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S U M M A R Y

The tool chain SEKAN 5 developed and constructed by PRAKLA-SEISMOS was proved to be capable of withstanding long-term operation under the given pressure and temperature conditions in a chemically active Dehydrill HT mud in the KTB Oberpfalz VB 1A (350 bar, 110 °C, pH 10-11). The tool comprises five identical seismic receiver sondes which are equipped with a three-component receiver system, an electrically driven clamping unit and a magnetic compass system.

The results of the reference tests and the measured compass values were subjected to critical checks. For the observation period the reference tests on different days for each individual sonde indicated good agreement with respect to specific signal forms. The differences in orientation determined from the seismic data and the compass values are between -11 degrees and -26 degrees. The cause of the differences can be explained in that the wave paths lie outside of the observation plane.

1 INTRODUCTION

Within the framework of the DEKORP continental reflection seismic programme, PRAKLA-SEISMOS AG, Hannover carried out extensive seismic surveys from July to November 1989, centred on the pilot well of continental deep drilling project (KTB, Kontinentales Tiefbohrprogramm) in the Oberpfalz.

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The survey comprised the following:

a) 3D seismics over an area of 20 x 20 km (p-wave)
b) 3D seismics in the wide angle range (p-wave)
c) Expanding spread surveys (p-wave)
d) Transmission measurements of mountainous area surrounding KTB pilot well
e) Multiple offset VSP with p-waves and s-waves
f) MSP for four tool chain positions (475 m covered area, p-wave)
g) Two vibroseismic reflection lines in steep angle range connected with two MSP profiles (s-wave)
h) Multi-azimuth shearwave experiment with p-wave and s-wave generation, the source points of which lie on concentric circles around the KTB pilot well, as well as two shearwave polarization experiments
i) Short refraction surveys with p-waves and s-waves for static corrections

With the exception of the short refraction surveys all experiments were to be recorded in parallel with the SEKAN 5 chain during the entire survey period in the pilot well. The Tool chain could not be left in the well all the time because inspections and repairs had to be carried out.

The SEKAN 5 tool chain designed and constructed by PRAKLA-SEISMOS proved to be capable of withstanding the long time operation under existing pressure and temperature conditions in a chemically active dehydril HT drilling fluid in the KTB pilot well in the Oberpfalz (350 bar, 110 °C, pH value 10 to 11, HEROLD, 1989). Of course, application of the tool was not without its problems. According to our knowledge the SEKAN 5 is the only tool chain on the world market which is equipped with five receiver tools with three-component systems, mechanical clamping system and magnetic compass.

The long time operation demanded extremely durable materials and in fact led to the introduction of new materials and new technical solutions.

During the development of the tool chain PRAKLA-SEISMOS could refer to experience the company had made with an analog chain consisting of four receiver tools. From this experience a new concept was developed for a receiver chain based on the following requirements and conditions:

- use of the internationally accepted 7-core well cable
- digital transfer of the seismic data
- electronic circuits in just one tool (main tool) so as to enable the electronic components to be cooled effectively at greater depths and higher temperatures
- Application of sensors for magnetic, electric or radio-active detection of accurate depth determination
- Maximum tool diameter: 95 mm
- Maximum hydrostatic pressure: 1200 bar
- Maximum ambient temperature: 200 °C

Within the framework of a feasibility studie a maximum ambient temperature of 200 °C, which has to be expected at a depth of 6000 m, was presumed. At present available electronic components are not capable of functioning properly at this temperature and therefore require extensive cooling techniques which, however, in the course of the development works, proved to exceed the frame of the development project.

For this reason the tool chain was developed in two steps: Firstly for maximum temperatures of up to 125 °C and secondly for maximum temperatures of up to 160 °C. During the survey in the KTB pilot well the tool chain for temperatures of up to 125 °C was applied.

Finally an important practical aspect of the application of the tool chain should be noted. The tool chain can be installed in about one hour and can, depending on the drilling fluid, be lowered into the well at a half to a quarter of the speed of the individual tools (approx 25 m/min, 1000 m in 35 min). This means on the one hand application is restricted in VSP surveys with few survey points, but on the other MSP and VSP surveys with a lot of survey points and different source distances can be performed more economically and effectively, and additional possibilities can then be considered that previously had to be neglected owing to reasons of cost.

2 CONSTRUCTION AND COMPONENTS OF THE TOOL CHAIN

Figure 1 shows the schematic construction of the receiver chain. It consists of five similar seismic receiver tools which are equipped with a three-component receiver system, an electrically driven clamp arm and a magnetic compass system. The chain terminates at the top at the connection piece (main tool) and at the bottom at the pilot tool. The pilot tool has the job of monitoring the free run-in of the chain and serves as the carrier of the electric, magnetic or radioactive sensors. Just small changes of the load on a cable load sonsor in the main tool indicate whether the pilot or receiver tool is beginning to set down and so enable complete setting down to be avoided.

The electric or magnetic sensors in the pilot tool serve the depth control.

