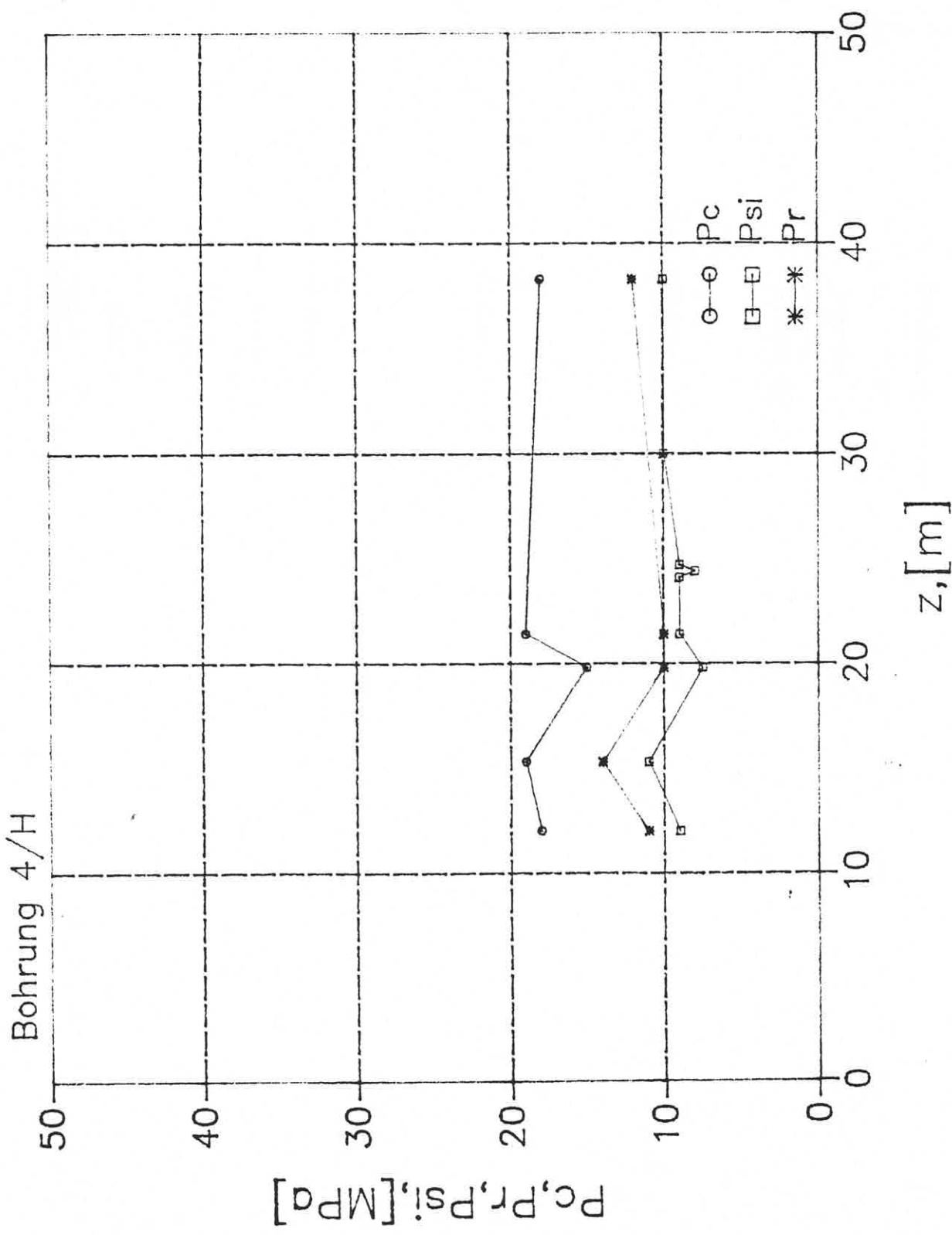


Abb. 5.10

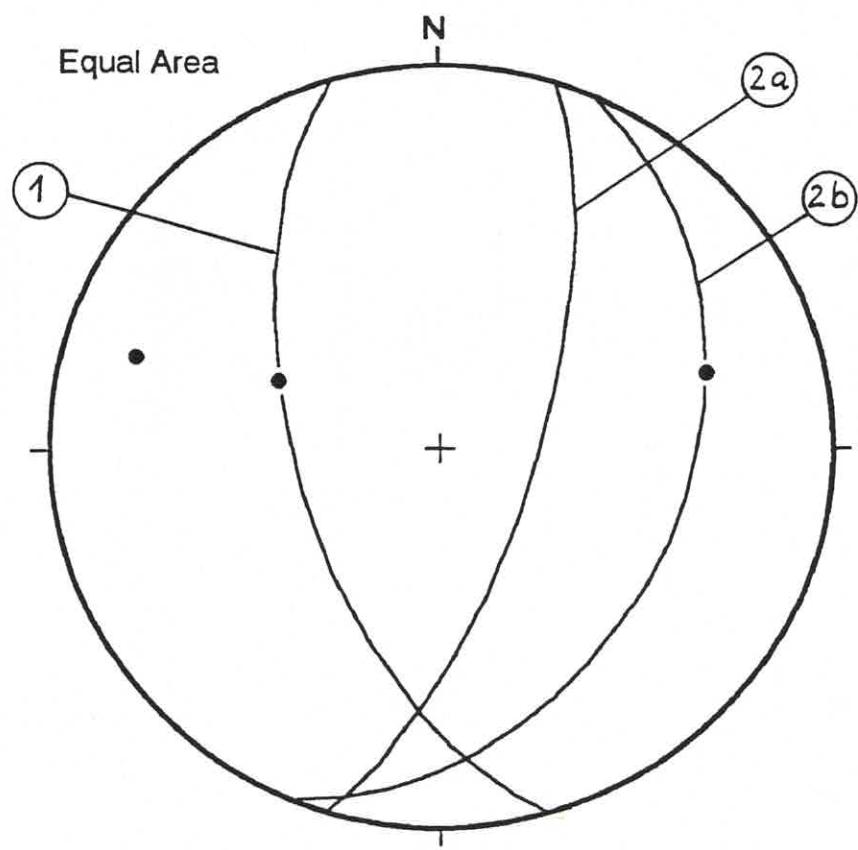


Abb. 5.11 Frac-Richtungen Bohrung 4/H (Pollagen und Großkreise der Frac-Flächen)

Tab. 5.11: Bohrung 8/H

z m	Test Nr.	P _c MPa	P _r MPa	P _{s i} MPa	θ/α Grad	β Grad
7.0+	1	30.5	25	21	--/--	---
10.0+	2	36	25	21	(162/39)	72
11.5*	12 a b	34	26	20.5	(160/99) (99/98)	250 (189)
13.0*	3	37.5	26	21	--/--	---
14.5*	13	36	26	21	--/--	---
16.0+	4	40	25	22.5	--/--	---
17.5*	14 a b	37.5	26	23.5	160/84 (64/54)	70 (154)
19.0+	5	36	26	24	162/55	72
20.5*	15	32(44)	26	24	--/--	---
22.0+	6	35.5	28	25	161/98	251
23.5*	16	33	28/26	24	(114/160)	204
25.0+	7	37	28	25	--/--	---
28.0+	8	36	28.5	26	161/123	251
29.5*	17	33.5	28	25	--/--	---
31.0+	9	37.5	30	27	--/--	---
32.5*	18	35	30	27	155/130	245
34.0+	10	42.5	34	31.5	--/--	---
37.0+	11	43.5	33	29.5	162/51	72
Mittelwerte		36.7 ± 3.6	27.6 ± 2.5	24.4 ± 3.0	160/ 91 ± 2.4/± 30	

+ : Messung September 1988

* : Messung Aug./ Sept. 1989

Bemerkung: 10 m stark verzweigtes Rißsystem/
unklare Datenangaben für Rechenprogramm

