GEOELEC TRAINING COURSE
DRILLING

STRASBOURG
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OUTLINE

- SCOPE
- INTRODUCTION. GEOTHERMAL VS PETROLEUM
- DEEP WELL DRILLING/COMPLETION FEATURES
  - Rig selection
  - Site preparation. Rig footprint
  - Drilling
  - Bits
  - Drilling fluids
  - Directional drilling
  - Casing/lining
  - Cementing
  - Fishing
  - Waste disposal/processing
- CASE STUDY. PARIS BASIN GDH TRIPLET
- MEDIUM ENTHALPY CHP EXPLORATION
  - Deep (4-5 km) exploratory project
  - Slimhole strategy
- UNCONVENTIONAL GEOTHERMAL WELL DESIGNS
  - Dual completion
  - Fiberglass lined anti-corrosion well
  - (sub)Horizontal well concept
- MISCELLANEOUS ISSUES
  - Water injection
  - Mining risk insurance
  - Sustainability
  - Environment
  - Workover
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

SCOPE

Provide an engineering insight into drilling and completion technology to future geothermal players with focus on design and implementation of deep, geothermal district heating (GDH) oriented, well doublets in sedimentary environments and urban/suburban locations.

Future, non conventional, well and completion designs are also discussed.

INTRODUCTION
GEOTHERMAL VS PETROLEUM

INTERCOMPARISON SUMMARY SHEET

CHARACTERISTICS	GEOPOWER	GEOHEAT/CHP	OIL & GAS
Reservoir Environment	Volcano-tectonic	Sedimentary	Sedimentary
Rock type(s)	Volcanic, metaporphic [1]	Carbonate, clastic	Carbonate, clastic, shale [2], source rocks [2]
Depth	1 000-3 000	1 000-5 000 [3]	1 000-10 000 [4]
Pressure ( )	Under pressured	Low to near hydrostatic	Low to high
Temperature	200-350° C	30-130° C	30-250° C
Flowrate	200-350 t/h [5]	150-350 m^3/h	10-5 000 bbd
Fluid state	Single phase (liquid, stean) Two phase (liquid, stean)	Single phase liquid, solution gas	Single (oil, gas) Two (oil/ water, gas/water) Three phase (oil, gas)
Porosity type	Dominantly featured	Intergranular (Matirx), Fractured	Intergranular (Matrix), Fractured Non connected[6]
Site location	Remote land	Urban [7], suburban [7], rural [8]	Remote land off/shore
Well design	Large diameter High delivery	Large diameter high delivery	Small medium diameter
Diameter	9"$^{5/8}$ csg x 7"/ 7" $^{5/8}$ (s.l.) or 8 "$^{1/2}$ (OH) [9]	13"$^{3/8}$ x 9"$^{5/8}$ x csg x 8"$^{1/2}$ (OH) or 7 s.l. or 6-7" screen	7" csg x 5" tbg x perforated cemented 7"/5" csg [11]
Completion	Fullbore casing production Slotted liner completion	Fullbore casing production. Openhole, slotted liner, screen	Inner tubing/packer/safety valve completion
Production	Self flowing 2 phase (vapour lift)	Artificial lift Self flowing	Artificial lift gravity, self flowing

INTERCOMPARISON SUMMARY SHEET

DRILLING/COMPLETION TECHNOLOGY AND PRACTICE

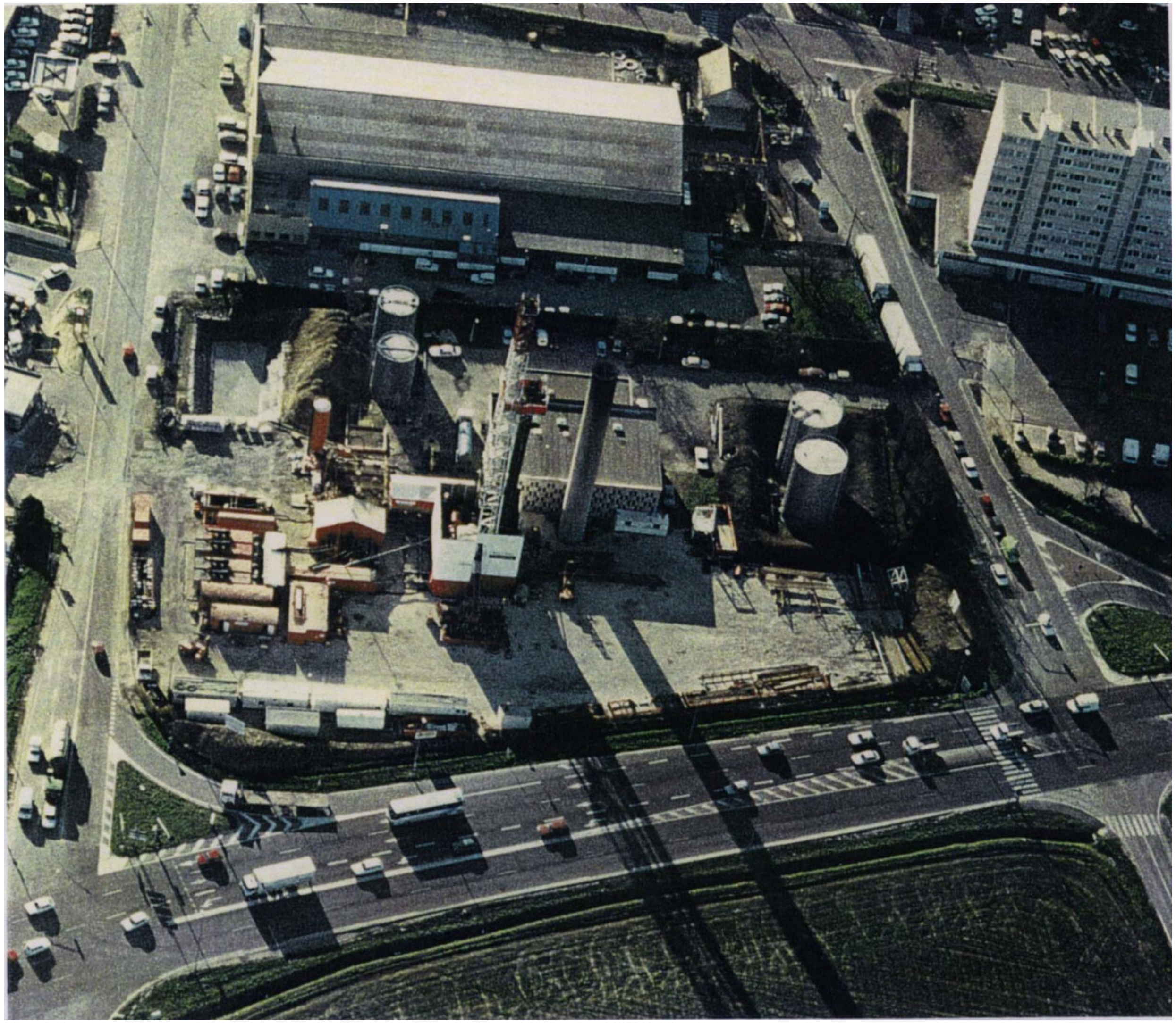
- Drilling of deep geothermal wells shares the same techniques and equipment in use in the oil and gas industry, whatever the significant differences, particularily in high enhalpy settings, existing between petroleum and geothermal resource environments with respect to petrography, formation temperatures and fluid thermochemistry.

- These differences require that, within a similar technological framework, specific drilling/completion procedures be implemented whenever dictated by reservoir/fluid conditions.

- Regarding low enthalpy (GDH) objectives the high production target implies appropriate customised completion (re)designs.

INTRODUCTION

WELL DRILLING AND COMPLETION AEREAL VIEW OF THE MELUN l'ALMONT DRILL SITE



RIG SELECTION
ITEMIZED DRILLING & COMPLETION SEQUENCE (Adapted from Hagen Hole)

- Reservoir engineering & Well targeting
- Well design and specification
- Materials specification & procurement
- Well pad & access road civil design and engineering
- Water supply design & engineering
- Civil construction supervision
- Well drilling engineering and supervision
- Provision of drilling rig and equipment
- Provision of drilling personnel
- Provision of top drive equipment & personnel
- Provision of cementing equipment, personnel & services
- Provision of directional drilling equipment & personnel
- Provision of mud engineering personnel
- Provision of aerated drilling equipment and personnel (optional)
- Provision of mud logging / geology equipment & personnel
- Drilling tool rental or purchase
- Drill pipe inspection & hard-banding
- Provision of well measurements equipment and personnel

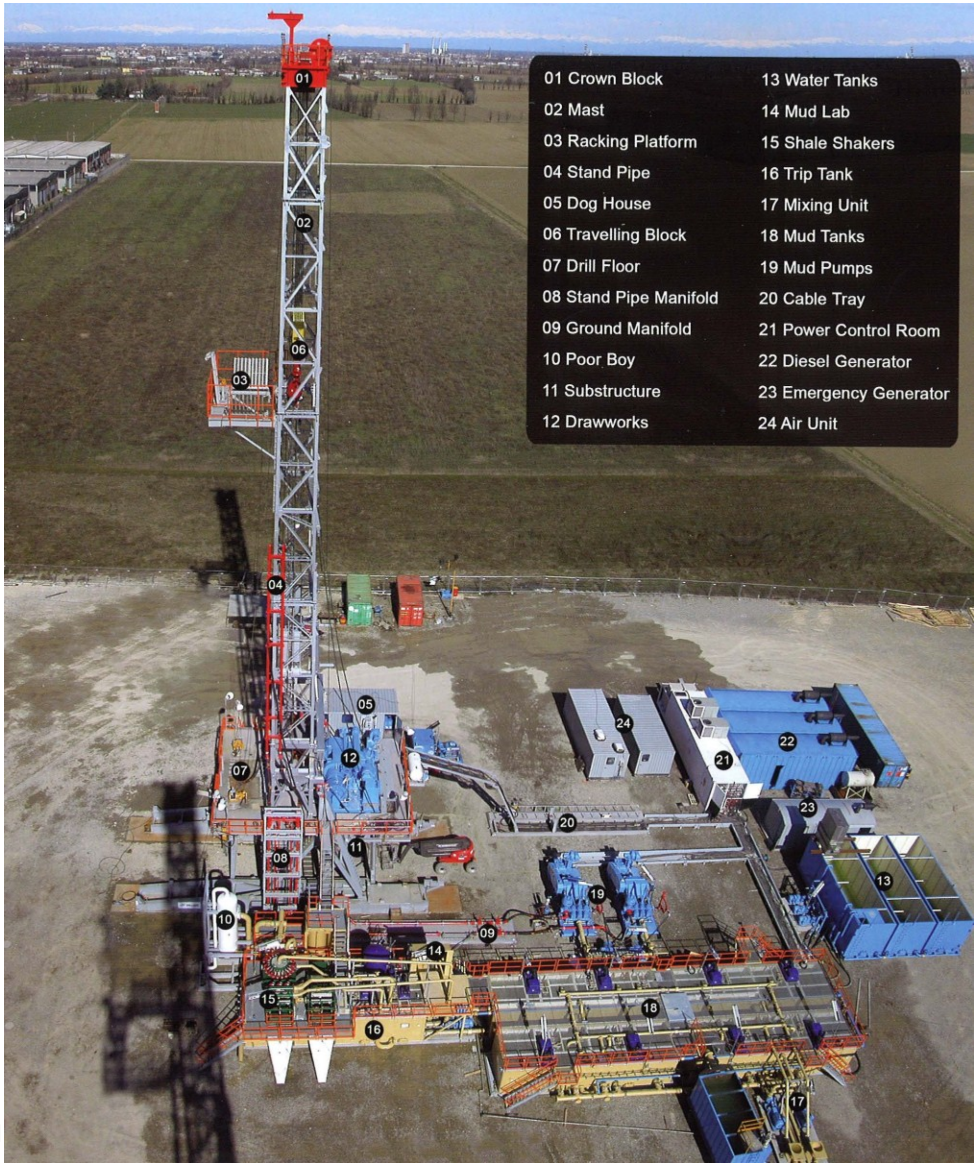
RIG SELECTION REQUIREMENTS

EXPLORATION	High risk, higher rig capacity (hook load impact on work specifications and contractor skills/experience)
DEVELOPMENT	Low risk, normal and optimised rig capacity and equipment standards and specification
DETH TARGET	Rig capacity
WELL ARCHITECTURE	Rig capacity
MAXIMUM WEIGHT IN HOLE	Rig capacity
ENVIRONMENTAL IMPACT	Low noise, low gas emission, stringent safety and waste disposal regulations, limited foot print
RISK ANALYSIS	Mandatory in assessing the technical/environmental/economic risk
FLUID COMPOSITION	Personnel (crew and neighbours) safety
RESERVOIR PRESSURE	BOP, high pressure equipment and monitoring equipment
RIG/PERSONNEL PERFORMANCE	Mandatory in ranking candidate competitor capability in meeting project specifications and selecting contractor

IDEALLY, GIVEN A 2000 M DEVIATED (35°C) 9"5/8
CASED WELL IN AN URBAN ENVIRONMENT, A 250 t dyn HOOK LOAD, ELECTRICALLY/HYDRAUCALLY POWERED, LIMITED FOOT PRINT, HIGH TORQUE TOP DRIVE AND 3600 l/min TRIPLEX PUMP CAPACITY WOULD BEST SUIT GDH SPECS.

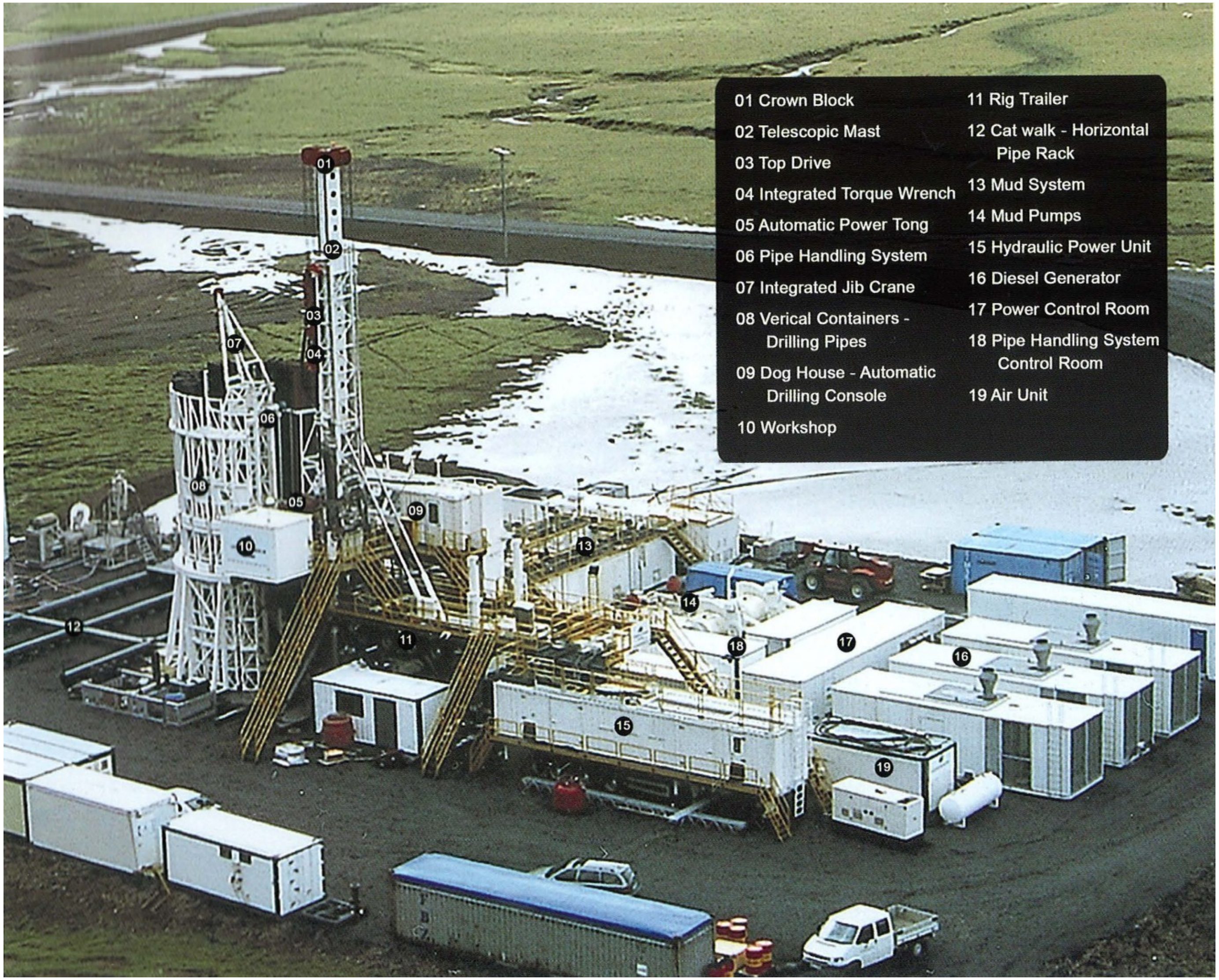
CONVENTIONAL RIG (200 t)