The transfer or main tool contains the electronic circuits with which the analog seismic signals are converted into specific pulse code signals for the transfer via the well cable. It is not the state of the binary signal but rather the time interval between changes of state that are transferred. For this reason the control electronics are housed here in order to switch the receiver tools to the various functions - drive clamp arm, survey, read compass, transfer pilot tool.

The maximum diameter of the tools amounts to 88 mm; considering the effective length of the clamp arm, the borehole diameter should be 100 to 330 mm.

In the following the construction and the functions of an individual tool are described (see Fig 2).

The receiver tools of the chain are connected mechanically and electrically to one another by separate low torsion steel cable and multi-core cables.

Above every receiver tool, surrounded by a protective housing, is a pressure and watertigtht push-on connection incorporated in the main cable that forms the electrical connection to the receiver tool. The multi-core main cable runs to the main tool along the side of the secondary tools an is protected by a w-shaped section. The five seismic receiver tools are equipped with a three-component system comprising six oscillation-coil velocity receivers of type SENSOR SM4/UHT10 Hz natural frequency which are connected in series. To enable data control and effective data processing it is essential that all geophones that are connected to the five receiver tools are almost identical with respect to their physical parameters. Particularly critical parameters are natural frequency, sensitivity and distortion. Figure 3 shows the natural frequency of 29 vertical and 48 horizontal receivers of the above described construction at 20 °C and 200 °C. The tolerance limit of 0.5 Hz at a resonant frequency of 10 Hz is exceeded by 0.1 Hz by two of the vertical receivers. The decrease of the medium resonant frequency at the vertical receivers is conspicuous and can be explained in a change of material characteristics of the springs which the coils are suspended from.

The sensitivity (24.4 + 5%) lies within the tolerance limits; the above-mentioned applies to the decreased sensitivity of the vertical receivers.

The distortion shows that the vertical geophones are dependent on temperature to a greater extent than the horizontal geophones are. The maximum value is 0.2%.

The clamping arm reaches a maximum value of 750 N when clamping the tools and has a safety ratchet device which is released when the well cable is pulled.

Each receiver tool is equipped with a magnetic compass system in order to determine the tool orientation. The compass is to be explained more detailed, as the measured compass values are of particular significance. The compass needle is equipped with a mirror, being sampled by a circulating, well-focused beam. If the beam of the sampling device strikes the mirror the light is reflected into a photo diode which releases a voltage impulse. The time of these impulses referred to the circulation time gives the tool orientation.

Prior to running in the hole the technical deviation of the compasses of the individual tools are determined in the following way. Each receiver tool is freely suspended from a tripod made of non-magnetic material and screwed into a device at the bottom end which allows the tool to be precisely directed towards north; subsequently it is turned 360 degrees in steps of 15 degrees from north via east. After each step the compass reading is taken via the well cable and the tool control unit and the deviation from the given value determined.

Figure 4 shows the deviations of the compass of tool 5 on different days and in different places; at KTB (30.07. to 28.10.1989), at PRAKLA-SEISMOS, in Hannover (28.11.1989).

The x-axis depicts the required angle and the y-axis the deviation, the angle read from the tool compass minus the required angle. The maximum deviation for this compass amounts to +\-20 degrees, if the deviation measurement of 30.07.1989 is ignored.

The deviation of the magnetic compass is caused by magnetic interference fields, which overlap the terrestrial magnetic field. They are due to various causes which are not to be discussed here.

In order to reduce interfering survey influences the average value of the deviation curves is taken, and the values read from the tool compasses are corrected by the average deviation value of each tool compass.

The compass values obtained in the well are to be discussed in chapter 4, Results.

3 EXPERIENCE

The operation periods of the tool chain and the dates of the deviation tests are listed in Table 1. The tool chain was in continuous operation for a maximum of 17 days at different depths and changing temperatures, thus proving its capability.

Main reasons for interruptions in the operation was a considerable wear of cables and push-on connections. After the first long time operation from 14.07. to 21.07.1989 (depth 3690 m, temperature 110 °C, pressure 370 bar) damages at tool connection cables, cable connections and the cable below tool 1 were discovered.

Elastomer-coated tool cables and push-on connections proved to be not suited for the purpose. The elastomer coat was partly swollen and showed holes and cracks which reached as far as the copper cores; polyurethane parts were almost completely decomposed. After termination of the first VSP survey the tool chain was equipped with new VITON-cables (special flourine caoutchouc) which show high chemical resistance and therefore are well-suited for the drilling fluid conditions of the KTB pilot well. Several technical changes have been carried out of which only one is important for compass measurements and should therefore be mentioned here. Owing to the tool construction the installed compasses were assumed to be subjected to deviation by the geophone magnets. For this reason geophone pairs, each with a different magnetic polarity, were installed for each single component. However, the deviation is still considerable and effective ways to avoid it have not been found yet.

The coupling of the individual tools at the measured depths was carried out without problems most of the time, as it can be realized in boreoles with a maximum diameter of 330 mm (13"). Although in depth ranges of about 1027 m and 1630 m there were narrow zones (approx 0.5 m) of > 330 mm according to a caliper, no coupling problems occurred.

