International Technical Workshop on Deep Borehole Disposal of Radioactive Waste

Panel 1- Experience in Deep Drilling in Crystalline Rocks

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Overview

- Deep Drilling Projects in Crystalline Rocks

- Experience in Deep Drilling in Crystalline Rocks
    - Drilling Performance
    - Directional Control
    - Borehole Stability and Fluids
    - The Value of a Characterization Borehole

- Conclusion

Deep Drilling Projects in Crystalline Rocks (Examples)

Name	Country	Year	Depth	Type	Remarks
Kola SG - 3	Russia	1970 - 1989	12.261 m	Geoscientific/ Ore Exploration	
Fenton Hill	USA	1975 - 1980	3.065 m - 4.663 m	Geothermal	3 wells
Rosemanowes	UK	1981	2.156 m - 2.186 m	Geothermal	2 wells
Ural SG-4 Krivoy Rog SG-8	Russia Ukraine	mid 80's	approx. 5.000 m	Geoscientific/ Ore Exploration	Some more wells in the NEDRA Program
Urach 3	Germany	1977 - 1978	3.334 m	Geothermal	Crystalline from 1.600 m
The Geysers/Prati 32	USA	1985	3343 m	Geothermal	Many more wells in the field
Sancerrre Couy	France	1986 - 1987	3.500 m	Geoscientific	GPF Program
Cajon Pass	USA	1986 - 1988	3.500 m	Geoscientific	DOSECC
NAGRA	Switzerland	1982 - 1999	1.306 m- 2.482 m	Nuclear Waste Disposal	Site investigation 8 wells

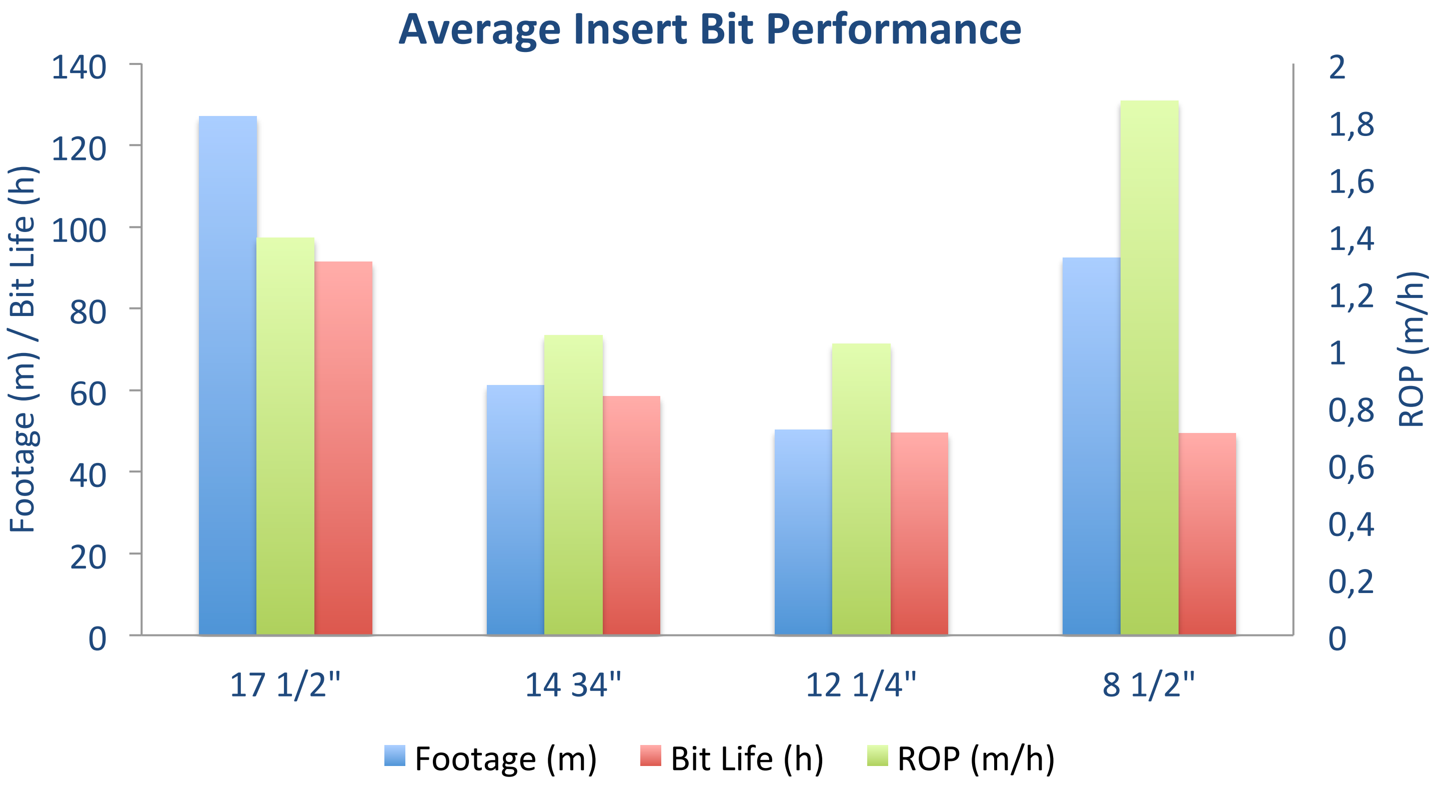
Deep Drilling Projects in Crystalline Rocks (Examples)

