Advanced Drilling Technology for the Continental Deep Drilling Program of the Federal Republic of Germany (KTB)

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Abstract

In scientific research drilling, a borehole may be reviewed as an endoscope into the Earth, as it happens to be the case, for example, in the international Ocean Drilling Program (ODP) and the Continental Deep Drilling Program of Germany (KTB). Development of the drilling technology in the last 15 years took place mainly in the two areas of deep and ultradeep drilling, and of horizontal drilling. The impact of big geoscientific research programs on deep drilling technology is remarkable. Scientific drilling projects need intensive and expansive R&D efforts on the one hand and produce an outstanding spin-off on the other hand.

The German Continental Deep Drilling Project (KTB) is part of the international lithosphere research. The two boreholes of the project penetrate crystalline rock from the surface. The 4,000 m deep pilot hole was drilled from September, 1987 to April, 1989. The ultradeep hole, planned for at least 10,000 m depth, was spudded in October, 1990. The pilot hole was drilled by applying a large diameter thin kerf wire line coring technology, which was improved to a high extent during drilling. A newly developed synthetic clay based mud has been used succesfully. For ultra-deep drilling, a straight vertical wellbore trajectory is a must, to minimize drag, torque, and wear. To obtain a vertical wellbore course, active vertical drilling systems were developed and for the first time successfully utilized at the KTB. A new heavy, technologically advanced drilling rig has been constructed and is working efficiently. Experiences gained when drilling the main well will be discussed.

Introduction

The German Continental Deep Drilling Program is a noncommercial project of basic geoscientific research. The deep and the superdeep borehole are an integral part of the program as well as the accompanying comprehensive geoscientific research program. Only a borehole can provide information dealing with the composition and the physical state of rocks and fluids at great depths which is necessary for a reliable interpretation of surface and well logging data, and which allows for a higher level of accuracy of geophysical evaluation - making the borehole a telescope into the earths crust.

The scientific community in Germany discussed the idea of a continental deep drilling project since the early 70th. During the evolving project planning fife major goals crystallized from these discussions:

* The nature of geophysical structures and phenomena: seismic reflectors, electric, magnetic and gravimetric anomalies.
* The stress field of the earths crust and the brittle-ductile transition: stress-orientation and magnitude as a function of depth.
* The thermic structure of the crust: temperature distribution, heatflow and heat production.
* Crustal fluids and transport processes: fluid sources, fluid reservoirs and fluid pathways.
* Structure and evolution of the internal zones of the Variscan belt of Central Europe: Charasteristics, deformation mechanism and dynamics of multi-reactivated crust.

The KTB-location in the Oberpfalz in eastern Bavaria was selected according to structural, petrological and geophysical pre-site investigations. The drilling site is situated in the metamorphic inner zones of the Central European Variscan arc.

The geoscientific targets, the results of the geophysical, geological and geochemical site exploration, and the available experience were the basis for the technical concept, drilling strategy, and the main topics of research and development of the KTB.

The drilling concept may be viewed as a synergism of the pilot hole, the ultra-deep hole and the research and development program.

The pilot hole (KTB-Vorbohrung)

With its important objectives, the pilot hole is an essential part of the KTB. It serves the following purpose

* Acquisition of a maximum of geoscientific information at lower costs and risk, as compared to the expensive operation of the heavy rig for the ultra-deep hole.
* Minimizing of coring runs and logging in the large diameter straight vertical upper section of the ultra deep hole.
* Analysis of the temperature profile for planning the ultra-deep hole.
* Obtaining data about problem sections with inflow or lost circulation, wellbore instabilities and/or breakouts.
* Test of drilling and logging tools with regard to the ultra-deep hole.

To accomplish these objectives, the pilot hole had to meet the following requirements:

* maximum depth of 5,000 m,
* 6" hole size
* continuous coring with maximum core recovery.

A new drilling concept was developed, combining the rotary drilling and the wireline coring techniques. A high speed top drive (Fig. 1), a 5 1/2" external flush mining drillstring (Fig. 2), a double tube wireline core barrel system, combined with memory tool recording of temperature and inclination, and high performance diamond core bits were developed, improved and tested successfully in the pilot hole. The availability of a newly developed geoscientifically compatible drilling fluid system on a synthetic clay base is another reason for the successful drilling operation in the pilot hole.

Drilling of the pilot hole started on September 22, 1987, and was finished on April 4, 1989, after 560 days of drilling and logging. Total depth is 4,000.10 m of which 3,594 m - 90 % have been cored (Fig. 3). 451m were cored with 10 5/8" rollercone core bits, and 3,143 m with 6" thin kerf diamond core bits. A total of 9 surface set and 60 impregnated diamond core bits (Fig, 4) were used, the average bit life of the diamond bits being 48 m and the rate of penetration (ROP) being 1.66 m/h. The bits purchased from 3 major manufacturers have been improved continually, 5 diamond bits had a bit life of more than 118 m, and a ROP of 2.3 m/h. Due to core breaking and jamming, the average length of a core run was 3.5 m, corresponding to the worldwide average.

Caused by lost bottom hole assemblies after unsuccessful fishing jobs, two side-tracks had to be performed, the first in 1,998 m depth, and the second in 3,767 m depth. The mining drillstring had to be taken out of operation in February 1989 due to oxygen-pitting-corrosion on the internal pipe wall between the couplings. Because of this, a Moineau downhole-motor with hard rock roller cone bits and a 3 1/2" rotary string were used after the successful second side track. The performance was much poorer compared to the diamond coring system, ROP being only 0.84 m/h and bit life 12.31 m, respectively.

The evaluation of the rig time break down and the overall performance (Fig. 5) shows that, despite the good results of bit life, ROP, and the excellent core recovery of 98 %, there is potential and need for further improvement of this type of drilling technology, firstly, to avoid directional drilling and fishing by using straight hole drilling technology, and secondly, to bring down the time for tripping the drillstring and the core barrel.

The pilot hole penetrated into a succession of highly metamorphic paragneisses and metabasites, of probably Precambrian or older Palaeozoic age. The rocks are folded, and, prevailingly, rather steeply inclined. They are disrupted by a great number of faults and by - often graphitebearing - cataclastic

The trajectory of the pilot hole (Fig. 6) is mainly determined by steep formation dip to the southwest down to a depth of about 3,000 m, and a change toward southeast below this depth. Total deviation is 190 m. Coring had to be interrupted three times for directional drilling to bring the hole back to nearly vertical direction. The upper side-track, caused by stuck pipe and a massive influx of cataclastic fine rock material into the borehole, was performed by conventional technique with benthousing and downhole motor. For the side-track in the deep section, an open hole packer was placed above the fish and then connected with an oriented wedging device normally used in cased holes (window cutting device).

