

Ing.-Büro Axel Sperber
Eddesser Straße 1
D-31234 Edemissen

*I ndependent
D rilling
E ngineering
A xel
S perber*

*Drilling Consulting & -Engineering
Supervision
Project Management*

The casing scheme ... most important factor for the success and the costs of a deep well?

Author: Dipl.-Ing. Axel Sperber, Ing.-Büro A. Sperber, Eddesser Straße 1, D-31234 Edemissen

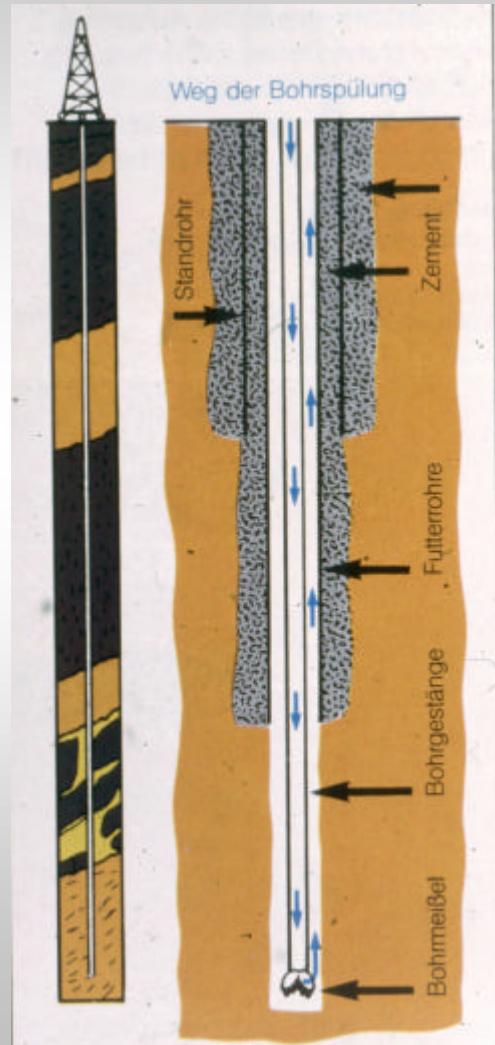
ENGINE – ENhanced Geothermal Innovative Network for Europe
workshop 4, Drilling cost effectiveness and feasibility of high-temperature drilling
Reykjavik, 2- 5 July, 2007

- 1 *Well Design - why run casing*
- 2 *Corresponding Bit and Casing Diameters*
- 3 *Influence of Casing Scheme on Well Costs*
- 4 *Standard Clearance vs. Slim Clearance Scheme*
- 5 *Cost Saving Potential with Slim Clearance Scheme*
- 6 *Casing Centralisation in Narrow Clearance Annuli*
- 7 *Casing Design Calculations*
- 8 *Conclusions*

The casing scheme ... most important factor for the success of a deep well?

Planning of the casing scheme
of a well = “Well Design”

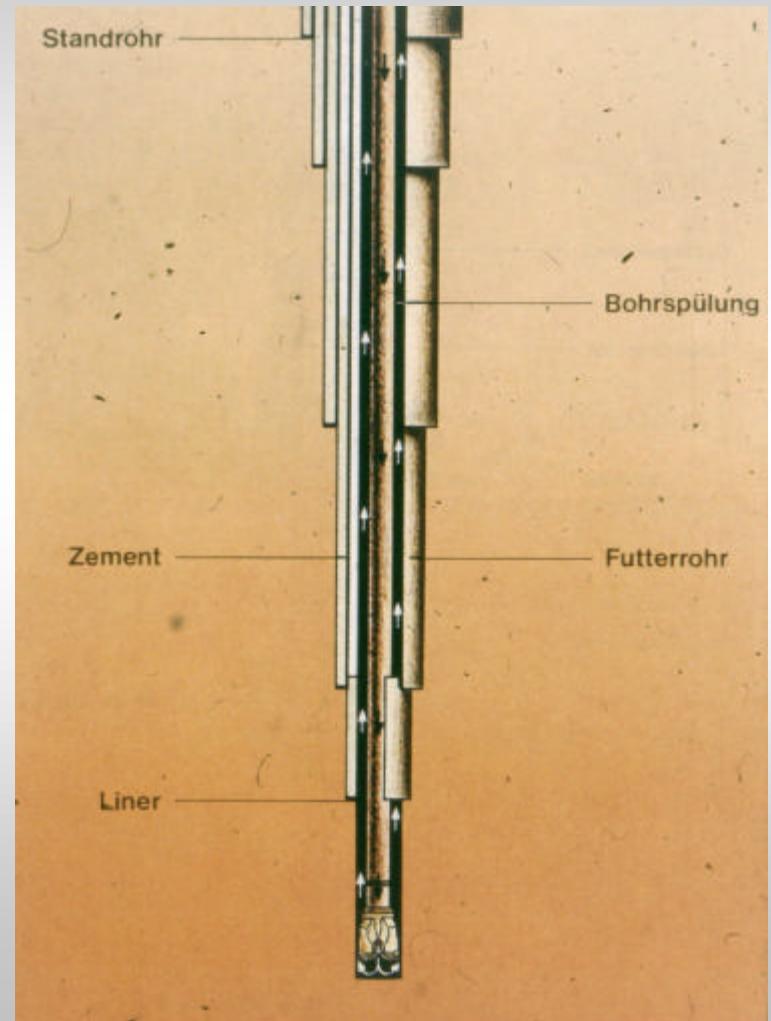
- “Well Design” means to answer the following questions
- where casings are to be set?
- which size of hole is to be drilled?
- which size of casing is to be run?