Name	Country	Year	Depth	Type	Remarks
Gravberg 1/Siljan	Sweden	1986 - 1989	6.770 m	Exploration Gas	
KTB Pilot Hole	Germany	1987 - 1989	4.000 m	Geoscientific	ICDP
KTB Main Hole	Germany	1990 - 1995	9.101 m	Geoscientific	ICDP
Soultz sous Forets	France	1993 - 2005	3.500 m - 5.000 m	Geothermal	4 Wells
Dabie-Sulu	China	2001 -2005	5.158 m	Geoscientific	CCSDP/ ICDP
SAFOD - MH	USA	2004 - 2005	3997 m	Geoscientific	
Outokumpu	Finland	2004 - 2005	2.516 m	Geoscientific/ Ore Exploration	ICDP
Basel	Switzerland	2007	5.000 m	Geothermal	
COSC-1	Sweden	2014	2495 m	Geoscientific	Mining Technology

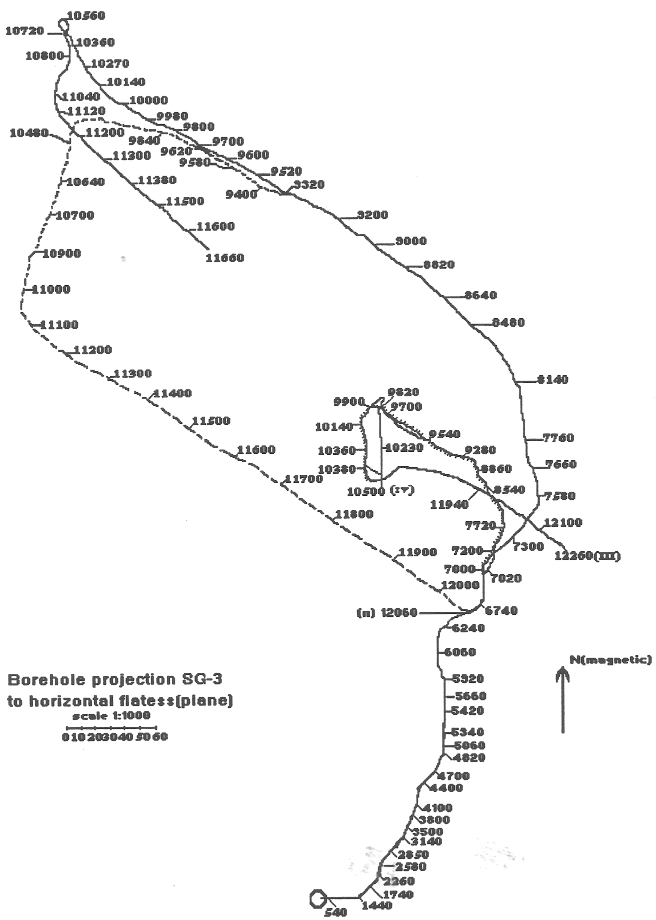
Drilling Performance in Crystalline Rocks