CONVENTIONAL HEAVY DUTY LAND RIG DESCRIPTION



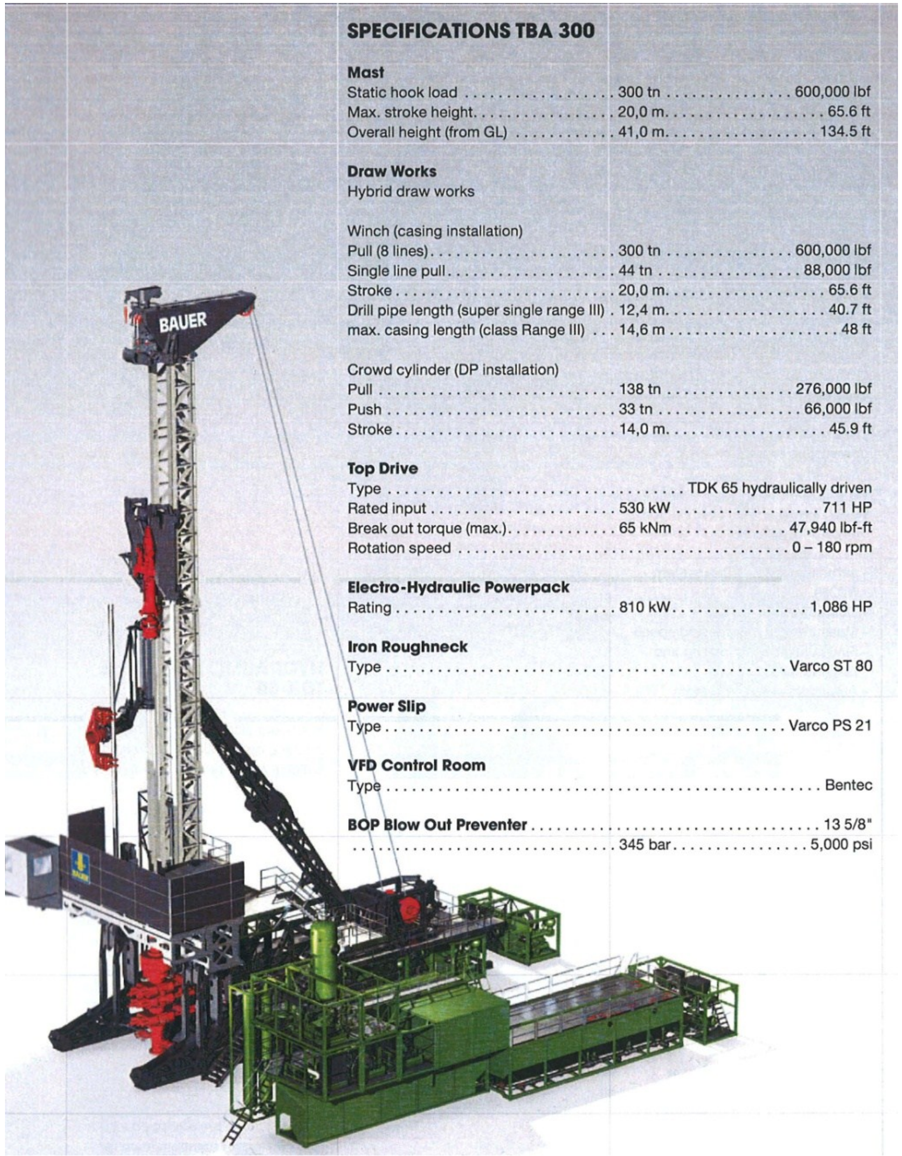
Source : DRILLMEC

NOVEL DESIGN
HEAVY DUTY HYDRAULIC RIG



Source : DRILLMEC

NOVEL COMPACT HYDRAULIC RIG DESIGN

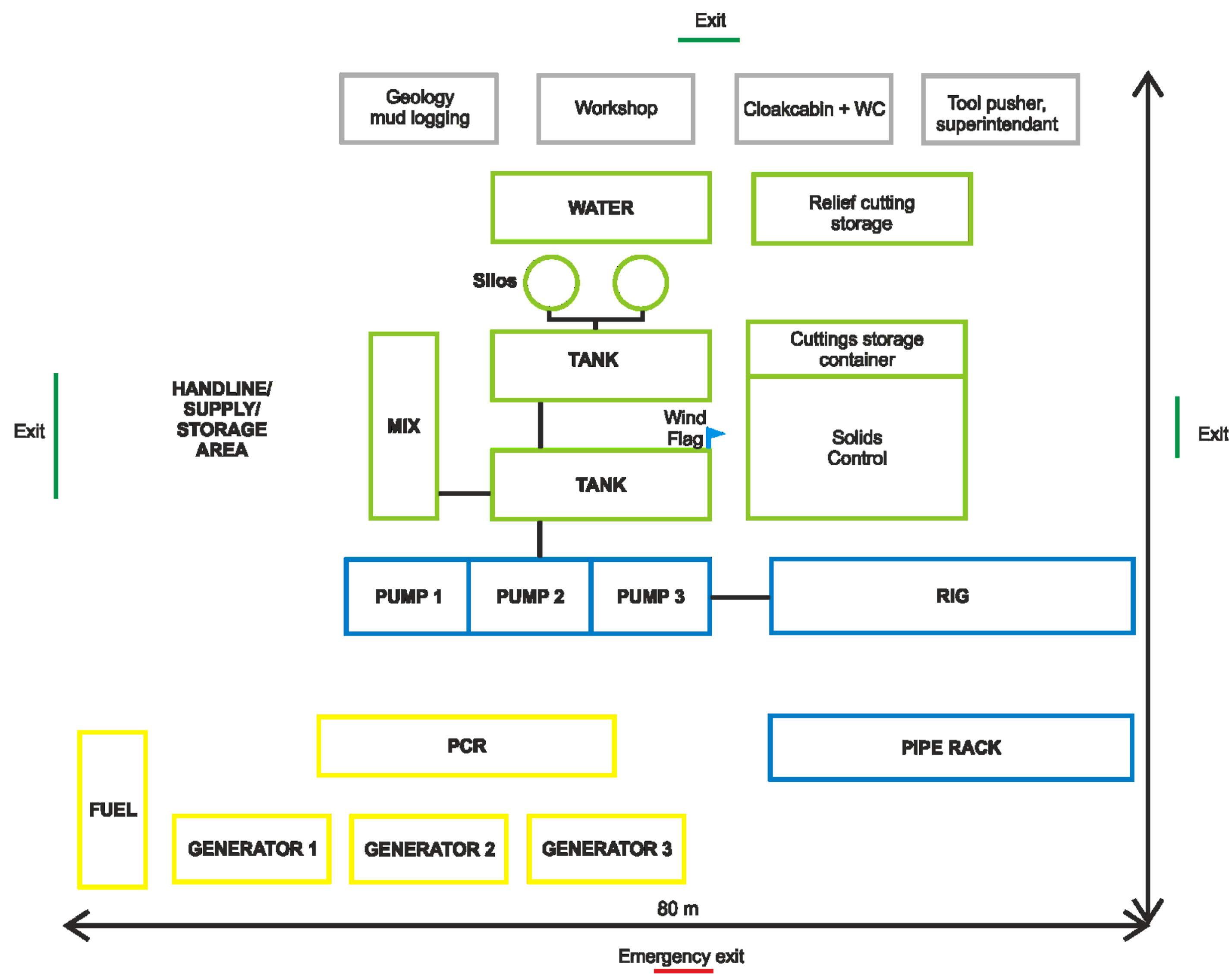


SPECIFICATIONS TBA 300

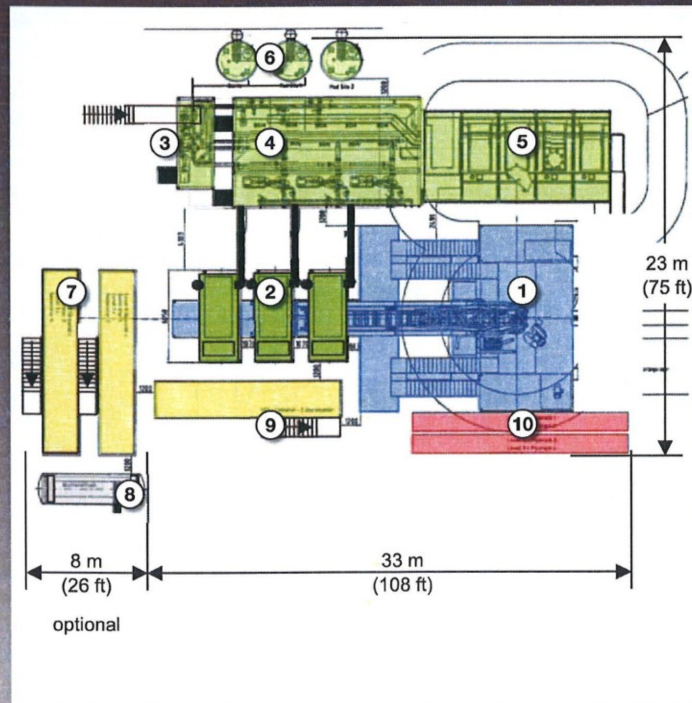
Mast		
Static hook load	300 tn	600,000 lbf
Max. stroke height	20,0 m	65.6 ft
Overall height (from GL)	41,0 m	134.5 ft
Draw Works		
Hybrid draw works		
Winch (casing installation)		
Pull (8 lines)	300 tn	600,000 lbf
Single line pull	44 tn	88,000 lbf
Stroke	20,0 m	65.6 ft
Drill pipe length (super single range III)	12,4 m	40.7 ft
max. casing length (class Range III)	14,6 m	48 ft
Crowd cylinder (DP installation)		
Pull	138 tn	276,000 lbf
Push	33 tn	66,000 lbf
Stroke	14,0 m	45.9 ft
Top Drive		
Type		TDK 65 hydraulically driven
Rated input	530 kW	711 HP
Break out torque (max.)	65 kNm	47,940 lbf-ft
Rotation speed		0 – 180 rpm
Electro-Hydraulic Powerpack		
Rating	810 kW	1,086 HP
Iron Roughneck		
Type		Varco ST 80
Power Slip		
Type		Varco PS 21
VFD Control Room		
Type		Bentec
BOP Blow Out Preventer		13 5/8"
	345 bar	5,000 psi

Source : BAUER

FOOT PRINT
HEAVY DUTY (200-300 t) RIG AND EQUIPMENTS



NOVEL COMPACT HYDRAULIC RIG FOOT PRINT

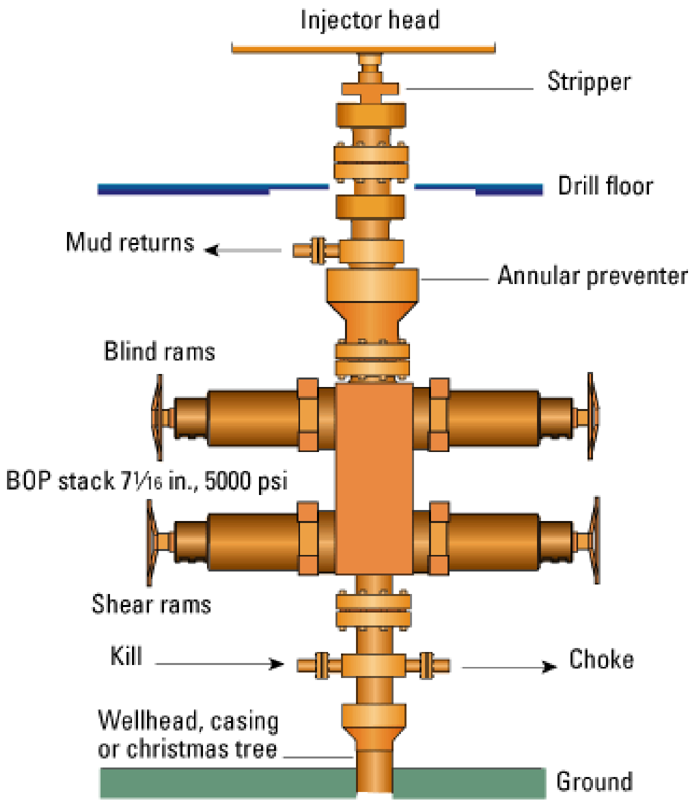


FOOTPRINT 23 m x 33 m

1	TBA 300	6	Additional tanks (barite, storage) (optional)
2	Mud pumps (3 x 900 kW)	7	Generators (4 x 1 MW) (optional)
3	Mixing station	8	Diesel tank
4	Mud tanks unit	9	VFD unit
5	Recycling unit	10	Pipe handling

Source : BAUER

BLOW OUT PREVENTER (BOP)



BOP schematic

BOP Stack

Source : J. Tester, 2011

TYPICAL DRILL BITS

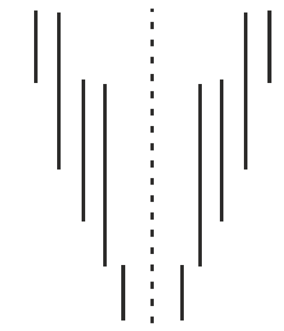
Roller Cone

Diamond Impreg

PDC

Source : IADC/SPE 72280
(quoted by J. Tester, 2011)

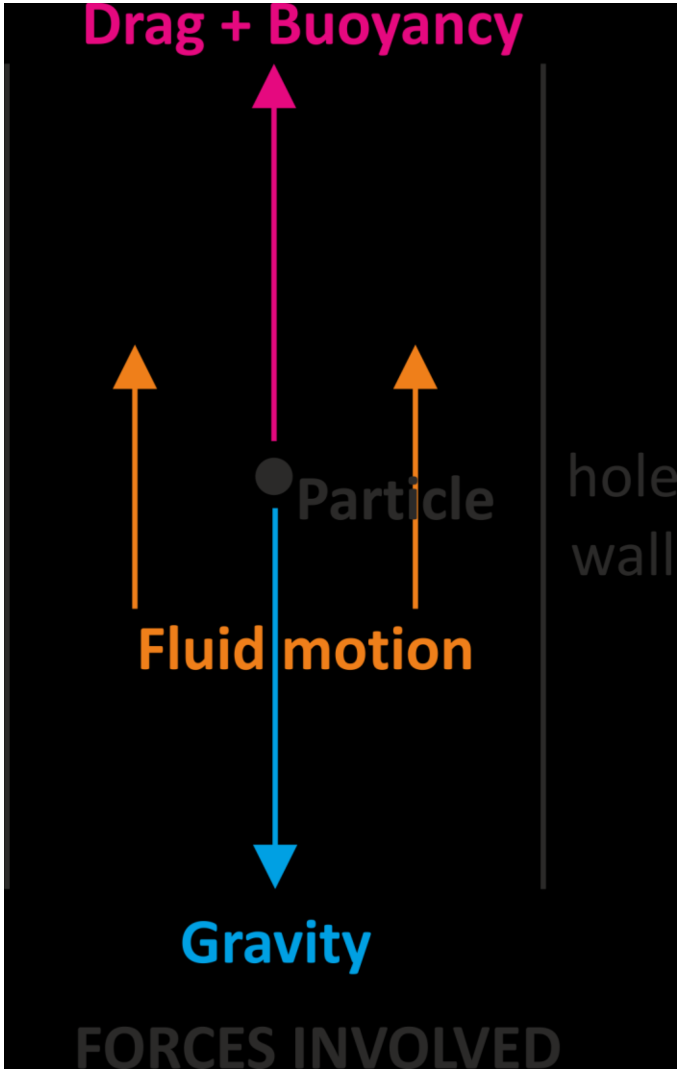
BITS
DRILLING BIT CASING COMPATIBILITIES

Phase	Hole (bit)	Casing	Well profile
Conductor pipe	30″	26″	
Technical casing	24″	18″5/8	
Pumping chamber	17″1/2	13″3/8	
Production casing	12″1/4	9″5/8	
Open hole	8″1/2		

DRILLING FLUID PROPERTIES

- **Cuttings Removal**
  - Factors involved
  - Fluid rheology
    - Velocity, viscosity, density
  - Particle (cuttings, chips, scale debris)
    - Size, shape, density
- **Forces involved**
  - Downwards = gravity * particle mass
  - Upwards = drag + buoyancy
  - Drag (fluid velocity & viscosity; particle mass & wetted surface)
  - Buoyancy (fluid density * particle displaced volume)

Slip velocity threshold
Gravity force = Drag force + buoyancy



DRILLING FLUID PROPERTIES

Limitations, Controls, Requirements

• Cuttings size & density	not controlled
• Drilling fluid density	partly controlled
• Drilling fluid velocity & viscosity	controlled
• Fluid velocity requirement	

Fluid velocity > Slip velocity

Exemple of typical fluid veolocties

Bentonite based mud	# 35 m/min
Water	# 45 m/min

DRILLING FLUID PROPERTIES

THIXOTROPY IS ESSENTIAL

- **Gel Strength**

Newtonian fluid	viscosity changes with shear stress
Non Newtonian fluid	viscosity varies with shear stress

- **Most drilling fluids and cement slurries are thixotropic**

Stationay fluid	viscosity increases
Non stationary fluid	viscosity decreases

- **Thixotropy allows to :**

Keep solids in suspension when not circulating

Release solids on shale shakers

Build up a cake on hole wall

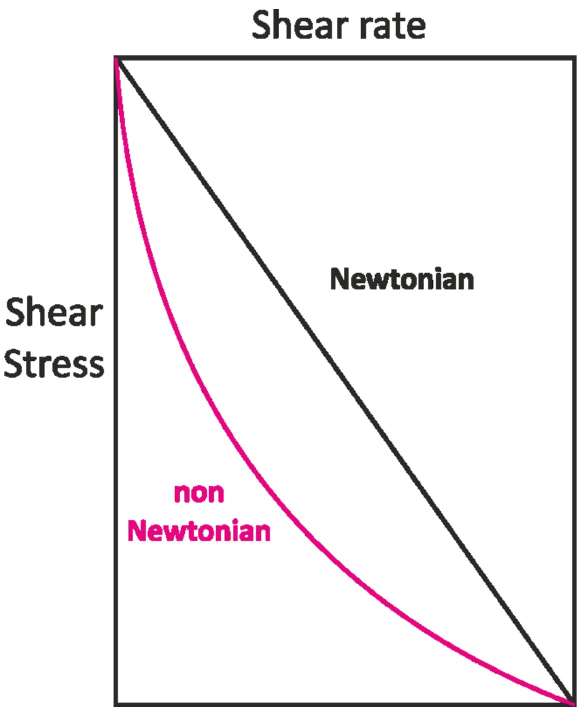
DRILLING FLUID PROPERTIES

MUD FORMULAE

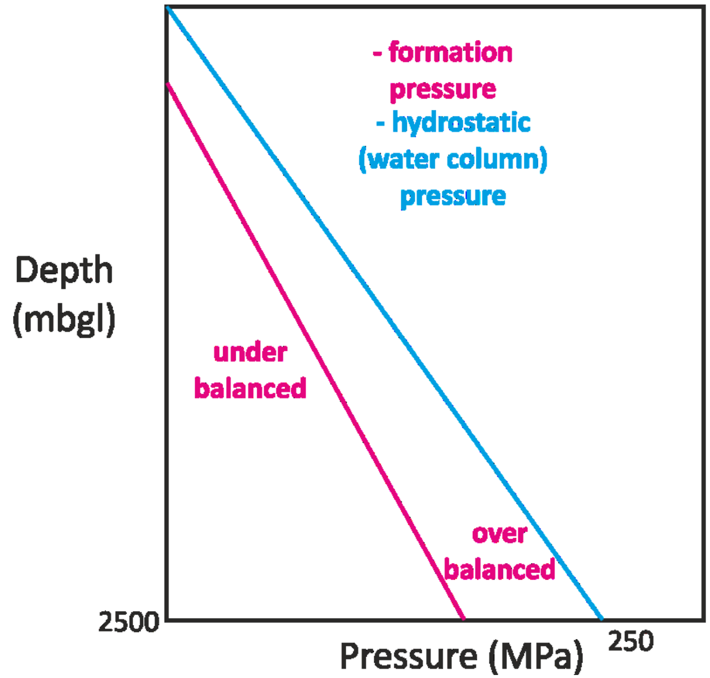
- **Water Based Bentonite**
  - Widely used because of its rheological properties
  - Eases solid removal from shakers, cyclone desauders/desilters
  - Adequate gelling and viscosifying properties (increasing with temperatures)
  - Recommended for overburden sections
- **Water Based (bio)Polymers**
  - Compulsory while drilling low enthalpy sensitive reservoir formations
  - Avoids plugging (particle invasion) damage
  - Environmetally friendly owing to its biodegradable nature
  - Adequate rheology
- **Water**
  - Recommended for drilling high enthalpy geothermal reservoirs and lost circulation zones. Requires high pumping rates and volumes. No cutting recovery.
- **Additives**
  - Thinners (viscosity, gel strength)
  - Lost circulation and cake contrôle
  - Weighting materials (salt, barite)
  - LCM
  - Corrosion control
  - pH control
  - Polymers

DRILLING FLUID PROPERTIES

GRAPHICS



Thixotropy Gel Strength



Under vs Overbalanced drilling

DRILLING FLUID PROPERTIES

UNDER VS OVER BALANCED DRILLING
PROS AND CONS

- **Definition (see graphics slide)**
  - Under balanced (under pressures)