The casing scheme ... most important factor for the success of a deep well?

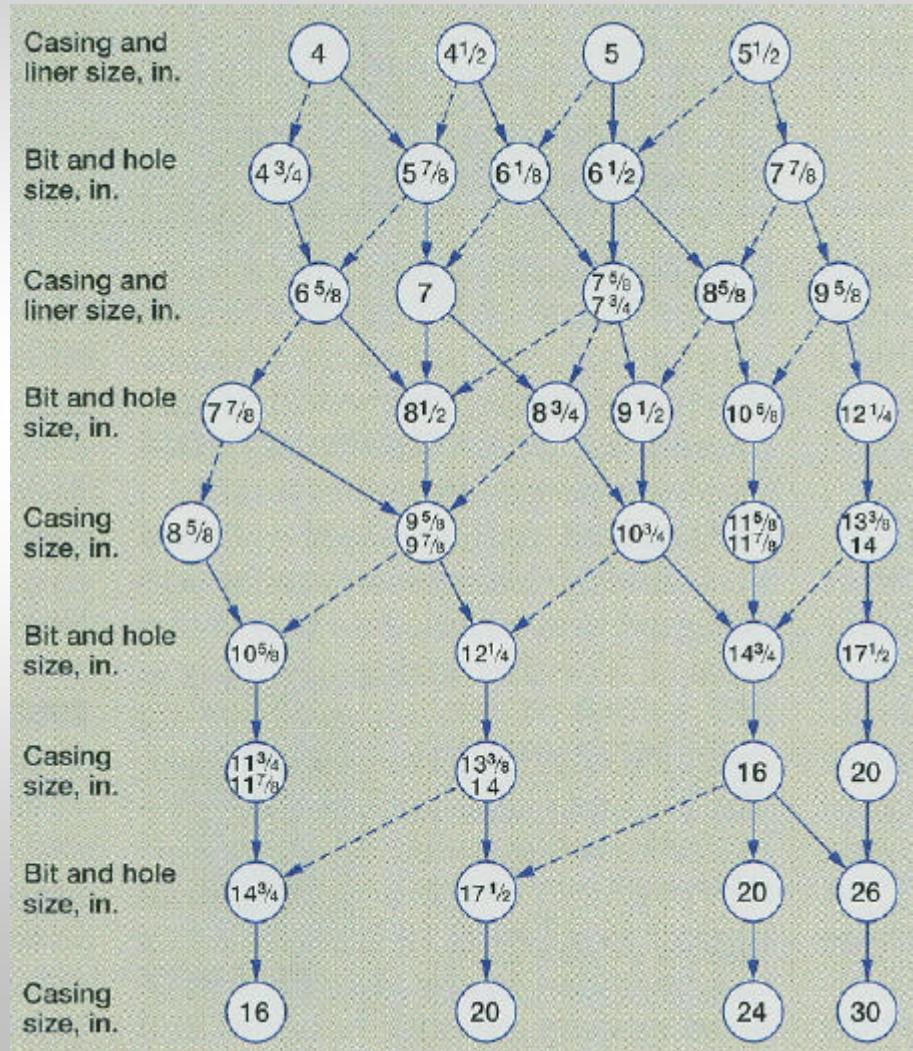
But ... why run casing?

- To secure drilled hole sections (e.g. in unstable formation)
- To separate hole sections/formations with different pressure gradients
- To seal formations against influx of fluids (gas, oil, water) from previous or next section.



The casing scheme ... most important factor for the success of a deep well?

- The needed number of casing/liner strings depends on the geology.
 - Planning starts at final depth with desired diameter and moves upwards stepwise (casing size by casing size).
 - Bit diameters and casing (pipe) diameters are (more or less) “standardized”
 - Casing diameters depend on bit diameters, bit diameters on casing diameters!



