Geothermal Drilling Overview

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My Point of View

- **No drilling engineer**
- **Developer and consultant for geothermal projects worldwide**
  - Germany
  - Switzerland
  - Tanzania
  - Indonesia
- **First well drilled in 2003**
  - Upper Rhine Valley / Offenbach an der Queich
  - Depth: 2360 m
  - Deviated well
  - No major drilling problems
  - But: …dry well
- **Research and development in drilling technology**
  - [illegible] rig "Herrenknecht Vader"
  - Downhole tool: Seismic prediction while drilling
  - Hard rock drilling using electrical impulse method

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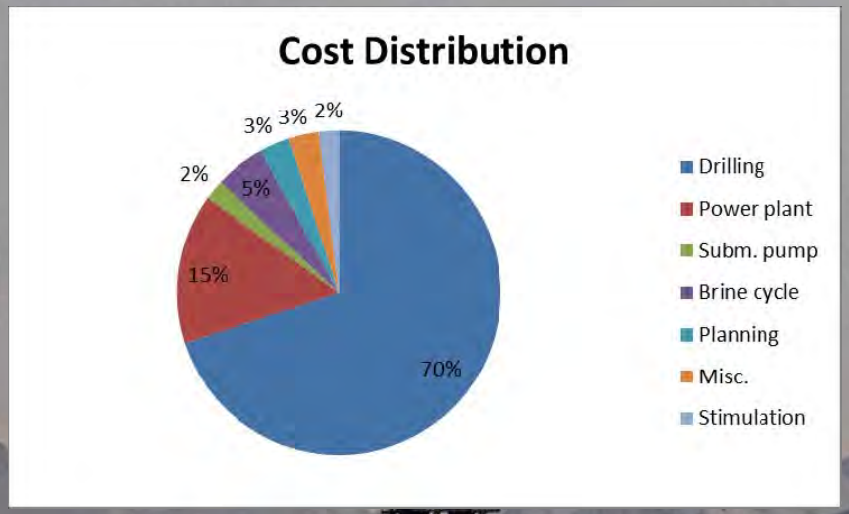
I. Importance of Drilling

- **Drilling cost vs. project cost**
  - Heat project up to 90 % (excluding distribution system)
  - Electricity project 50 – 70%



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- **Drilling risk**
  - Lost in hole
  - Stuck pipe
  - Casing ins[illegible]y
  - Side-tracks
  - You can loose a well but you cannot loose a power plant !