    Formation pressure < drilling fluid hydrostatic pressure
  - Over balanced

    Formation pressure > drilling fluid hydrstatic pressure
- **Pros and Cons**

Balancing	PROS	CONS
Under balanced	Fast penetration rate Formation integrity No lost circulation	Reservoir inflow Kick/blow out risk Formation collapse Stuck drill pipe
Over balanced	Safety (no inflow) Consolidated hole (thick cake)(*)	Lost circulation Mud filtrate loss (cake impact) Reduced penetration rate Differencial pressure (stuck drill pipe)

(*) may be seen conversely at a disadvantage (reservoir plugging)

- **Conclusion :**

  keep as close as possible to balance drilling conditions unless otherwith dictated (blow out control)

DIRECTIONAL DRILLING OBJECTIVES

- Adapt to site limitations and accessibility
- Terrain availability
- Optimum target matching from drill site
- Optimum well delivery by intersectiing (near) vertical fractures
- Side tracking whenever needed
- Relief well(s)
- Cluster drilling
- Cost cuts

DIRECTIONAL DRILLING CLUSTERS

- **ADVANTAGES**
  - Multiwell array (f.i. GDH doublet) drilled from a single pad
  - Easy and cheaper site preparation
  - Cheaper land acquisition costs
  - Reduced rig mob/demob costs
  - Reduce well connection (f.i. GDH primary loop) costs
  - Easier planning and operation
- **DISADVANTAGES**
  - One way ticket stategy (redhibitory in case of exploration failure)

DIRECTIONAL DRILLING TRAJECTORIES
RADIUS OF CURVATURE

RADIUS OF CURVATURE AND PROJECTION IN THE VERTICAL PLANE

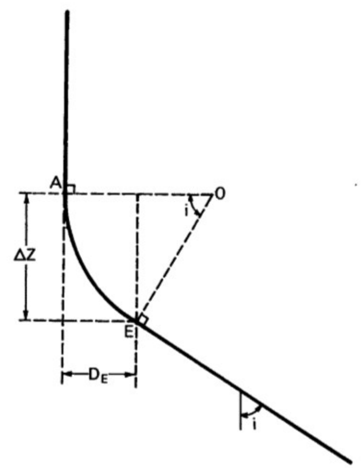
$AE = L$	Length drilled from A to E
$R = \frac{360}{2\Pi}\frac{\Delta L}{\Delta i}$	Radius of curvature (m)
$gbu = \frac{\Delta i}{\Delta L}$	Rate of buildup (°/10 m)

in general $\frac{\Delta i}{\Delta L}$ is kept as constant as possible during kickoff (constant radius of curvature)

Hence:

$$R = \frac{573}{gbu}$$

$$D_E = R(1 - \cos i) \quad \text{(m)}$$
$$\Delta Z = R \sin i \quad \text{(m)}$$



Radius of curvature for different rates of buildup:

gbu (°/10 m)	0.5	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
R (m)	1146	573	382	286	191	143	115	95	82	72	64	57

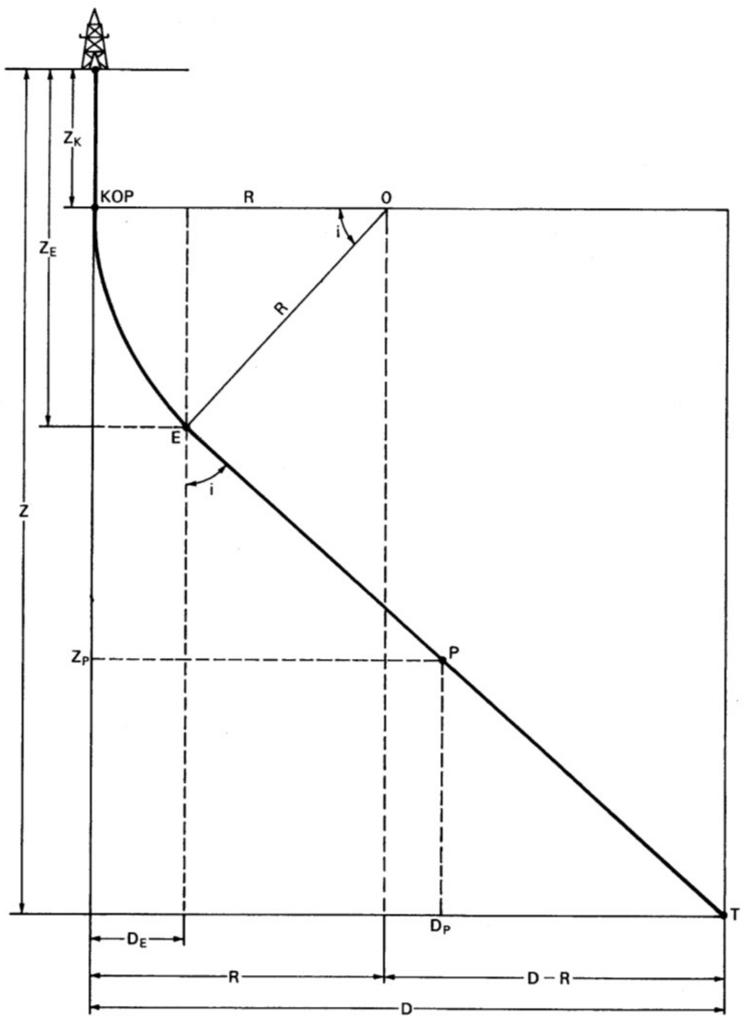
m × 3.28 = ft   °/10 m × 3.048 = °/100 ft

Source : IFP/TECHNIP

DIRECTIONAL DRILLING TRAJECTORIES
J SHAPED HOLE (1)

CALCULATION OF CHARACTERISTIC POINTS OF THE THEORETICAL VERTICAL PROFILE

J* hole: *D* > *R



	Measured depth L (TMD)	Vertical depth Z (TVD)	Inclination	Displacement
Kickoff point (K)	Z_K	Z_K	0	0
End of deviation (E)	$L_E = Z_K + \frac{\Pi i R}{180}$	$Z_E = Z_K + R \sin i$	i	$D_E = R(1 - \cos i)$
Target (T)	$L_T = Z_K + \frac{\Pi i R}{180} + \frac{Z - Z_K - R \sin i}{\cos i}$	Z	i	D

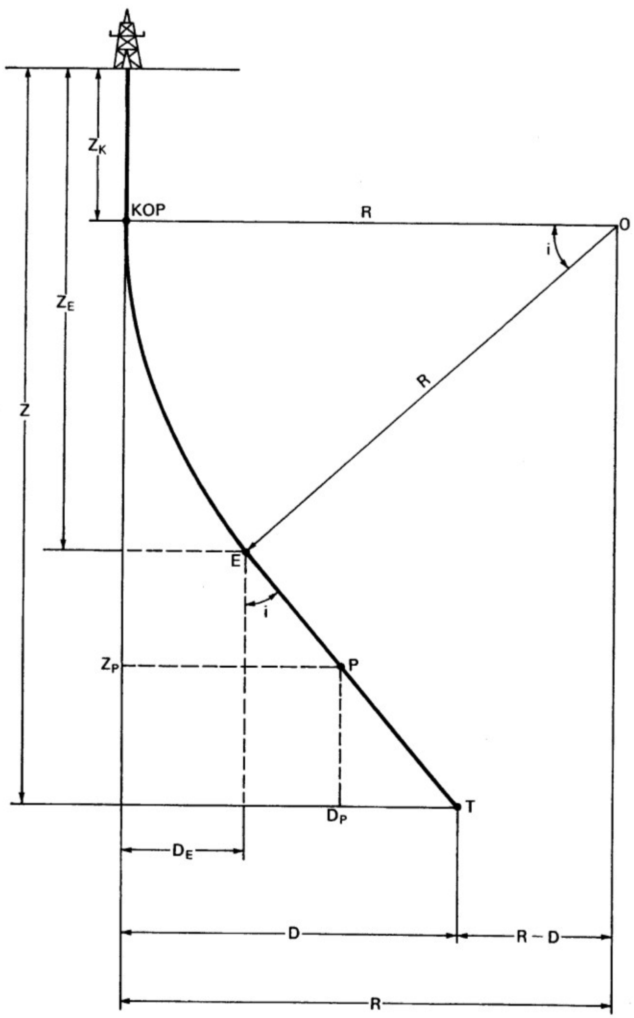
Vertical depth Z_P as a function of drilled depth L_P at point P:

$$Z_P = Z_K + \frac{573}{gbu} \sin i + \left(L_P - Z_K - \frac{10 i}{gbu}\right) \cos i$$

Source : IFP/TECHNIP

DIRECTIONAL DRILLING TRAJECTORIES
J SHAPED HOLE (2)

CALCULATION OF CHARACTERISTIC POINTS OF THE THEORETICAL VERTICAL PROFILE
J* hole: *D* < *R



	Measured depth L (TMD)	Vertical depth Z (TVD)	Inclination	Displacement
Kickoff point (K)	Z_K	Z_K	0	0
End of deviation (E)	$L_E = Z_K + \frac{\Pi i R}{180}$	$Z_E = Z_K + R \sin i$	i	$D_E = R(1 - \cos i)$
Target (T)	$L_T = Z_K + \frac{\Pi i R}{180} + \frac{Z - Z_K - R \sin i}{\cos i}$	Z	i	D

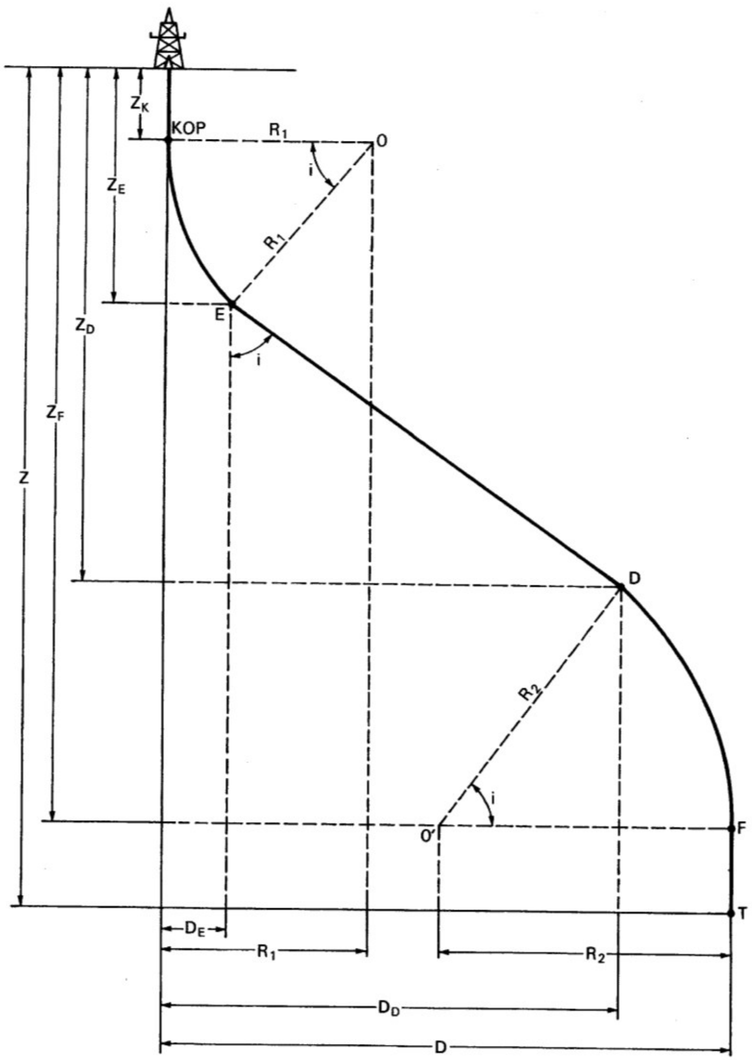
Vertical depth Z_P as a function of drilled depth L_P at point P:

$$Z_P = Z_K + \frac{573}{gbu} \sin i + \left(L_P - Z_K - \frac{10 i}{gbu}\right) \cos i$$

Source : IFP/TECHNIP

DIRECTIONAL DRILLING TRAJECTORIES
S SHAPED HOLE (1)

***S* hole: $R_1 + R_2 < D$**



***S* hole: $R_1 + R_2 < D$ (continued)**

Assuming a return of the well to the vertical at F, the inclination i depends on the depth selected for point F:

$$i = 180 - \tan^{-1}\left[\frac{Z_F - Z_K}{D - R_1 - R_2}\right] - \cos^{-1}\left[\frac{R_1 + R_2}{Z_F - Z_K}\sin \tan^{-1}\frac{Z_F - Z_K}{D - R_1 - R_2}\right]$$

The remaining calculations are identical to those in J 5 and J 7 up to D (Z_D, D_D).

Vertical projection at D:

$$Z_D = Z_F - R_2 \sin i$$

Measured depth at D:

$$L_D = Z_K + \frac{\Pi i R_1}{180} + \frac{Z_D - Z_K - R_1 \sin i}{\cos i}$$

Displacement at D:

$$D_D = R_1 (1 - \cos i) + (Z_D - Z_K - R_1 \sin i) \tan i$$

Measured depth at F:

$$L_F = L_D + \frac{\Pi i R_2}{180}$$

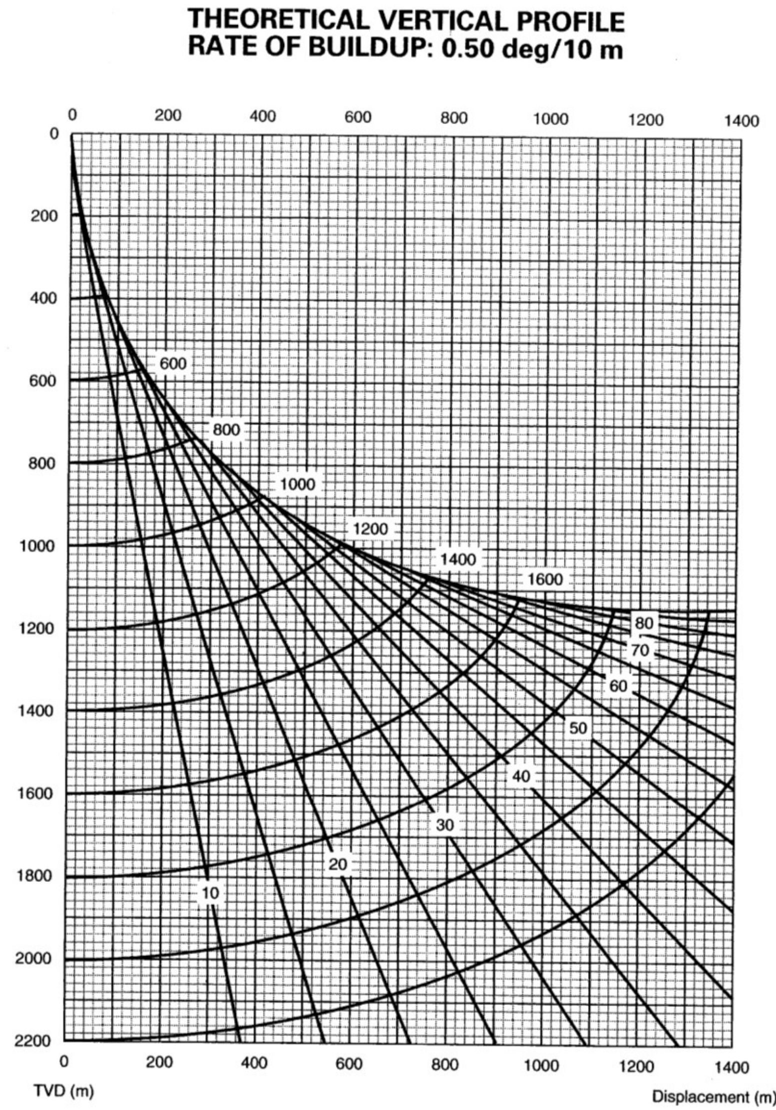
Total measured depth at T:

$$\boxed{L_T = Z_K + \frac{\Pi i R_1}{180} + \frac{Z_D - Z_K - R_1 \sin i}{\cos i} + \frac{\Pi i R_2}{180} + Z - Z_F}$$