Temperature at 4,000 m depth is 118 °C, quite higher than predicted.

The ultra-deep well (KTB-Hauptbohrung)

Based on the results of the pilot well (rock instabilities in fault zones, steeply dipping formation and tendency of inclination build up while drilling, water sensivity of rock, breakouts, and core discing), the planning for the ultra-deep well, which is located at 200 m distance from the pilot well, had to be revised. The critical temperature range with respect to drilling and logging technology of 250 to 300 °C, investigation of the process occuring at these temperatures in the crust is a major geoscientific objective, will be reached at 10,000 m depth or less.

The technical planning and therefore the funding was based on 10,000 m total depth, including an option to continue drilling down to 12,000 m, if the temperature is lower than expected. Due to the wellbore instabilities encountered in the pilot hole, the drilling and casing program for the ultra-deep well had been restricted to open hole sections not longer than 3,000 m. Because of the positive experience with the installation of the 16" and 13 3/8"-casings, together with the availability of a special designed high strength drill pipe and field proven heavy liner technology, it was decided to plan to extend the 12 1/4" drilling phase to 10,000 m (Fig. 7). Benefits are an increased efficiency of 12 1/4" roller cone bits as well as the improved conditions for verticality and performance for specially developed tools like active vertical drilling and coring systems.

To make use of bits and downhole equipment of international standards and dimensions, proven bit sizes have been selected, and the final diameter at total depth is planned to be 12 1/4", at least not smaller than 8 1/2". In the top sections, where the availability and efficiency of vertical drilling systems was presumed, reduced clearances were planned, while in the lower sections, due to an expected poorer performance of vertical drilling systems, caused by higher temperatures, large clearances have been chosen.

The coring concept

Due to the extensive coring and logging program in the pilot well, coring in the upper section of the ultradeep well (corresponding to the total depth of the pilot well) can be avoided, and logging can be minimized. Below the depth of the pilot well, a total length of 1,500 m of core section is planned, and comprehensive logging programs before installing the casing strings will be run. Sampling and evaluation of cuttings are performed continuously.

Since cores in good quality and sufficient numbers are of vital importance for the scientific success of the project, major R & D efforts are dedicated to coring strategies and systems. In the 14 3/4" section at depths greater than 4,000 m (pilot hole depth), coring was performed with a double tube core barrel, equipped with roller cone core bits. Core recovery ranges from 40 % to total loss. In addition to the common technology two new systems have been developed and tried. The pilot coring system, similar to the corresponding tool in the Ocean Drilling Program (ODP) could not be brought to operation: The system implies a small core barrel driven by a positive displacement motor, with thin kerf diamond core bit, landed hydraulically through a conventional roller cone core bit at the end of the bottom hole assembly. The large diameter coring system is a success, and, due to the tremendous rock volume, of high scientific acceptance. The system consists of a double tube core barrel 12 1/4" x 9 5/8", internal memory, and jamming indicator, and drills cores of 245 mm OD and 6 m maximum length. Due to smoother running the recovery will be improved.

The vertical drilling strategy

Theoretical investigations as well as drilling experiences from the KTB pilot hole, the Russian Kola Well, and other drilling operations in crystalline rock, have identified the need for a straight wellbore trajectory in the KTB ultra-deep horehole (KTB-HB). At least the upper section down to about 6,000 m must be drilled with a minimum of directional changes, in order to attain low values of torque and drag between drillstring and borehole wall and good conditions for running the narrow clearance 16" and 13 3/8" casing. To achieve a straight trajectory, it should be drilled preferably as vertical as possible (Fig. 8).

The Russian strategy to drill a vertical hole is to use a special passive system which performed satisfactorily in seven boreholes (Fig. 9). A twin turbine set (RTB), approximately 12 m in length with two roller cone bits, sized for borehole diameters from 394-640 mm, is rotated from the surface with 11 - 15 RPM.

KTB engineers worked out a computer program for calculating the equilibrium angle based on the analytical approach of Lubinski. Data on dip of foliation and rock anisotropy factor combined with BHA-dimensions and drilling parameters are taken into consideration. Provided with the data on wellbore trajectory, drillstring, weight, and friction coefficients of the drilling fluid, another program calculates the total frictional forces causing torque and drag. The friction coefficients have been calibrated using the evaluation of data from the pilot hole.

The frictional forces have been taken into consideration when designing the drillstring for an ultra-deep hole. The calculations carried out with the KTB computer program showed clearly that, despite of a substantial reduction of drag forces when using a light metal alloy drillstring, there is no other way to reach a target depth of 10,000 m than

* to drill a straight and vertical hole,
* to use a high strength steel special designed tapered drillstring with sufficient load and hydraulic capacity and
* downhole motors till final depth.

A straight vertical hole is a very ambitious goal especially in crooked hole areas characterized by steeply inclined formations with anisotropic rock properties and severe breakout.

The KTB approach is the so-called active system. Intensive R&D efforts and sufficient funding are allocated to this strategy. Self adjusting steerable systems seem to be a promising approach. Within joint development projects funded by KTB, different concepts for vertical drilling tools using active compensation of deviations through a radial force generation (Fig. 10), were followed. Such a selfcontained vertical drilling tool, positioned just above the bit, follows a vertical borehole course. Upon any force acting on the system which causes a deviation from the vertical, a radial counterforce is generated within the tool. The resulting steering forces push the corresponding stabilizer against the borehole wall. Data on performance and orientation is transmitted to the surface by mud pulsing technology (MWD).

New heavy deep drilling rig

To meet the requirements imposed by the target depth and by scientific crystalline rock drilling, several contracts were awarded for studies of rig layout and construction. The result has been the decision to build a new rig with a hook retractor system, and an automated pipehandling system and with a load capacity for at least 12,000 m depth (Fig. 11). It is considered to be the world's highest and strongest and one of the technologically most advanced rigs:

* Height: 83 m
* Capacity: 12,000 m
* Max. hook load: 8,000 kN
* Remote controlled gear driven drawworks
* Advanced drilling instrumentation and data processing.
* Electrified rig with reversal power generating break systems
* Central rig controls from the drillers cabin.

To meet strong environmental demands, the rig is large-scale noise insulated, and the impact on the environment is controlled by a disposal water conditioning plant.

State of work in the ultradeep borehole

Drilling started October 6th, 1990. Opening the 17 1/2" borehole to 28", using for the first time roller cone equipped hole openers in this type of hard crystalline rock, proceeded quite satisfactorily. The 24 1/2"-casing was set and cemented down to 292 m depth.