23.5 m keine Aufzeichnung der Rißspuren vorhanden

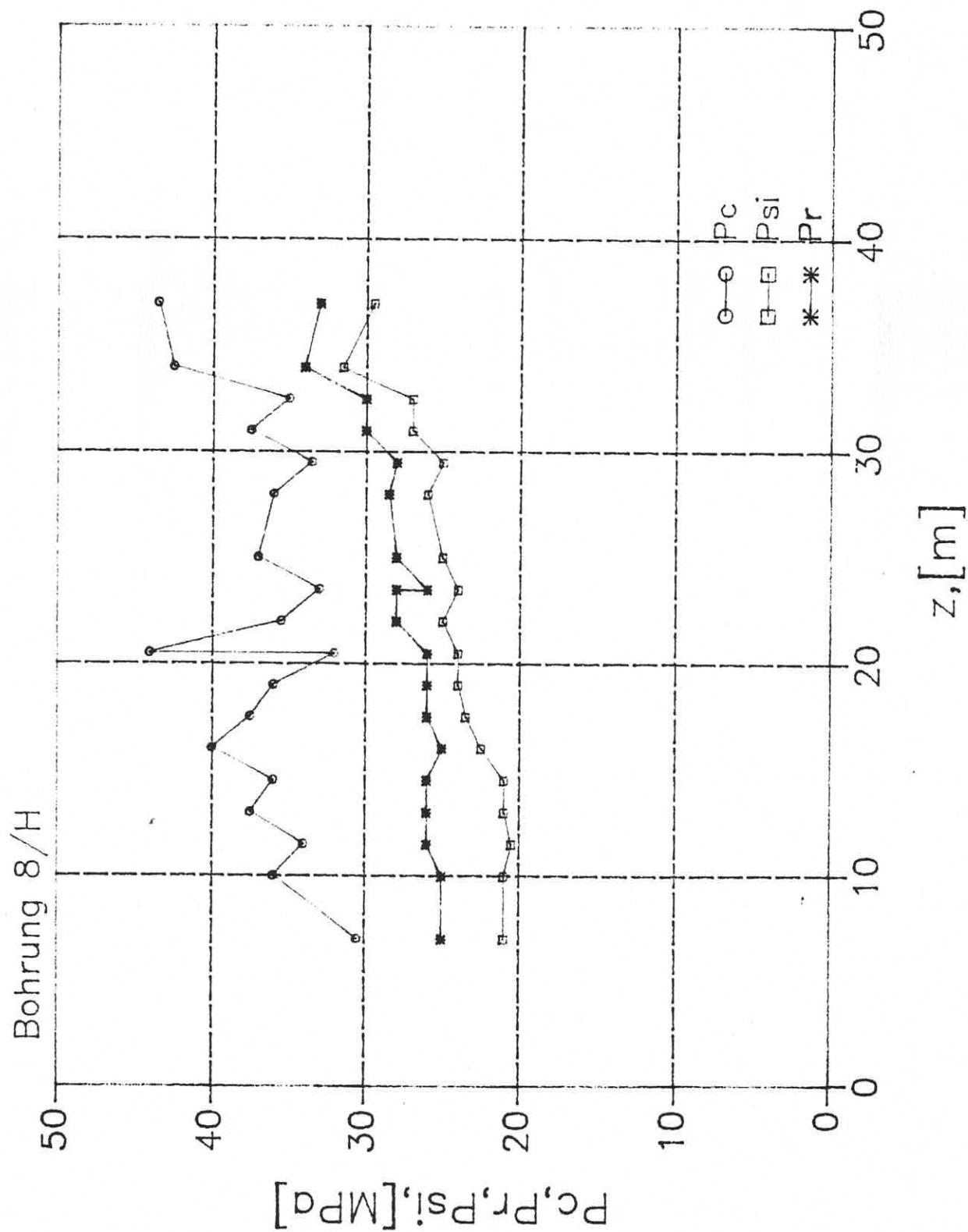


Abb. 5.12

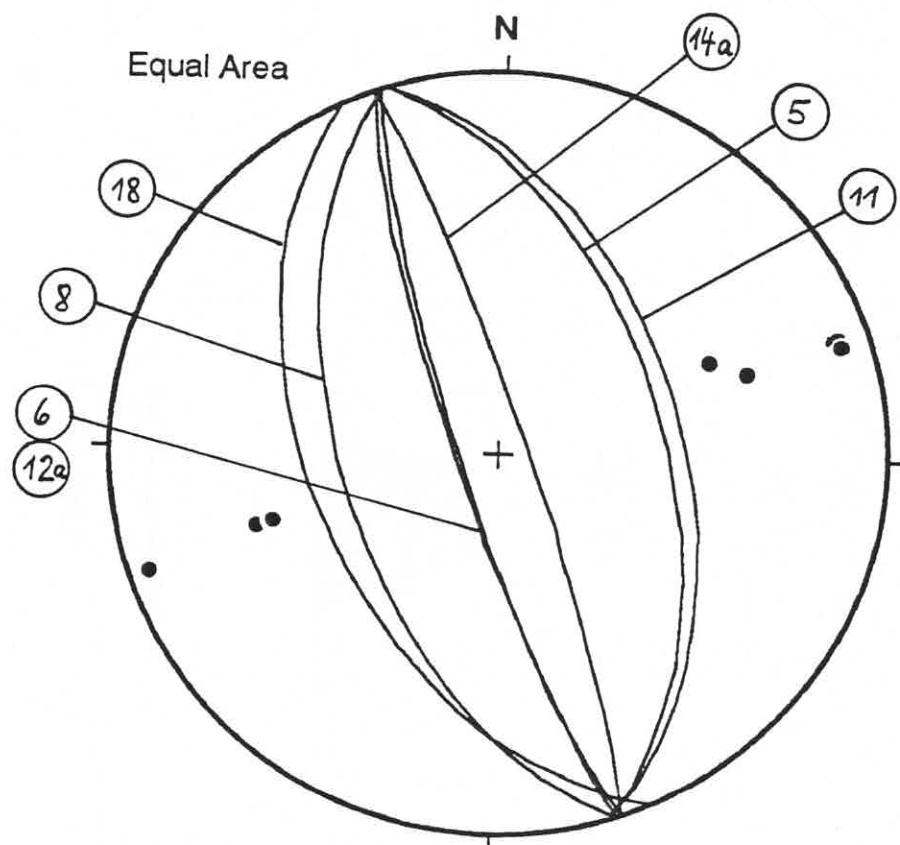


Abb. 5.13 Frac-Richtungen Bohrung 8/H (Pollagen und Großkreise der Frac-Flächen)

Tab. 5.12: Bohrung 9/H

Tiefe m	Test Nr.	P _c MPa	P _r MPa	P _{s i} MPa	Θ Grad	α Grad	β Grad
5	1	--	10	12	---	---	---
8	2	--	18	15	---	---	---
18	13	19.5	15	15	---	---	---
20	4	24.5	18	14	194	42	104
23	5	22	19	16	---	---	---
24.5	12	26	22	17	147	13	57
26	6	29.5	22	17	---	---	---
29	7	34	27	19	174	44	84
32	8	34.5	26	21	---	---	---
33	11	32	27	21.5	195	107	285
35	9	34	28	22	---	---	---
37	10	a b	39 30	22.5	195 195	166 149	285 285
Mittelwerte		29.9 ± 6.2	21.8 ± 6.0	17.7 ± 3.5	183 ± 20	(87) (± 63)	

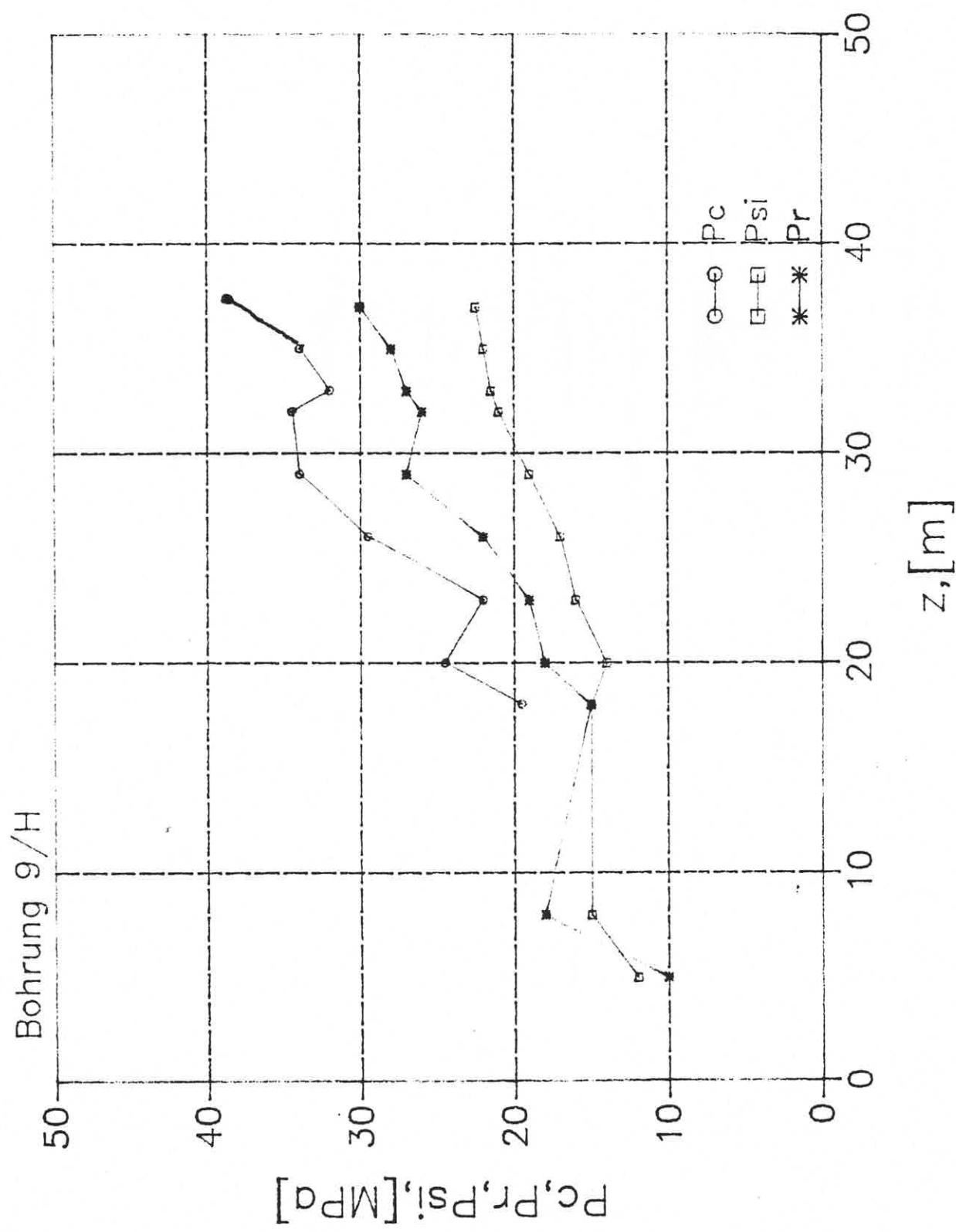


Abb. 5.14

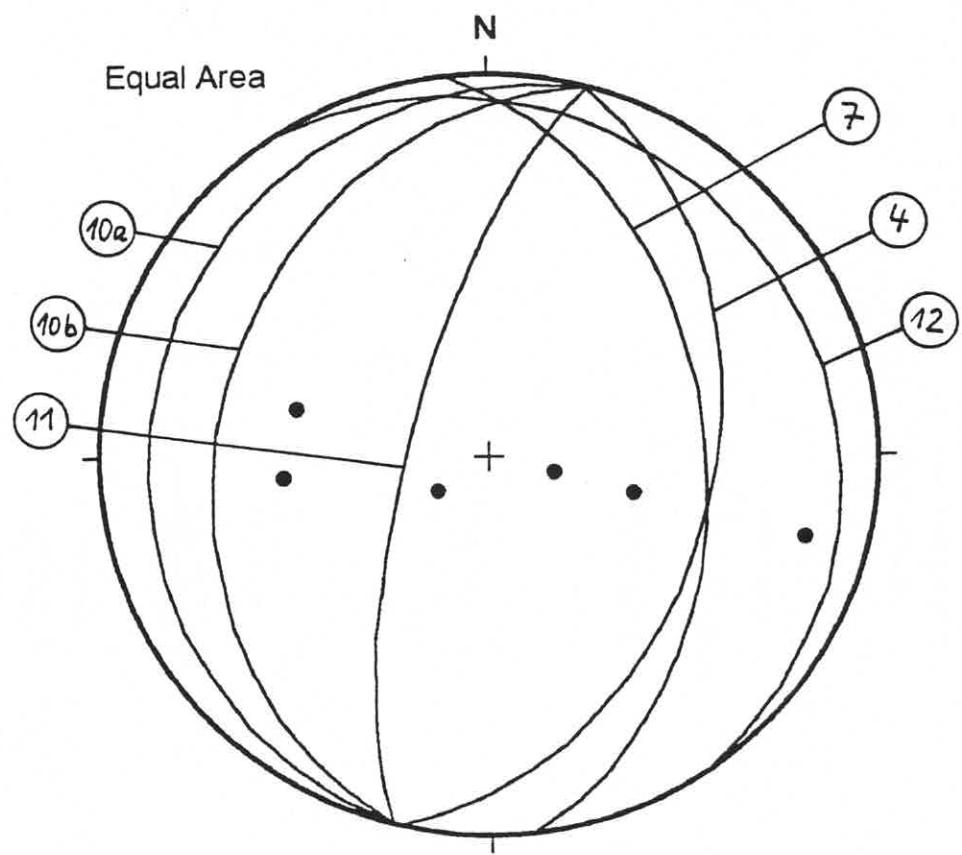


Abb. 5.15: Frac-Richtungen Bohrung 9/H (Pollen und Großkreise der Frac-Flächen)

Tab. 5.13 : Bohrung 12/H

Tiefe m	Test Nr.	P _c MPa	P _r MPa	P _{si} MPa	Θ Grad	α Grad	β Grad
6	1	--	2 (?)	8 (?)	---	---	---
9	2	31	24	17	181	61	271
15	3	33.5	23	16	---	---	---
18	4	29	22	18	161	81	71
21	5	34	24	19	---	---	---
24	6	31	24	19	160 133 (69) (69) (82)	86 87 (145) (35) (40)	70 223 (339) (159) (172)
27	7	32	26	20	---	---	---
30	8	40.5	28	20	---	---	---
33	9	32	26	20	194	83	284
36	10	36	27	20	---	87 (?)	---
39	11	40	28	20	---	---	---
Mittelwerte		33.5 ± 3.7	25.2 ± 2.0	18.9 ± 1.4	166 ± 21	80 ± 10	