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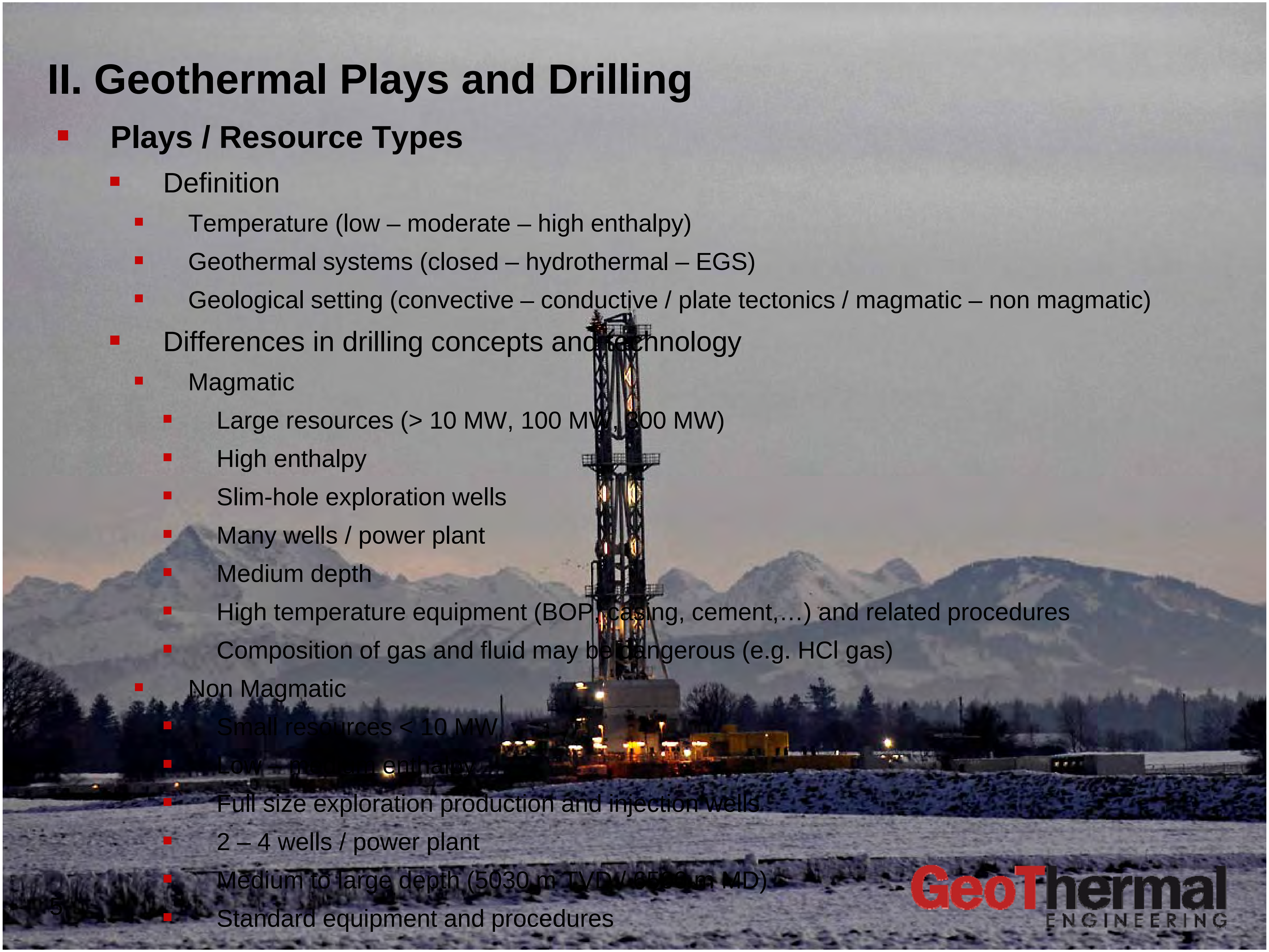

II. Geothermal Plays and Drilling

- **Plays / Resource Types**
  - Definition
    - Temperature (low – moderate – high enthalpy)
    - Geothermal systems (closed – hydrothermal – EGS)
    - Geological setting (convective – conductive / plate tectonics / magmatic – non magmatic)
  - Differences in drilling concepts and technology
    - Magmatic
      - Large resources (> 10 MW, 100 MW, 300 MW)
      - High enthalpy
      - Slim-hole exploration wells
      - Many wells / power plant
      - Medium depth
      - High temperature equipment (BOP, casing, cement,…) and related procedures
      - Composition of gas and fluid may be dangerous (e.g. HCl gas)
    - Non Magmatic
      - Small resources < 10 MW
      - Low – medium enthalpy
      - Full size exploration production and injection wells
      - 2 – 4 wells / power plant
      - Medium to large depth (5030 m TVD / 6500 m MD)
      - Standard equipment and procedures