The strategy for drilling the 3,000 m section with 17 1/2" bit size had been based mainly on application of tools and techniques as listed:

1. Use of low RPM, high flow and high torque Moineau downhole motors for smoother running conditions, and to reduce wear, and to enhance borehole wall stability.
2. Continous MWD to control the performance of the vertical drilling systems and the deviation.
3. Use of active vertical drilling systems.
4. Packed hole assembly with continous MWD act as back up for the active systems.
5. Navigational (Motor steering-) systems add further redundancy.

When drilling started, only one prototype each of the two active systems ZBE 5000 and VDS 3 were available. Due to positive experiences with respect to verticality, the number of the systems was increased to 5. Nevertheless, the productivity has not been satisfactory, when held against proven comparable downhole equipment. Long dead time for repair and reconstruction had to be bridged using packed hole assemblies and motor steering systems (Fig.12). Out of a total of 50 runs of vertical drilling systems, 23 were not productive, resulting in a waste of rigtime. But the progress in stepping up the learning curve continues in a remarkable way. Despite severe conditions - a large borehole in hard crystalline steeply folded rock with oversize sections due to breakouts - ,the requirements of very limited borehole curvatures were met, average deviation being less than 0,5°, and the offset in 3,000 m depth amounting to about 12 m.

End of May, 1991, the 17 1/2"-borehole was cased with a 16"/84 lb/ft casing string down to 3,000.5 m. Due to the strict verticality, the 3,600 kN heavy string could belowered down to bottom without any difficulties, the clearance between the Hydril-couplings and the borehole wall being only 14 mm. The string was cemented to the surface with a complete displacementof the mud behind the casing, including the oversize sections.

The 14 3/4" section, from 3,003 to 6,018 m depth, was planned to be drilled following the same strategy as in the 171/2" section, using the active selfsteering vertical drilling systems (VDS), alternating with packed bottomhole assemblies (PHA). Fig. 13 shows the operational performance in the 14 3/4"-section, finished in March 1992. Productivity and reliability have improved substancially (VDS 4).Despite steep dip of the foliation and broken out sections in the borehole, curvature could be kept below 0,5°/10 m dog leg severity, total deviation in 6,000 m depth being below 10 m. From 5,519 to 5,596 m, due to high deviation built up of 1°/6 m with a PHA-run, a new hole was drilled by sidetracking this section using VDS, after having cemented the deviated section. The 14 3/4"-section was cased with 13 3/8"-Mannesmann-casing (with special slim Mid Omega XSC-couplings), with a weight of 7.000 kN. Despite having only a clearance of 1/2" between bit size and casing OD in the nearly vertical borehole, the string could be lowered to final depth without any problems and was cemented up to 3,000 m. Shrinkage by cooling caused some problems. But by heating up again by circulation from bottom up, the casing could be landed correctly in the hanger.

Drilling was continued with 12 1/4"'-bit size using the same technology as before. End of July 1992 in 6,760.5 m depth the bit got stuck and during the following sidetrack - due to problems with a milling job - additional already drilled section had to be given up. The borehole was now sidetracked successfully from 6,461.5 m using a specially designed motor steering system (MSS) in combination with drift indicator and tool face. The MSS is similar to the VDS, but equipped with only one hydraulic actuated member, pushing the bit in the predetermined direction.

Total depth midth of April 93 is 7,219.5 m. From 7,125 m biaxial breakouts up to 40" did not allow to continue active steering of the borehole course, resulting in deviation built up of 6°. The mud system was changed to a multicomponent weighted water based design, improving the rheological and hole stabilizing characteristics. The breakout section had been cemented and a new bypassing hole was drilled using the KTB-motor steering systems and double tilted bentsub devices. This utmost complicated sidetrack operation in a borehole, enlarged from 12 1/2" BS to 40" by severe breakout in hard cristalline rock is a world premiere. The old borehole could be bypassed in safe distance. Reasons for the drilling problems are rock instabilities and severe well bore breakouts, diameter being up to 5 bit sizes, developing just after drilling. Stress release seems to be of more concern than kataclastic deformation. The viscous mud invades into the fissures of the penetrated rock, and if the mud contains some free water (as usual), the void volume will be filled by this. Under these conditions, pressure pulses and temperature changes caused by the drilling procedure, may enhance breakout formation.

Extrapolation of bottom hole temperatures measured at 6 km depth leads to an undisturbed temperature of 174 to 178° C at this depth, corresponding to a geothermal gradient of about 28° C in the depth range from 4 to 6 km. This means that in a depth of 7 km the static temperature is about 200° C. Due to these conditions the change to high temperature mud polymers was a must, since longer circulation interruptions cannot be avoided. While drilling 12 1/4" BS the borehole is cooled by circulation with a flowrate between 2,200 and 2,400 l/min by up to 100° C. These high temperature differences mean rather low operating temperatures for temperature sensitive downhole equipment, as electronics, positive displacement motors etc.

After running in and cementing the 13 3/8 - 13 5/8" casing, a hydrofrac experiment was performed at a depth of 6 km. The preliminary evaluation of the pressures recorded during and after the injection, together with information about breakouts, leads to an estimate of σ_h of about 114 MPa, and of σ_H of about 224 MPa.

Drilling 12 1/4"-bit size is planned to be continued to a total depth of 10,000 m, using active vertical steering devices down to 8,000 m. If necessary, a 9 5/8'"-liner may be installed. End of drilling operation is expected in late 1994.

Geoscientific Results

Down to 7,200 m depth, a steeply dipping succession of medium to high pressure amphibolites and gneisses was penetrated. Since the geological results are partly unexpected the deep outcrop will provide fundamentally new insights to the development and architecture of the orogene. Due to the recent political development in Europe the KTB project obtained strongly increased importance for the international scientific cooperation.