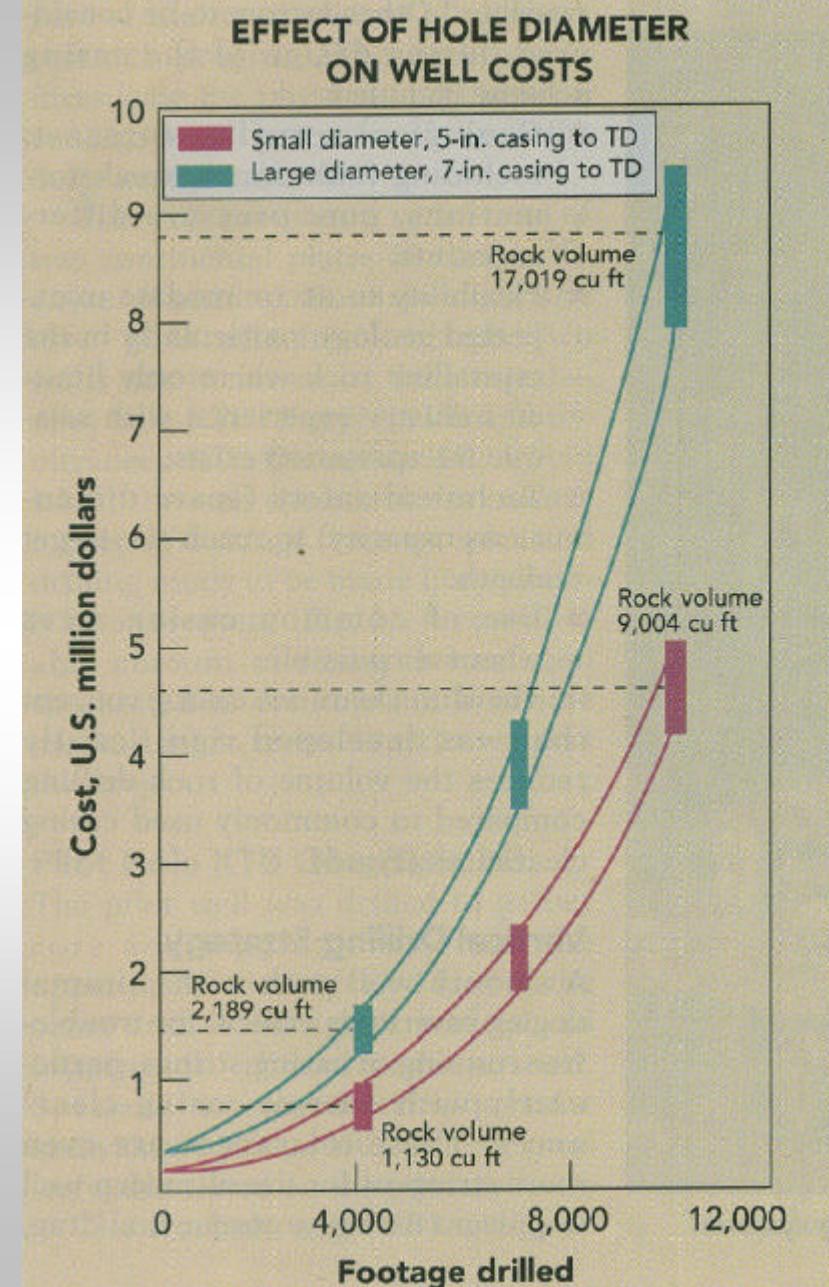
The casing scheme ...an important factor for the costs of a deep well!

“Golden rule”:

Drill as small as possible,
but as large as necessary!

Reason:

The cost of a well is +/-
proportional to the total
volume of drilled
(destroyed) rock !



The casing scheme ...an important factor for the costs of a deep well?

But ...

advantages and disadvantages of different schemes should be evaluated thoroughly in each case!

In each case valid:

- OH-diameter > casing-OD!
- But how much difference is necessary??
 - sufficient to run casing string in hole to planned depth
 - sufficient for proper cementation!

Important for the quality of a casing cementation, particularly in deviated wells:

- “Clearance” (= diameter difference between open hole and casing) and
- “stand-off” (= concentricity of casing in open hole)
- Avoid fracturing when displacing cement! (high ECD in narrow annulus!)

The casing scheme ...an important factor for the costs of a deep well?

Alternative 1:

Standard Clearance Bitsize & Casing Scheme						
Hole diam. inch	Max. Depth m	Caving Factor	Volume of OH Section m^3	Top of Cement m	cemented Annulus m^3	
30,00	950	1,3	563,2	0	274,3	
23,00	2.600	1,25	552,8	700	302,6	
17,50	3.600	1,2	186,2	2.500	105,1	
12,25	4.200	1,15	52,5	3.500	28,4	
8,50	4.500	1,1	12,1	4.100	6,2	
Volumes cumul.		1.366,8		716,6		

Alternative 2:

"Slim Clearance in Top Sections"						
Hole diam. inch	Max. Depth m	Caving Factor	Volume of OH Section m^3	Volume rel. to Standard Scheme	cemented Annulus m^3	Volume reduction OH % Cement %
23	950	1,3	331,0	58,8%	164,1	41,2% 40,2%
17,5	2.600	1,25	320,1	57,9%	122,1	42,1% 59,7%
14,75	3.600	1,2	132,3	71,0%	45,8	29,0% 56,4%
12,25	4.200	1,15	52,5	100,0%	28,4	0,0% 0,0%
8,5	4.500	1,1	12,1	100,0%	6,2	0,0% 0,0%
Volumes cumul.		847,9	62,0%	366,5	38,0%	48,9%

Proposed Casing for Alternative No. 1

OD inch	Material Grade	Nom. Wt lb/ft	Conn. type	Conn. OD inch
24,5	K-55/N-80	140	BTC	25,5
18,625	K-55/N-80	87,5 - 96,5	BTC	20
13,375	K-55/L-80	61 - 68	BTC	14,375
9,625	L-80/C-95	43,5 - 47	BTC	10,625
7	L-80/P-110	26 - 32	BTC	7,656

Proposed Casing for Alternative No. 2

OD inch	Material Grade	Nom. Wt lb/ft	Conn. type	Conn. OD inch	standard mm	slim mm
18,63	K-55/N-80	87,5 - 96,5	BTC	20	57,15	38,10
16	K-55/N-80	75 - 84	e.g. H 521	16,155	38,10	17,08
13,38	K-55/L-80	61 - 68	e.g. H 521	13,62	39,69	14,35
9,625	L-80/C-95	43,5 - 47	BTC	10,625	20,64	20,64
7	L-80/P-110	26 - 32	BTC	7,656	10,72	10,72

The casing scheme ...an important factor for the costs of a deep well?