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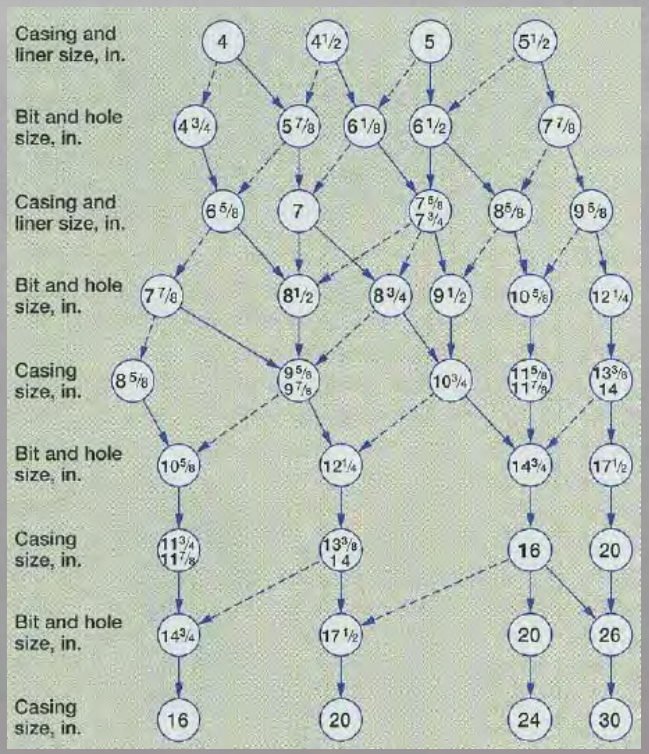
III. Geothermal vs. Oil and Gas Drilling

- **Differences**
  - Low - medium enthalpy
    - Well size
    - Less horizontal drilling
    - Reservoir protecting drilling methods
    - EGS: Hard rock drilling
  - High enthalpy
    - All of above
    - High temperature equipment
    - High temperature safety procedures
    - Less electronics



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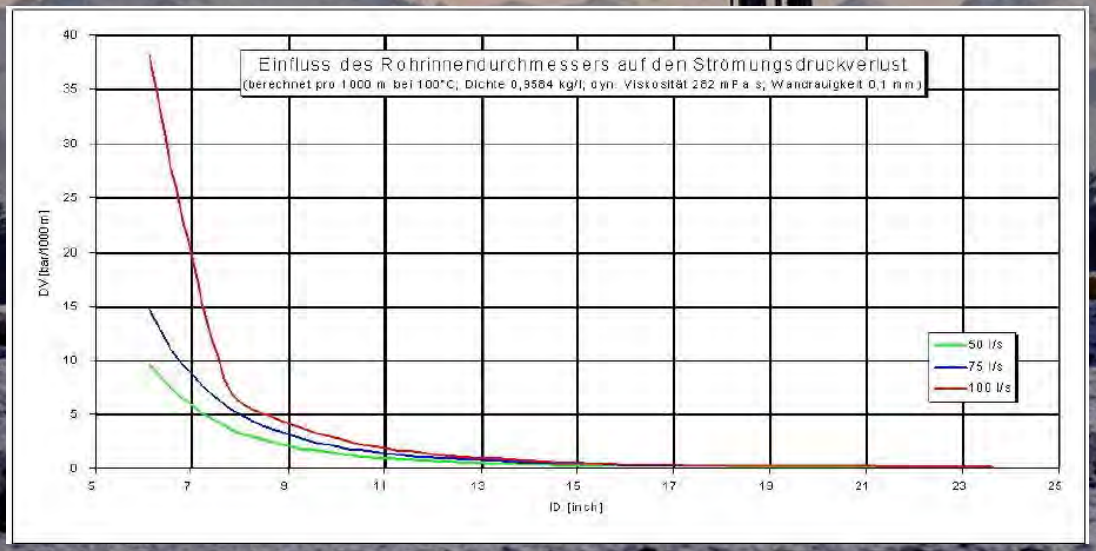

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IV. Drilling as a Team Effort

- **Drilling and drilling service**
  - Drilling rig
  - Services:

Mud	Cement
Logging	Casing
Directional drilling	Geological sampling
Supervision	Data acquisition
Coiled tubing	Drill bit
Stimulation	Drilling tools