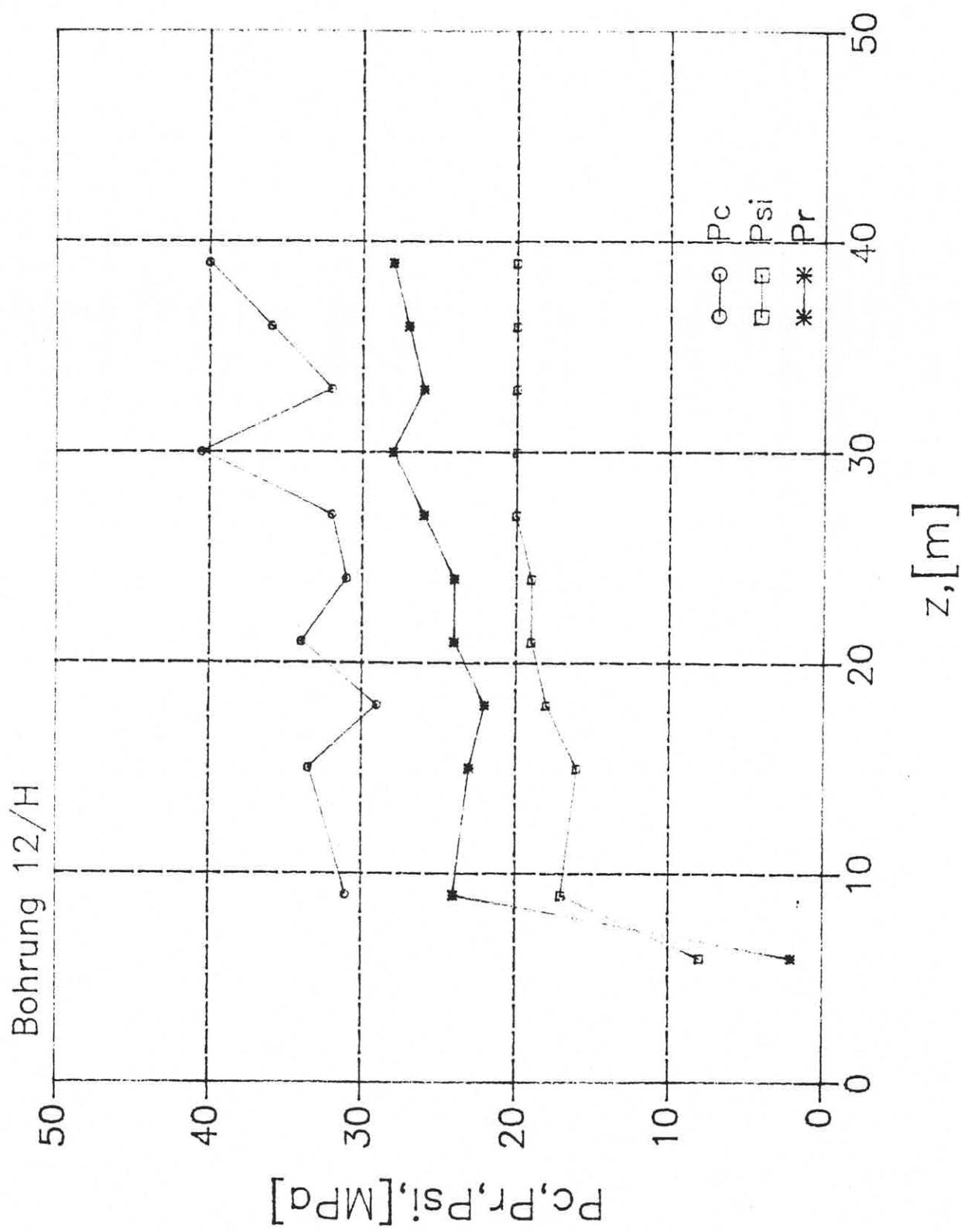


Abb. 5.16

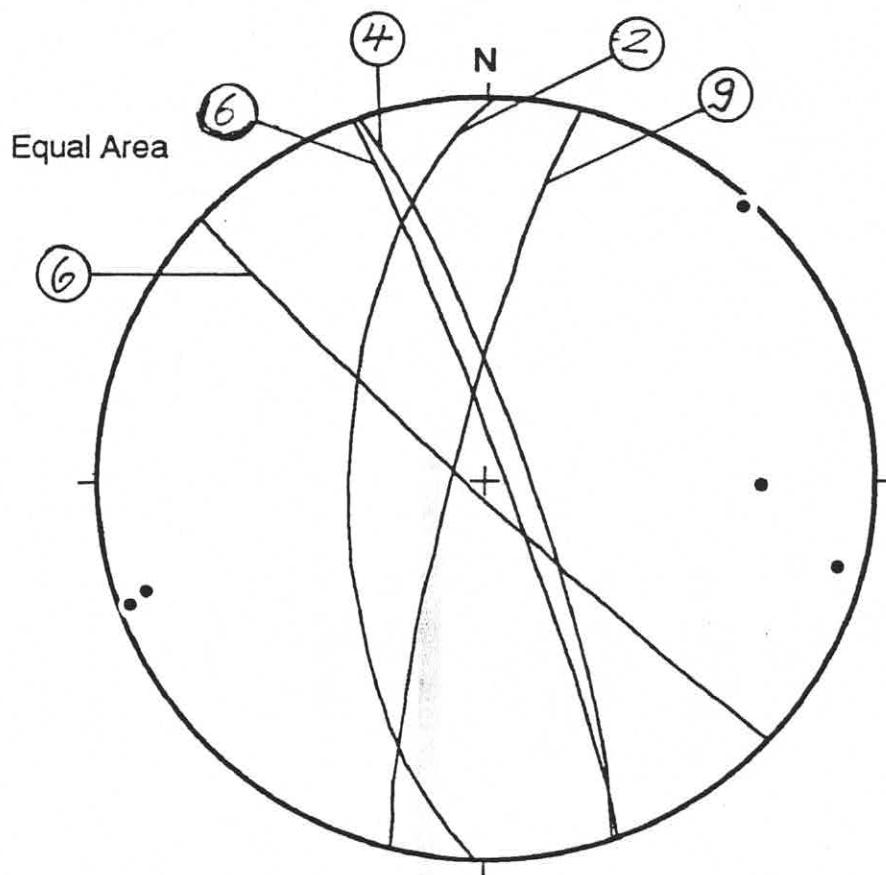
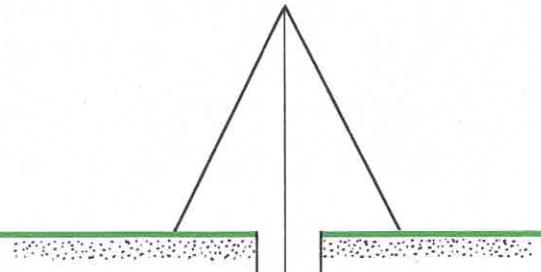


Abb.5.17: Frac-Richtungen Bohrung 12/H (Pollagen und Großkreise der Frac-Flächen)



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

ADDENDUM TO

**COMPIRATION OF EXISTING
HYDROFRAC IN - SITU STRESS DATA
FOR THE RUHR CARBONIFEROUS**

- INDIVIDUAL CHARACTERISTIC PRESSURE DATA
OF HYDRAC TESTING IN EACH BOREHOLE -

Client	Conoco Mineraloel GmbH
Order No.	031 - 94
Date of Order	10.10.94
MeSy Quotation No.	119.07.94 dated 20.07.94
Report prepared by	Prof. Dr. F. Rummel Dipl. Geophys. U. Weber
Report Date	09.12.94
Report No.	28.94

FOREWORD

Upon request of Mr. K. Thomas, Conoco Mineraloel GmbH Essen, in addition to the mean characteristic pressure data P_{si} (shut-in pressure), P_c (breakdown pressure), P_r (fracture re-opening pressure) given in Tables of Section 7 of the report and used for stress estimation, this addendum contains all of the individual pressure and frac - orientation data observed during each individual test in all of the boreholes.

The presentation follows the order given in the report, i.e. starting with borehole data from mine Friedrich - Heinrich to mine Westfalen.

As far as available, the data are given in the form of tables, graphical plots of pressure values versus borehole depth, or polar diagrams for frac orientations.

The tables and figures are directly copied from the original reports. In most cases, the mean pressure values used during the original stress estimate are given. These mean pressure values may not correspond to the mean values given in Tables of Section 7 for cases a re-interpretation was necessary.

Even, using the individual data given here, it may be necessary to go back to the original reports to consider the comments made to the individual stress estimate and understand the individual interpretation.

.....
Prof. Dr. F. Rummel

**HYDROFRAC - DATA FROM
MINE FRIEDRICH - HEINRICH**

Test-Nr.	Teufe	Frac-Druck [MPa]	Shut-in-Druck [MPa]	Refrac-Druck [MPa]	Bem.
1	37.6	17.2	11.7	(12.3)	
2	35.6	18.2	11.8	13.0	
3	33.6	22.0	12.5	15.0	
4	31.6	23.2	14.0	16.5	
5	29.6	(15.0)	14.0	(13.0)	prim. Riß
6	27.6	22.0	16.0	18.0	
7	25.6	(18.0)	13.5	18.0	prim. Riß
8	23.6	(16.0)	(14.0)	(13.0;15.0)	prim. Riß
9	21.6	23.8	14.0	14.2	
10	19.6	24.8	14.0	16.5	
11	17.6	19.3	14.0	16.4	
12	15.6	20.2	13.0	14.8	
13	13.6	19.0	12.8	15.5	
14	11.6	19.5	12.2	13.0	
15	9.6	21.5	10.2	12.8	
		20.9	13.1	15.3	
		<u>±2.4</u>	<u>±1.4</u>	<u>±1.8</u>	

Tab.1: Druckwerte der Vertikalbohrung 0420/K617-T/V

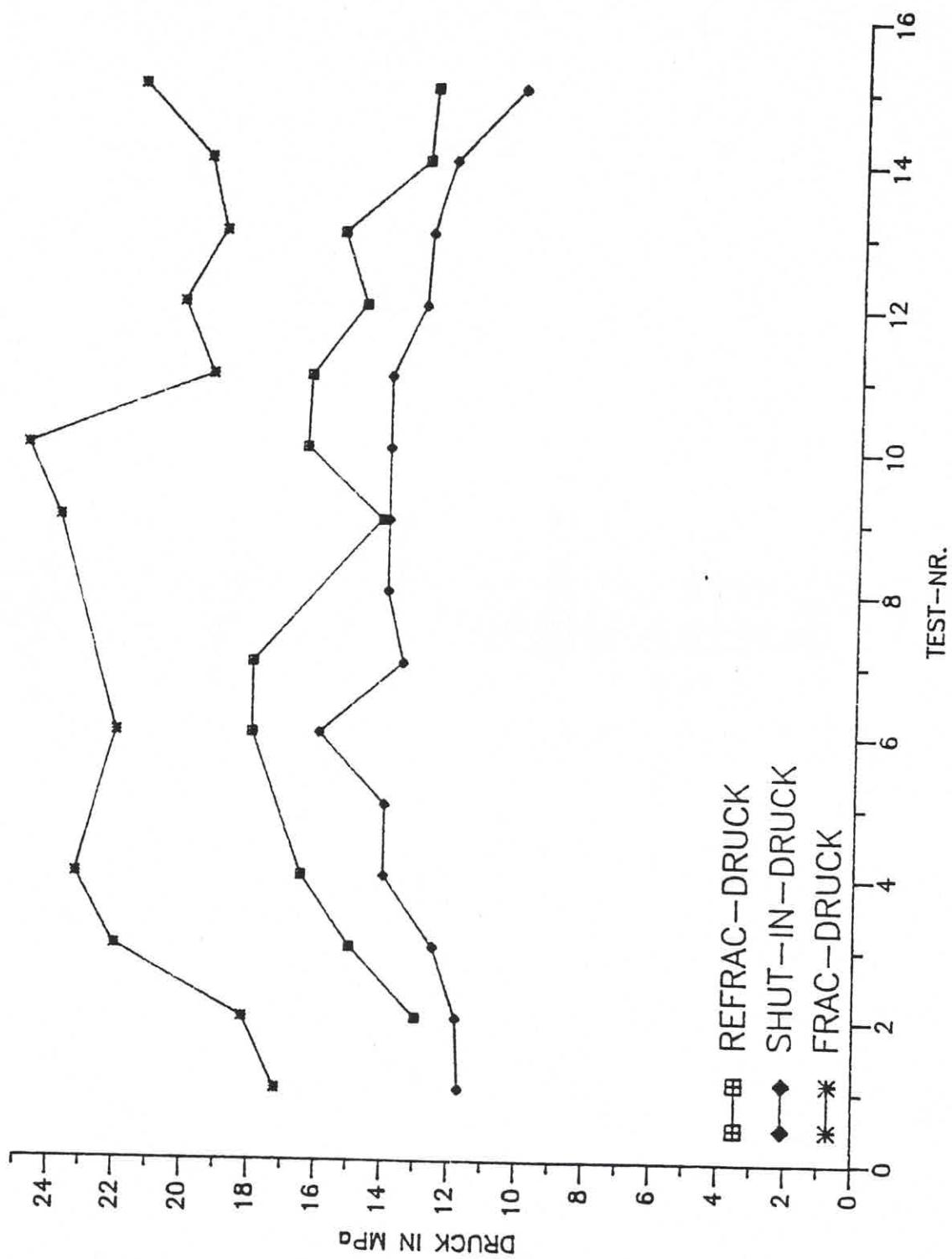


Abb. 1 Druckverlauf Vertikalbohrung 0420/K617-T/V

Test Nr.	Teufe [m]	Streich- richtung [GRAD]	Richtung des Einfallens [GRAD]	Einfallen der Riß- fläche [GRAD]	Bem.
1	37.6		kein Abdruckversuch		
2	35.6	110	200	80	
3a	33.6	129	219	84	
3b		138	228	84	
4	31.6	137	227	84	
5a	29.6	98	188	90	
5b		(106)	(196)	(75)	Abdruck nicht eindeutig
6	27.6		Abdruck nicht auswertbar		
7	25.6	125	215	79	
8	23.6	111	200	85	
9a	21.6	(98)	(8)	(90)	Abdruck nicht eindeutig
9b		(77)	(347)	(86)	
10	19.6	(198)	(286)	(69)	Ausreißer
11	17.6	134	223	85	
12	15.6	118	208	72	
13	13.6	119	209	68	
14	11.6	119	209	67	
15	9.6	133	223	34	
		123 ± 12	212 ± 12	76 ± 15	