Owing to the special conditions related to tool chain operations appropriate ways for obtaining control of all tool chain components over a longer period of time had to be found. During the survey with a tool chain or individual tool at the beginning of each survey day reference tests were carried out. For this purpose a p-wave or s-wave vibrator located at a fixed position about 150 m east of the pilot well was used for generating energy. Two to four reference shots were fired daily; the data form part of the respective experiments. The data were recorded with a GEOMETRICS ES 2420, correlated on the MicroMax on site with the software from ADVANCE and presented for control purposes.

3 RESULTS

The numerous experiments MASE, SCMP, VSP, MSP, 3D seismics, 3D expanding spread etc were recorded by the receiver chain or in case of break down via the individual tool. The results are not presented here.

In the following the results of the reference tests are presented. The measured compass values were subjected to critical checks.

Figure 5 shows reference generating during the period from 03.01. to 07.10.89 at depths of 3310 and 3435 m. (The depths refer to the lowest tool position.) The correlated seismic traces are sorted according to depth, receivers and components to enable observing the data quality at each tool in course of the time. The normalization of the seismic traces was effected on the amplitude maxima of the single traces in a delay time range of 0.5 s to 1.2 s. Looking at a depth of 3310 m and the vertical receivers of tools 1 to 5 the reference records from 04.10. to 07.10.89 are presented in left to right direction. During this time a shearwave vibrator was used for generating energy. In delay time ranges from 0.5 s to 0.7 s and from 0.9 s to 1.1 s the signals of the direct p-wave and direct s-wave respectively can be recocgnized. Comparing the signal forms and investigating the noise signals it becomes clear that the signals of direct p-waves and direct s-waves from generations on different days are to a great extent identical for each individual tool. Only tool 5 shows a higher noise level, the reason for which could not be found.

In conclusion a few remarks to the measured compass values: The compass values determined in the well have been corrected using the averaged deviation of every tool. The quality of the measured compass values can be checked by means of the seismic records, the reference tests or the results of the MSP surveys. Assuming the existence of a homogeneous, isotropic half-space and the absence of noise, the tool orientation, determined from the seismic data of the MSP survey, must be the same for all source points or show a phase difference of 180 °C for source points on this side and source points on the other side of the well.

The investigated MSP profile has 198 source points and the tool chain was kept at a constant depth of 3310 m.

The technique for determining the tools orientation from seismic data will not be entered into in more detail, however, it must be noted that the arrivals of the direct p-wave were used for calculation and that previously a filtering in the frequency range of the sweep (12 to 80 Hz) was applied.

Of course the assumptions are not fulfilled, however, knowing that the source points at the surface were on average 50 m apart it can be expected that the wave paths of adjacent points do not differ substantially from one another.

Figure 6 shows the result of the calculation of the tool orientation for the receiver tool 2 at a depth of 3285 m. The x-axis shows the vibrator points at equal intervals and the y-axis the determined angle. From VP (vibrator point) 101 to 253 or 254 to 298 the average amounts to -110 degrees (250) or 49 degrees respectively and the mean divergence is 7 degrees or 9 degrees respectively.

The phase shift from -110 degrees to 49 degrees becomes evident by the change in direction of the incidence of the signals. Theoretically the phase should be 180 degrees, however, it cannot be observed at any of the receiver tools; it varies between 158 and 223 degrees.

Depending on the incidence of the signals, two angles are obtained with a theoretical difference of 180 degrees. Considering the angles from VP 101 to 253 and VP 254 to 298, and supplementing the angles from VP 101 to 253 by 180 degrees the following result is obtained:

TABLE 2: Comparing the results of the orientation determination (angle in degrees)

Tool	Depth (m)	Direction of the horizontal comp. H1 acc. to compass	Direction of the horizontal comp. H1 determined from seismic data		Differences	
		H1K	VP101-253	VP254-298	H1k-VP101	H1k-VP254
5	3210	119	155	145	-36	-26
4	3235	335	376	358	-41	-23
3	3260	256	310	267	-54	-11
2	3285	28	70	49	-42	-21
1	3310	242	285	256	-43	-14

The differences show the deviation in direction determined from seismic data on the one side and from compass data on the other.

The maximum difference amounts to -26 degrees, the minimum is -11 degrees. That means that there is general agreement in the calculated directions, however, the indiviual values are associated with errors of varrying orders. The cause of the differences can be explained in that the wave paths lie outside of the observation plane.

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TABLE 1

Dates of deviation tests	Survey time	Number of days	Remarks
	07.06.-09.06.	3	3000 m, 1st functions test
11.07.			1st survey on site, neglected
	12.07.-21.07.	2	3000 m, 2nd functions test
	14.07.-21.07.	8	3690 m, MSP
30.07.			2nd survey, neglected
	01.08.-03.08.	3	710 to 3660 m, VSP
31.08			survey after exchanging geophones
	31.08.-14.09.	15	3685 m, transmission measurement and MSP
14.09.			after dismantling of tool chain
01.10.			before installation of tool chain
	01.10.-17.10.	17	3560 m, 3425 m, 3310 m, MSP wide angle seismics, transmission measurement
28.10.			before installation of tool chain
	28.10.-31.10.	4	710 to 3660 m, VSP
	02.11.-06.11.	5	710 to 3660 m VSP, transmission measurement
	09.11.-21.11.	13	3420 m, transmission measurement
28.11.			Survey on PRAKLA-SEISMOS premises

The values refer to the depth of the lowest tool postions. (Tool 1, tool interval 25 m.)