Source : IFP/TECHNIP

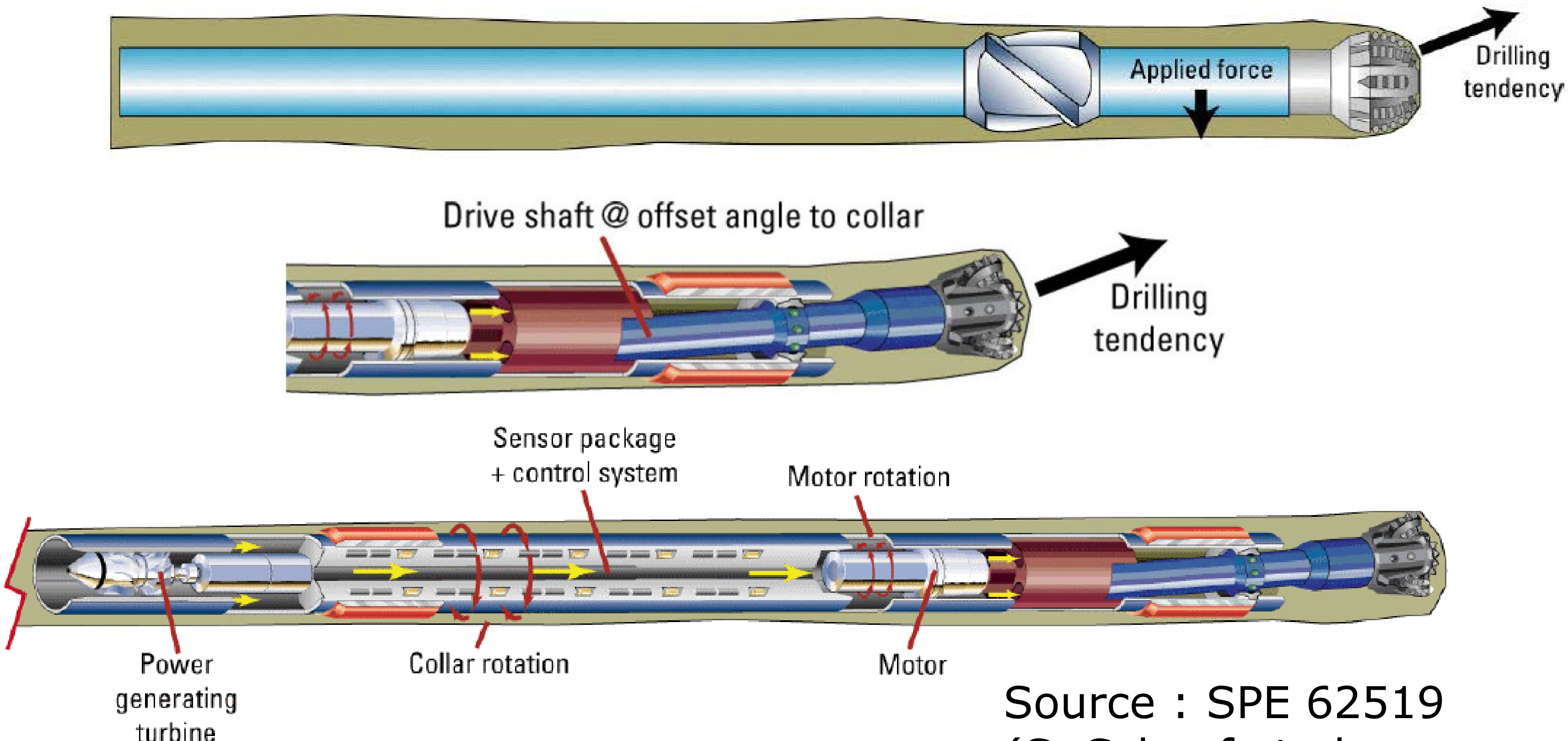
DIRECTIONAL DRILLING TRAJECTORIES DISPLACEMENT VS DEPTH AND INCLINATION

Build up rate = 10/10 m



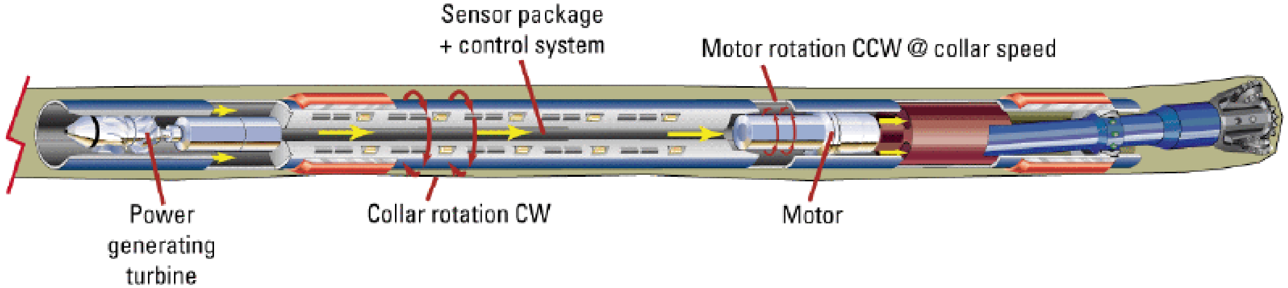
Source : IFP/TECHNIP

TYPICAL BOTTOM HOLE ASSEMBLIES FOR DIRECTIONAL DRILLING

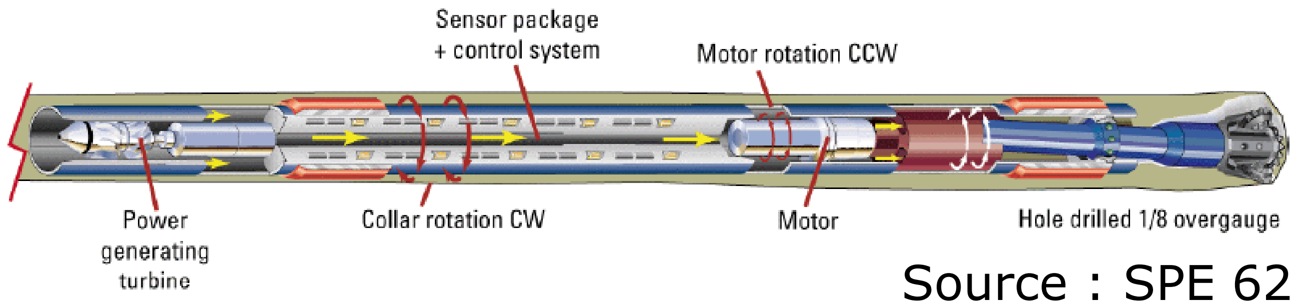


Source : SPE 62519
(S. Schaaf et al.,
quoted by J. Tester, 2011)

TYPICAL BOTTOM HOLE ASSEMBLIES FOR DIRECTIONAL DRILLING



Steering mode showing tool drilling in-gauge hole



Tool drilling in straight mode

Source : SPE 62519
(S. Schaaf et al.,
quoted by J. Tester, 2011)

CASING LINING
CASING CHARACTERISTICS

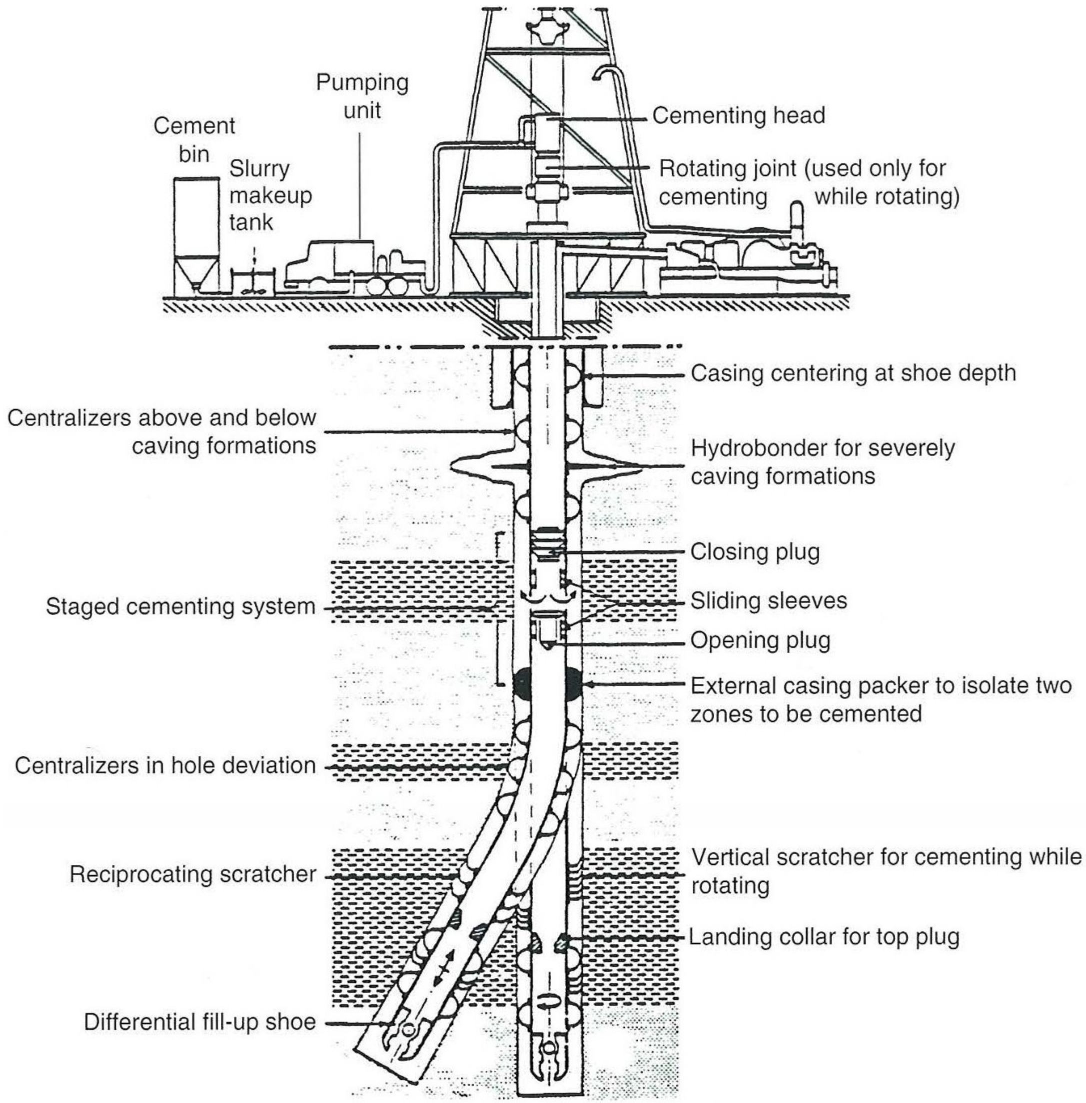
Diameter (OD)"	Nominal Weight (lb/ft)	Wall thickness (mm)
4 1/2	9.5-15.10	5.20-8.56
5 (1)	11.5-24.10	5.59-12.70
5 1/2	14-43.10	6.20-22.22
6 5/8	20-32	7.32-12.06
7	17-57.10	5.87-22.22
7 5/8 (2)	24-55.30	7.62-19.05
8 5/8	24-49	6.71-14.15
9 5/8	32.30-75.60	7.92-20.24
10 3/4 (3)	32.75-85.30	7.09-20.24
11 3/4	42-71	8.46-14.78
13 3/8	48-72	8.38-13.06
16	65-109	9.53-16.66
18 5/8	87.50	11.05
20	94-133	11.13-16.13

(1) Lining of damaged 7" csg

(2) Lining of damaged 9" 5/8 csg

(3) Lining of damaged 13" 3/8 csg

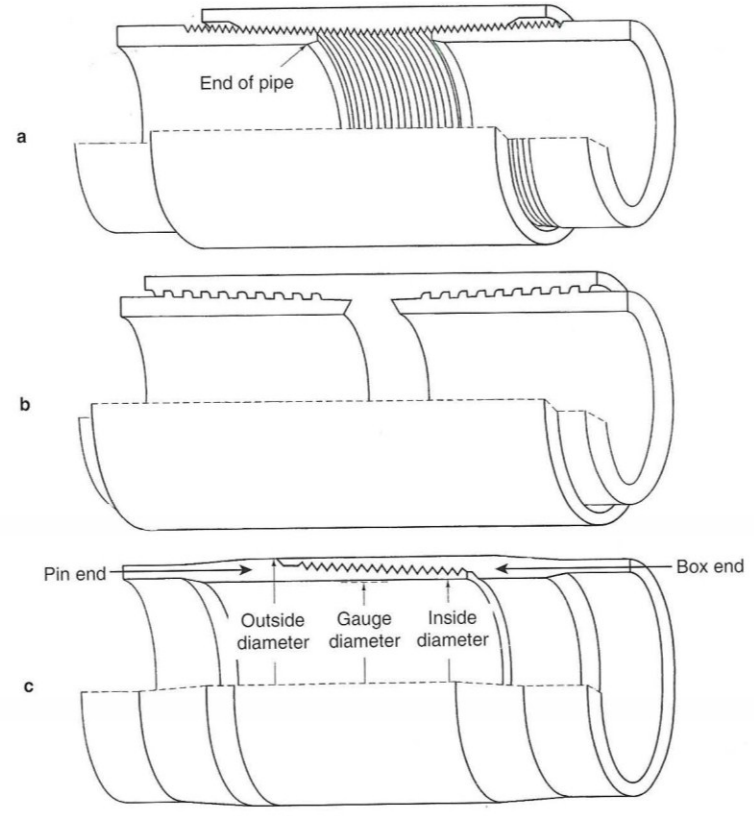
CASING/LINING
RUNNING CASING STRING



Source : Gaz de France

CASING/LINING

Pipe couplings



a. API round
b. VAM
c. Extreme line

Source : Drilling Data Handbook, Editions Technip, Paris, 1989)

CEMENTING
CEMENT CLASSES

API Spec 10

Class	Type
A	For use from surface to 1830 m (6000 ft) depth when special properties are not required. Ordinary type.
B	For use from surface to 1830 m (6000 ft) depth when conditions require moderate to high sulfate resistance.
C	For use from surface to 1830 m (6000 ft) depth when conditions require high early compressive strength. Available in low, moderate and high sulfate-resistant types.
D	For use from 1830 m (6000 ft) to 3050 m (10,000 ft) depth under conditions of moderately high temperatures and pressures. Available in moderate and high sulfate-resistant types.
E	For use from 3050 m (10,000 ft) to 4270 m (14,000 ft) depth under conditions of high temperatures and pressures. Available in moderate and high sulfate-resistant types.
F	For use from 3050 m (10,000 ft) to 4880 m (16,000 ft) depth under conditions of extremely high temperatures and pressures. Available in moderate and high sulfate-resistant types.
H	For use from surface to 2440 m (8000 ft) depth as manufactured, or can be used with accelerators and retarders to cover a wide range of well depths and temperatures. Available only in moderate sulfate-resistant type.
J	For use from 3660 to 4880 m (12,000 to 16,000 ft) depth under conditions of extremely high temperatures and pressures. Available only in sulfate-resistant type.

Source : J.P. NGUYEN

CEMENTING
CEMENT ADDITIVE CHARATERISTICS

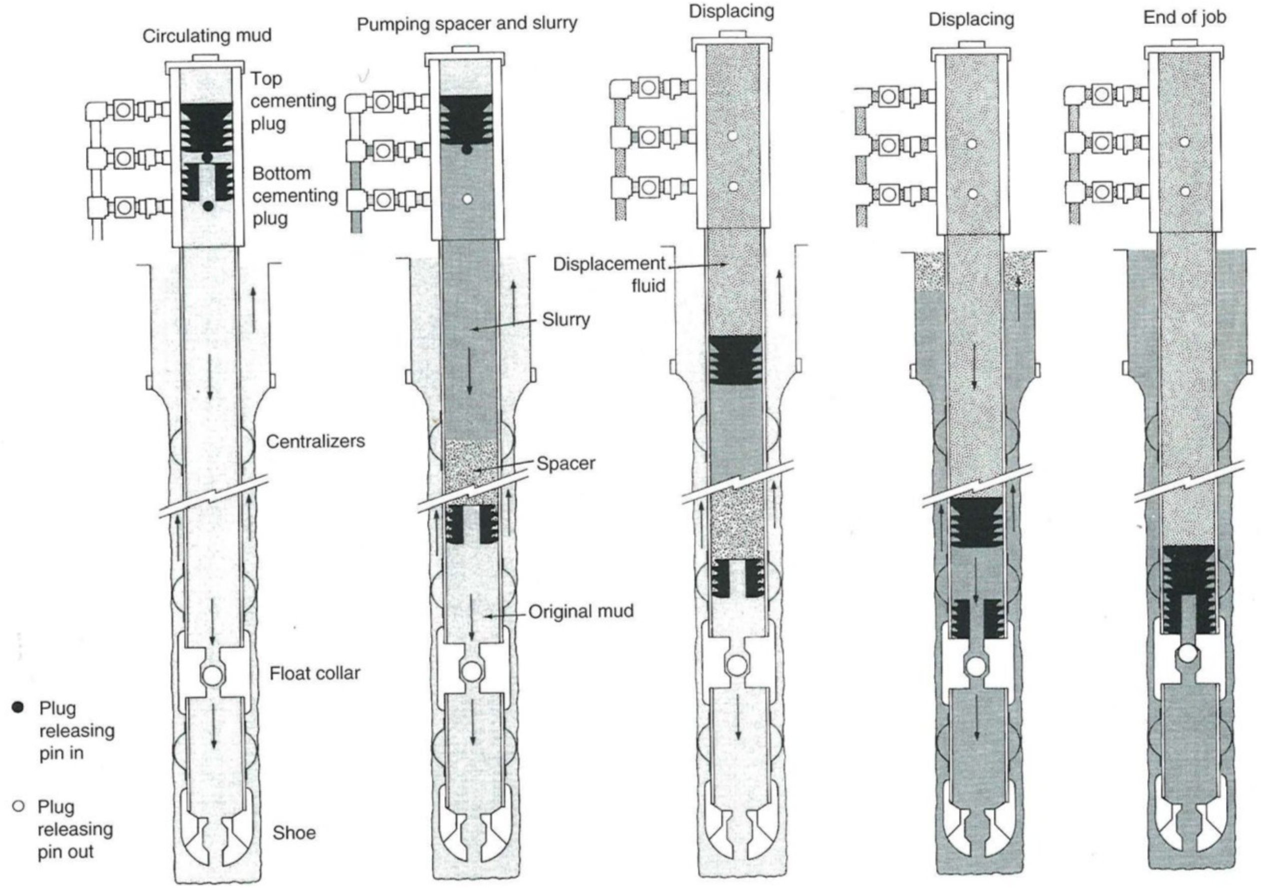
Cement Characteristics	Cement Additives / Effect	Bentonite	Perlite	Diatomaceous earth	Pozzolan	Sand	Barite	Hematite	Calcium chloride	Sodium chloride	Lignosulfonate	CMHEC ([1])	Diesel oil	Water loss additive	Lost circulation material
Density	Decreased	•	•	•	•										
	Increased					•	•	•	x	x	x				
Water required	Decreased										•				
	Increased	•	x	•	x	x	x	x							x
Viscosity	Decreased								x		•				
	Increased	x	x	x	x	x	x	x							
Thickening time	Accelerated	x					x	x	•	•					
	Retarded			x						x	•	•	x	x	
Setting time	Accelerated						x	x	•	•					
	Retarded	x	x	x	x						•	•		x	
Early strength	Decreased	x	x	x	x		x	x			•	•		x	x
	Increased								•	•					
Final strength	Decreased	x	x	•	x		x					x		x	x
	Increased														
Duration	Decreased	x	x	x									x		x
	Increased				•										
Water loss	Decreased	•									x	•	x	•	x
	Increased		x	x											

x Denotes minor effect
• Denotes major effect and/or purpose of additive
([1]) Carboxymethyl hydroxyethyl cellulose