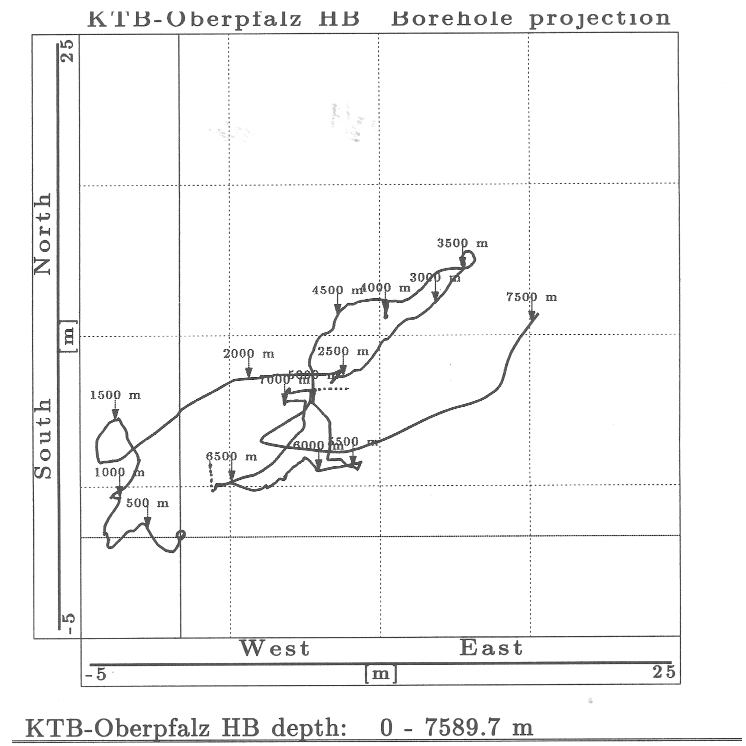
Name	Country	Lithology	Bit Size (inch)	ROP (m/h)	Remarks
KTB Pilot Hole	Germany	Gneiss/ Amphibolite	6 "	0,8	Insert Bit
KTB Main Hole	Germany	Gneiss/ Amphibolite	17 1/2 " 14 3/4 " 12 1/4 "	1,39 1,05 1,02	Insert Bit Insert Bit Insert Bit
The Geysers	USA	Greywacke/ Microgranite	10 5/8 "	8,0	C.Otte et al. 1990
Fenton Hill	USA	Granite/ Gneiss	8 3/4 "	3,5	C.Otte et al. 1990
Coso	USA	Granite	8 3/4 "	3,0	C.Otte et al. 1990
Lardarello	Italy	Phylite/ Quarzite	8 1/2 "	1,7	C.Otte et al. 1990
Gravberg 1/Siljan	Sweden	Granite	17 1/2 " 12 1/4 "	3,0 3,4	Insert Bit Insert Bit