Estimated Cost Savings w. "Slim Clearance Scheme" - Mud, Disposal, Cement

Hole diameter "standard" inch	Hole diameter "slim " inch	Max. Depth m	Mud- volume- factor	Mud- cost Euro/m³	Mud- disposal Euro/m³	Cement- cost Euro/m³	Cost Saving by Alternative 2 ("slim ") Mud Euro Cem. Euro
30,00	23	950	6	100	150	250	348.249 27.551
23,00	17,5	2.600	5	200	250	300	523.783 54.168
17,50	14,75	3.600	5	250	250	350	134.816 20.762
12,25	12,25	4.200	4	300	250	350	0 0
8,50	8,5	4.500	4	100	250	350	0 0
							1.006.848 102.481
							Total Euro 1.109.329

Further Cost Reductions to be expected due to ...

- lower pump rates => reduced fuel/energy consumption
- better bit hydraulics => faster drilling => reduced rig time
- smaller bits => reduced bit cost
- smaller casing OD => thinner wall sufficient => less steel => reduced cost
- smaller casing OD => higher BUR => shorter trajectory => reduced cost
- reduced cement volumes => faster cement jobs
- ? smaller rig sufficient ? => reduced rig cost!
- ? smaller rig site ? => less environmental impact!

Centralisation in Narrow Clearance Annuli

Problem:

- Standard centralizer ring OD larger than pipe OD
- stop collar OD larger than pipe OD
- reduction of the annular cross section area
- *critical in narrow clearances!*

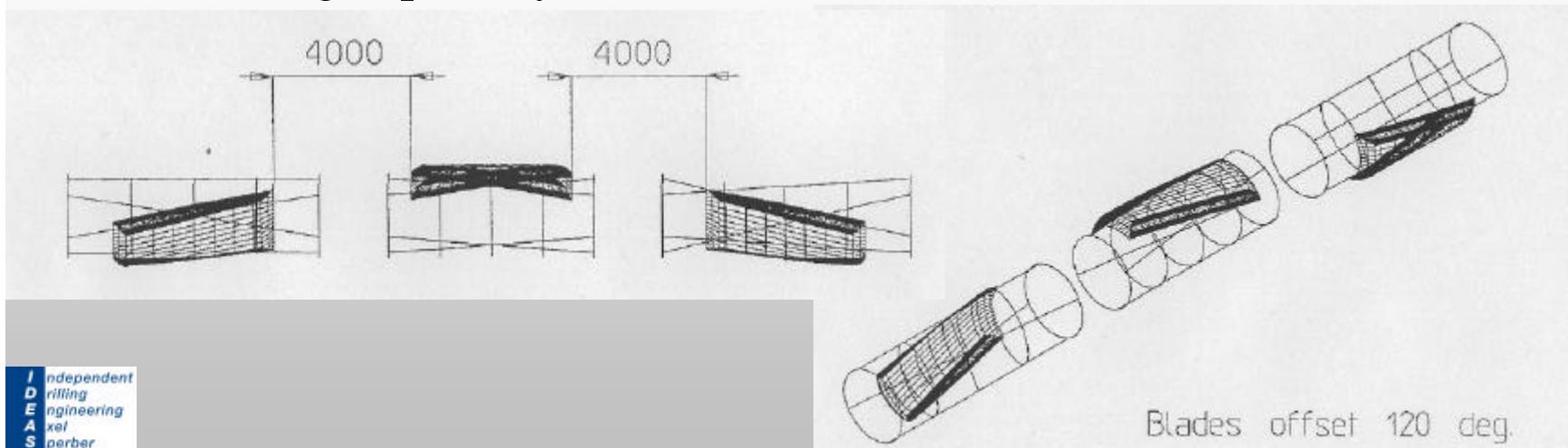


**Non-Weld
Straight Centralizer**

Centralisation in Narrow Clearance Annuli

Solution:

- Centralizer without rings and stop collars!
- ribs mounted directly to the pipe body
- ideal in narrow clearance application
- various rib distribution pattern possible (e.g. equidistant)
- different shapes possible (straight, spiral, ring, etc.)
- only minor reduction of the annular cross section area
- reduction of drag (low friction coefficient, no additional sideforces)
- reaming capability



Centralisation in Narrow Clearance Annuli

Material: CRB Ceramic/Carbon Fiber Composite

- **Carbon fiber** (improves structural support in terms of tensile, shear, and toughness)
- **Silicon Carbide and Titanium Nitride** (for abrasion resistance and impact resistance)
- **Combination of Novalac resins and two stage hardener systems**



Centralisation in Narrow Clearance Annuli

- Comparison of 16"-Casing in 17 1/2"-OH

nom. pipe-OD*	OH-Diam.	Blade Type	Blade dimensions	Blades per centralizer	Blade-distribution	corrected. OD	open area in annulus
inch	inch		L inch B inch H inch			inch	inch ² mm ²
16,000	406,40	17,500	old shape #18 23,622 5,906 0,571	3	distributed	16,134 409,79	36,1 23.286
16,550	420,37	17,500	bow type 20,000 2,000 0,475	6	bow-type	16,768 425,90	19,7 12.713

* with standard centralizers/bei Standardcentralizern: Ring-OD

- Comparison of 13 3/8"-Casing in 16"- and 14 3/4"-OH

nom. pipe-OD*	OH-Diam.	Blade Type	Blade dimensions	Blades per centralizer	Blade-distribution	corrected. OD	open area in annulus
13,375	339,73	16,000	#18 (mod.) 23,622 5,906 1,300	3	distributed	13,736 348,88	52,9 34.118
13,900	353,06	16,000	bow type 20,000 2,000 1,050	6	bow-type	14,466 367,43	36,7 23.687
13,375	339,73	14,750	old shape #18 23,622 5,906 0,571	3	distributed	13,535 343,78	27,0 17.420
13,900	353,06	14,750	bow type 20,000 2,000 0,420	6	bow-type	14,129 358,88	14,1 9.088

* with standard centralizers/bei Standardcentralizern: Ring-OD

The casing scheme ...

most important factor for the success of a deep well?