Source : Drilling Data Handbook, Editions Technip & Dowell Schlumberger

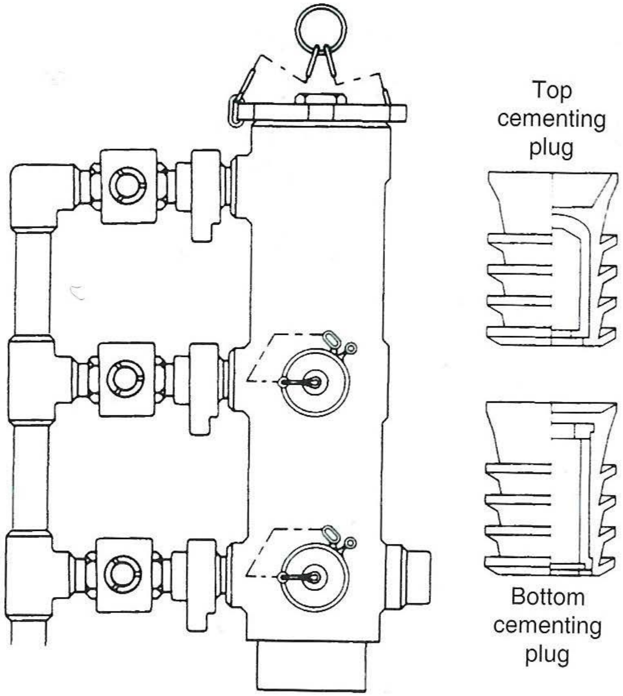
CEMENTING
PRIMARY CASING CEMENTING SEQUENCE

Primary casing cementing sequence



Source : Dowell Schlumberger

CEMENTING
TWIN-PLUG CEMENTING HEAD



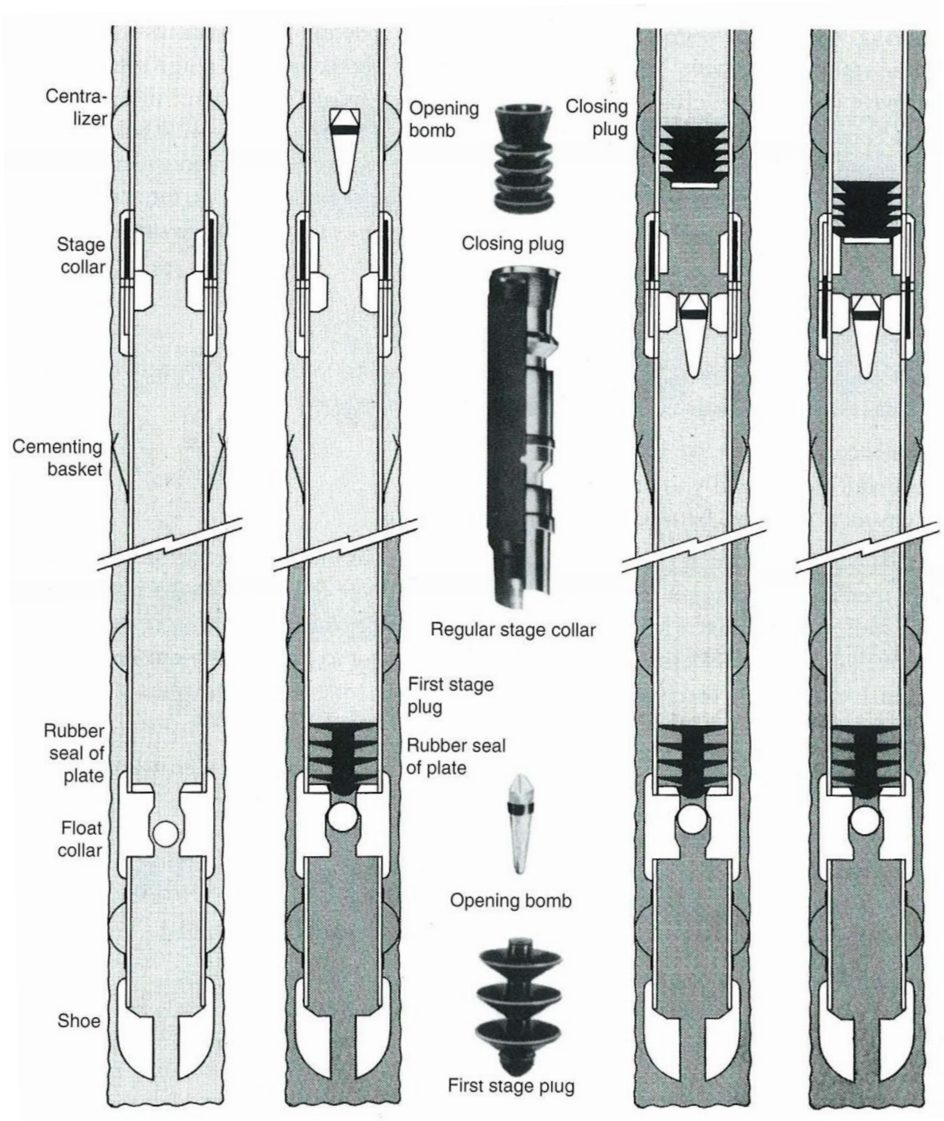
HEAD

PLUGS

Top **Bottom**

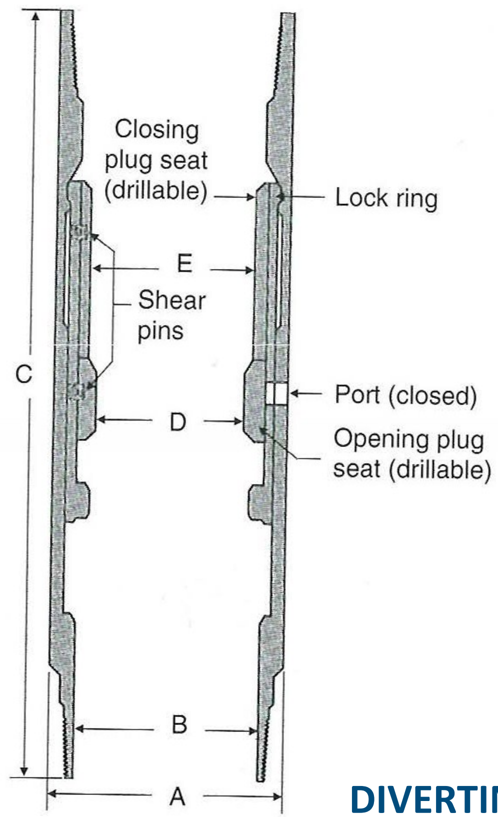
Source : Weatherford

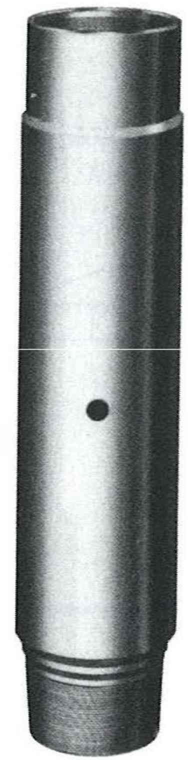
CEMENTING
TWO-STAGE CEMENTING SEQUENCE



Source : Weatherford

CEMENTING
TWO-STAGE CEMENTING EQUIPMENT





DIVERTING VALVE

Closing plug

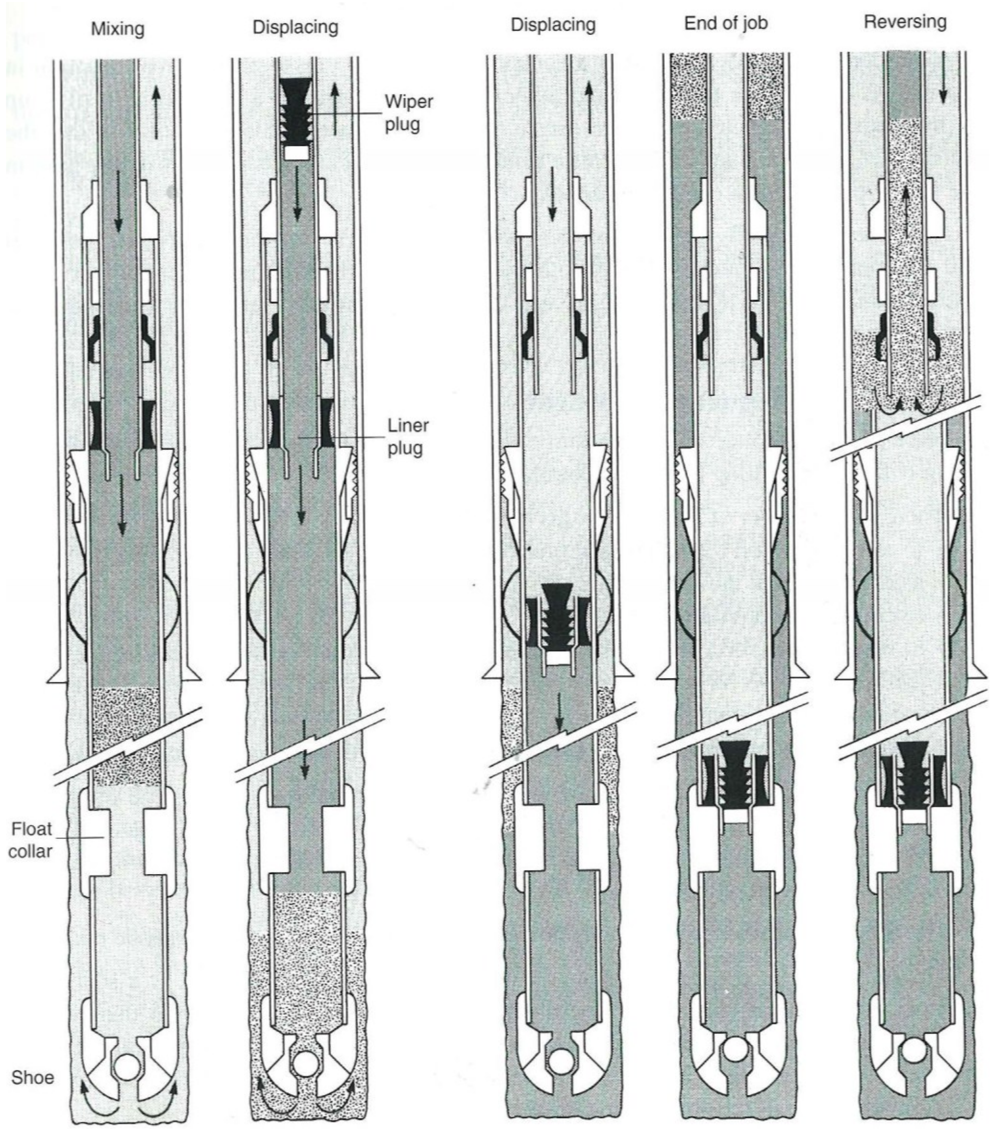
PLUG

Free fall plug

PLUGS

Source : BJ Hughes

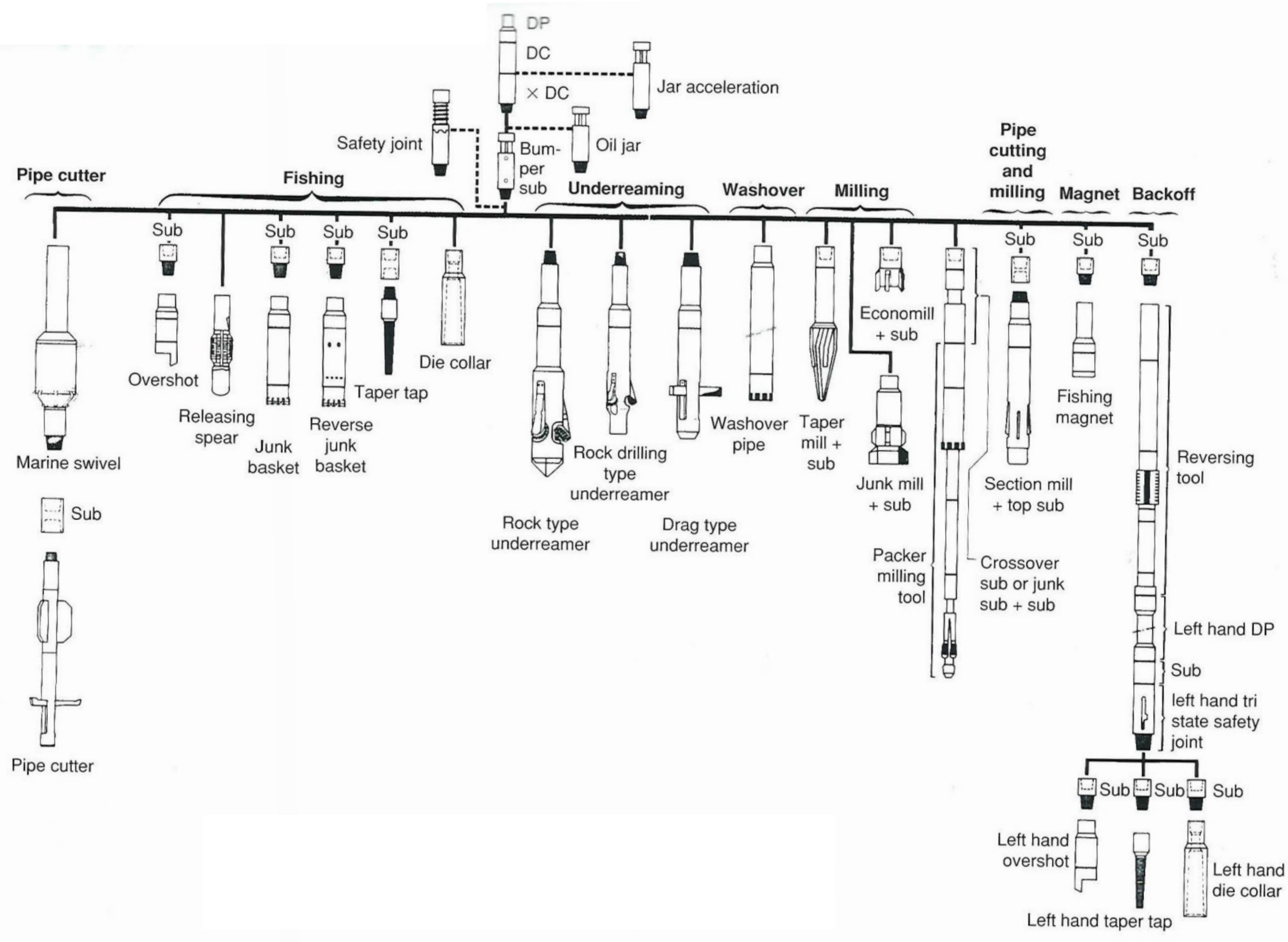
CEMENTING
LINER CEMENTING SEQUENCE



LINER

Source : Weatherford

FISHING
TYPICAL FISHING, MILLING AND BACK OFF STRINGS



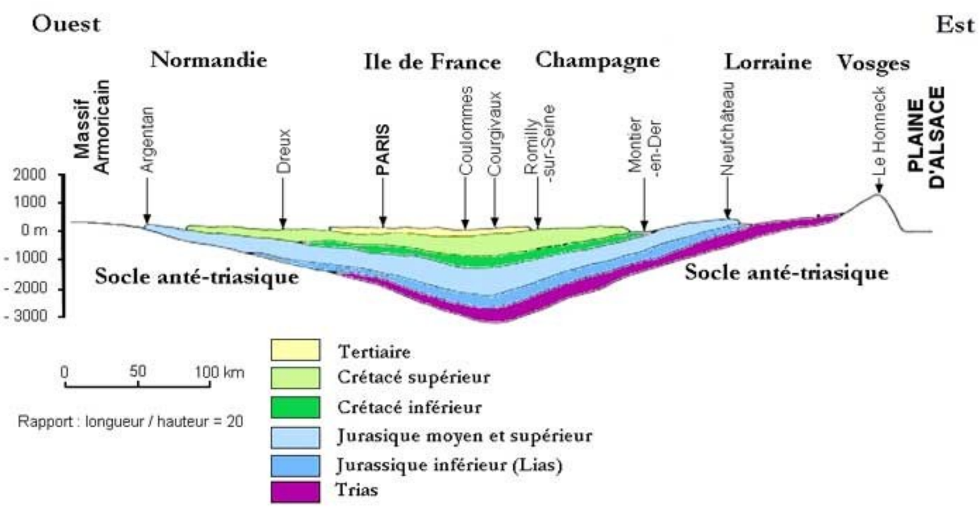
Source : Drilling Data Handbook, Editions Technip, Paris)

ITEMIZED COST BREAKDOWN

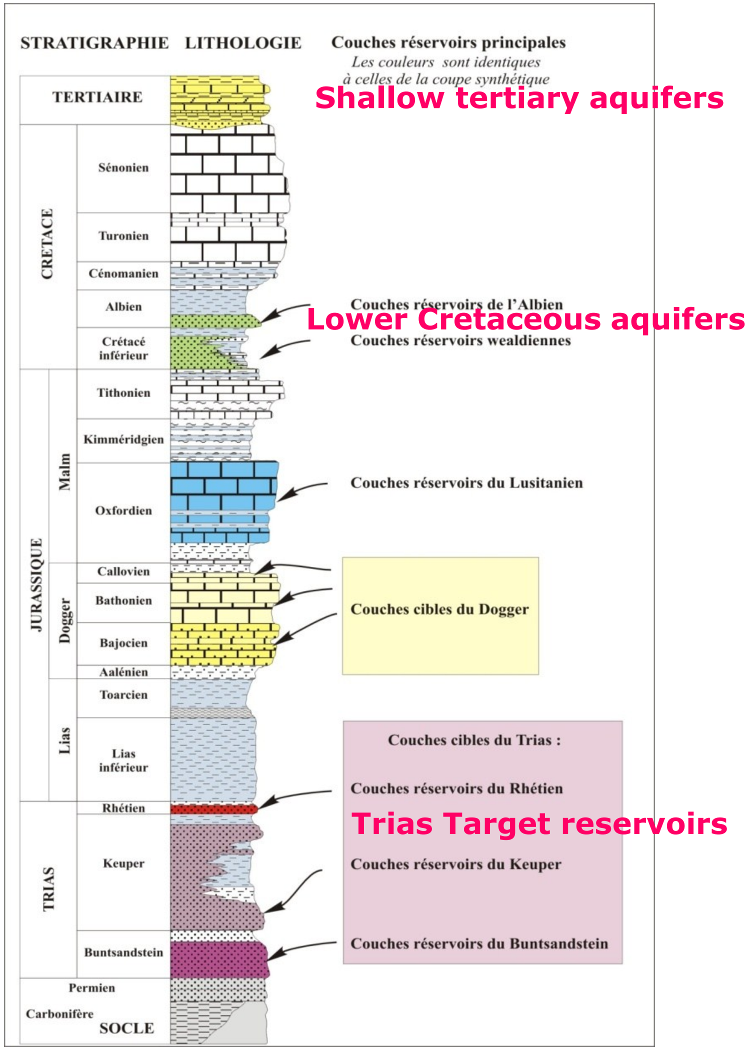
1. Site preparation. Forewell
2. Rig & equipment move in/rig up
3. Rig time (daily rate basis)
4. Bits
5. Drilling/completion fluids
6. Directional drilling
7. Wireline (OH, CH, PLT) logging
8. Mud loging (well site geological control)
9. Casing/lining/completion
10. Tong service
11. Cementing & accessories
12. Fishing
13. Well stimulation
14. Well (bottomhole) testing/fluid sampling
15. Waste processing/disposal
16. Wellhead
17. Engineering/supervision/ reporting
18. Insurances
19. Rig down/rig & equipment move out
20. Site rehabilitation
21. Contingencies