Until now essential progress was reached, e.g.:

* The depth forecast of a major seismic reflector in 7 km depth was very precise. The Hauptbohrung recovered samples from the reflector zone, which is made up of a thick cataclastic fault zone.
* Graphite and saline fluids occuring in the depth allow to understand electrical conductivity a anomalies.
* Magnetic bodies extend to depths deeper than estimated previously.
* Hydraulic fracturing experiments and observations of the borehole wall yield data of the magnitude and orientation of stress up to six km depth. These data and seismological observations show that the location is in a tectonically active regime.
* The geothermal gradient (28 +/- 1°/km) shows no effecient decrease up to 7 km depth. The heat flow is higher than predicted from shallow boreholes.
* Fluids play an important role. The recent fluid system is governed by Ca-Na-Cl enriched waters rich in dissolved N2 and CH4 from below 3 km towards at least 7 km. They are hosted in partially separated complex fracture systems.
* Fluid inclusions document the pressure-temperature history with formerly active systems of fundamental divergent composition.
* Zones of young metamorphic reactions and exchange processes were reached recently

Wireline logging

Limited experience exists for logging in crystalline rocks.The logging tools, used in the oil industry, have been developed for the evaluation of sediments. The concept of KTB to drill a pilot hole before spudding the ultra-deep borehole, provided the opportunity to test the logging systems and their response characteristics in crystalline formations. Utilizing the tools from the service industry and newly designed sondes from universities and research institutes, an extensive logging program was executed in the pilot hole drilled with 6'" diameter. Series of logs have been recorded at intervals of 500 meters. Nearly complete core and cutting analysis data allowed the calibration of the logging and evaluation methods. The results obtained in the pilot hole strongly influenced the planing of the logging program for the ultra-deep borehole. Only correlation logs have been recorded in this well to a depth of 3,000 meters. Down to casing depth at 6,000 meters, two logging series have been run with standard and special tools. From there down to final depth at 10,000 meters, the logging program will have to be reduced due to high temperature and the restricted availability of hostile environment logging tools.

To support the drilling operation, the control of the trajectory and of the borehole condition is essential. The Borehole Geometry Tool (BGT), combined with temperature and mud resistivity measurement, provided this information. A deviation of the pilot hole towards northeast down to about 3,000 m and a gradual change towards northwest below this depth has been observed. While the total deviation of the pilot hole was 190 m, the ultra-deep hole deviated in the same direction, but only to about 12 m, due to the vertical drilling method applied. The information obtained with this technical log has geological significance. A steeply southwest dipping structure with strongly foliated formation had been penetrated. This was confirmed by the Formation Micro-Scanner (FMST) and the Borehole Televiewer (BHTV) revealing dips between 45 and 85 degrees. The change of lithology around 3,000 meters predicted from seismic site surveys turned out to be a change of formation dip to 20 degrees only. In addition, the folded texture of the formation and fractures became visible by these modern scanning devices. The continuous record of the mud resistivity indicated higher conductivity in the vicinity of these fractures. These zones had been tested and produced water with up to 80,000 ppm salinity.

Using the Dual Laterolog (DLL), Sonic (SDT), Density (LDT), Neutron (CNL) in combination with the results from the Geochemical Logging Tool (GLT), a detailed geological profile was reconstructed and correlated with the profile established from core and cutting analysis.

The EFA-Log, an electro-facies log developed by the University of Aachen, separated 37 facies from log responses. The mineral content of the formation was estimated by applying appropriate models for the main rock types - gneiss and amphibolite - to the ELAN program. The cross-correlation with X-ray diffraction measurements is striking. Special minerals like graphite, pyrite, magnetite, haematite and pyrrhotine could be detected on a qualitative basis.

From the Borehole Gravity (BHGM) measurement and the Density Log (LDT), the true thickness of the amphibolite layers drilled through could be evaluated. The dip of the layers calculated from these recordings was in accordance with the results from the Formation MicroScanner.

The magnetic anomaly, known from surface soundings, was confirmed by downhole measurements.

Due to the extremely steeply dipping and faulted structure, the results from the Vertical Seismic Profiles (VSP) are difficult to correlate with the surface seismic profiles. Several reflectors with only limited areal extension are visible, confirming the tectonically disturbed geology.

The unique opportunity of calibrating downhole measurements against results from laboratory analysis opened the way for the development of new interpretation methods for crystalline rocks. The methods proved to be applicable even when logs are recorded unter such different conditions like in the KTB pilot and ultra-deep boreholes.

Conclusions

In conclusion, the experiences and results from ultra-deep scientific drilling in Germany are summarized:

1. The certainty of scientific and economic success of the "two-borehole-concept", allocating clearly defined and optimal feasible programs to each technology, is higher than the one of a "single borehole concept".

2. The drilling technology of the pilot well, using the hoisting capability of a rotary rig, a high speed top drive and a new 5 1/2" variable thread mining drillstring, and the so-called intelligent core barrel with wireline technology, and last not least the novel mud, was a breakthrough. Implementing a straight vertical hole technology, a potential depth range of 5,000 to 6,000 m with 6" diameter totally cored seems to be realistic for this drilling concept.

3. Since 1985, it has been recognized that in the upper section of an ultra-deep hole, its trajectory should be vertical. Passive vertical drilling systems have the disadvantage that side forces, generated from formation inhomogeneities, are overcome by a reaction force depending directly on the inclination angle. Small angles will only generate small compensation forces. Active systems will use the inclination angle only as a signal to activate pistons, ribs, or other devices which are pressed radially against the borehole wall.

radially against the borehole wall.

4. The international, and the KTB experience in deep and ultra deep crystalline drilling led KTB to a bit- and casing-program for the ultra-deep hole with open hole sections not longer than 3,000 m to 4,000 m. The advantages are
   - zones of fluid inflow or mud loss and of rock instability (especially in the upper large diameter sections) are cased earlier,
   - with no effect of swab and surge to the open borehole wall in the cased sections, the pulling and lowering velocities during tripping can be optimized, making full use of the pipe handler.
5. For the depth range of max. 12,000 m, a special heavy rig had to be constructed, using, wherever possible, proven moduls, and was equipped with a pipe handler, and a hook retractor system.
6. Drilling an ultradeep research borehole needs interdisciplinary cooperation, including all available know how and experience in science and industry. Short term continous interactive planning and controlling are necessary due to limited predictability.

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Fig. 1 SMAG–430kW–Topdrife

Fig. 2 Coupling of the 5 1/2"–drillstring for wireline diamond coring (DCS)