Casing Design – what is to be done?

Calculation of ...

- o Expected pressures on casing strings
 - External
 - Internal
- o Expected loads on casing strings
 - string weight
 - bending (doglegs, deviated wells)
 - Drag
 - additional tension (or compression)

Calculation of ...

- o pressure capacities of casing (pipe body & connection)
 - against collapse
 - against burst
- o load capacities of casing (pipe body & connection)
 - yield strength
 - tensile strength
- o temperature influence
 - strength of steel is reduced by elevated temperatures
 - reduction of pressure capacities of pipe
 - reduction of load capacities of casing (pipe body & connection)

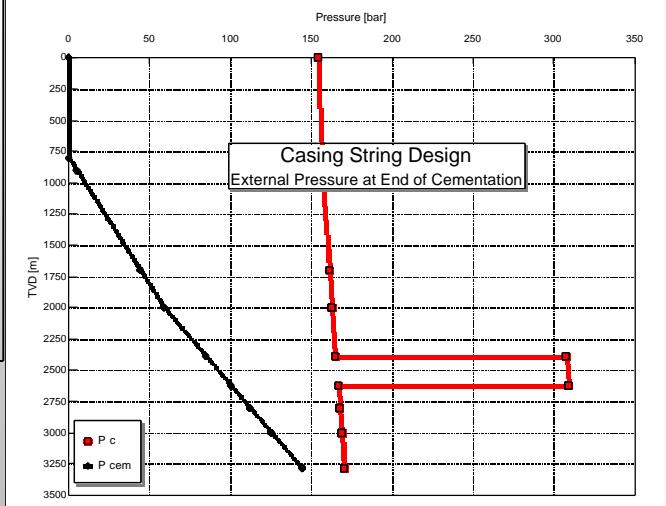
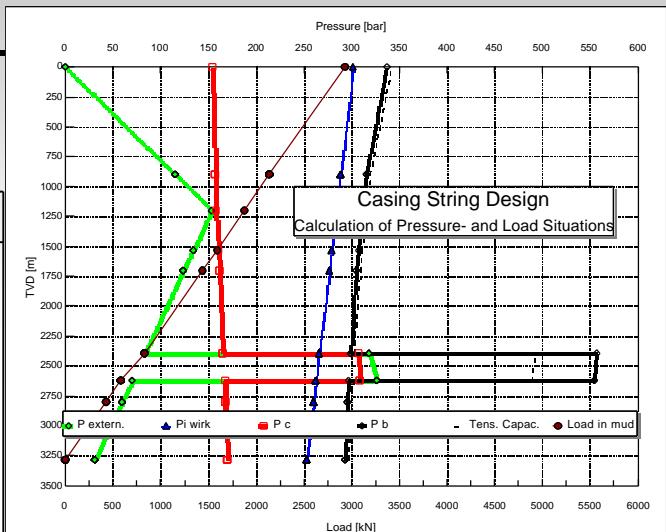
The casing scheme ...

most important factor for the success of a deep well?

Casing Design – results of calculations

Example GT-well

Casing-Design	13 3/8"- Intermediate String/-Liner							Type:	Z
General Assumptions								gas bear. form. expected in next section ?	N
Csg. Top Depth	m	0,0	0,0					Frac through this string?	J
Shoe Depth	m	3285,0	3285,0					empty Pipe (Losses) to (m)	1200,0 m (red. !)
Drill-out Depth	m	3835,0	3835,0					empty Pipe (Kick) to (m)	1534,0 m
s.G. mud "r.i.h."		1,3 kg/l						Lead-Slurry	1,8 kg/l
s.G. mud "next phase"		1,9 kg/l						Tail-Slurry	1,98 kg/l
after Completion		1,05 kg/l						Mud behind Pipe	1,15 kg/l
Mud Loss-Situation		1 kg/l						T.O.C. Lead	800 m
expected Pore Pressure (equiv.)		1,9 kg/l						T.O.C. Tail	2000 m
Salt Gradient		2,3 kg/l						relative Density of Gas	0,66508
Frac Gradient (at casing shoe)		1,8 kg/l						Rpwarm=Rp/20^b*T^a;b =	-0,08
Frac Gradient (at frac depth)		1,8 kg/l						additional Tension	- kN
Frac Depth		3285,0 m						add. Burst Press. Reserve (top)	- bar
Density of Frac Fluid		1,00 kg/l						T wellhead & at next shoe [°C]	20 135
Casing String Sections	RS	1	2	3	4	5	6		7
from TVD	3285,0	3284,5	3000,0	2800,0	2620,0	2390,0	1700,0		900,0
to TVD	3284,5	3000,0	2800,0	2620,0	2390,0	1700,0	900,0		-
OD (inch)	13,375	13,375	13,375	13,375	13,625	13,375	13,375		13,375
nominal Weight (lbs/ft)	72	72	72	72	88,2	72	72		72
Grade	L-80	L-80	L-80	L-80	Q-125	L-80	L-80		L-80
Quality (HC/API)	API	API	API	API	API	API	API		API
Connection Type	H 521	H 521	H 521	H 521	H 513	H 521	H 521		H 521
Salt formation (yes = 1)	-	-	-	-	1	-	-		-
avg. Inclination (°)	-	-	-	-	-	-	-		-
AHD down (m)	3285,0	3284,5	3000,0	2800,0	2620,0	2390,0	1700,0		900,0
AHD top (m)	3284,5	3000,0	2800,0	2620,0	2390,0	1700,0	900,0		-
Section Length (m)	0,5	284,5	200,0	180,0	230,0	690,0	800,0		900,0
Yield Strength Red. (bttm.)	13,3%	13,3%	12,7%	12,4%	12,0%	11,5%	9,6%		6,6%
max. DLS (°/10m)	0,5	0,5	0,5	0,5	0,5	0,5	0,5		0,5
additional Tension (kN)	-	-	-	-	-	-	-		-