Drilling Performance - KTB

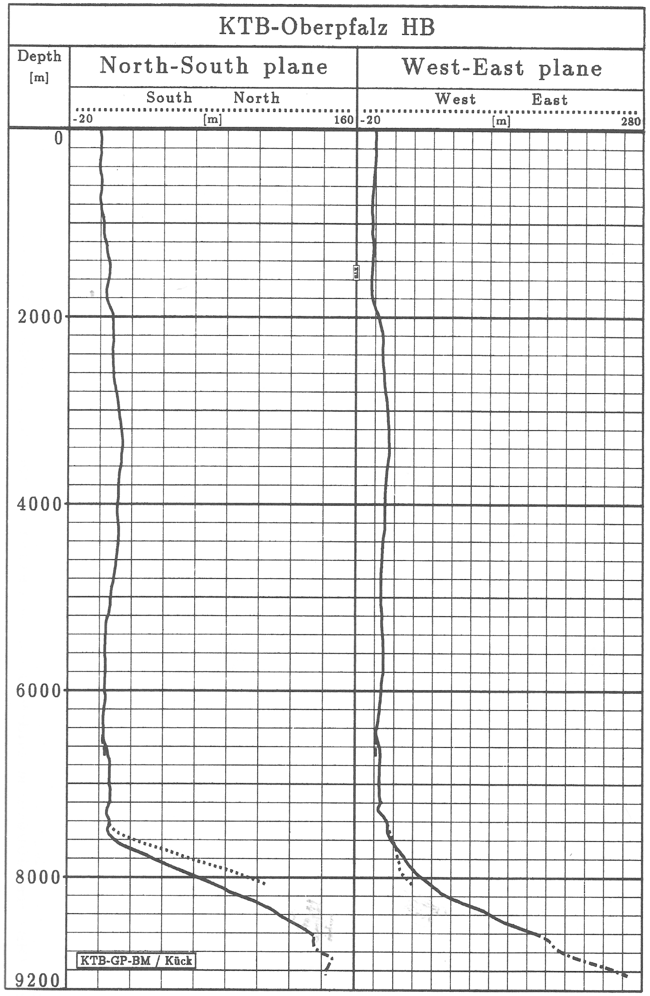


Directional Control - Kola SG 3 vs. KTB





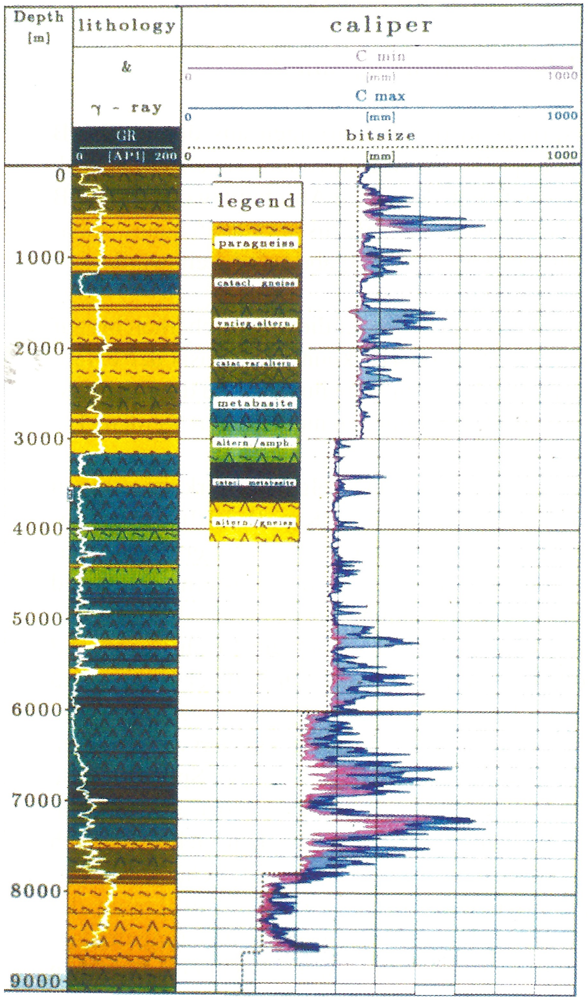
Directional Control - KTB Vertical Drilling System



Borehole Stability and Fluids

Name	Observation	Source
KTB Pilot Hole	During a four month test period 756 m3 fluid was produced (thereof 302 m3 Gas)	R.Emmermann Geowissenschaften, ISSN 0933-0704
KTB Main Hole	Several Hydraulic Tests were conducted @ 3000m > 5,3 m3 influx @ 6000m > 30 m3 influx @ 9000m > 4,8 m3 influx over 12h, during first 5 minutes 157 l/min > fracture zone communication between Main and Pilot Hole	B.Engeser KTB - Bohrtechnische Dokumentation ISSN 0939-8732
Sancerre-Couy	Deep fossil fluids in the basement. Influx of 500 l/h in fracture zones (gneiss) over several days	C.Megnien 6th int. Symposium on the Observation of the Continental Crust through Drilling, 1992
Kola	High permebility and fluid saturation of Earth's Crust were revealed down to a depth of 12 km	B.N.Khakhaev 6th int. Symposium on the Observation of the Continental Crust through Drilling, 1992
Gravberg 1/Siljan	Driling through highly fractured, unstable granite was difficult. Severe breakout of the formation led to problems for cementing, tripping, running casing and drilling.	P.L.Moore, T.L. Brttittenham International Symposium in Mora and Orsa, 1987

Borehole Stability - KTB



- 17 1/2" borehole to 3.003 m, no severe drilling problems
- Below 2.100 m polymer added to drilling mud to reduce fluid loss
- 14 3/4" borehole to 6.018 m, below 5.000 m stress induced breakouts
- 12 1/4" borehole to 8.328 m, severe drilling problems

- Breakouts are common in crystalline boreholes depending on lithology, stress field, hole size, mud properties and exposure

Open Sillimanit-Muscovit-Biotit Gneiss Cleft cored at 3447 m - KTB VB

The Value of a Characterization Borehole (Pilot Hole)

- A Pilot Hole provides valuable data of the specific drill site (e.g. lithology, mineralogy, local stress field, borehole stability, fluid influx zones, thermal conductivity)
- Enables development or tests of specific drilling equipment e.g. drill bits, coring technology, mud properties, mud logging
- The Field Test Borehole can be exonerated from logging, coring and hydraulic test programs
- Development or tests of specific sample methods e.g. x-ray diffractometry and fluorescence analysis of mineralogical composition of drilled rock
- Training of personal on the determination of cuttings and interpretation of logs
- Cross hole tests between Pilot Hole and Field Test Borehole possible e.g. KTB > Integrated Hydrofrac/Seismic Experiment
- Smaller diameter > less costs

Conclusion

- Rotary drilling experience in crystalline rocks is available from a considerable number of boreholes
- Drilling experience in crystalline rocks for 12 1/4" borehole diameter and bigger is only available from a limited number of boreholes
- Drilling in crystalline rocks differs from drilling in sediments primarily by rock hardness
- Drilling performance is considerably less compared to Oil & Gas wells. For 17 1/2" borehole diameter it may vary between 1 m/h to approx. 3 m/h (Siljan: 2,46 m/h)
- Borehole instability is a major challenge but can be controlled
- Drilling of a Pilot Hole provides valuable data and exonerates the Field Test Borehole from coring, logging and test programs

Core Drilling Technology - KTB

Coring Performance - KTB