Tab.3: Lage der Rißflächen der Vertikalbohrung 0420/K617-T/v

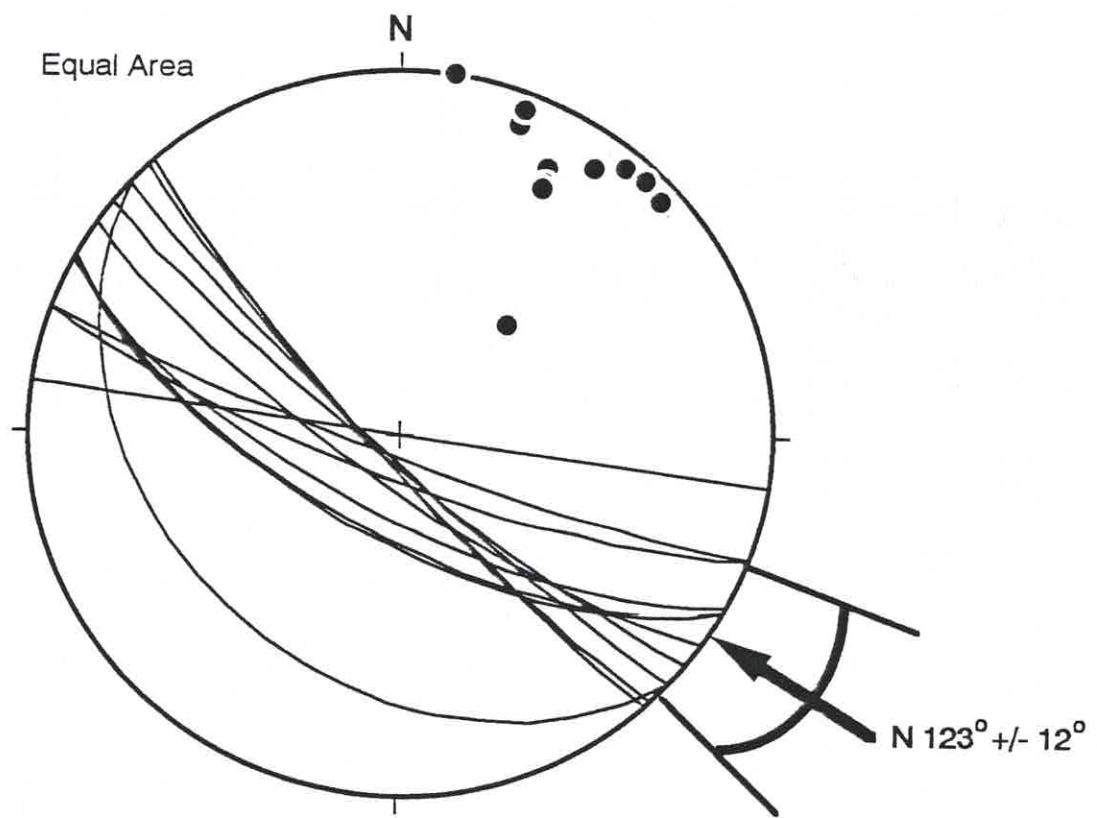


Abb. 3 Pollagendiagramm der Fracflächen der Vertikalbohrung

Test-Nr.	Teufe [m]	Frac- Druck [MPa]	Shut-in- Druck [MPa]	Refrac- Druck [MPa]	Bem.
1	34.25		nicht auswertbar		
2	32.25	21.2	10.5	17.4	
3	30.25	23.0	11.3	21.5	
4	28.25	22.0	12.2	18.4	
5	26.25	(14.5)	12.2	14.5	Störungszone
6	24.25	21.0	12.0	12.5	
7	22.25	21.8	10.8	17.0	
8	20.25	20.0	10.0	17.9	
9	18.25	23.2	11.0	18.0	
10	16.25	22.0	12.0	19.7	
11	14.25	14.9	5.6	8.4	
12	12.25	18.0	5.8	11.3	
13	10.25	17.8	6.3	12.1	
14	8.25	19.4	6.0	12.7	
15	6.25	11.6	6.0	10.8	
T1 - T10:		21.8 <u>+1.0</u>	11.3 <u>+0.8</u>	17.4 <u>+2.6</u>	
T11 - T15:		16.3 <u>+3.1</u>	5.9 <u>+0.3</u>	11.1 <u>+1.6</u>	

$$\overbrace{18.3}^{\nearrow} \quad \overbrace{15.2 \pm 3.9}^{\nearrow} \quad \overbrace{\qquad\qquad}^{\rightarrow}$$

9.4 ± 2.8

Tab.2: Druckwerte der Horizontalbohrung 0420/K617-T/H

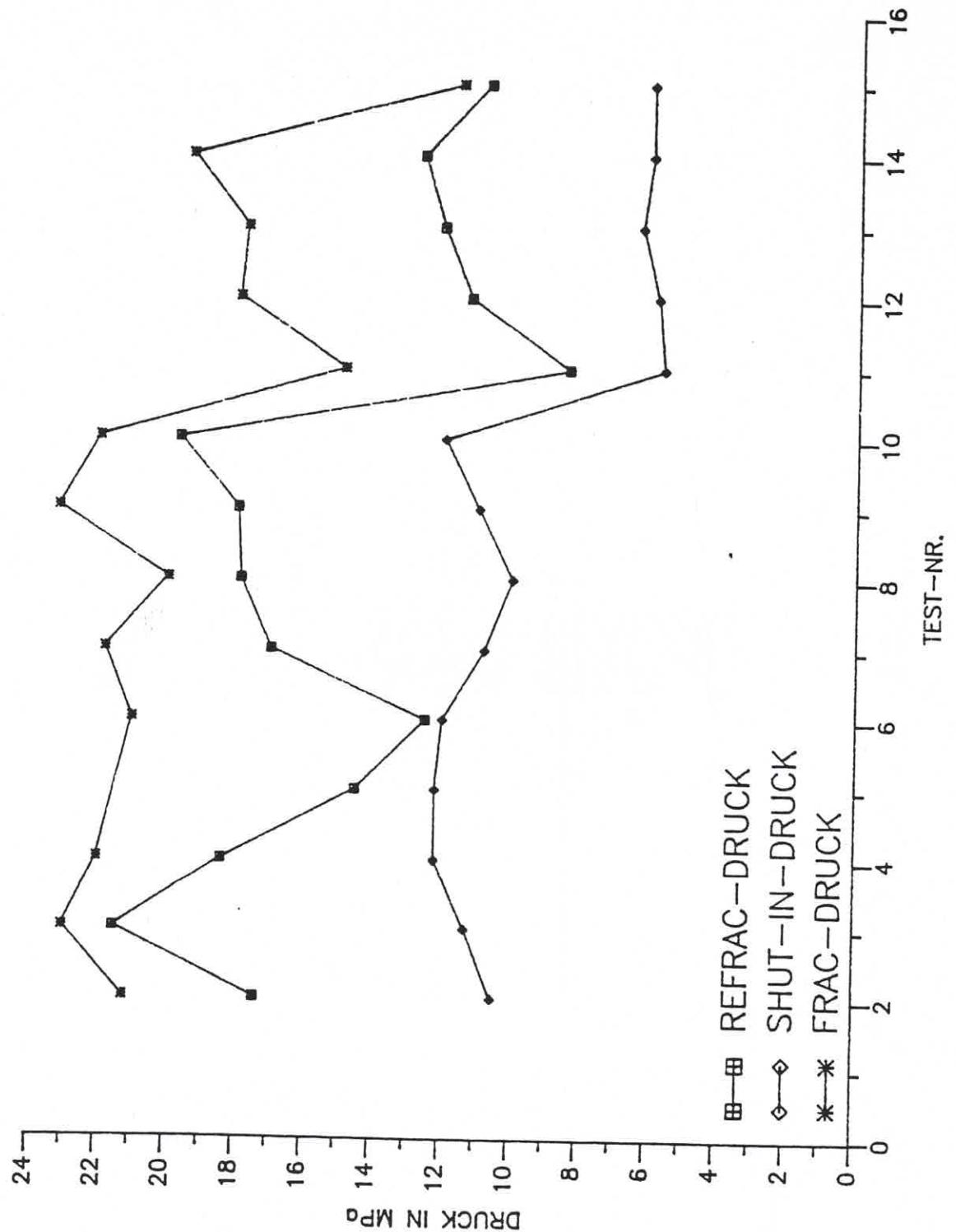


Abb. 2 Druckverlauf Horizontalbohrung 0420/K617-T/H

Test Nr.	Teufe [m]	Streich- richtung [GRAD]	Richtung des Einfallens [GRAD]	Einfallen der Riß- fläche [GRAD]	Bem.
1	34.25		kein Abdruckversuch		
2a	32.25	147	57	70	
2b		105	15	89	
3a	30.25	(25)	(295)	(42)	prim. Riß
3b		139	229	77	
4a	28.25	116	206	75	
4b		(11)	(101)	(25)	Schieferungs- fläche
5a	26.25	(143)	(233)	(29)	Störungszone
5b		(155)	(245)	(50)	Störungszone
5c		113	203	80	
6a	24.25	153	63	87	
6b		(125)	(215)	(19)	Störungszone
6c		(92)	(182)	(12)	mit Quarz
7	22.25	(152)	(62)	(29)	prim. Riß
8	20.25	178	88	70	
9	18.25	(154)	(64)	(66)	Störungszone mit Axialriß
10	16.25	(155)	(245)	(54)	nicht ein- deutig
11	14.25	(175)	(85)	(87)	nicht ein- deutig
12	12.25	115	25	71	
13	10.25	174	265	74	
14	8.25	(133)	(223)	(88)	Störungszone
15	6.25	160	249	74	
		140		90	
		<u>+26</u>		<u>+15</u>	

Tab.4: Lage der Rißflächen der Horizontalbohrung 0420/K617-T/H

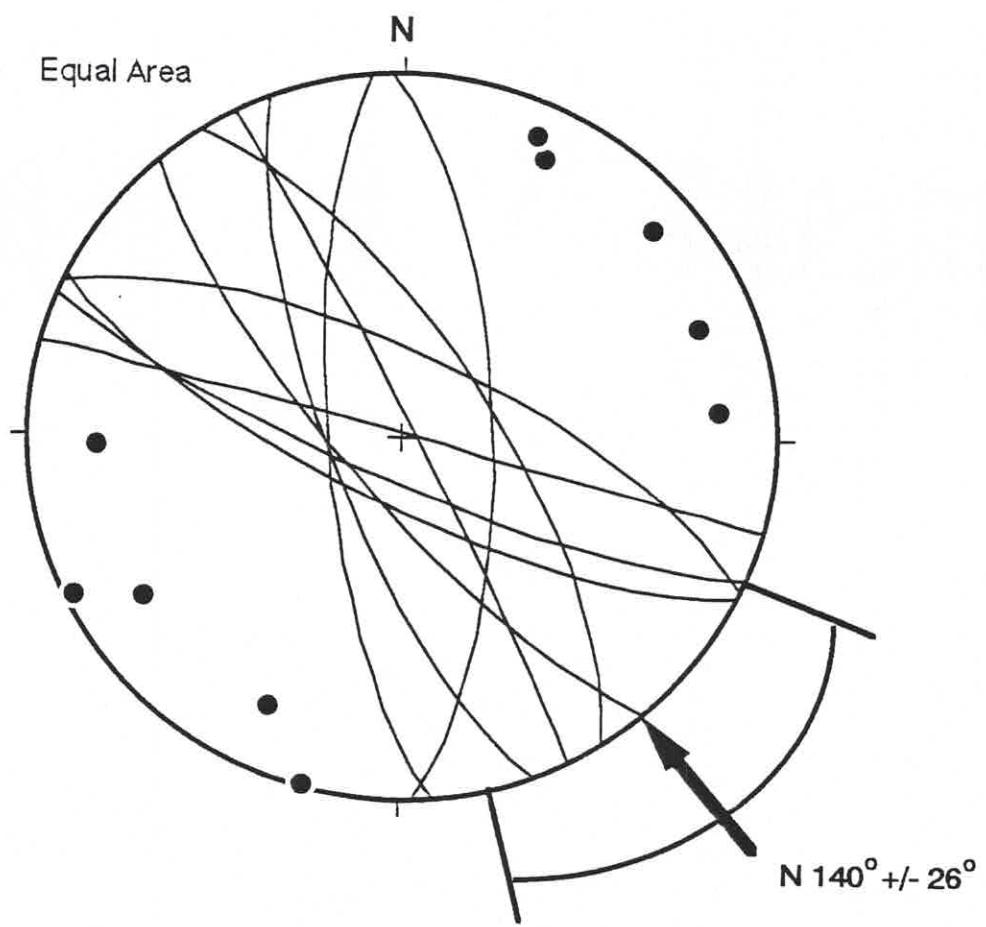


Abb. 4 Pollagendiagramm der Fracflächen der Horizontalbohrung

**HYDROFRAC - DATA FROM
MINE LOHBERG**

Tiefe [m]	P_c [MPa]	P_r [MPa]	P_{si} [MPa]	S_H [MPa]	S_h [MPa]
3.2	---	(8.0)	(4.5)	(5.5)	(4.5)
10.0	---	(16.0)	(14.3)	(26.9)	(14.3)
13.0	25.2	20.5	17.0	30.5	17.0
16.0	24.3	21.0	19.0	36.0	19.0
19.0	24.0	20.0	19.5	38.5	19.5
22.0	20.0	19.5	18.3	35.4	18.3
25.0	(23.0)	(19.0)	(17.8)	(34.4)	(17.8)
		23.4 ± 2.0	20.3 ± 0.6	18.5 ± 0.9	18.5 ± 0.9

Tab.1: Druck- und Hauptspannungswerte in Bohrung B1V.