Diagramm of Seismic Receiver Chain for Deep Wells SEKAN 5

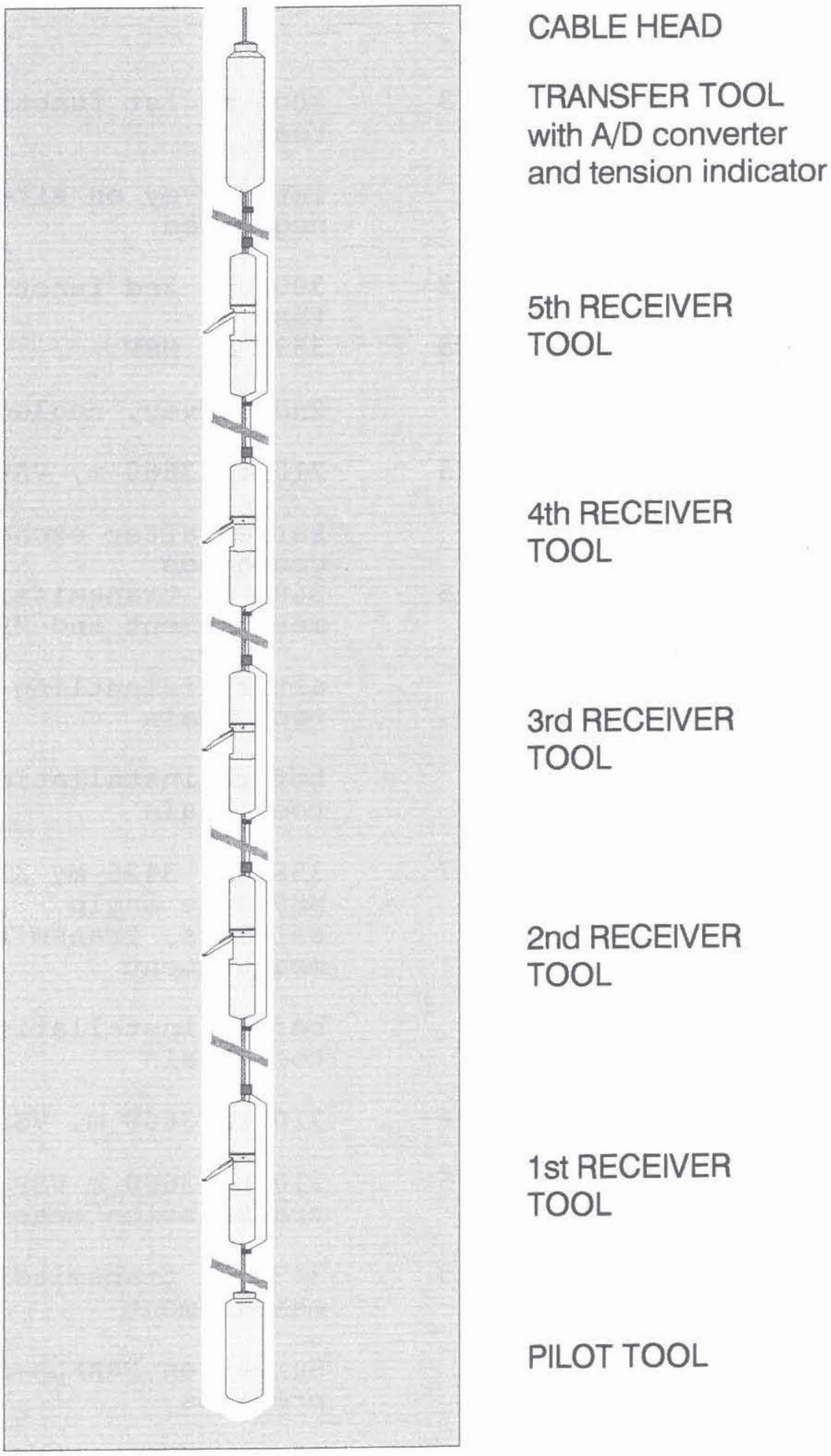


Abb. 1

PRAKLA-SEISMOS AG

Schematic Presentation of Seismic Receiver Sonde BGCA with Carrier Cable and Electrical Cable Connected