CASE STUDY
PARIS BASIN. GEOLOGICAL SKETCHES

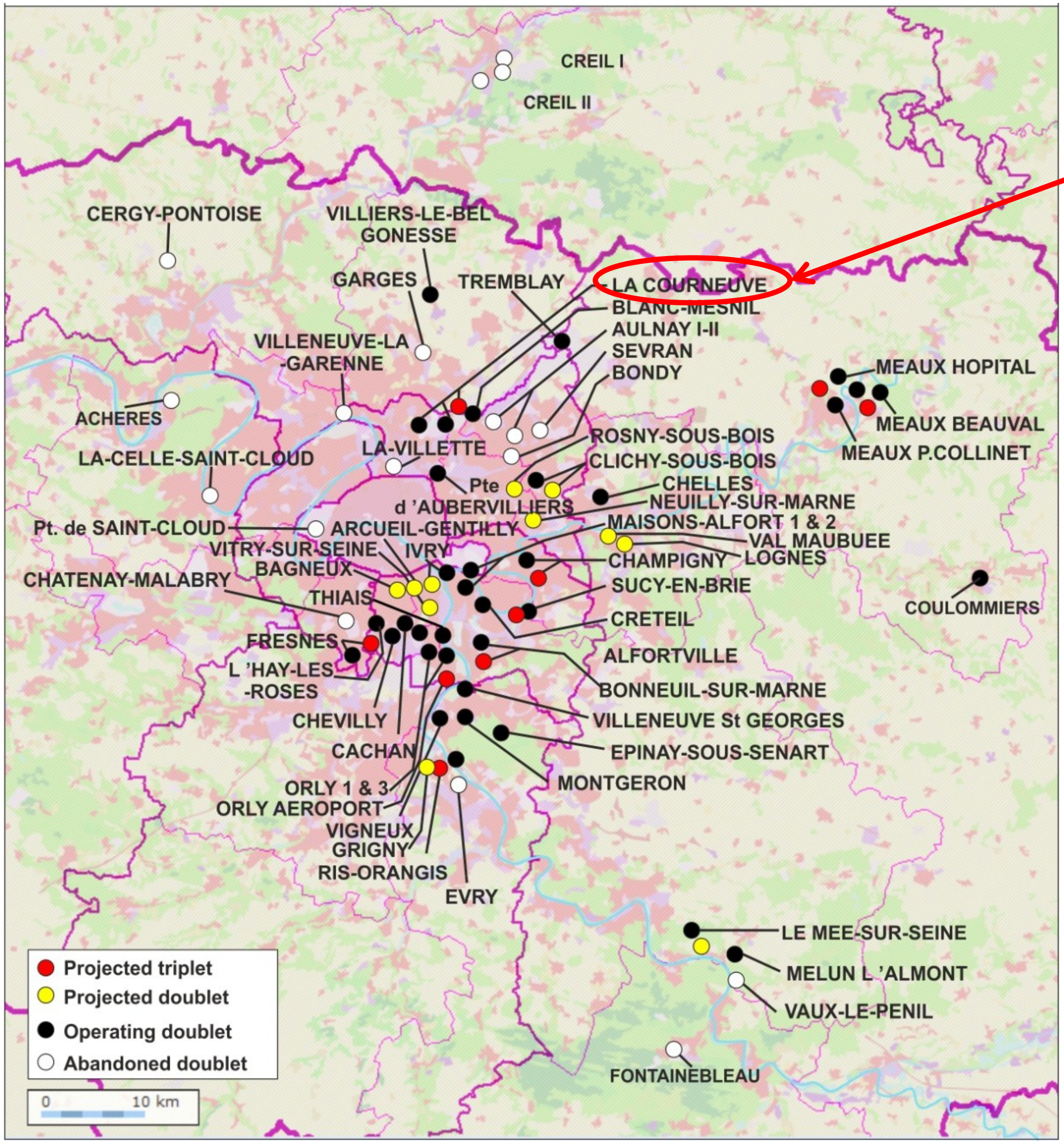
West East Cross Section



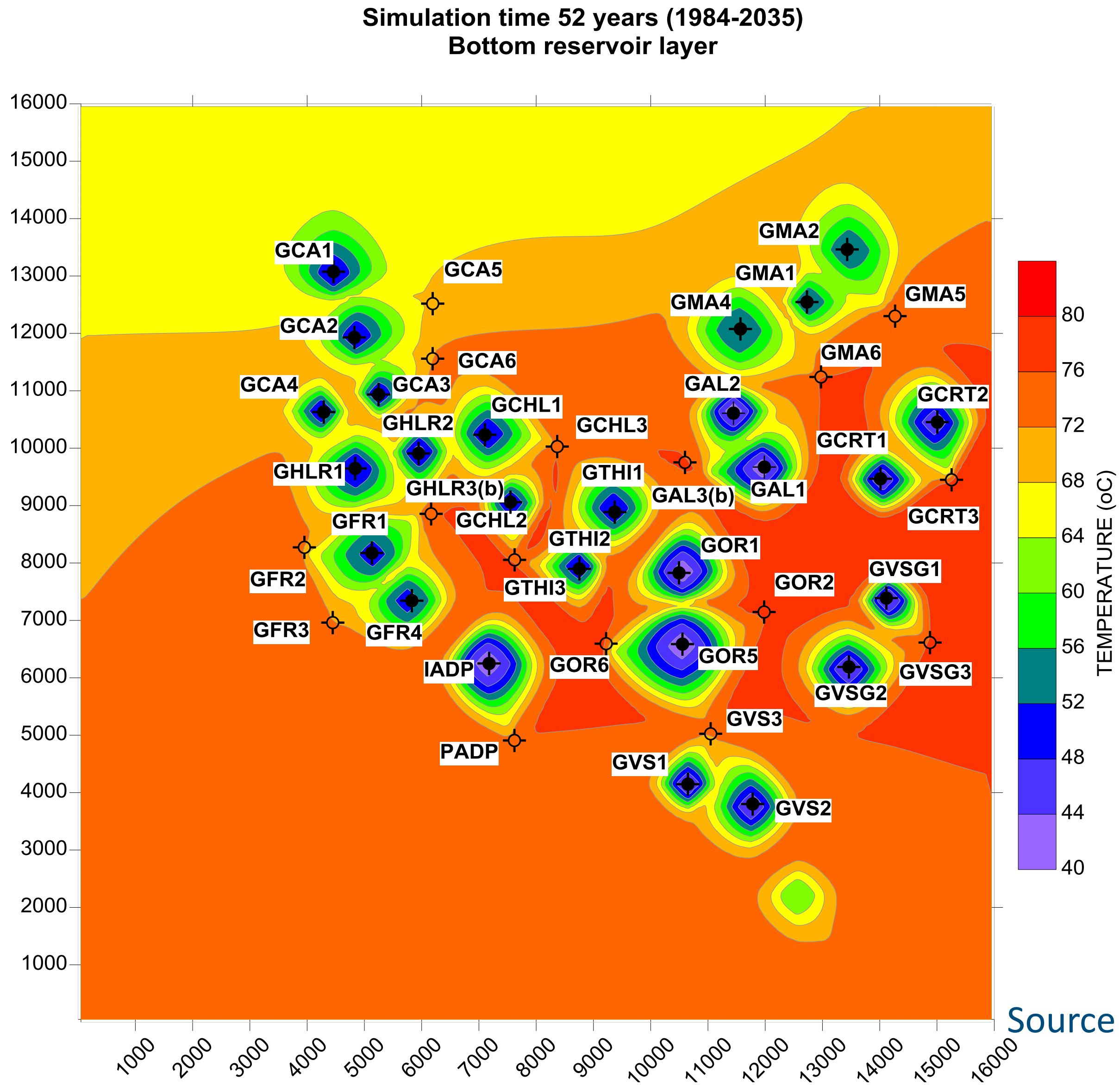
Lithostratigraphic column and target reservoir horizons



CASE STUDY
PARIS BASIN GDH STATUS (@ JAN. 2012)

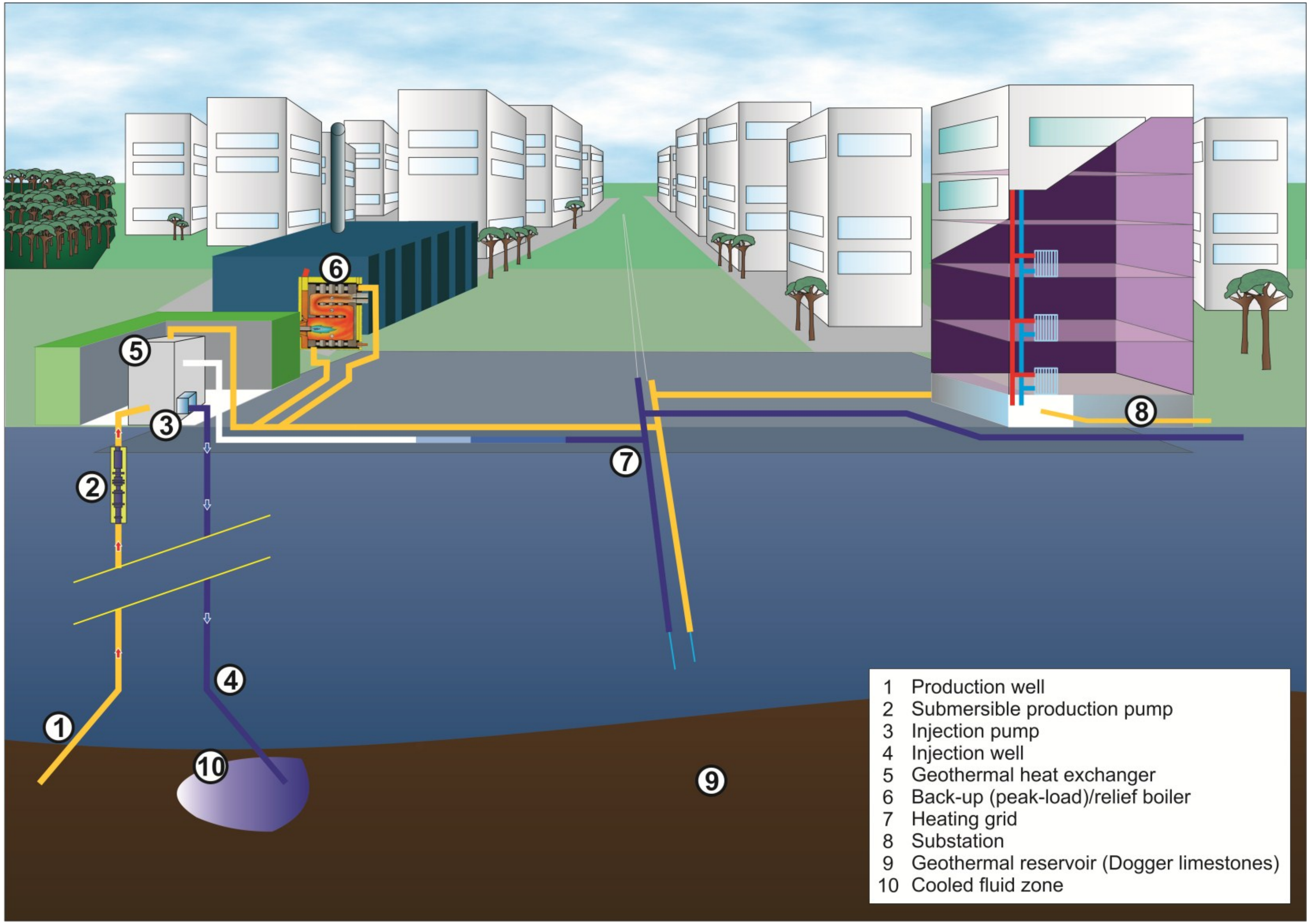


CASE STUDY
PARIS BASIN GDH EXPLOTATION STATUS (PARIS SOUTH)



Source : Maria Papachristou

CASE STUDY
PARIS BASIN GDH SCHEME

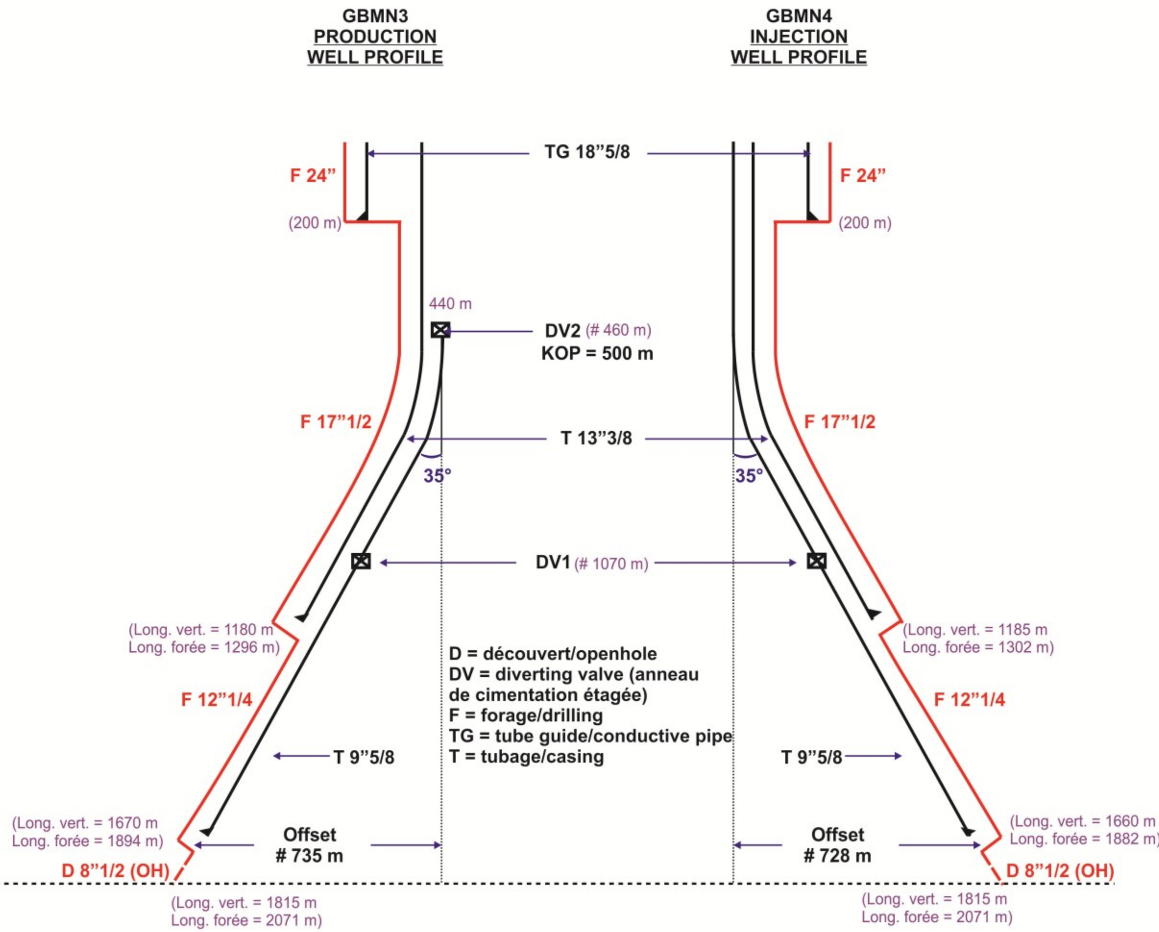


CASE STUDY
TYPICAL GDH WELL ARCHITECTURES

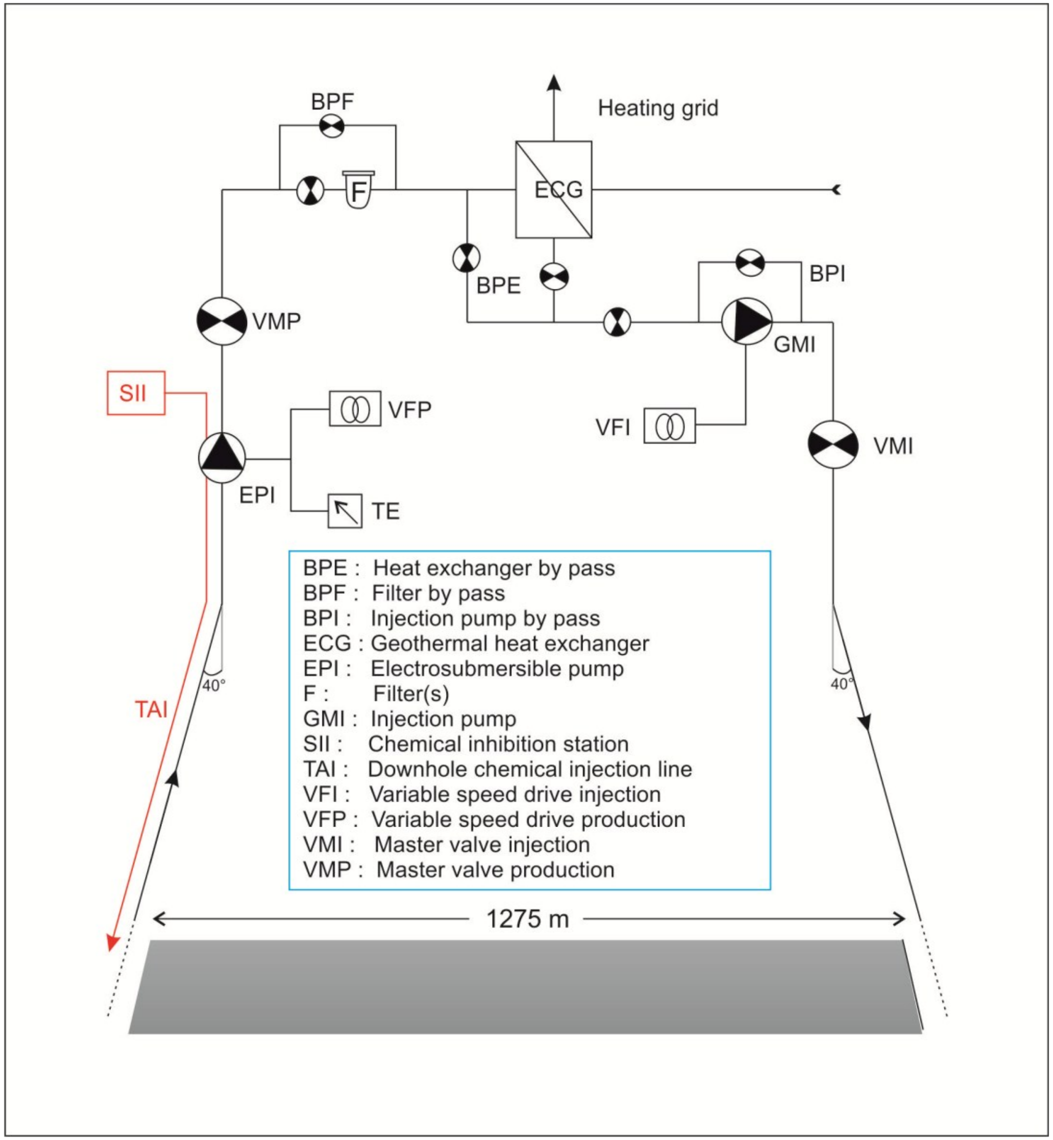
VERTICAL DEPTH (m/sol): 0 m, 50 m, 200 m, KOP 500 m, 1200 m, 1710 m, 1830 m