The casing scheme ...

most important factor for the success of a deep well?

Casing Design – how is it done?

Calculation of Pressure Situations

- External pressure
 - Inside (partially) empty; outside mud
 - Inside mud; outside (partially) cement
 - Squeezing formations (salt, shales)
- Internal pressure
 - Influx (brine, gas, etc.)
 - Stimulation (Hydrofrac)

Calculation of Pressure Capacities (acc. API Bul. 5C3)

- Collaps
 - API-formulae
 - D/t-relation (4 different cases)
 - Strength of material (steel type);
yield strength = f(temperature)!
- Burst (Internal Yield Pressure)
 - API-formula
 - Wall thickness
 - Strength of material (steel type);
yield strength = f(temperature)!

The casing scheme ... most important factor for the success of a deep well?

Casing Design – how is it done?

Calculation of Pressure Capacities (acc. API Bul. 5C3)

- **Yield Strength Collapse Pressure Formula:** $P_{Yp} = 2 Y_p [\{ (D/t) - 1 \} / \{ (D/t)^2 \}]$
- **Plastic Collapse Pressure Formula:** $P_p = Y_p [A/(D/t) - B] - C$
- **Transition Collapse Pressure Formula:** $P_T = Y_p [F/(D/t) - G]$
- **Elastic Collapse Pressure Formula:** $P_E = (46,95 \times 10^6) / [(D/t) \{ (D/t)-1 \}^2]$
- **Collapse Pressure under Axial Tension Stress**
$$Y_{pa} = [\{ 1 - 0.75 (S_a/Y_p)^2 \}^{1/2} - 0.5 S_a/Y_p] Y_p$$

with:
 Y_p = yield strength of pipe [psi]
 S_a = axial tension stress [psi]
 Y_{pa} = yield strength of axial stress equivalent grade [psi]
- **Internal Yield Pressure:** $P = 0.875 [(2 Y_p t) / D]$

Remark: factor 0.875 is for 87.5% of nominal wall thickness t (12.5% wall reduction is allowed!)

The casing scheme ...

most important factor for the success of a deep well?

Casing Design – how is it done?

D/t- Relation (acc. API Bul. 5C3)

Grade	Yield Collapse	Plastic Collapse	Transition Collapse	Elastic Collapse
J/K-55	</= 14.81	14.81 - 25.01	25.01 - 37.21	> 37.21
L/N-80	</= 13.38	13.38 - 22.47	22.47 - 31.02	> 31.02
P-110	</= 12.44	12.44 - 20.41	20.41 - 26.22	> 26.22
Q-125	</= 12.11	12.11 - 19.63	19.63 - 24.46	> 24.46

Factors used in the Collapse Formulae (acc. API Bul. 5C3)

Grade	Plastic Collapse			Transition Collaps	
	A	B	C	F	G
J/K-55	2.991	0.0541	1206	1.989	0.0360
L/N-80	3.071	0.0667	1955	1.998	0.0434
P-110	3.181	0.0819	2852	2.066	0.0532
Q-125	3.239	0.0895	3301	2.106	0.0582

The casing scheme ...

most important factor for the success of a deep well?

Casing Design – how is it done?

Wall thicknesses of common Casing & Tubing Sizes
 (bold = common wall thickness range)

D/t =	7,1		12,11		37,21		46,1	
OD [inch]	wall thickness							
	[inch]	[mm]	[inch]	[mm]	[inch]	[mm]	[inch]	[mm]
2,375	0,335	8,50	0,196	4,98	0,064	1,62	0,052	1,31
2,875	0,405	10,29	0,237	6,03	0,077	1,96	0,062	1,58
3,5	0,493	12,52	0,289	7,34	0,094	2,39	0,076	1,93
4,5	0,634	16,10	0,372	9,44	0,121	3,07	0,098	2,48
5	0,704	17,89	0,413	10,49	0,134	3,41	0,108	2,75
7	0,986	25,04	0,578	14,68	0,188	4,78	0,152	3,86
9,625	1,356	34,43	0,795	20,19	0,259	6,57	0,209	5,30
10,75	1,514	38,46	0,888	22,55	0,289	7,34	0,233	5,92
13,375	1,884	47,85	1,104	28,05	0,359	9,13	0,290	7,37
16	2,254	57,24	1,321	33,56	0,430	10,92	0,347	8,82
18,625	2,623	66,63	1,538	39,06	0,501	12,71	0,404	10,26
24,5	3,451	87,65	2,023	51,39	0,658	16,72	0,531	13,50

The casing scheme ... most important factor for the success of a deep well? Casing Design – how is it done?