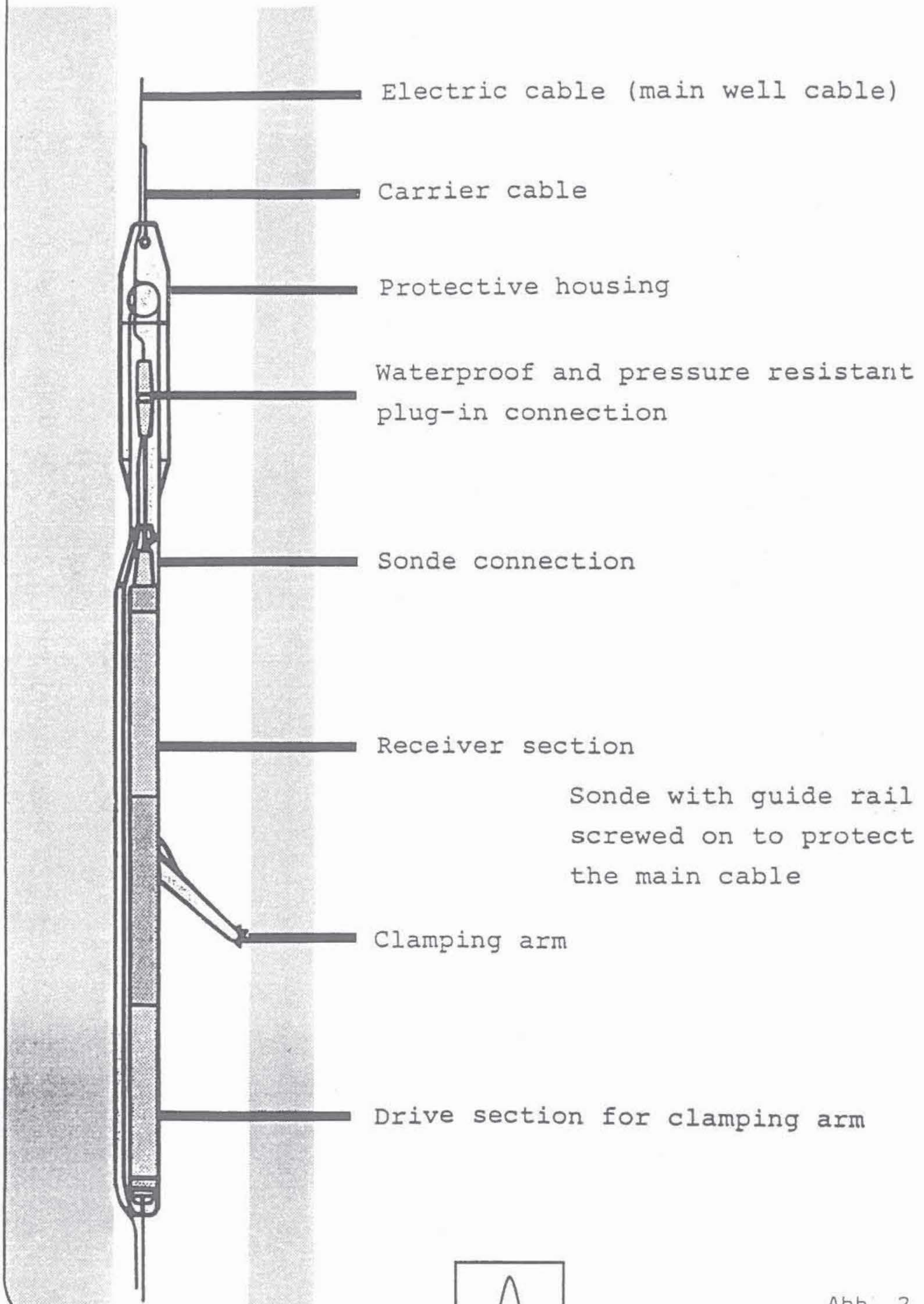
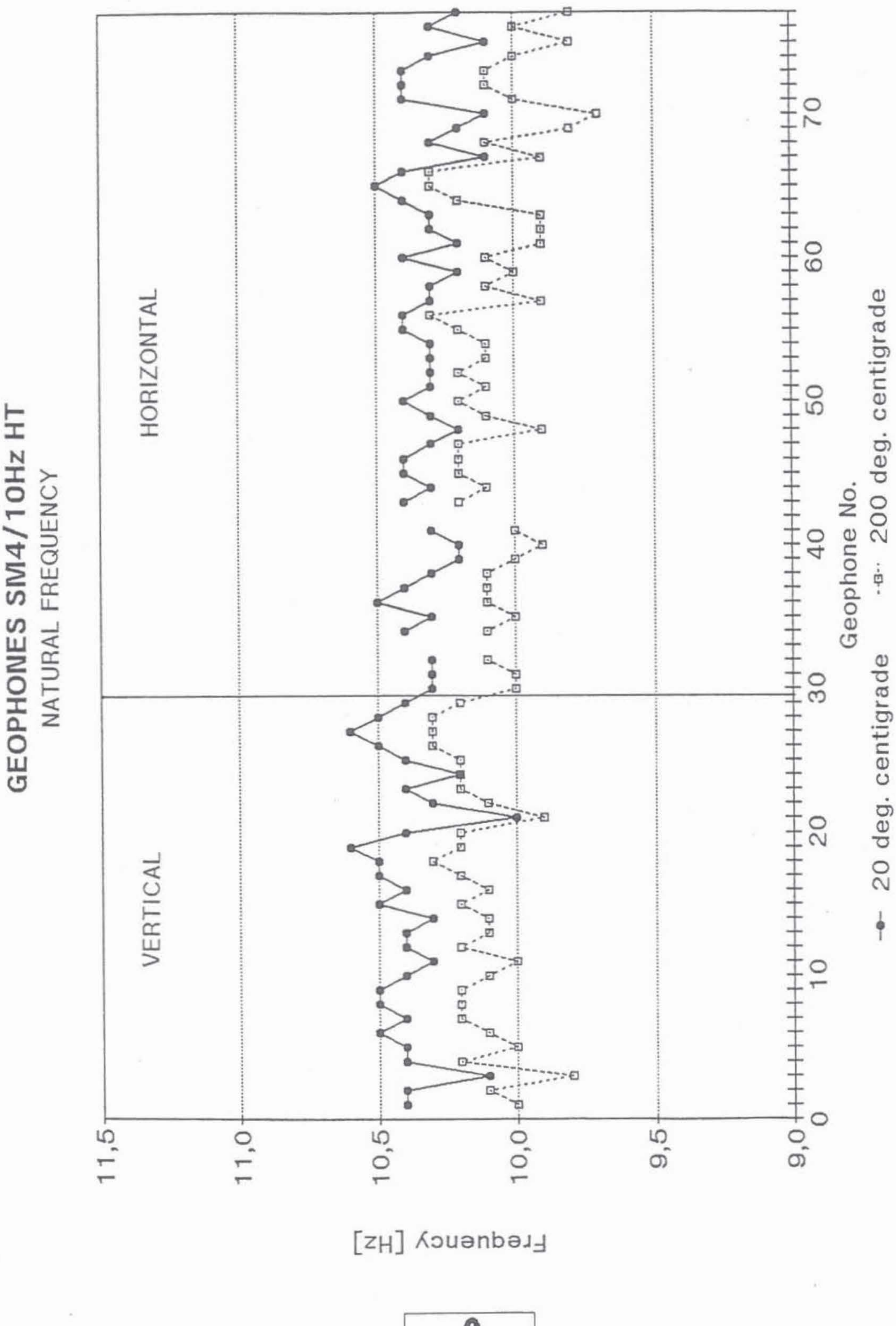