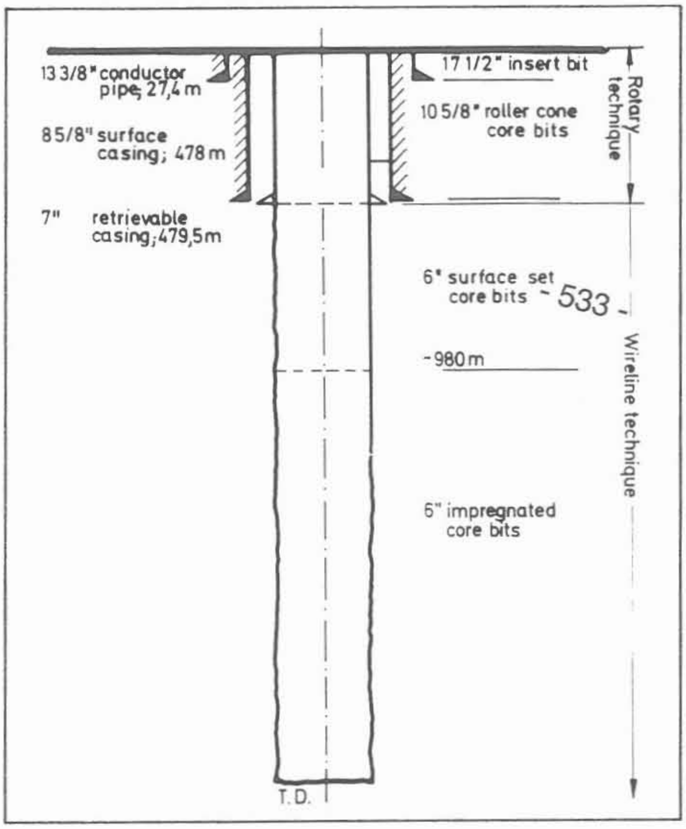


Fig. 3 Bit and casing programm of the pilot hole

Fig. 4 High performance impregnated diamond core bit, after drilling 140m

KTB–PILOT WELL, TOTAL RIG TIME BREAKDOWN
TD = 4000.10m, 560 days

	PLANNED	REACHED
BIT LIFE (DCS)(m)	20	48
AVERAGE CORE LENGTH (m)	4	3,5
AVERAGE ROP (m/h)	1,5	1,68
TRIPPING DRILLSTRING (h/1000m)	3	4,5
TRIPPING WL–CORE–BARREL (h/1000m)	1,15	0,95
CORE RECOVERY (%)	85	98