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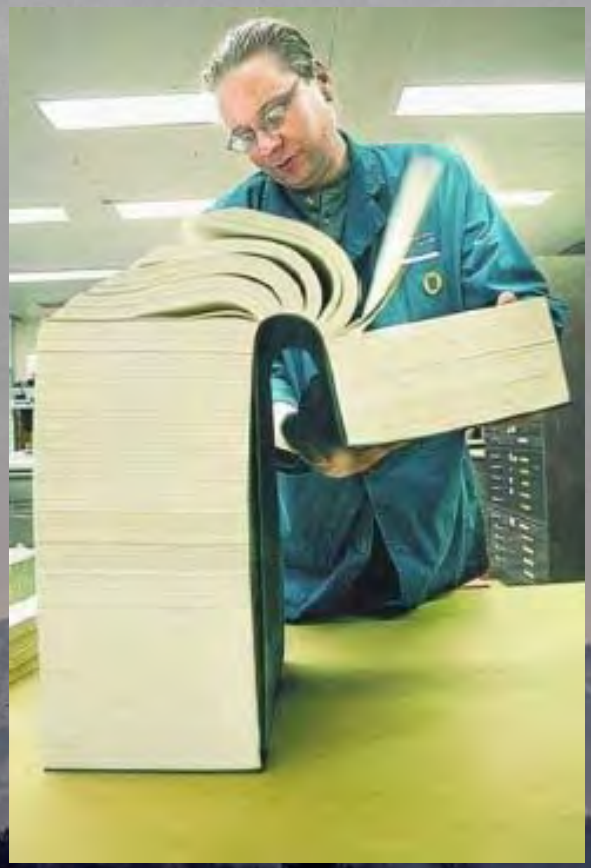
V. Planning

- **Drilling program**
  - Drilling procedure (section by section)
  - Casing and cementing program
  - Drilling fluids program
  - Drill bit program
  - Directional program
  - Well logging
  - Geological sampling program / mud logging
  - Drilling data acquisition
  - Testing program
  - Procurement
  - Communication
  - Safety program
  - Waste disposal

Interface management

- **Contracts**
  - Day rate — Meter contract
  - Turn key — Open books



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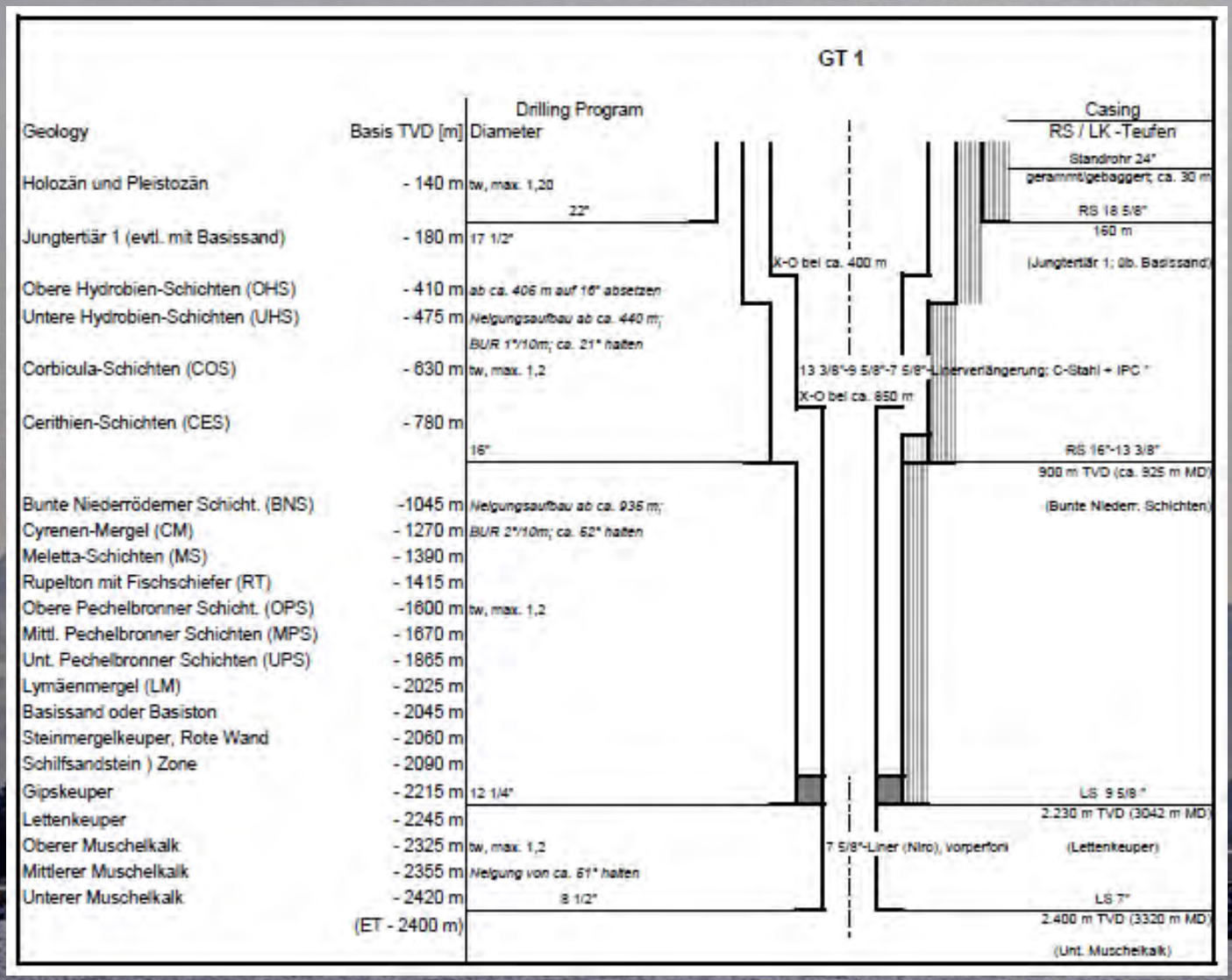
V. Planning