Abb. 2

PRAKLA-SEISMOS AG



GEOPHONES SM4/10Hz HT
NATURAL FREQUENCY
VERTICAL
HORIZONTAL
Frequency [Hz]
11,5
11,0
10,5
10,0
9,5
9,0
0
10
20
30
40
50
60
70
Geophone No.
20 deg. centigrade
200 deg. centigrade

Abb. 3

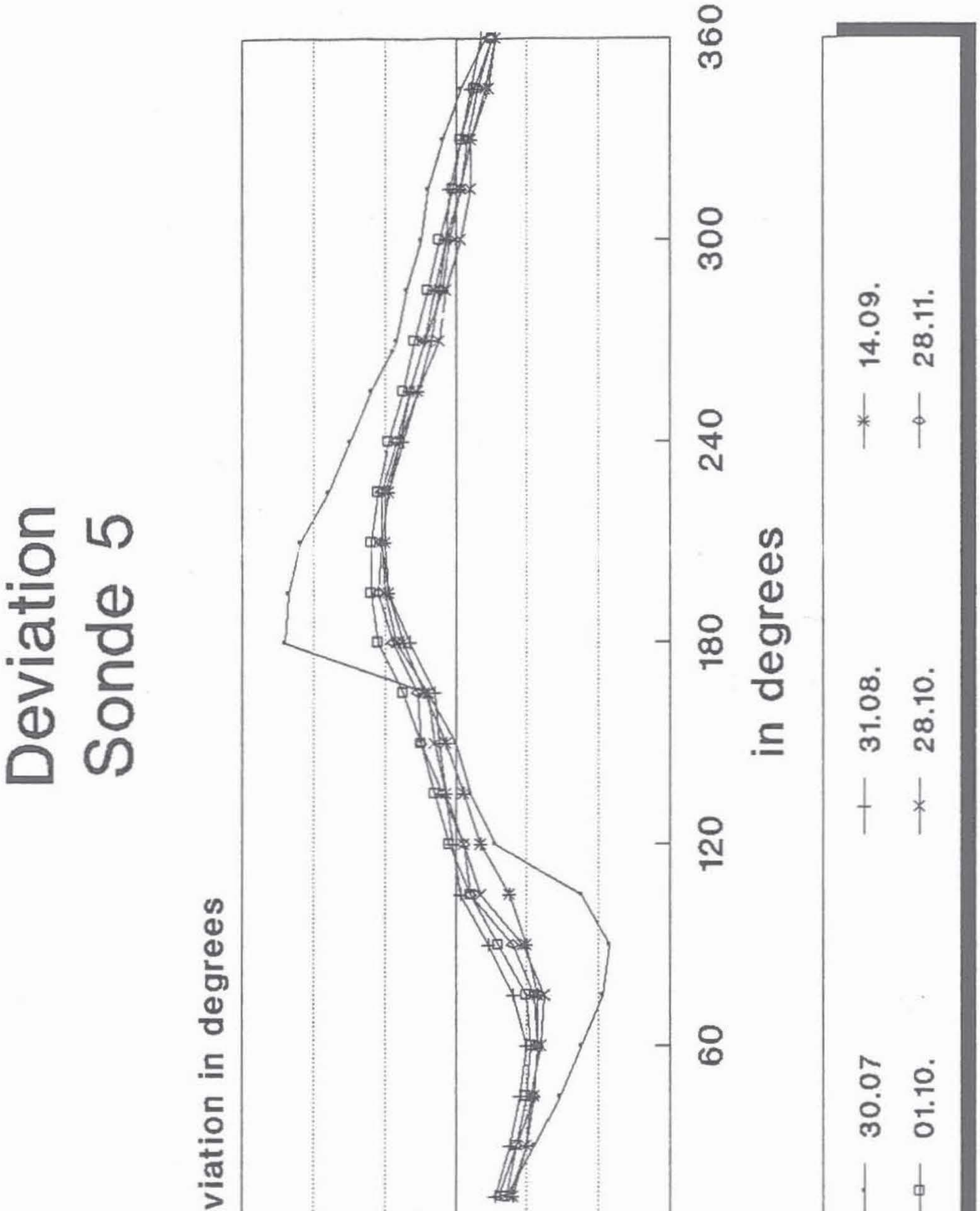


Abb. 4

PRAKLA-SEISMOS AG