Tiefe [m]	Bez.	Θ [°]	α [°]	β [°]
3.2	7A	(56.8)	(147)	(45)
	7B	(168.2)	(78)	(90)
10.0	6A	(165.2)	(75)	(74)
	6B	(165.2)	(75)	(58)
	6C	(164.2)	(254)	(90)
13.0	5A	173.0	83	81
	5B	146.8	57	78
	5C	157.3	67	81
16.0	4A	142.8	53	82
	4B	127.2	37	81
	4C	142.8	53	81
19.0	3A	153.0	63	82
	3B	163.6	74	81
22.0	2A	170.6	81	83
25.0	1A	(76.0)	(166)	(90)
	1B	(130.5)	(221)	(90)
	1C	(59.0)	(330)	(90)
	1D	(95.0)	(185)	(90)
		153 ± 14	63 ± 14	81 ± 1

Tab.2: Lage der Rißflächen in Bohrung B1V (Θ : Streichen der Rißfläche, α : Richtung des Einfallens, β : Einfallen der Rißfläche).

Lohberg, B1/V

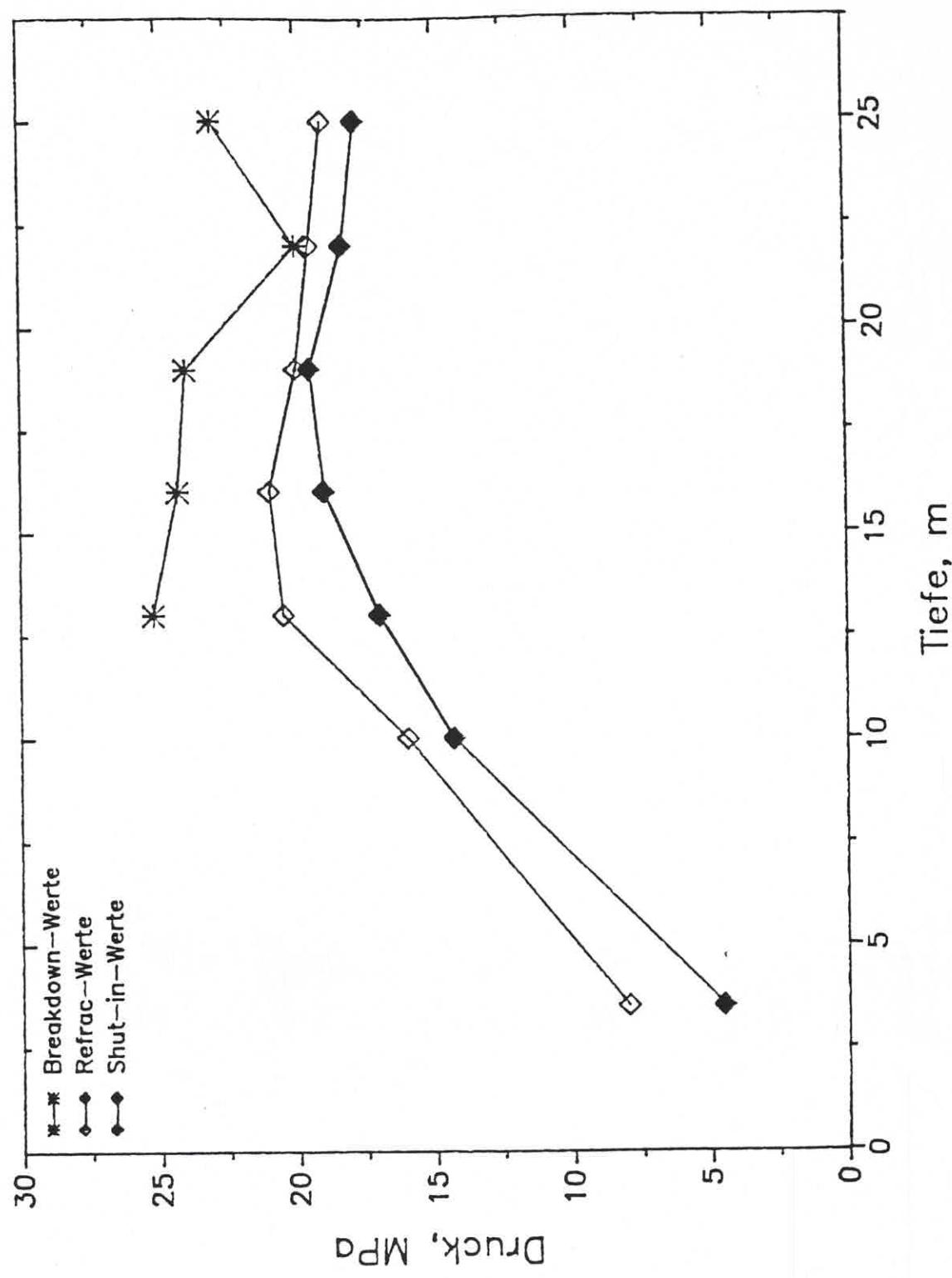


Abb.2: Druckverlauf in Bohrung B1V.

Tiefe [m]	P_c [MPa]	P_r [MPa]	P_{si} [MPa]	S_h [MPa]
3.35	(28.5)	(21.0)	(12.0)	(12.0)
6.35	(27.0)	(20.0)	(15.0)	(15.0)
9.35	26.0	20.0	16.5	16.5
12.35	24.0	18.0	16.2	16.2
15.35	28.5	20.0	16.2	16.2
18.35	33.8	18.5	16.2	16.2
21.35	34.0	29.0	17.0	17.0
24.35	---	18.0	14.5	14.5
27.35	33.5	17.0	16.0	16.0
30.35	26.0	19.0	16.0	16.0
33.35	26.0	19.0	17.0	17.0
36.35	24.8	19.0	16.7	16.7
		28.5 ± 3.9	19.8 ± 3.2	16.2 ± 0.7
				16.2 ± 0.7

Tab.3: Druck- und Hauptspannungswerte in Bohrung B1H90°

Tiefe [m]	Bez.	Θ [°]	α [°]	β [°]
3.35	12A	(178.1)	(268)	(76)
6.35	11A	(157.3)	(67)	(86)
	11B	(76.0)	(166)	(13)
	11C	(16.5)	(107)	(16)
9.35	10A	169.6	260	81
12.35	10B	(76.0)	(166)	(78)
12.35	9A	156.9	67	87
15.35	8A	166.0	76	90
	8B	(76.0)	(166)	(12)
18.35	7A	166.0	76	90
21.35	6A	156.0	246	70
24.35	5A	166.0	76	90
	5B	166.5	76	67
27.35	4A	158.4	248	61
30.35	3A	140.3	230	63
33.35	2A	161.8	252	68
36.35	1A	158.4	248	66
		160±8	169±87	76±11

Tab.4: Lage der Rißflächen in Bohrung B1H90° (Θ : Streichen der Rißfläche, α : Richtung des Einfallens, β : Einfallen der Rißfläche).

Lohberg, B1/H 90°

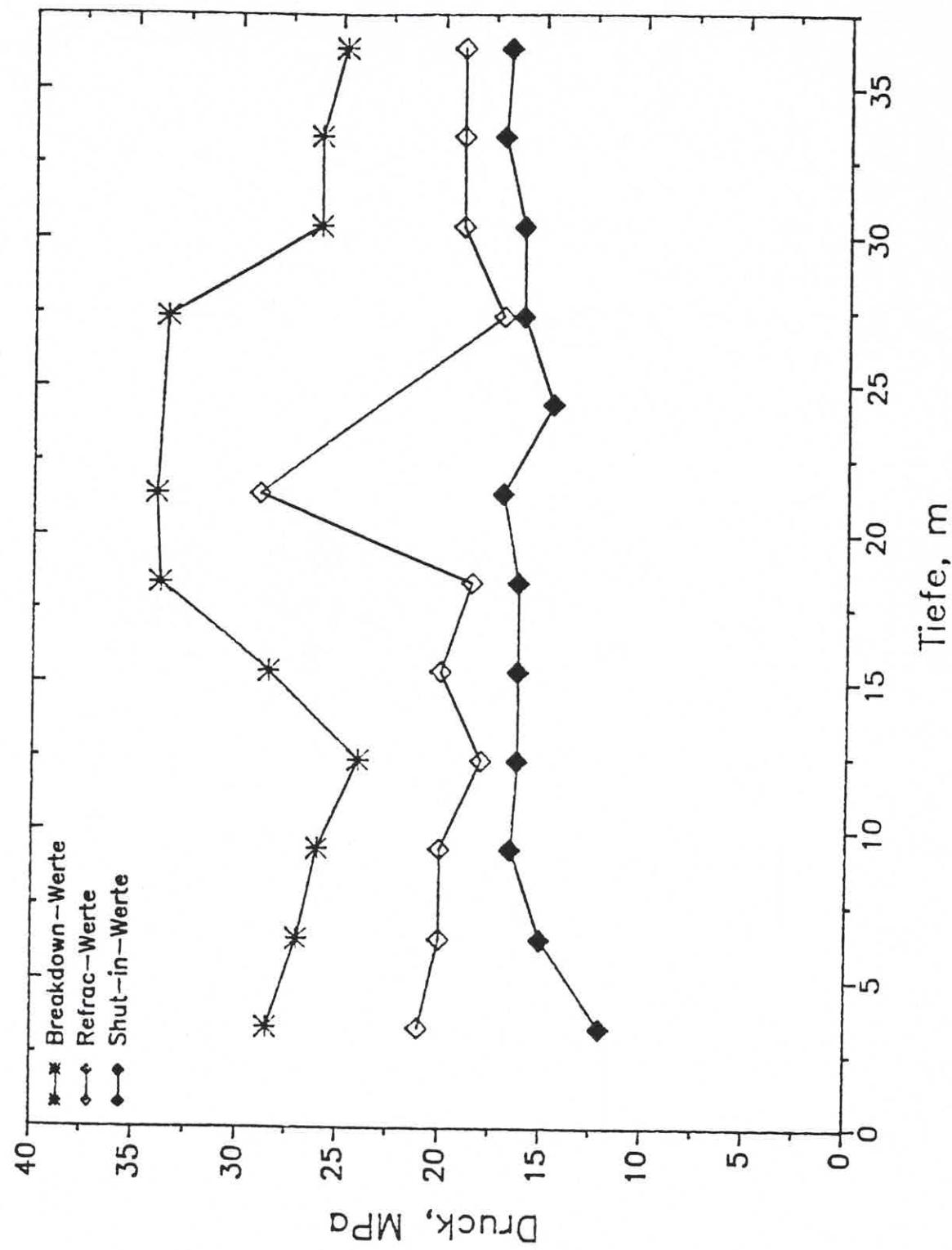


Abb. 3: Druckverlauf in Bohrung B1H90°.