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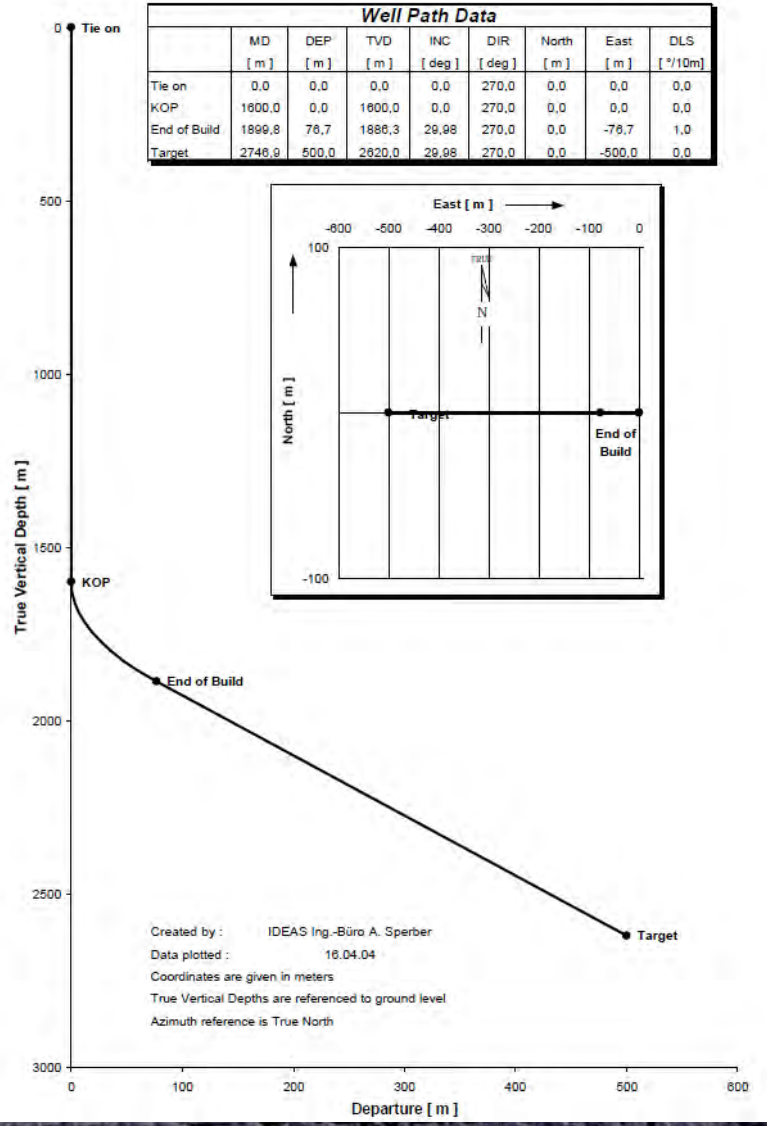
V. Planning