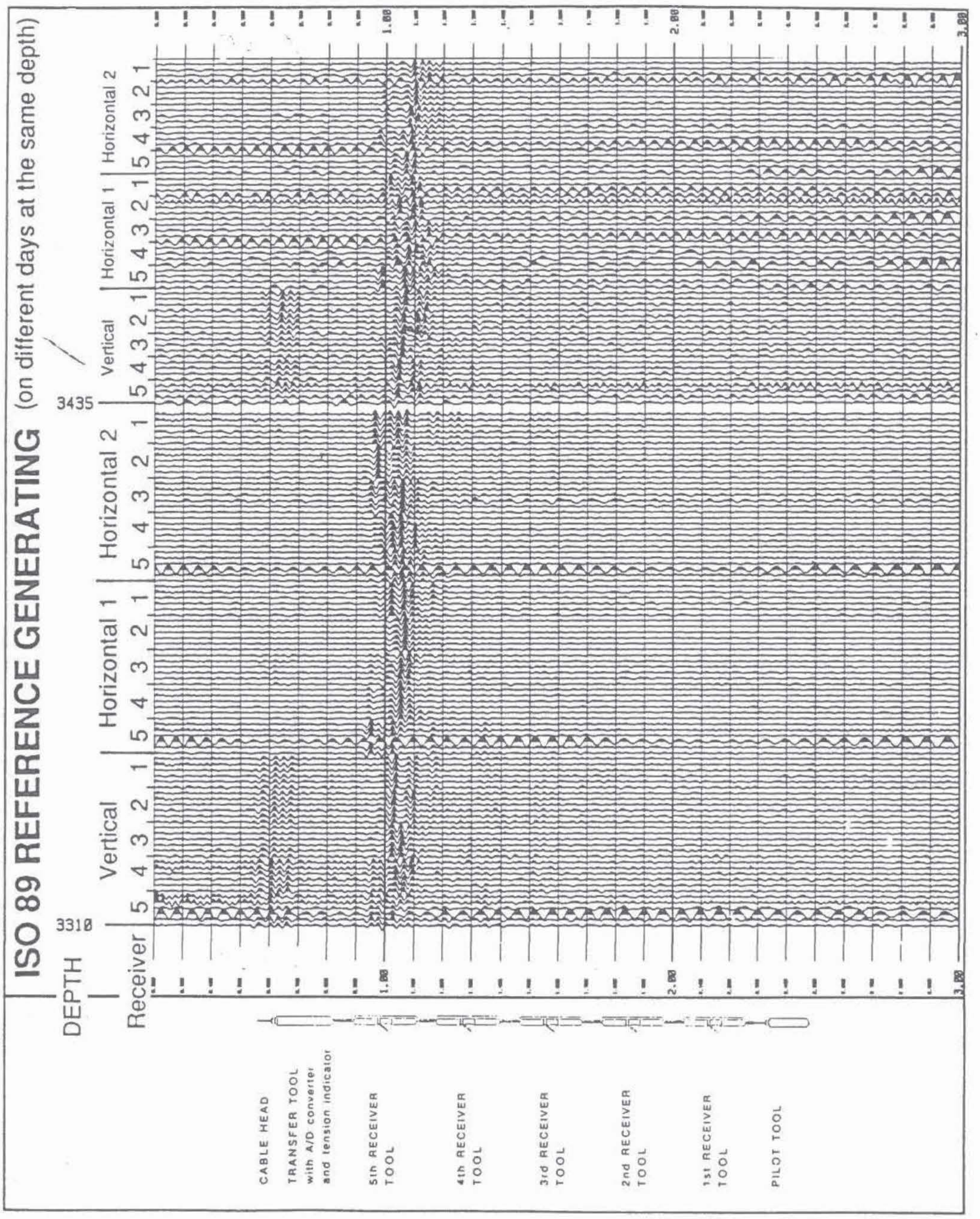

ISO 89 REFERENCE GENERATING (on different days at the same depth)
DEPTH
Receiver
3310
3435
Vertical
Horizontal 1
Horizontal 2
5 4 3 2 1
1.00
2.00
3.00
CABLE HEAD
TRANSFER TOOL with A/D converter and tension indicator
5th RECEIVER TOOL
4th RECEIVER TOOL
3rd RECEIVER TOOL