Tiefe [m]	P_c [MPa]	P_r [MPa]	P_{si} [MPa]	S_h [MPa]
3.8	(20.0)	(16.0)	(10.0)	(10.0)
6.8	(27.0)	(20.0)	(13.5)	(13.5)
9.8	25.0	21.5	17.0	17.0
12.8	23.0	20.0	15.0	15.0
15.8	22.0	19.0	12.8	12.8
18.8	(16.3)	(18.0)	(12.0)	(12.0)
21.8	25.0	22.0	17.5	17.5
24.8	26.0	22.0	18.0	18.0
27.8	29.3	20.0	15.2	15.2
30.8	25.0	21.0	16.5	16.5
33.8	24.5	21.0	18.0	18.0
36.8	39.0	28.0	15.5	15.5
	26.5 ± 4.8	21.6 ± 2.5	15.8 ± 2.0	15.8 ± 2.0

Tab.5: Druck- und Hauptspannungswerte in Bohrung B1H45°.

Tiefe [m]	Bez.	Θ [°]	α [°]	β [°]	
33.8	1A	(33.8)	(304)	(47)	Rißhöhe unbekannt
	1B	(79.6)	(170)	(75)	dto.
	2A	174.7	265	(27)	dto.
	2B	150.0	240	(33)	dto.
	2C	141.4	231	(49)	dto.
		155 ± 14	245 ± 14	---	

Tab.6: Lage der Rißflächen in Bohrung B1H45° (Θ : Streichen der Rißfläche, α : Richtung des Einfallens, β : Einfallen der Rißfläche).

Lohberg, B1/H 45°

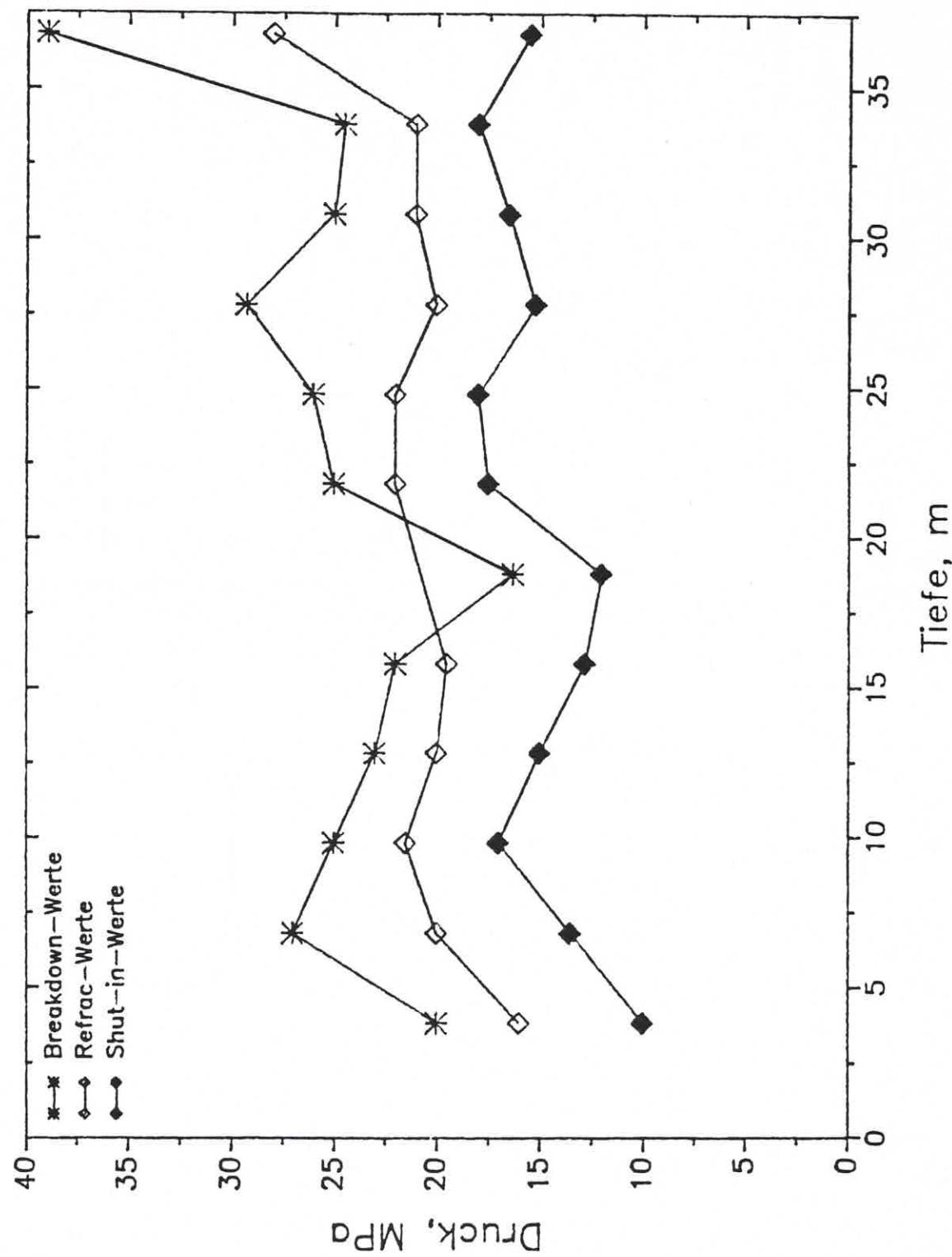


Abb. 4: Druckverlauf in Bohrung B1H45°.

Tiefe [m]	P_c [MPa]	P_r [MPa]	P_{si} [MPa]	S_H [MPa]	S_h [MPa]
3.5	---	(>3.0)	---	---	---
6.5	---	(>4.0)	(>2.5)	---	---
10.4	---	---	---	---	---
11.4	31.0	22.0	19.0	35.0	19.0
12.0	---	---	---	---	---
13.4	28.8	26.5	24.5	47.0	24.5
16.4	35.5	31.5	27.3	50.4	27.3
19.4	44.0	28.5	29.0	58.5	29.0
		34.8 ± 5.8	27.1 ± 3.5	25.0 ± 3.8	47.7 ± 8.5
					25.0 ± 3.8

Tab.7: Druck- und Hauptspannungswerte in Bohrung B2V.

Tiefe [m]	Bez.	Θ [°]	α [°]	β [°]
11.4	7A	142.6	53	36
13.4	3A	(59.6)	(330)	(90)
	3B	(56.6)	(327)	(90)
	3C	148.6	59	20
	3D	154.7	65	20
	3E	144.6	55	18
16.4	2A	144.2	234	90
	2B	154.8	65	90
	2C	126.8	36	90
19.4	1A	170.1	260	90
	1B	160.3	70	90
		150 ± 12	101 ± 79	60 ± 33

Tab.8: Lage der Rißflächen in Bohrung B2V (Θ : Streichen der Rißfläche, α : Richtung des Einfallens, β : Einfallen der Rißfläche).

Lohberg, B2/V

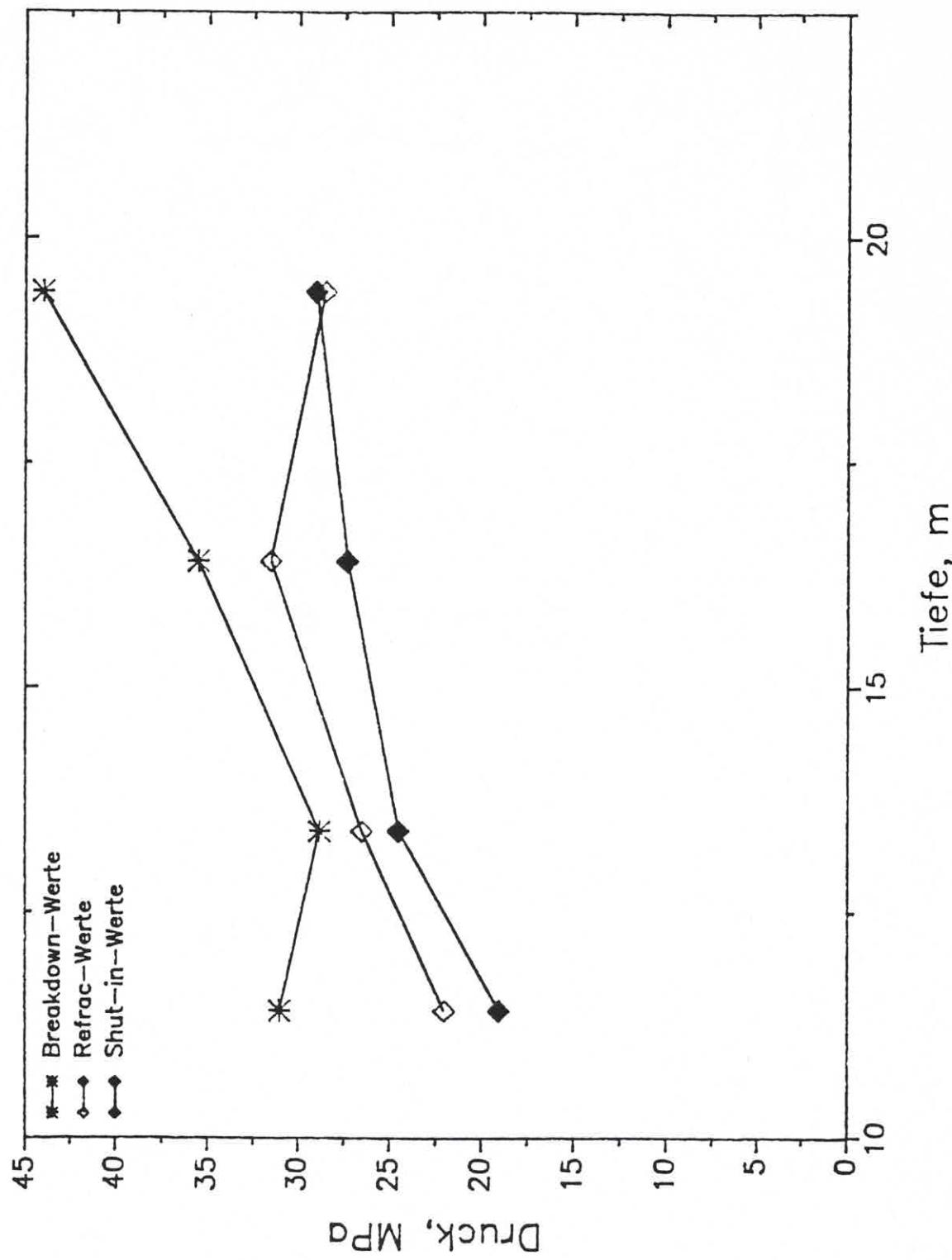


Abb. 5: Druckverlauf in Bohrung B2V.

Tiefe [m]	P_c [MPa]	P_r [MPa]	P_{si} [MPa]	S_h [MPa]
9.5	---	---	---	---
12.5	(28.7)	(17.0)	(11.0)	(11.0)
15.5	29.5	17.0	13.0	13.0
18.5	27.8	17.5	14.0	14.0
21.5	31.5	18.0	15.3	15.3
24.5	34.6	23.0	17.0	17.0
27.5	32.5	22.2	17.8	17.8
30.5	35.0	22.2	18.8	18.8
<hr/>				
	31.8 ± 2.6	20.0 ± 2.5	16.0 ± 2.1	16.0 ± 2.1

Tab.9: Druck- und Hauptspannungswerte in Bohrung B2H90°.