LITHO-STRATIGRAPHIC COLUMN

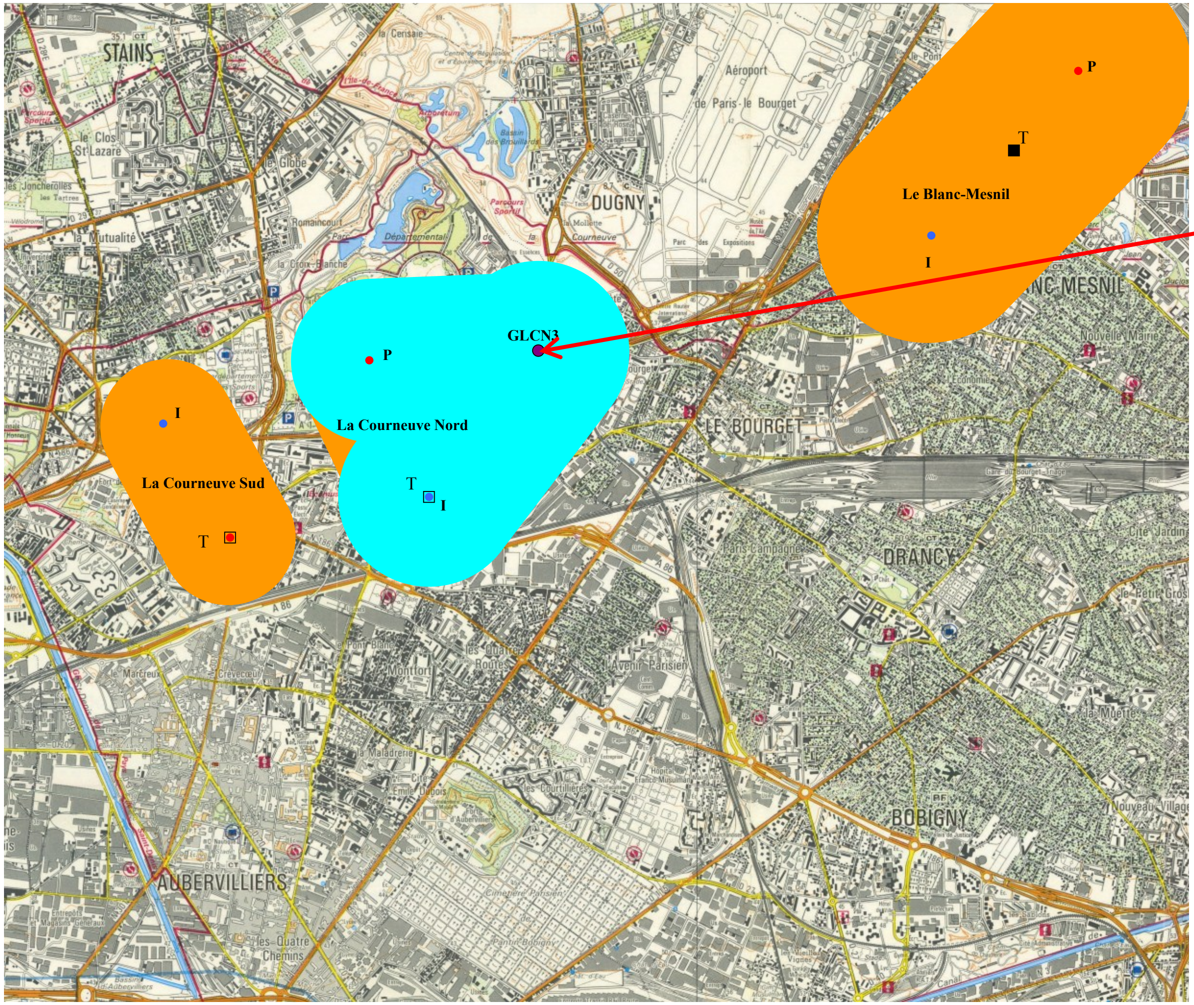
SÉRIE STRATIGRAPHIQUE		Vert. Depth
Récent et tertiaire		47
Crétacé sup.	Sénonien	137
	Turonien	512
Crétacé moyen	Cénomanien	649
	« Gault »	717
	Albo-Aptien	752
Crétacé inférieur	Barrémien	857
	Néocomien-Wealdien	887
Jurassique supérieur	Purbeckien	992
	Portlandien	1007
	Kimmeridgien	1137
	Sequanien	1267
	Rauracien	1367
	Argovien	1457
	Oxfordien	1557
Jurassique moyen	Callovien	1627
	Dogger	1667
	Prof. finale (TVD)	1817



CASE STUDY
GEOTHERMAL LOOP DESIGN

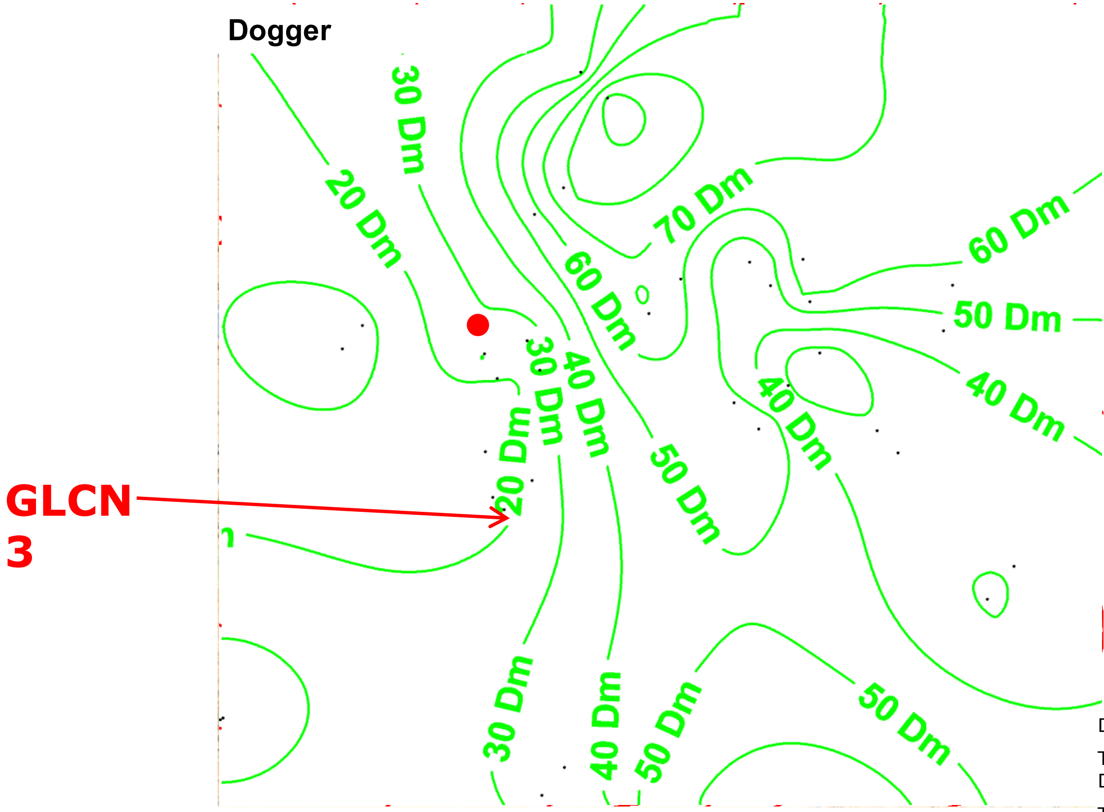


CASE STUDY GLCN3 WELL. EXPLORATION/EXPLOITATIONPERIMETERS OF EXISTING AND FUTURE (TRIPLET/DOUBLET) GDH SYSTEMS



NEW TRIPLET PRODUCTION WELL

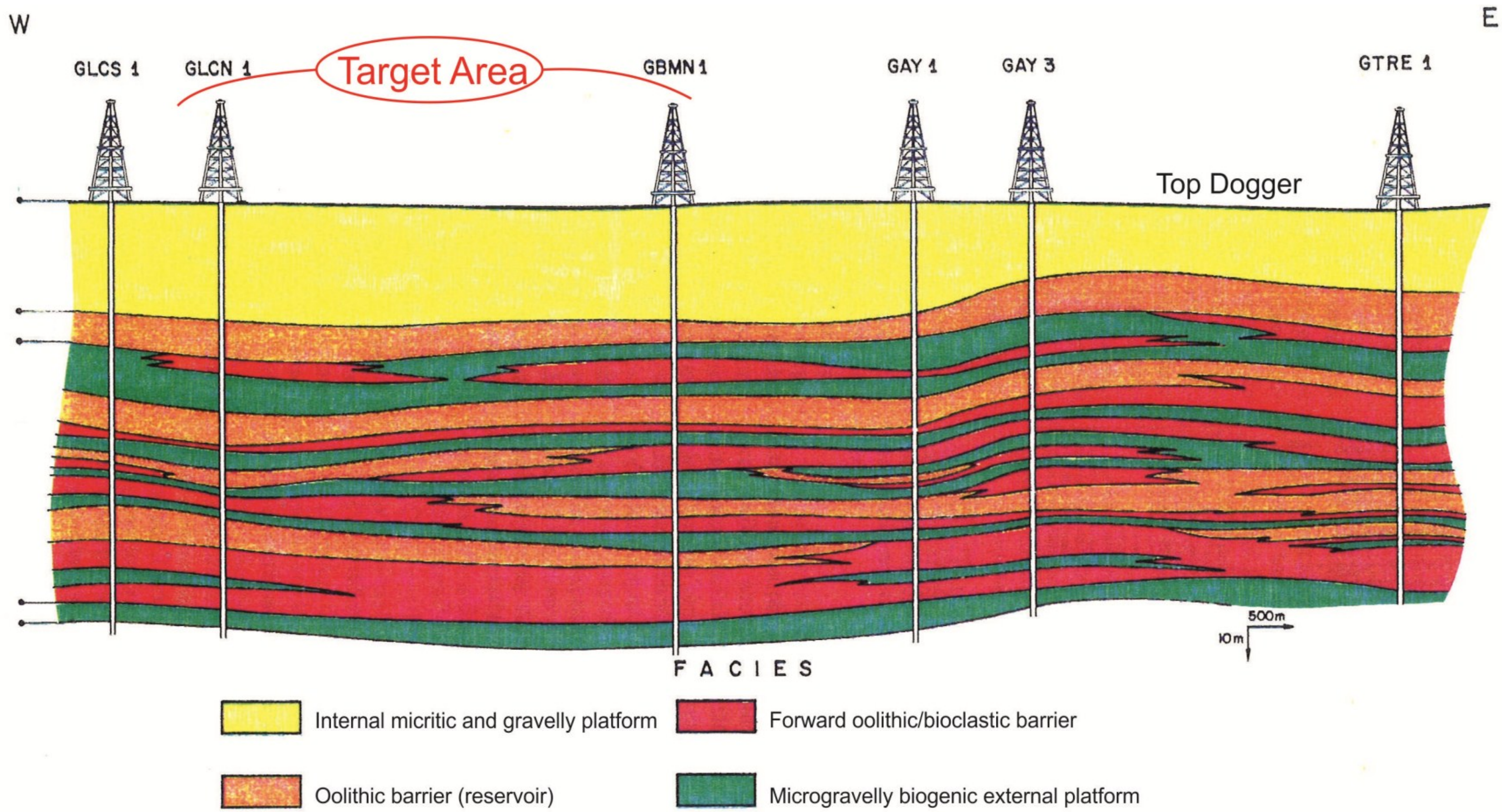
CASE STUDY GLCN3
DOGGER RESERVOIR CHARACTERISTICS. PARIS NORTH



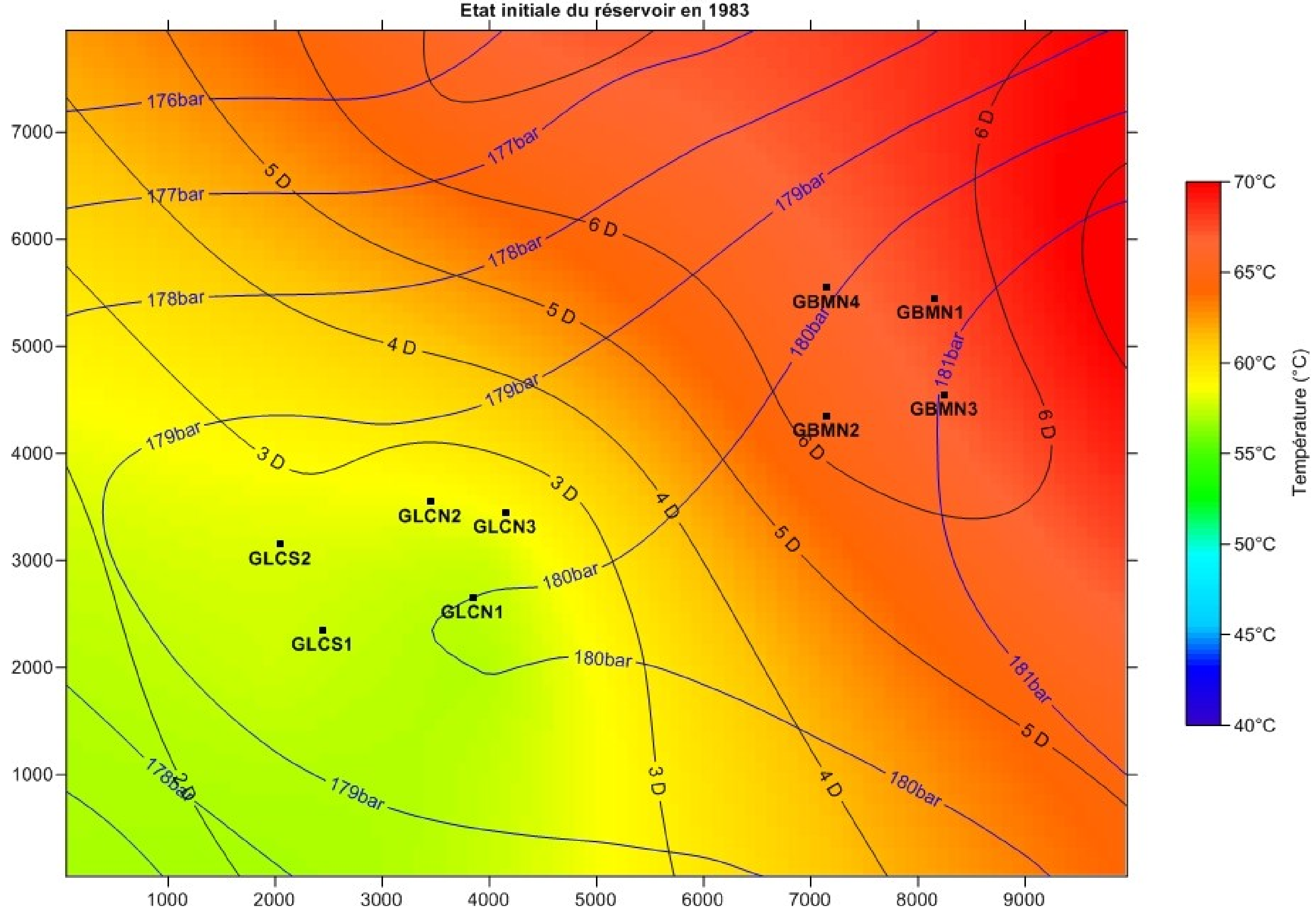
- Depth :
-1500 to -1650 m NGF
- Temperature :
57 to 74°C
- Transmissivity :
Variable, from 5 to 90 Dm
- Hydrochemistry :
Carbonate water
High salinity (20-30 g/l)
Solution gases (CO_2, H_2S, CH_4)
- WHP > 0 (5-9 bars)
(flowing well)

Depth to Dogger (mNGF)
Temperature @ top Dogger (°C)
Transmissivity (Darcy.m)

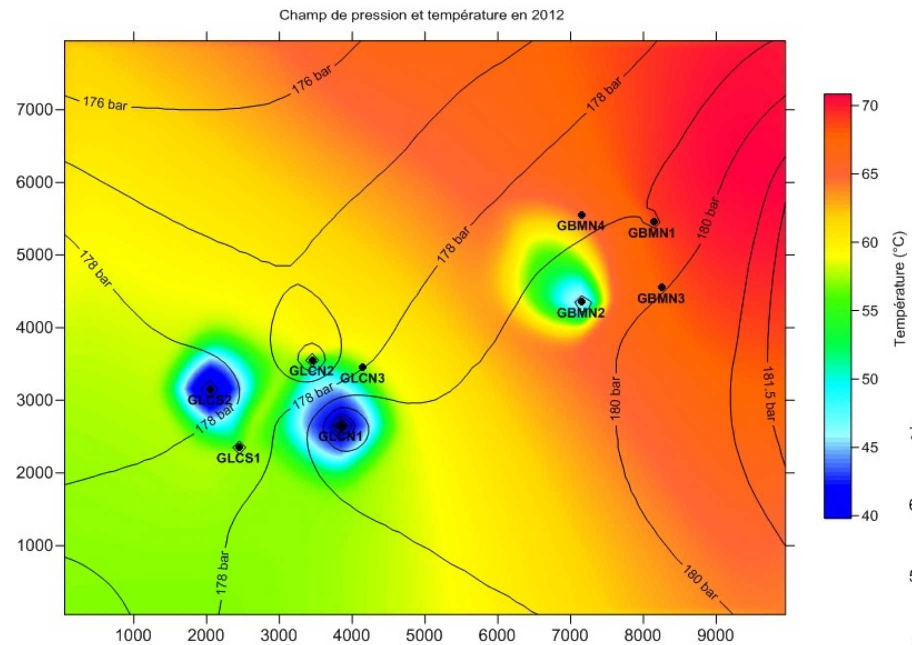
CASE STUDY GLCN3
RESERVOIR ASSESSMENT TENTATIVE FACIES CORRELATIONS. PARIS NORTH



CASE STUDY GLCN3. RESERVOIR SIMULATION
INITIAL PRESSURE, TEMPERATURE & PERMEABILITY STATE
(@ YEAR 1982)

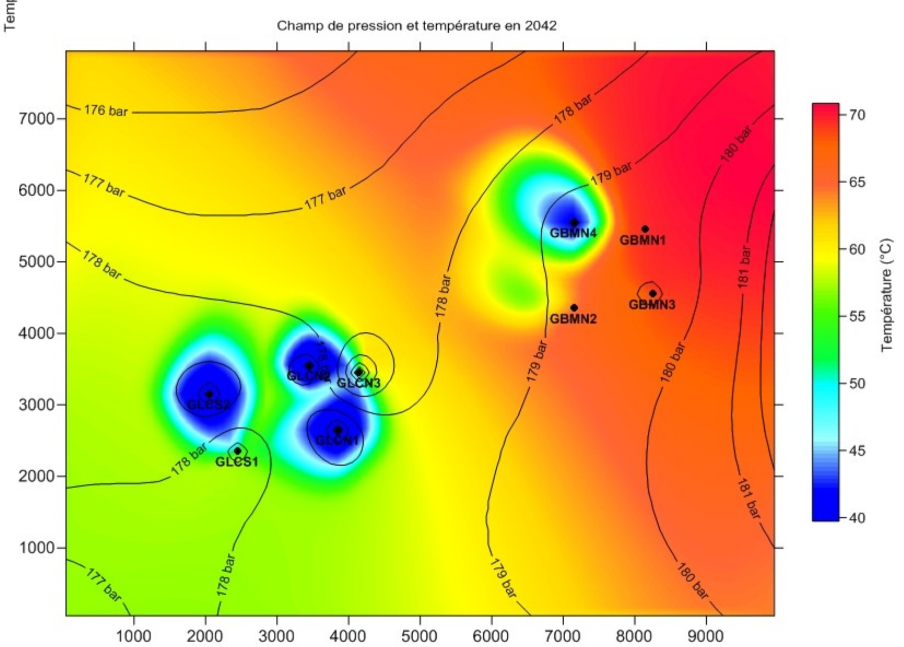


CASE STUDY GLCN3
RESERVOIR SIMULATION. BHP & BHT FIELDS (1982-2042)