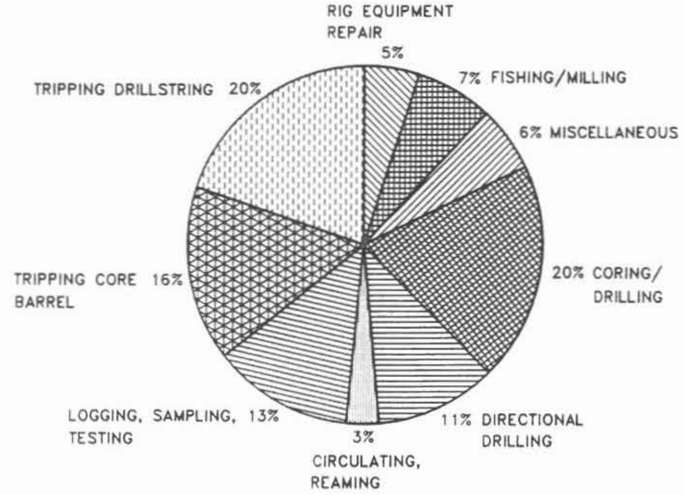


Fig. 5 Rig time break down and performance data of the pilot well

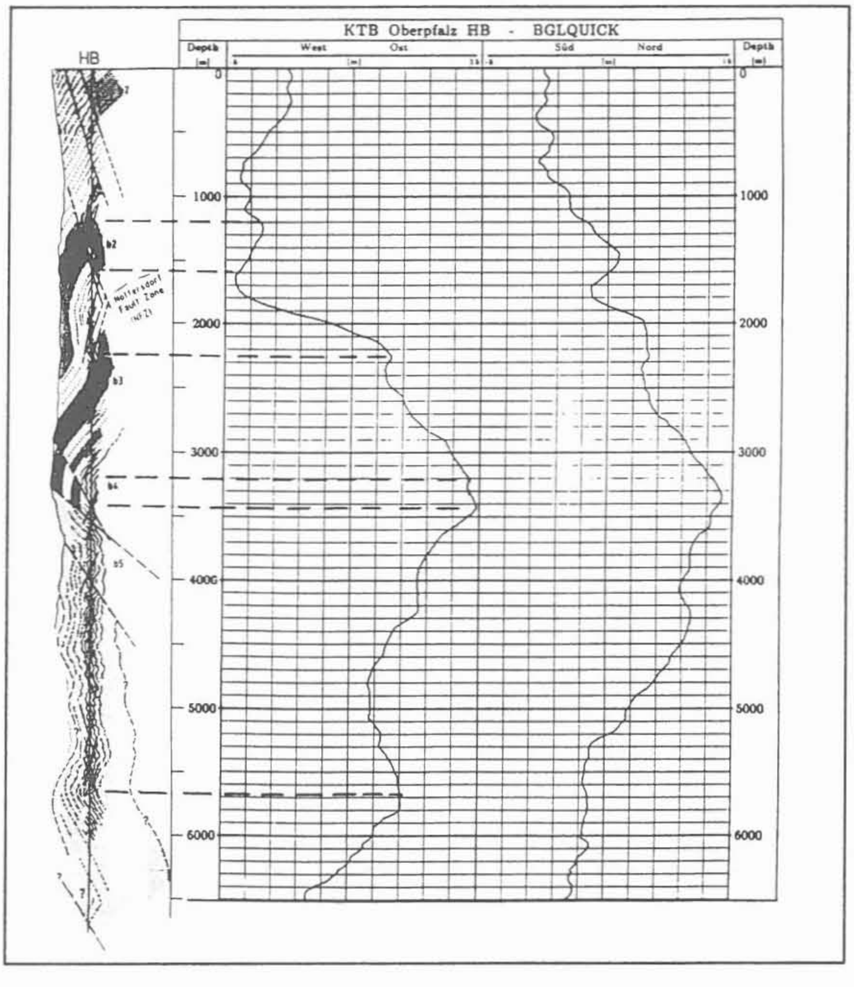


Fig. 6 Main hole trajectory

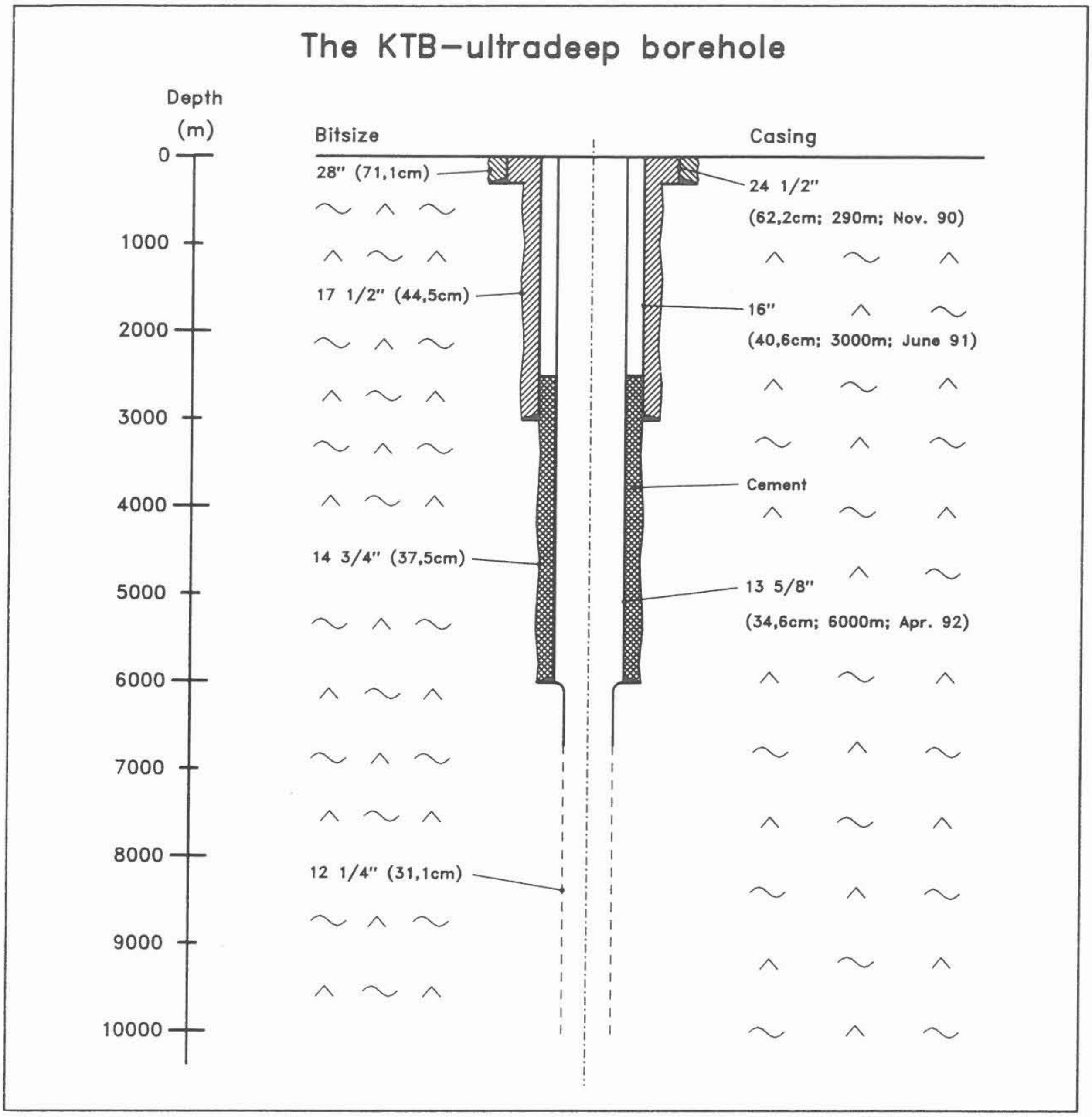


Fig. 7 Bit and casing program of the main hole

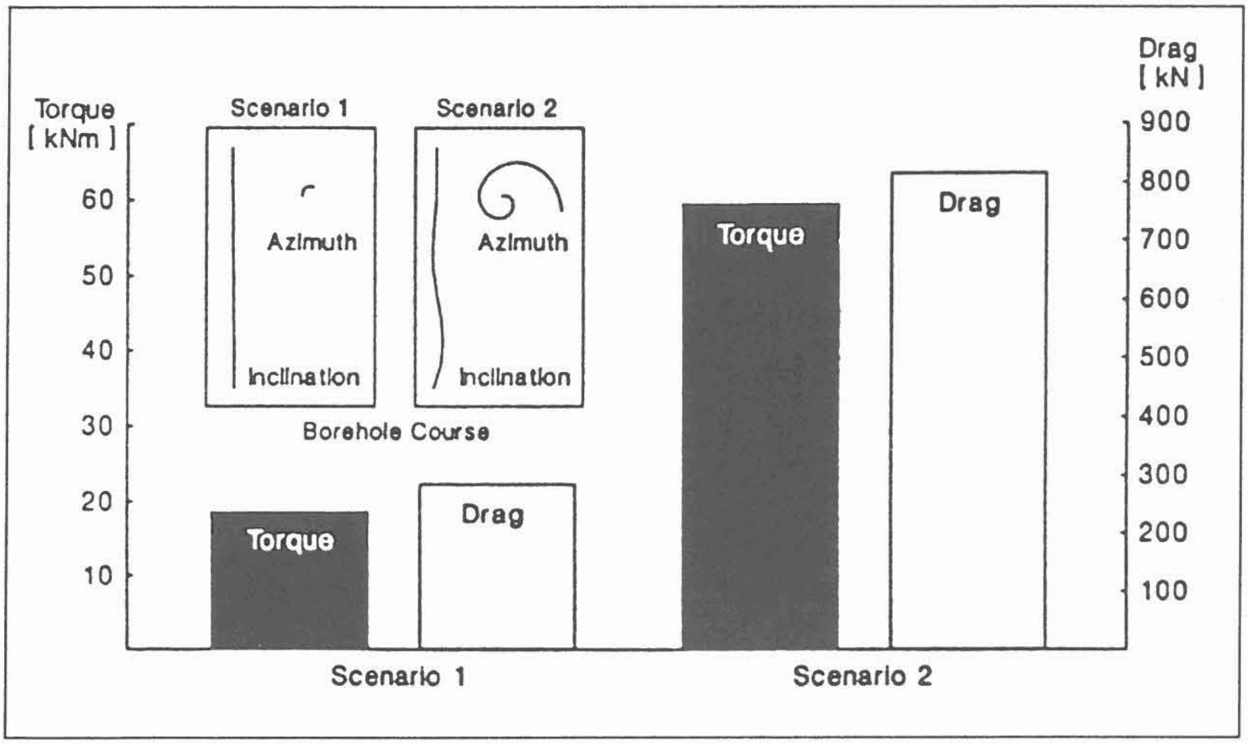
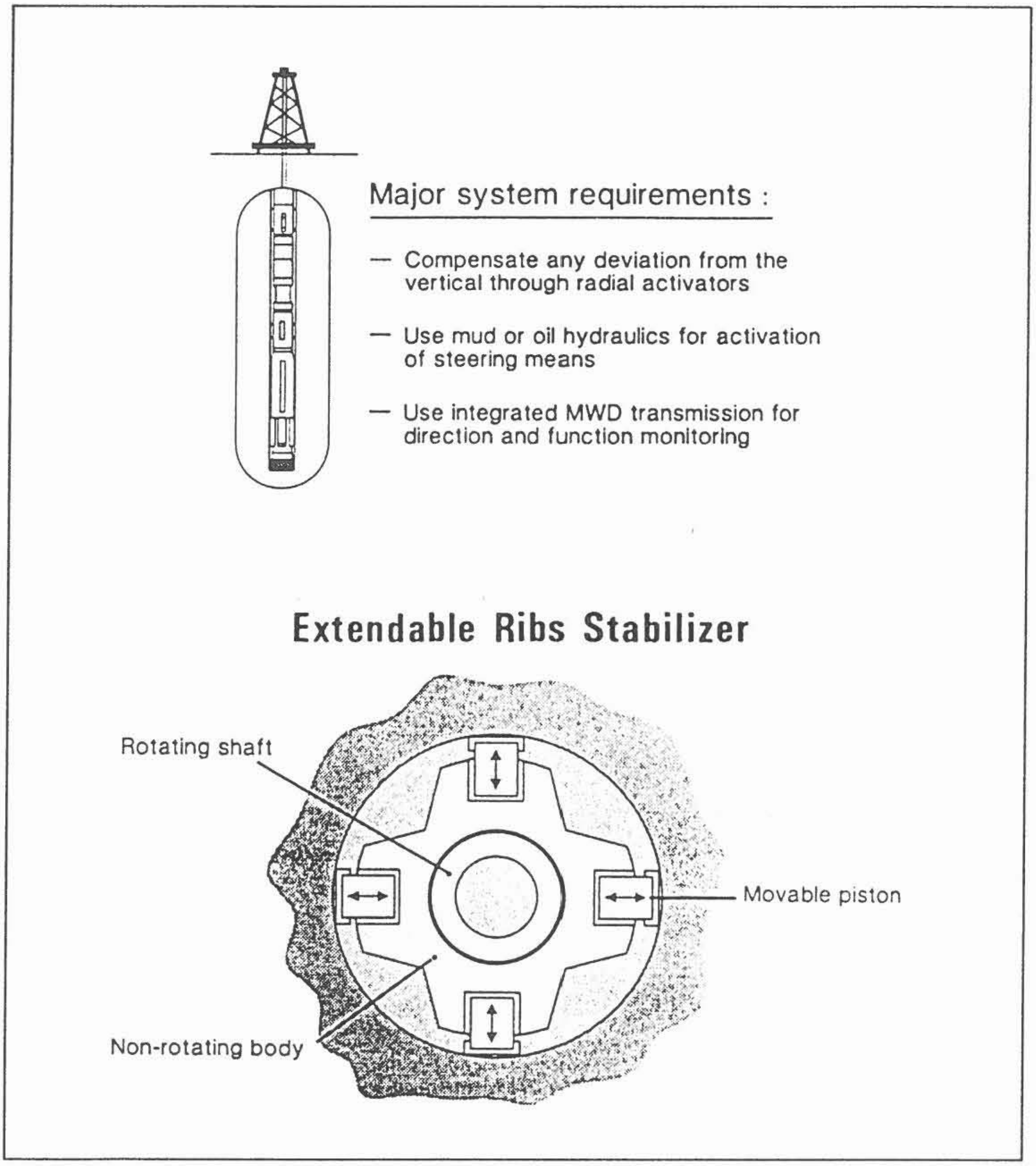