Lohberg, B2/H 90°

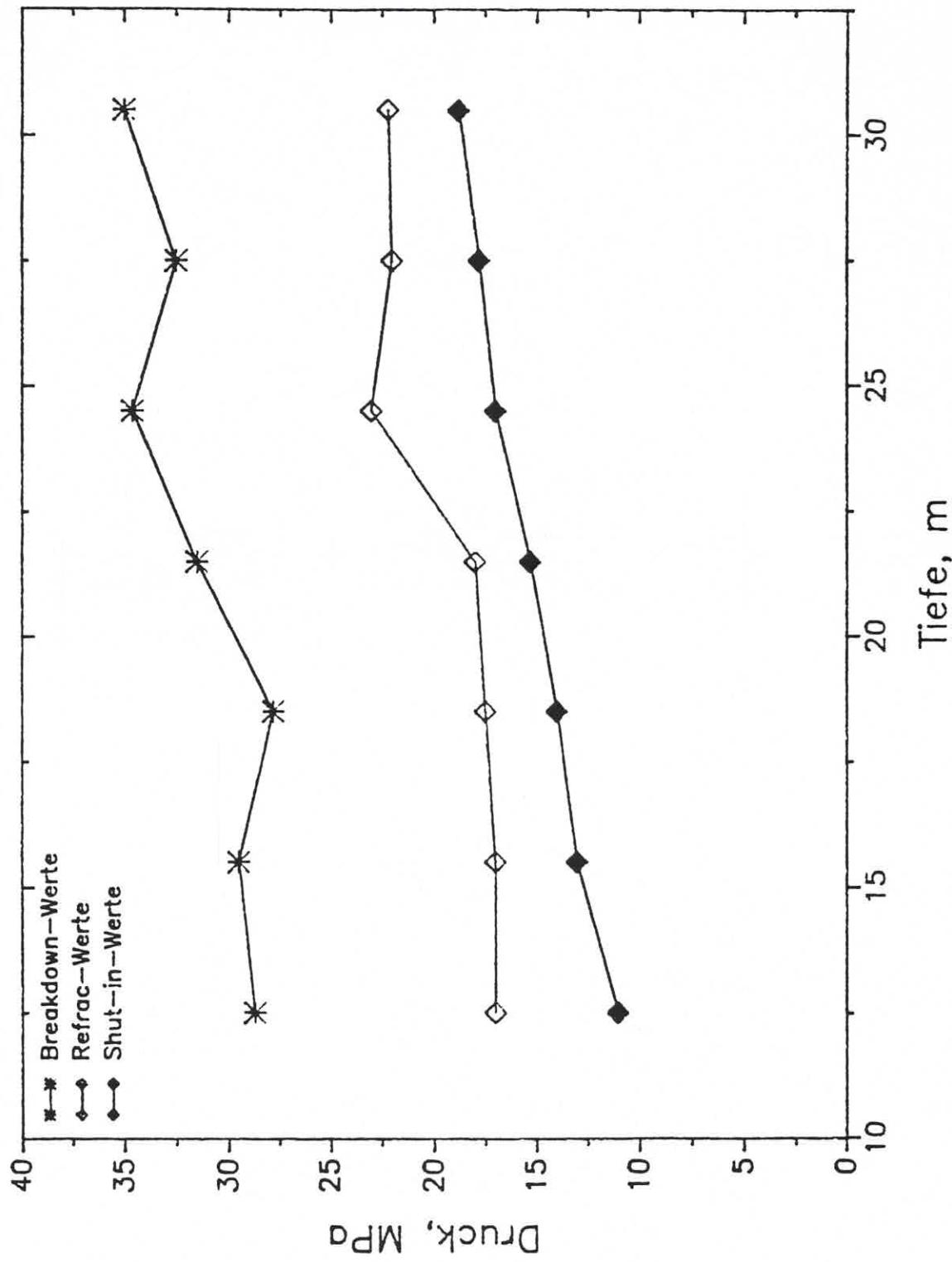


Abb. 6: Druckverlauf in Bohrung B2H90°.

Tiefe [m]	P_c [MPa]	P_r [MPa]	P_{si} [MPa]	S_h [MPa]
3.8	(17.5)	(10.0)	(4.8)	(4.8)
6.8	(18.3)	(15.3)	(8.3)	(8.3)
9.8	(15.5)	(14.5)	(9.2)	(9.2)
12.8	(17.8)	(15.0)	(10.0)	(10.0)
15.8	21.4	17.0	11.6	11.6
18.8	21.2	18.5	13.7	13.7
21.8	23.1	22.0	15.0	15.0
24.8	22.7	22.0	16.5	16.5
27.8	25.0	23.0	18.0	18.0
30.8	25.8	23.5	19.2	19.2
33.8	26.0	23.0	20.0	20.0
36.8	28.4	24.5	20.8	20.8
39.8	29.5	28.5	21.7	21.7
42.8	35.0	30.0	23.2	23.2
		25.8 ± 4.0	23.2 ± 3.7	18.0 ± 3.5
				18.0 ± 3.5

Tab.10: Druck- und Hauptspannungswerte in Bohrung B2H45°.

Tiefe [m]	Bez.	Θ [°]	α [°]	β [°]
6.8	3A	(17.9)	(288)	(36)
	13B	(36.4)	(306)	(51)
9.8	12A	(38.6)	(309)	(42)
	12B	(32.8)	(303)	(51)
12.8	11A	(39.5)	(310)	(18)
	11B	(38.4)	(308)	(51)
15.8	10A	160.2	70	81
18.8	9A	38.6	309	60
21.8	8A	143.0	53	79
	8B	31.1	121	13
24.8	7A	39.5	310	33
	7B	104.4	14	33
27.8	6A	3.8	274	35
30.8	5A	25.9	296	71
	5B	38.4	308	47
	5C	151.4	61	2
33.8	4A	36.4	126	74
36.8	3A	37.1	307	88
	3B	36.8	127	83
42.8	1A	100.5	10	28
	1B	90.8	181	17
		69 ± 50	171 ± 114	50 ± 28

Tab.11: Lage der Rißflächen in Bohrung B2H45° (Θ : Streichen der Rißfläche, α : Richtung des Einfallens, β : Einfallen der Rißfläche).

Lohberg, B2/H 45°

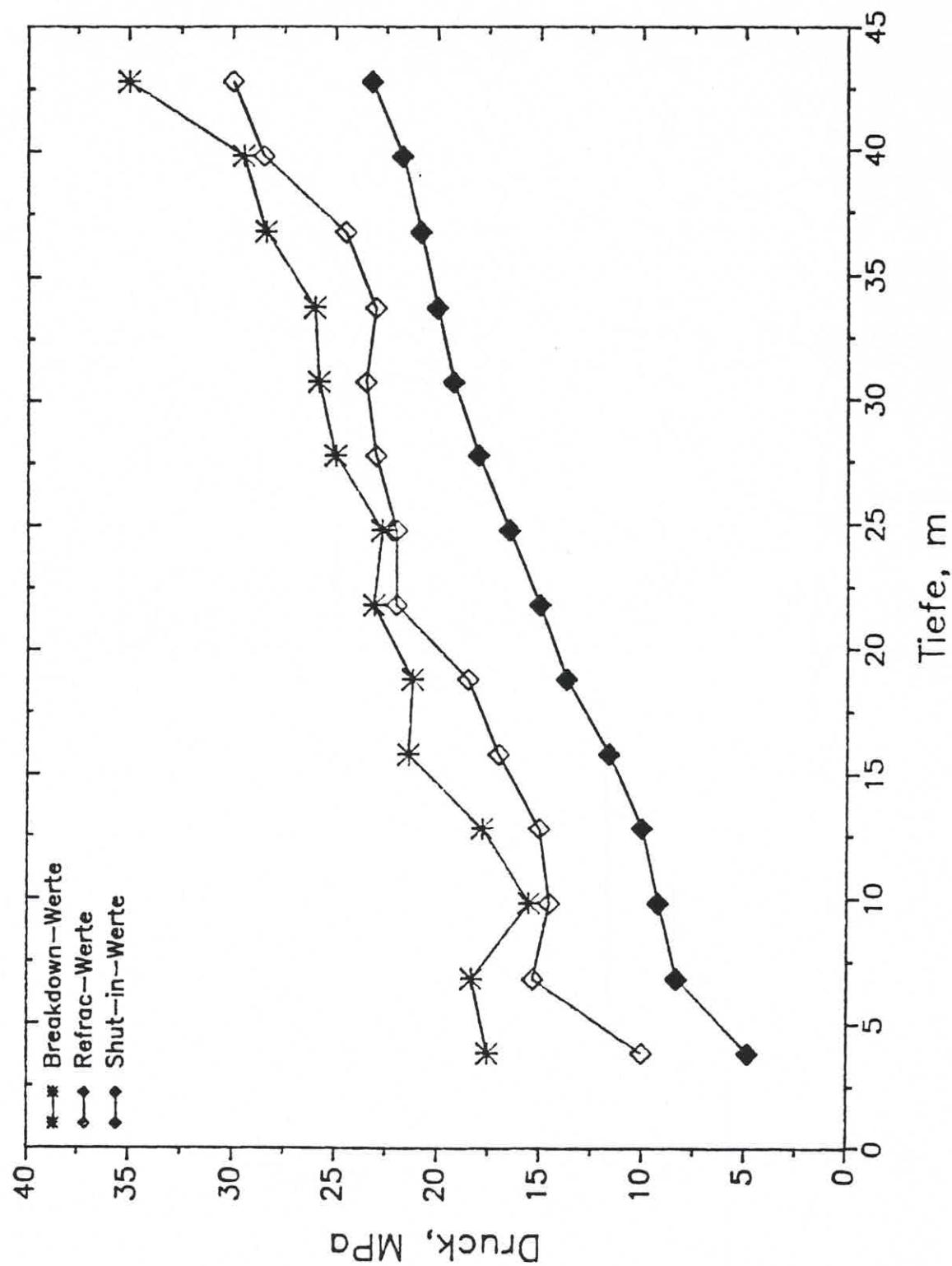


Abb. 7: Druckverlauf in Bohrung B2H45°.

Tiefe [m]	P_c [MPa]	P_r [MPa]	P_{si} [MPa]	S_H [MPa]	S_h [MPa]
3.5	(15.4)	(8.0)	(1.9)	----	(1.9)
6.5	(21.0)	(18.0)	(6.1)	(0.3)	(6.1)
9.5	(22.0)	(18.0)	(9.0)	(9.0)	(9.0)
12.5	20.0	19.5	15.5	27.0	15.5
	20.0	19.5	15.5	27.0	15.5

Tab.12: Druck- und Hauptspannungswerte in Bohrung B3V.

Tiefe [m]	Bez.	Θ [°]	α [°]	β [°]
6.5	3A	(89.5)	(359)	(70)
	3B	(81.1)	(351)	(68)
9.5	2A	(82.6)	(173)	(48)
12.5	1A	169.7	80	90
		169.7	80	90

Tab.13: Lage der Rißflächen in Bohrung B3V (Θ : Streichen der Rißfläche, α : Richtung des Einfallens, β : Einfallen der Rißfläche).

Lohberg, B3/V

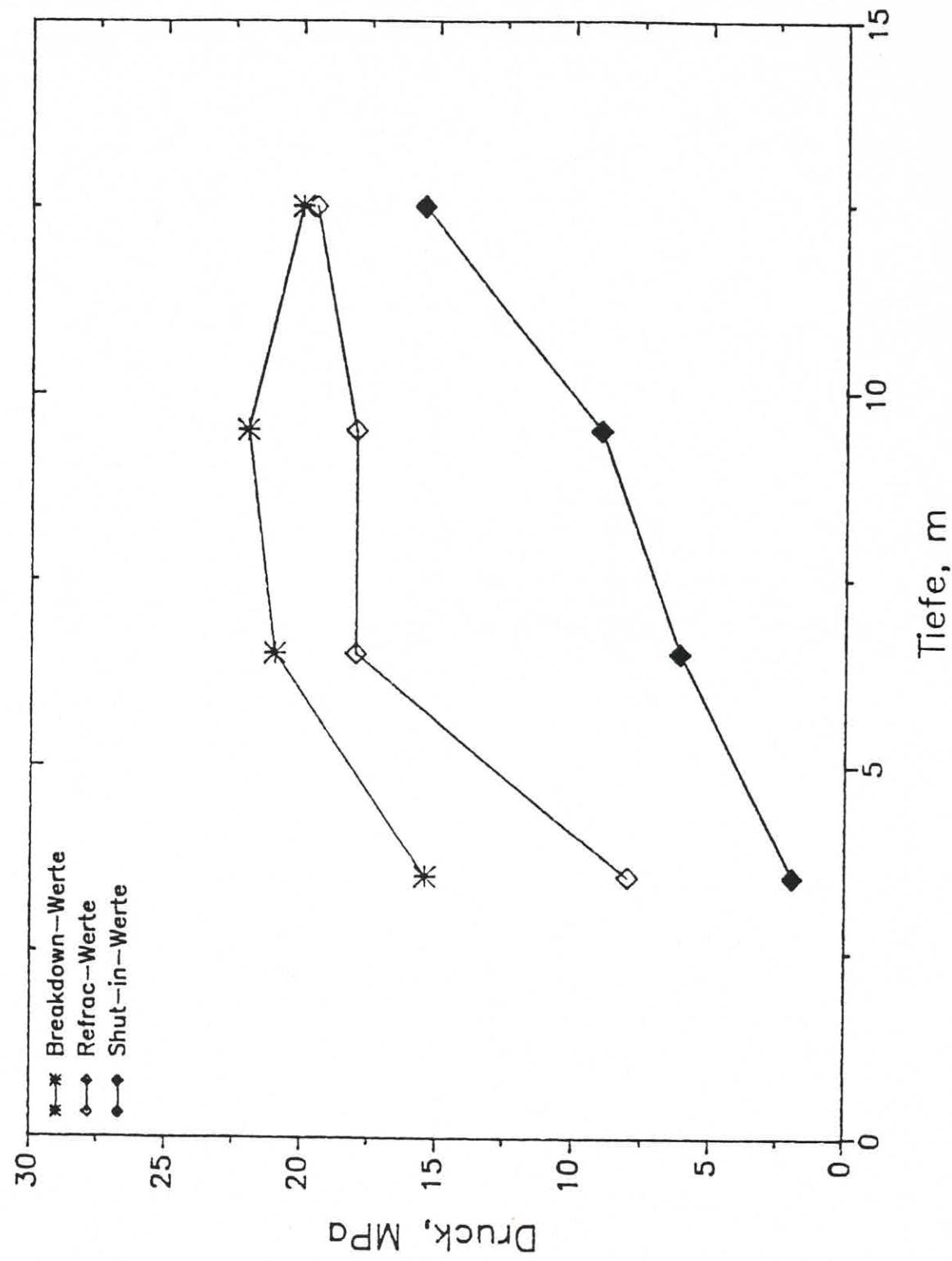


Abb. 8: Druckverlauf in Bohrung B3V.