Influence of Pipe Diameter on Pressure Capabilities

(calculated acc. APIBul. 5C3; same wall thickness and grade)

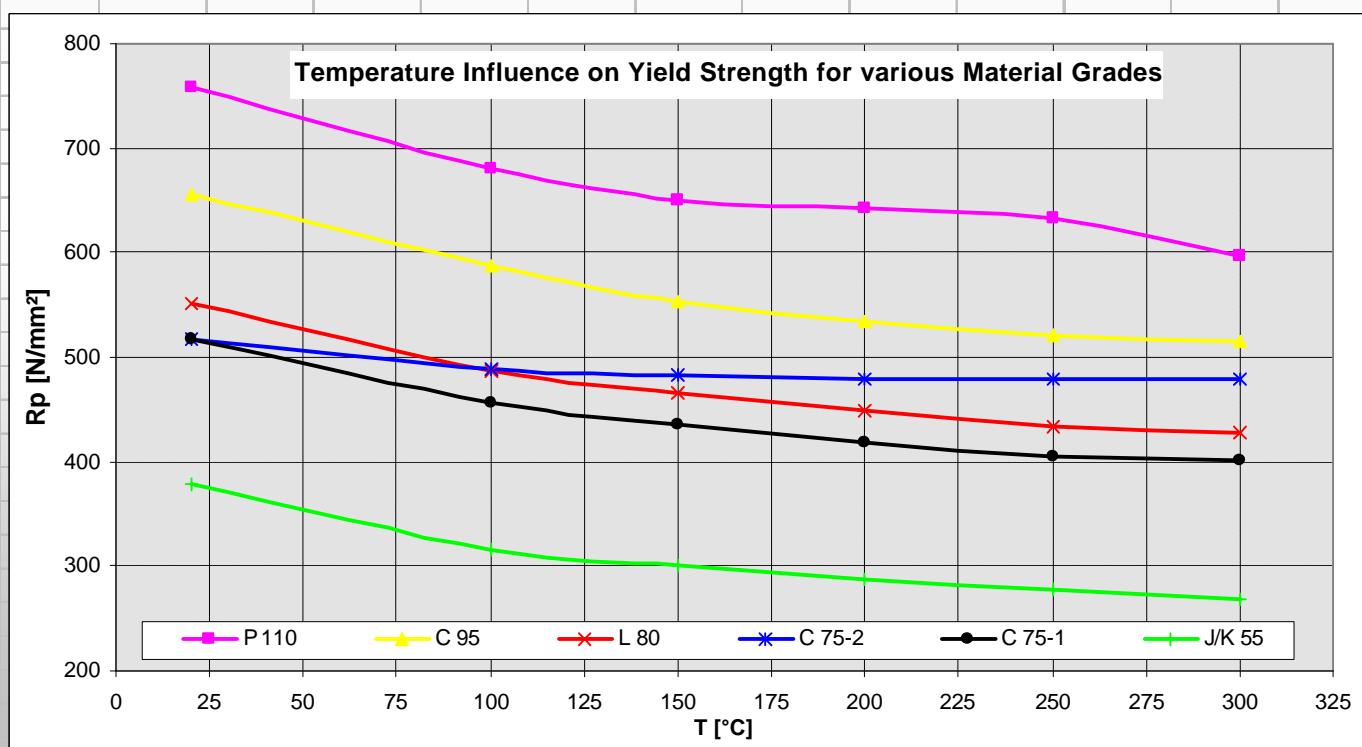
OD [inch]	24,5	20	18,625	16	13,375	11,75	10,75	9,625
p.e. weight [lb/ft]	111,3	90,5	84,2	72,0	59,9	52,4	47,7	42,5
p.e. weight [kg/m]	165,8	134,8	125,4	107,3	89,2	78,0	71,1	63,3
wall [mm]	11	11	11	11	11	11	11	11
Grade [ksi]	K-55	K-55	K-55	K-55	K-55	K-55	K-55	K-55
	internal yield pressure							
bar	117	144	154	180	215	245	267	299
	collapse pressure							
bar	19	34	43	68	108	142	169	222

The casing scheme ...

most important factor for the success of a deep well?