Fig. 8 Torque, drag and borehole curvature, principles

The History of Well Drilling with RTB Systems
(after VNIIBT, April, 1991)

Name of the well	Interval drilled, m	RTB diameter, mm	Deviation (at bottom), deg.
Krivorojskaya	0 - 850	640	0.00
	850 - 2,800	480	1.00
Muruntauzskaya	0 - 1,000	590	0.00
Uralskaya	0 - 258	640	0.00
	258 - 4,000	590	2.50
Tumenskaya	0 - 1,700	490	1.75
Almetiavskaya	1 - 1,000	394	0.00
Timano-Pechorskaya	1,000 - 1,400	394	2.00
Krasnodarskaya	800 - 2,750	490	1.25
New Well	0 - 1,350	445	1.75

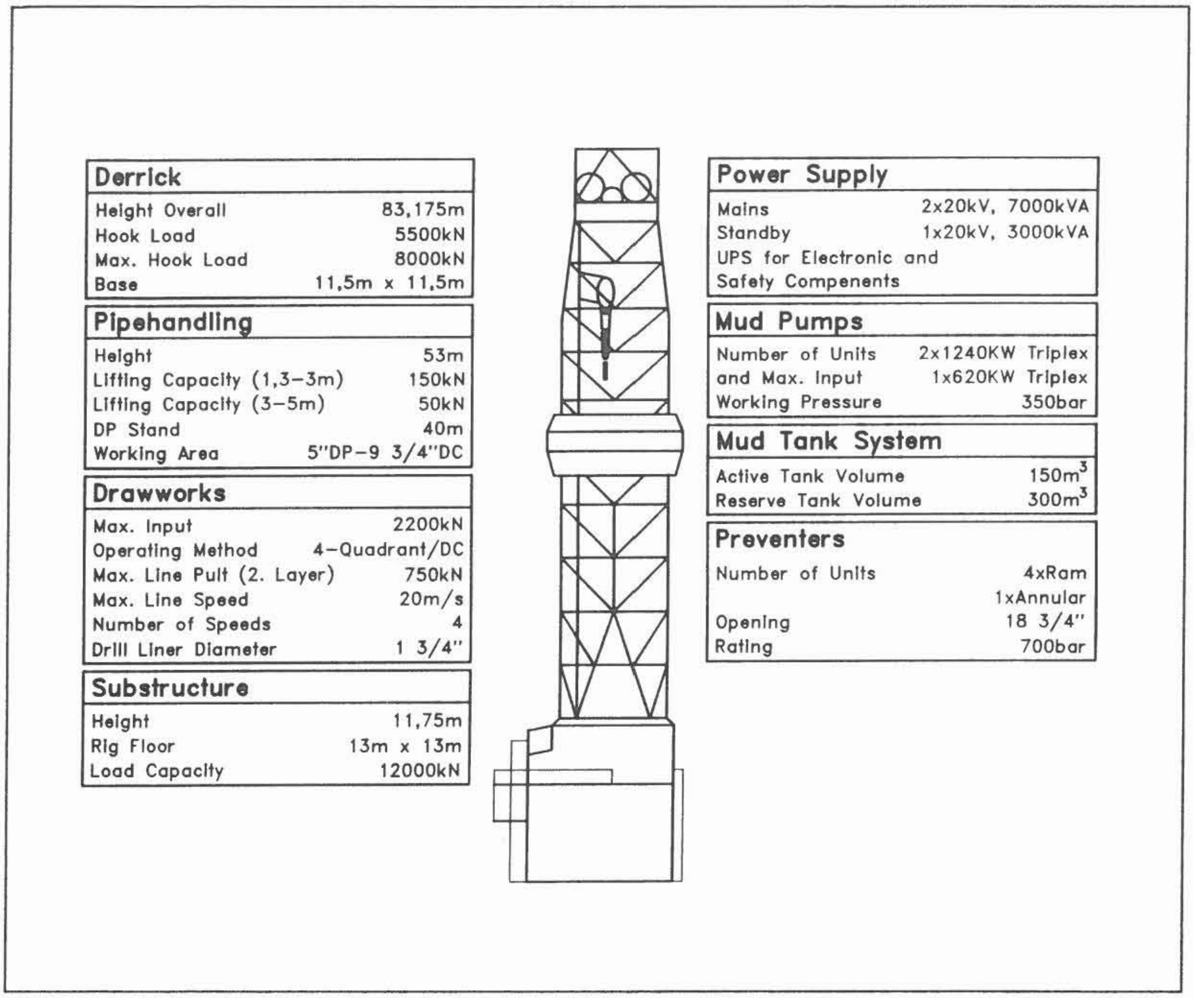
Fig. 9 Performance of KTB–Systems (table)