Tiefe [m]	P_c [MPa]	P_r [MPa]	P_{si} [MPa]	S_h [MPa]
3.5	(14.9)	(13.0)	(7.8)	(7.8)
6.5	36.7	14.2	11.0	11.0
9.5	34.6	14.4	12.1	12.1
12.5	35.2	14.0	11.9	11.9
15.5	31.5	14.0	12.3	12.3
18.5	25.5	15.2	11.9	11.9
21.5	28.5	16.0	12.0	12.0
24.5	37.8	15.4	11.8	11.8
27.5	>38.0	---	---	---
30.5	37.7	22.6	12.9	12.9
33.5	29.2	17.0	13.3	13.3
36.5	>39.0	---	---	---
		33.0±4.2	15.9±2.6	12.1±0.6
				12.1±0.6

Tab.14: Druck- und Hauptspannungswerte in Bohrung B3H90°.

Tiefe [m]	Bez.	Θ [°]	α [°]	β [°]
3.5	12A	(172.6)	(83)	(87)
6.5	11A	(169.3)	(79)	(84)
	11B	165.0	255	88
9.5	10A	166.0	256	86
12.5	9A	175.3	265	86
15.5	8A	176.7	267	82
	8B	173.4	263	79
18.5	7A	175.4	265	77
	7B	(74.8)	(165)	(59)
	7C	(93.0)	(3)	(7)
21.5	6A	156.7	67	90
24.5	5A	170.5	260	73
30.5	3A	174.9	265	73
33.5	2A	175.5	265	87
	2B	(27.8)	(118)	(3)
	2C	(149.2)	(239)	(18)
		171± 6	243±59	82±6

Tab.15: Lage der Rißflächen in Bohrung B3H90° (Θ : Streichen der Rißfläche,
 α : Richtung des Einfallens, β : Einfallen der Rißfläche.)

Lohberg, B3/H 90°

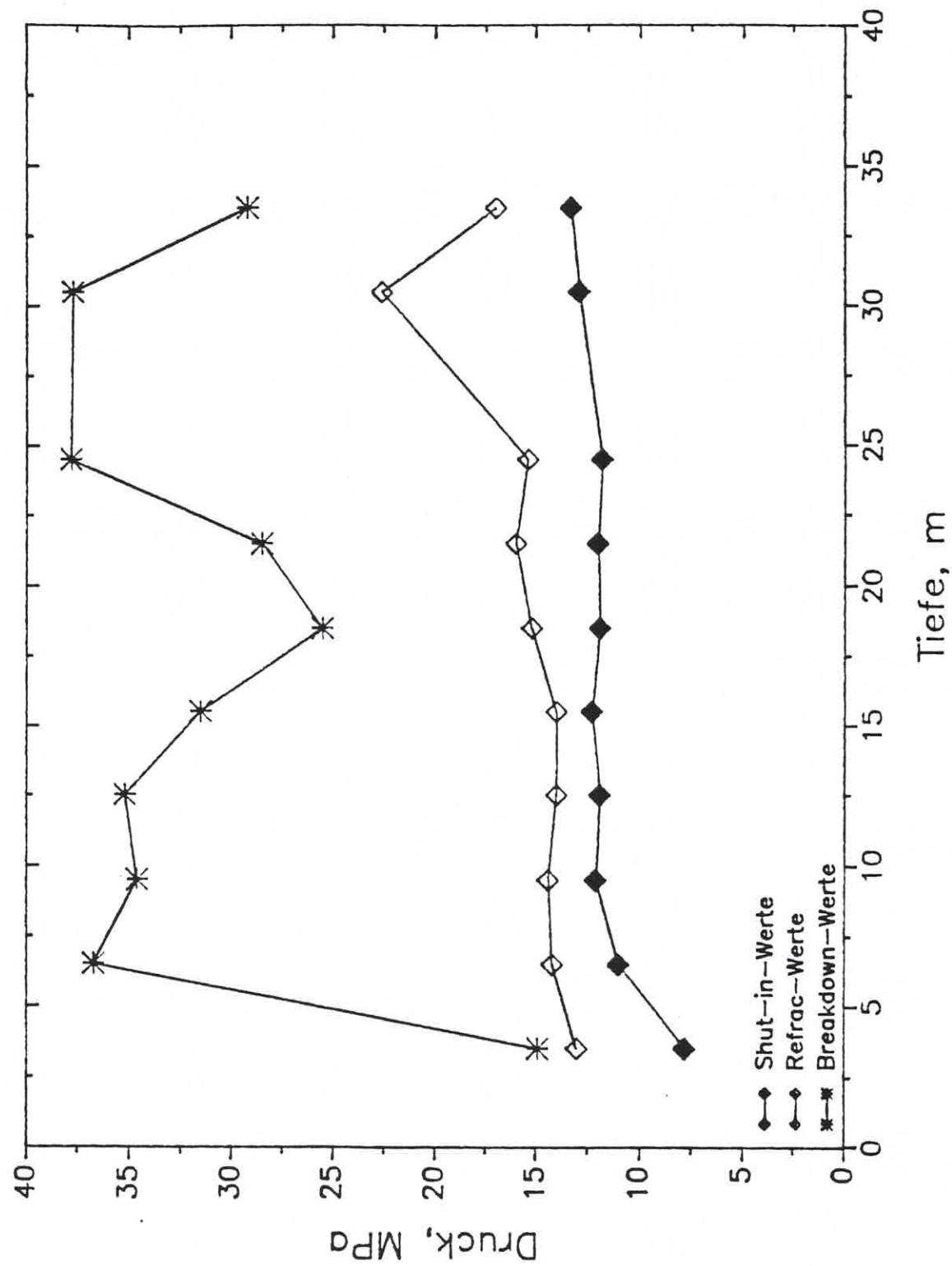


Abb. 9: Druckverlauf in Bohrung B3H90°.

Tiefe [m]	P_c [MPa]	P_r [MPa]	P_{si} [MPa]	S_H [MPa]	S_h [MPa]
25.0	(10.9)	(10.5)	(8.0)	(13.5)	(8.0)
28.0	(13.9)	(13.0)	(10.0)	(17.0)	(10.0)
31.0	19.6	13.5	12.1	22.8	12.1
34.0	15.1	14.5	13.0	24.5	13.0
37.0	22.0	19.9	16.0	28.1	16.0
	18.9±2.9	16.9±2.8	13.7±1.7	25.1±2.2	13.7±1.7

Tab.16: Druck- und Hauptspannungswerte in Bohrung B4V.

Tiefe [m]	Bez.	Θ [°]	α [°]	β [°]
25.0	5A	(74.7)	(165)	(90)
28.0	4A	(18.0)	(288)	(90)
31.0	3A	134.0	224	90
34.0	2A	(16.7)	287	(90)
	2B	161.5	72	34
37.0	1A	177.7	88	84
	1B	171.2	81	65
		161±17	116±63	68±21

Tab.17: Lage der Rißflächen in Bohrung B4V (Θ : Streichen der Rißfläche, α : Richtung des Einfallens, β : Einfallen der Rißfläche.)

Lohberg, B4/V

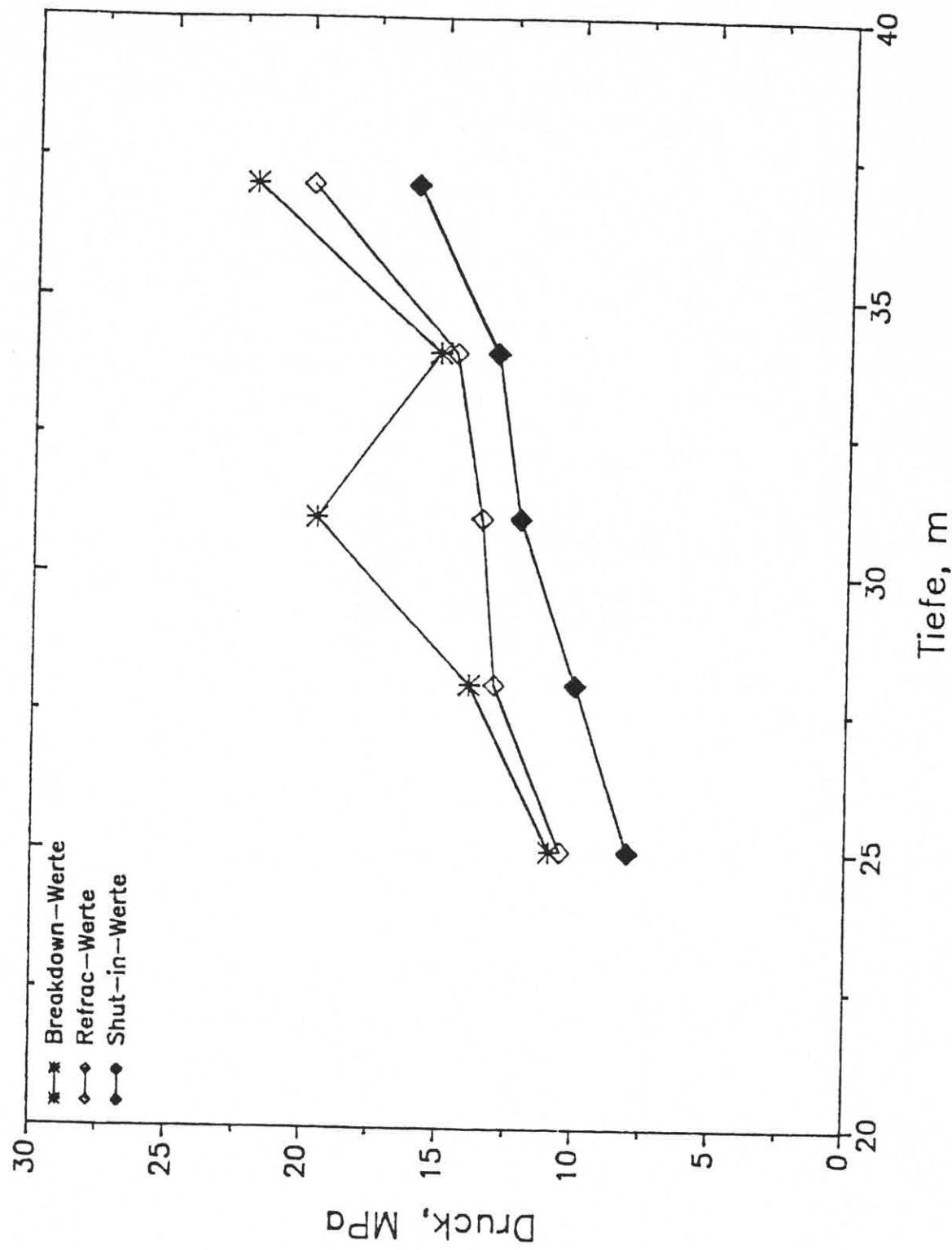


Abb. 10: Druckverlauf in Bohrung B4V.

Tiefe [m]	P_c [MPa]	P_r [MPa]	P_{si} [MPa]	S_h [MPa]
10.5	11.5	11.0	5.0	5.0
13.5	25.5	14.0	6.5	6.5

Tab.18: Druck- und Hauptspannungswerte in Bohrung B4H80°.