Casing Design - Temperature Influence on Yield Strength

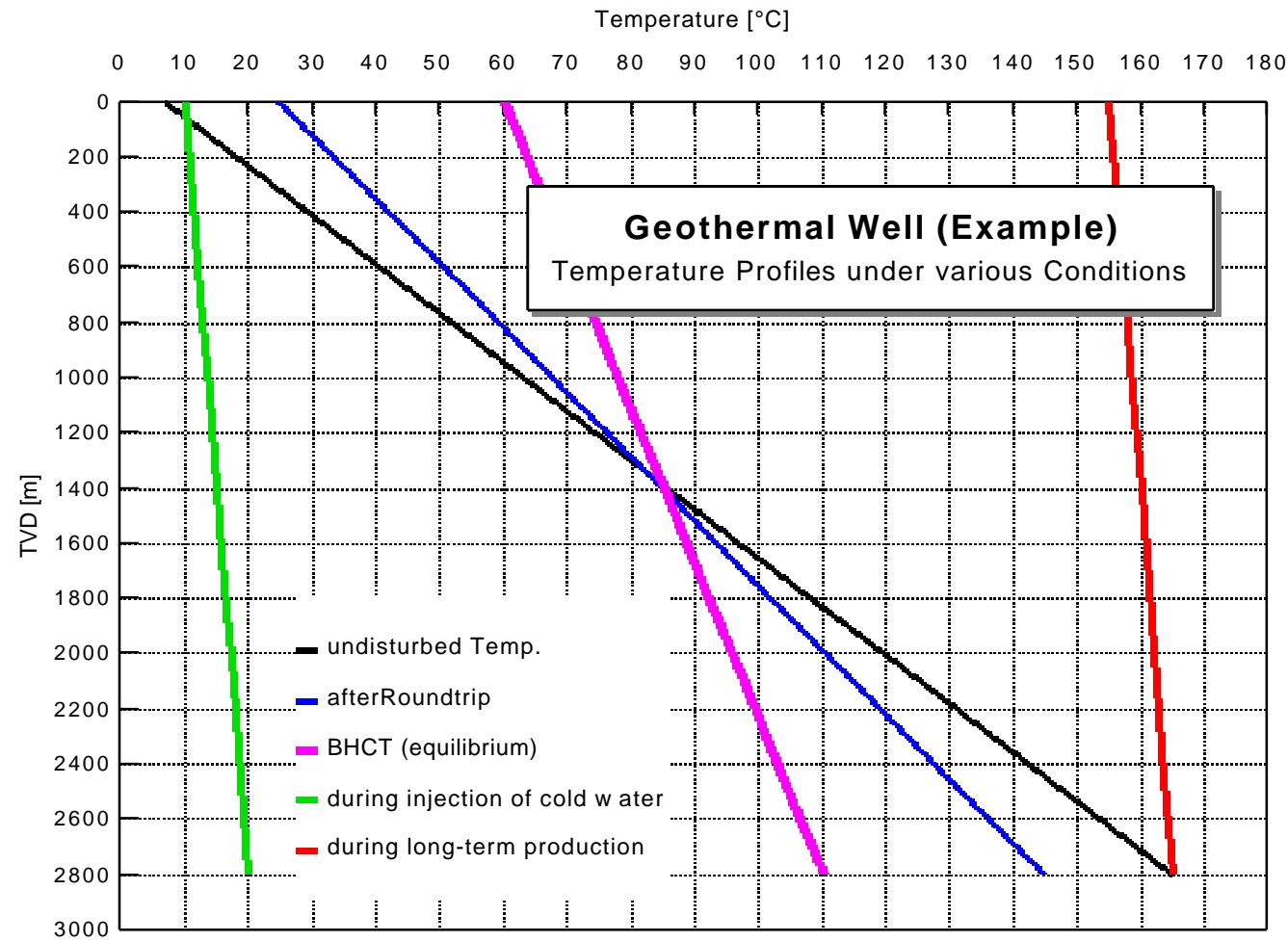
Temp. °C	J/K 55		C 75-1		C 75-2		L 80		C 95		P 110	
	N/mm ²	%										
20	379	100,0%	517	100,0%	517	100,0%	552	100,0%	655	100,0%	758	100,0%
100	315	83,1%	456	88,2%	488	94,4%	487	88,2%	587	89,6%	681	89,8%
150	300	79,2%	435	84,1%	483	93,4%	465	84,2%	554	84,6%	651	85,8%
200	288	76,0%	419	81,0%	480	92,8%	448	81,2%	535	81,7%	643	84,8%
250	277	73,1%	406	78,5%	480	92,8%	434	78,6%	521	79,5%	632	83,4%
300	269	71,0%	401	77,6%	479	92,6%	428	77,5%	515	78,6%	597	78,7%



The casing scheme ...

most important factor for the success of a deep well?

Casing Design - Temperature Changes in the Borehole



The casing scheme ...

most important factor for the success of a deep well?

Casing Design - Temperature Changes in the Borehole

Length Change due to Temperature Change and resulting compensation load					
Pipe OD	(inch)	18,625	16,000	13,375	9,625
Pipe wall	(mm)	12,32	11,13	10,92	10,03
nominal weight	lb/ft	96,5	75	61	40
cross section area	(mm ²)	17833	13821	11280	7387
Grade		L-80	L-80	L-80	L-80
weight per m	kg	140	108	89	58
Collapse pressure	bar	60	70	115	213
Burst pressure	bar	251	264	310	396
Top of cement	m	500	500	500	500
avg. delta t *	°C	60	60	60	60
delta l *	m	0	0	0	0
* across free length of casing string					
F compensation	kN	2696	2090	1706	1117
	t metric	275	213	174	114

Calculation Procedure:

1. Calculation of Length Change

- o $\Delta l = TOC * \alpha_{therm} * \Delta t$
- o $(\alpha_{therm} \text{ steel} = 12 * 10^{-6} / {}^\circ C)$

2. Calculation of the Tension to obtain the equivalent Length Change

- o $F_{res} = E * A * \Delta l / TOC * 10^{-3}$
- o $(E_{steel} = 2,1 * 10^5 \text{ N/mm}^2)$

3. Calculation of the necessary Landing Weight

- o $F_{land} = F_{res} + G_{toc} + \text{add. slip load}$

Conclusions

- Slim Clearance Casing Schemes are technically feasible
- Slim Clearance Casing Schemes can offer technical advantages
- Slim Clearance Casing Schemes must not reduce tubing diameter and Flowrate Potential
- Improved planning is mandatory
- Proper centralisation of casing is important
- *Slim Clearance Casing Schemes can reduce overall well cost and can contribute to the economy of a geothermal project!*

*A well done
Well Design is
the Base of a
technically
and
economically
successfull
Well!*

*This is the end
(of my presentation)!*

*Thank you for your
attention*

... any questions?