Major system requirements :

- Compensate any deviation from the vertical through radial activators
- Use mud or oil hydraulics for activation of steering means
- Use integrated MWD transmission for direction and function monitoring

Fig. 10 Vertical drilling system



Derrick	
Height Overall	83,175m
Hook Load	5500kN
Max. Hook Load	8000kN
Base	11,5m x 11,5m

Pipehandling	
Height	53m
Lifting Capacity (1,3–3m)	150kN
Lifting Capacity (3–5m)	50kN
DP Stand	40m
Working Area	5"DP–9 3/4"DC

Drawworks	
Max. Input	2200kN
Operating Method	4–Quadrant/DC
Max. Line Pult (2. Layer)	750kN
Max. Line Speed	20m/s
Number of Speeds	4
Drill Liner Diameter	1 3/4"

Substructure	
Height	11,75m
Rig Floor	13m x 13m
Load Capacity	12000kN

Power Supply	
Mains	2x20kV, 7000kVA
Standby	1x20kV, 3000kVA
UPS for Electronic and Safety Compenents	

Mud Pumps	
Number of Units and Max. Input	2x1240KW Triplex 1x620KW Triplex
Working Pressure	350bar

Mud Tank System	
Active Tank Volume	$150m^3$
Reserve Tank Volume	$300m^3$

Preventers	
Number of Units	4xRam 1xAnnular
Opening	18 3/4"
Rating	700bar

Fig. 11 Drilling Rig UTB–1

Fig. 12 Motor steering system

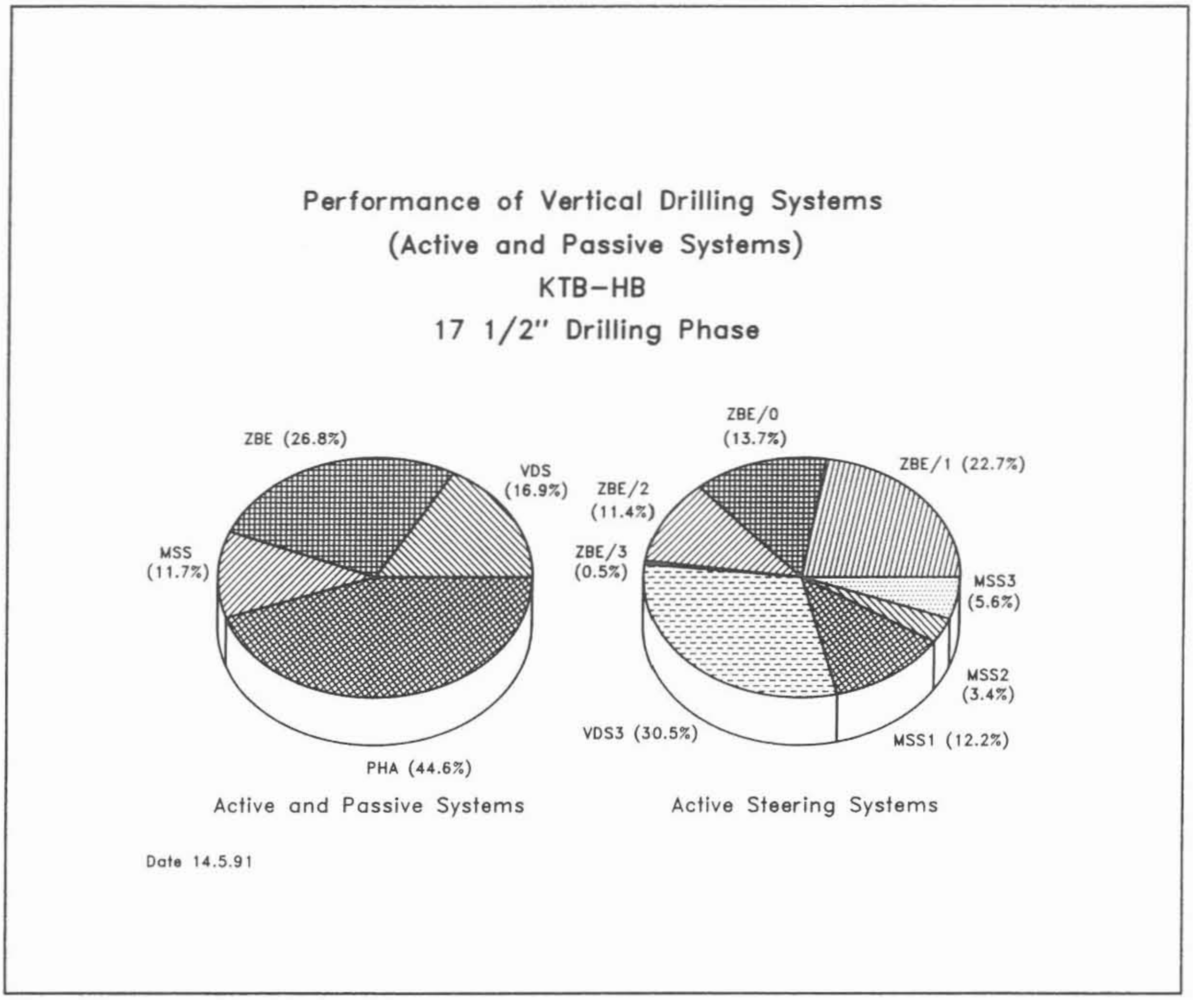


Fig. 13 Performance of steering systems in 17 1/2"-Bitsize