2nd RECEIVER TOOL
1st RECEIVER TOOL
PILOT TOOL

Abb. 5

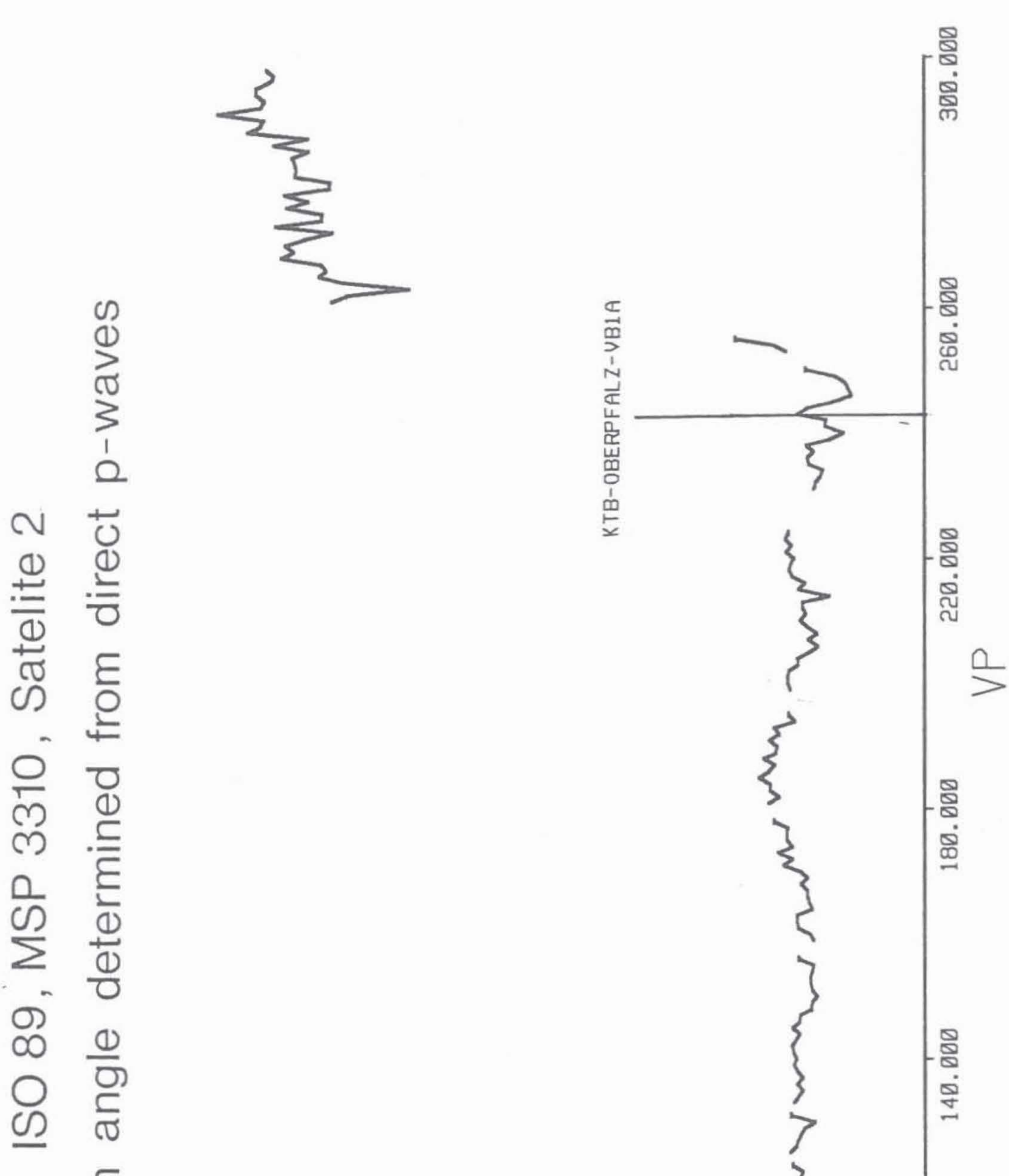

ISO 89, MSP 3310, Satelite 2
Rotation angle determined from direct p-waves
KTB-OBERPFALZ-VB1A
ANGLE
100.000
50.000
0.000
-50.000
-100.000
-150.000
VP
100.000
140.000
180.000
220.000
260.000
300.000

Abb. 6