Well Path Data

	MD [m]	DEP [m]	TVD [m]	INC [deg]	DIR [deg]	North [m]	East [m]	DLS [°/10m]
Tie on	0,0	0,0	0,0	0,0	270,0	0,0	0,0	0,0
KOP	1600,0	0,0	1600,0	0,0	270,0	0,0	0,0	0,0
End of Build	1899,8	76,7	1886,3	29,98	270,0	0,0	-76,7	1,0
Target	2746,9	500,0	2620,0	29,98	270,0	0,0	-500,0	0,0

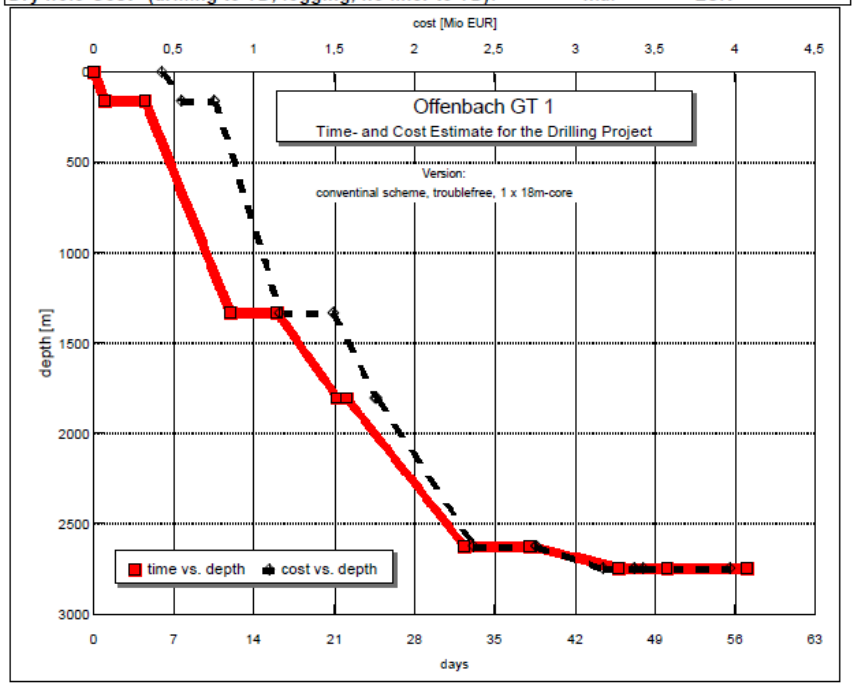


Time- and Cost Estimate for the Drilling Project

Version: conventinal scheme, troublefree, 1 x 18m-core

Phase	1	2	3	4	5	6
to depth [m]	155	1335	1800	2624	2750	2750
hole diameter [inch]	22	16	12,25	12,25	8,5	8,5
work steps	D/L/Cas/Cem	D/L/Cas/Cem	D	D/L/Cas/Cem	D/L/Cas	Compl/T
ROP drilling [m/h]	10	8	5	4	2	
ROP coring [m/h]					1	
time/phase	4,50	11,50	6,00	16,00	12,00	7,00
time cumulated	4,50	16,00	22,00	38,00	50,00	57,00
* Abbrev.: R= rig up/down, PB= plug back, KO= kick off, D= drilling, H= hole open./underr, L= logging, Cas= run casing, Lin= run liner, Cem= Cementing, Compl= completion, T= testing						
costs *						
drilling related	119.442	408.665	263.503	603.606	416.193	54.411
EUR/m	771	346	567	733	3.303	
EUR/h	5.745	2.292	2.084	2.425	2.220	
EUR/d	137.873	54.998	50.026	58.210	53.278	
non-drilling related	146.676	329.845	10.007	388.165	197.521	443.509
miscellaneous						
site, de-/mob.	487.025					100.108
total phase	753.143	738.510	273.511	991.770	613.714	598.028
cum. well	753.143	1.491.653	1.765.163	2.756.934	3.370.648	3.968.676
* incl. a risk margin of	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%

Dry hole-Cost" (drilling to TD, logging, no liner to TD): n.a. EUR



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VI. Must Haves

- **Quality**
  - Rig and material
  - Experienced drilling crew
  - Planning and supervision
  - Team spirit
  - Kick-off meeting
- **Interface Management**
  - Services
  - Timing
  - Cost
- **Risk management**
  - A good drilling plan is risk mitigation
  - There will always be something happening you do not expect!

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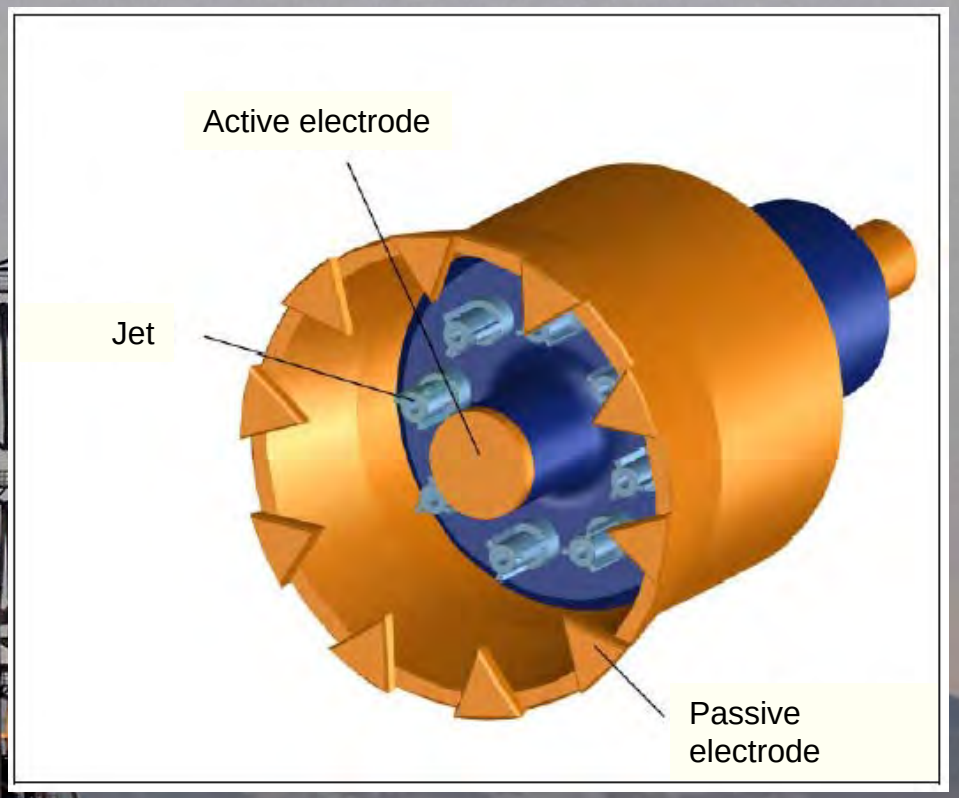
VII. Present and Future

- **Wells**
  - Present
    - Deviated wells
    - Side-tracks
  - Future
    - Horizontal wells
    - Multilaterals
- **Technology**
  - Present
    - Mechanically cutting drilling bits
    - Hydraulic hammer
  - Future
    - Spallation drilling
    - Electro impulse drilling
  - But beware of
    - Iron core drilling (melting)
    - Unrealistic speed-drilling 5000 m in 7 days
    - ....



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Thank you for your attention! **Questions?**

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