2012

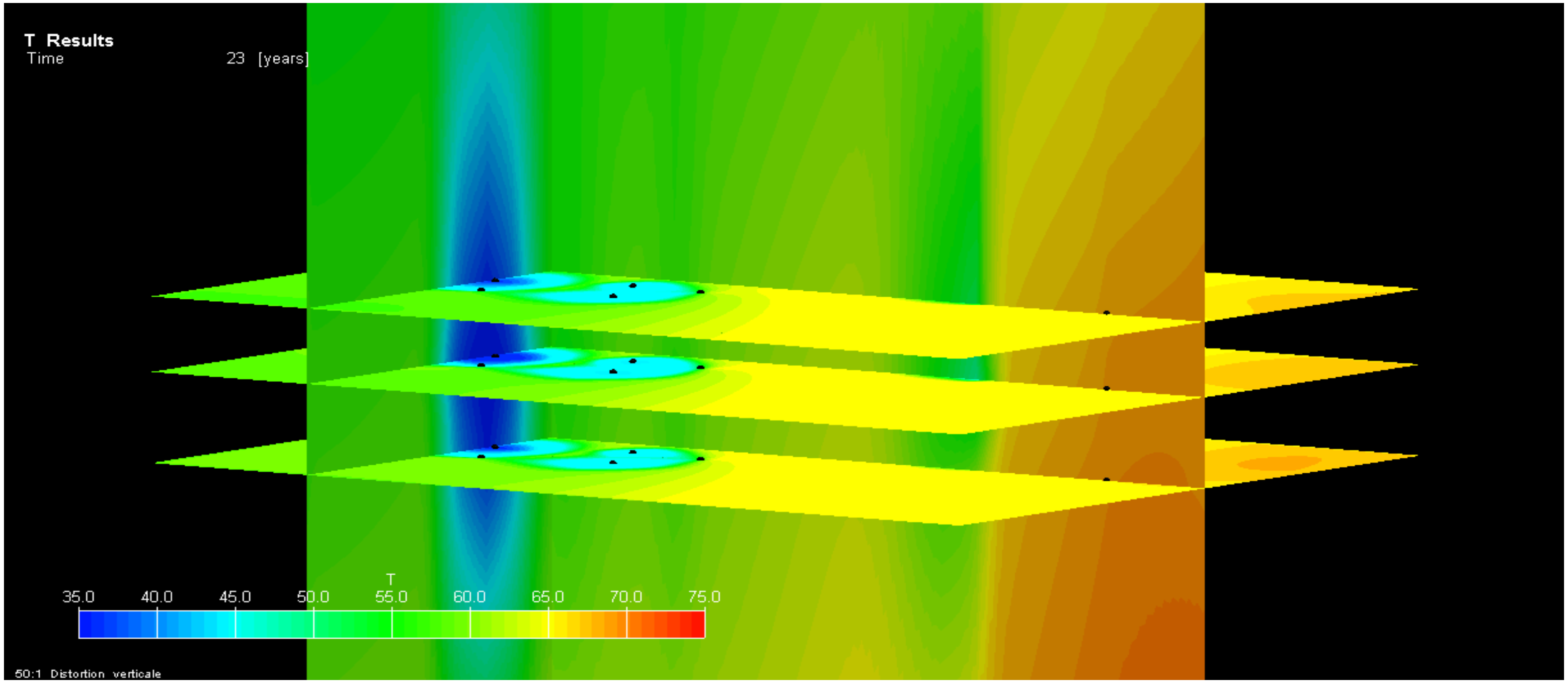
2042



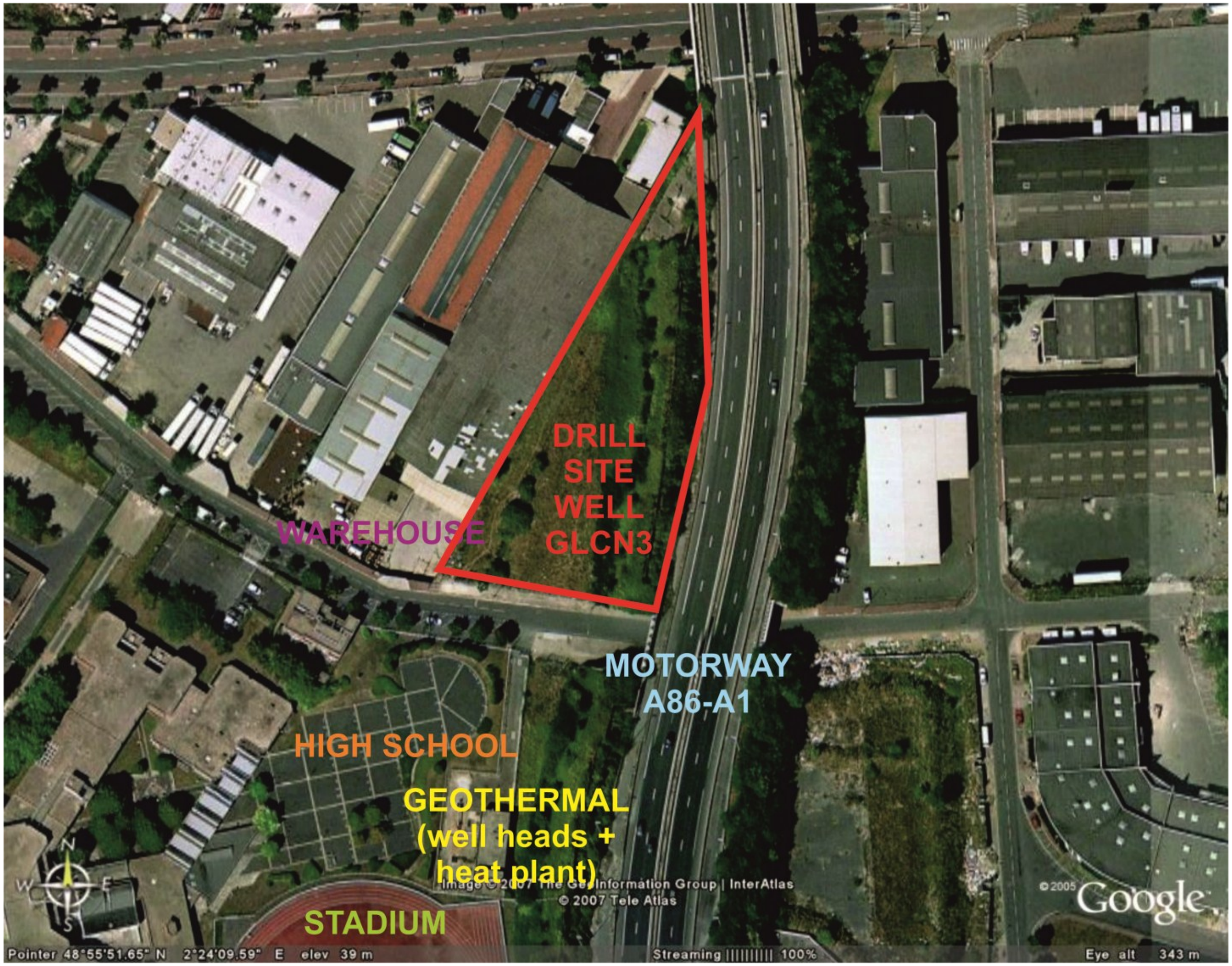
CASE STUDY
RESERVOIR SIMULATION

3D display of cooling kinetics (year 2035)
(280 m^3/hr)

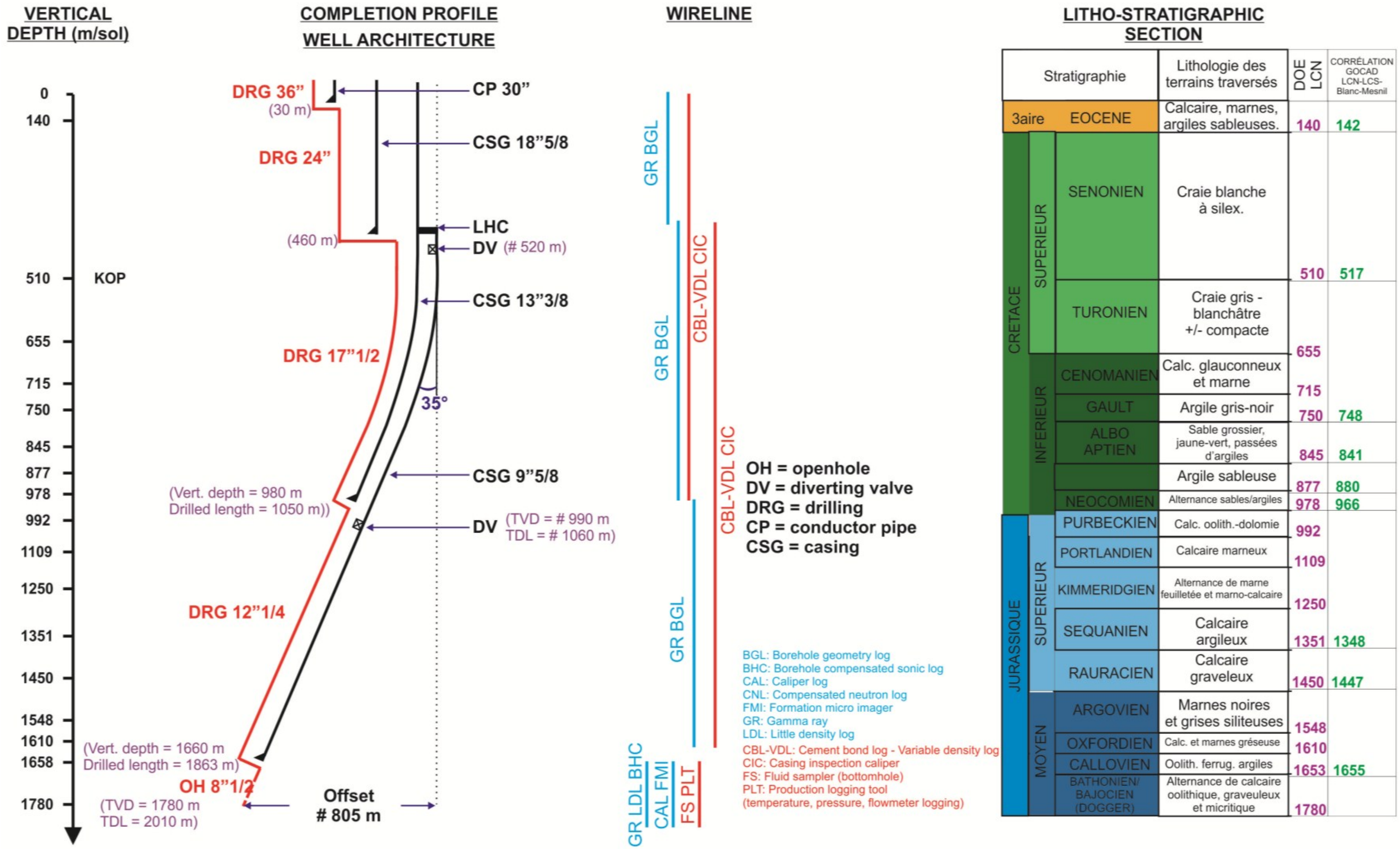
Qnom = 280 m3/h



CASE STUDY
AEREAL VIEW OF GLCN3 DRILL SITE

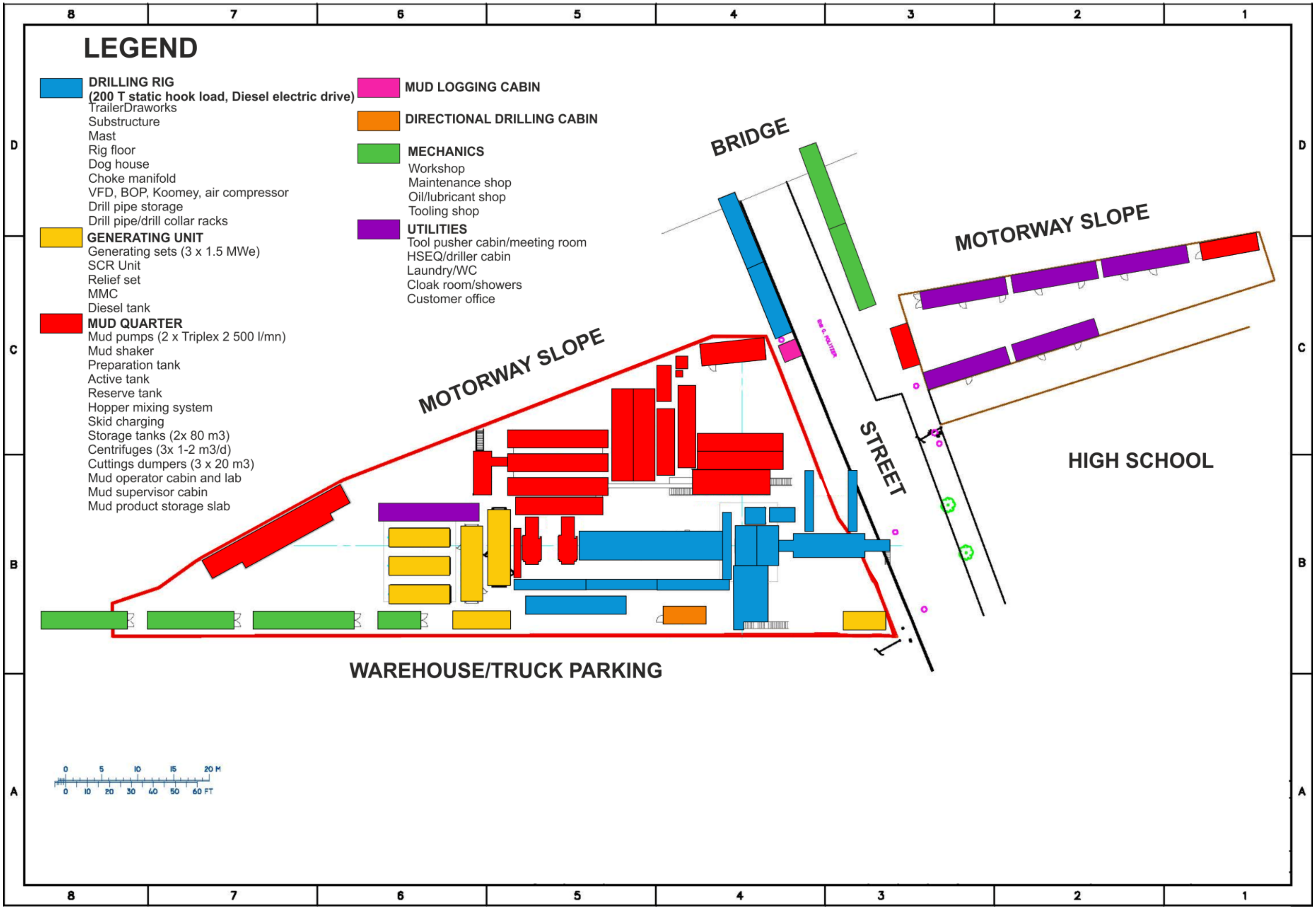


CASE STUDY
GLCN3 WELL PROFILE



CASE STUDY
DRILLING RIG

CASE STUDY GLCN3 DRILL SITE
RIG & EQUIPMENT LAYOUT



CASE STUDY
CANDIDATE DRILLING/COMPLETION PROGRAMME

DRILLING PHASES		CASING PHASES						
Diameter (")	Drilled interv (mbgl)	Diameter (")	Depths (mbgl) and lengths (m) drilled	Range	Material/grade	Unit weight (lbs/ft)	Thread	REMARKS
A. STEEL/STEEL COMPLETION								
36	0-30	30	0-30	2	Steel conductor pipe	320.6	ATL	Forewell
24	30-460	18 5/8	0-458	3	K/JSS steel	87.5	BTC	KOP @ 520 mbgl
17 1/2	460-1050	13 3/8	0-1048	3	K/JSS steel	54.5	BTC	
12 1/4	1050-1880	9 5/8	0-1878	3	K/JSS steel	43.5	BTC	Cut@ # 450 mbgl
8 1/2	1880-2026		OPENHOLE					2 DV@ # 1060 & 520 mbgl
B. COMBINED STEEL CASING/FIBERGLASS LINING COMPLETION								
36	0-30	0-30	30	2	Steel conductor pipe	320.6	ATL	Forewell
24	30-460	0-458	18 5/8	3	K/JSS steel	87.5	BTC	
17 1/2	460-1880	446-1878	13 3/8	3	K/JSS steel	61	BTC	KOP @ 520 mbgl Cut@ # 450 mbgl
		0-450	13 3/8	2	Epoxy resin armored fiber glass type E	36.5	API 8 RD	Twin filament winding with axial
		450-1878	9 5/8	2		16.9	API 8 RD	Seat receptacle @ 450 mbgl
12 1/4	1880-2026		OPENHOLE					

CASE STUDY GLCN3
BIT RECORD GLCN3

Bit type	Bit size	Depth start (mbgl)	Depth end (mbgl)	Total length (m)
Drill bit	24″	36	466	430
Drill bit	17″1/2	471	1058	587
PDC bit	12″1/4	1065	1860	795
Drill bit	8″1/2	1849	1990	141

CASE STUDY
DRILLING MUD FORMULAE

DRILLING PHASE [diam.(")/interval (mbgl)]	DENSITY Sp. Gr	VM[1] s/l	FILTRATE cc/30 mn	YP[2] lbs/100"2	GELS Os/10 mn	MUD FORMULAE
A. STEEL/STEEL COMPLETION						
ø 24- 0-460	1.15	60-80		25-30	3/15	BBS[3]
ø 17 1/2 460-655 (Chalk)	1.20[4]	60-80[4]		18-22[4]		Fresh water + viscous plugs
655-1050	≤ 1.14	50-55	9-8	18-20	3-15	Cellulosic polymer based mud
ø 12 1/4 655-1880	"	"	"	"	"	"
ø 8 1/2 1880-2026	≤ 1.11	45-50	10-8	10-12	2/12	Brine (10g/l eq.NaCl) biopolymer based mud
B. COMBINED STEEL CASING/FIBERGLASS LINING COMPLETION						
ø 24 0-460	1.15	60-80		25-30	3/15	BBS[3]
ø 17 1/2 460-655 (Chalk)	1.00 - 1.20[4]	60-80[4]		18-22[4]		Fresh water + viscous plugs
655-1880	≤ 1.14	50-55	9-8	18-20	3/15	Cellulosic polymer based mud
ø 12 1/4 1880-2026	≤ 1.11	45-50	10-8	10-12	2/12	Brine (10g/l eq.NaCl) biopolymer based mud

(1) VM = Marsh viscosity
(2) YP = Yield point
(3) BBS = Simple bentonitic mud
(4) Viscous plug rheology

CASE STUDY
CEMENTING

Drilled interval (mbgl)		Diameter (")	Casing diameter (")	Unit volume (l/m)	Total volume (l)	Cement (*) (t)	Water (m^3)
A. STEEL-STEEL COMPLETION							
0	460	24	18 5/8	116.1	53 406,0	45,07	32,15
460	1050	17 1/2	13 3/8	108.02 (460-1050 m); 112.76 (0-460 m)	95 605,6	80,69	57,55
1050	1880	12 1/4	9 5/8	29.1 (1050-1880 m); 33.70 (520-1050 m)	42 014,0	35,46	25,29
				TOTAL	**191 025,6**	**161,22**	**114,99**
B. STEEL CASING-FIBERGLASS LINING COMPLETION							
0	460	24	18 5/8	116.1	53 406,0	45,07	32,15
460	1880	17 1/2	13 3/8	108.02	153 644	129,68	92,49
				TOTAL	**207 050,0**	**174,75**	**124,64**

(*) Class G cement

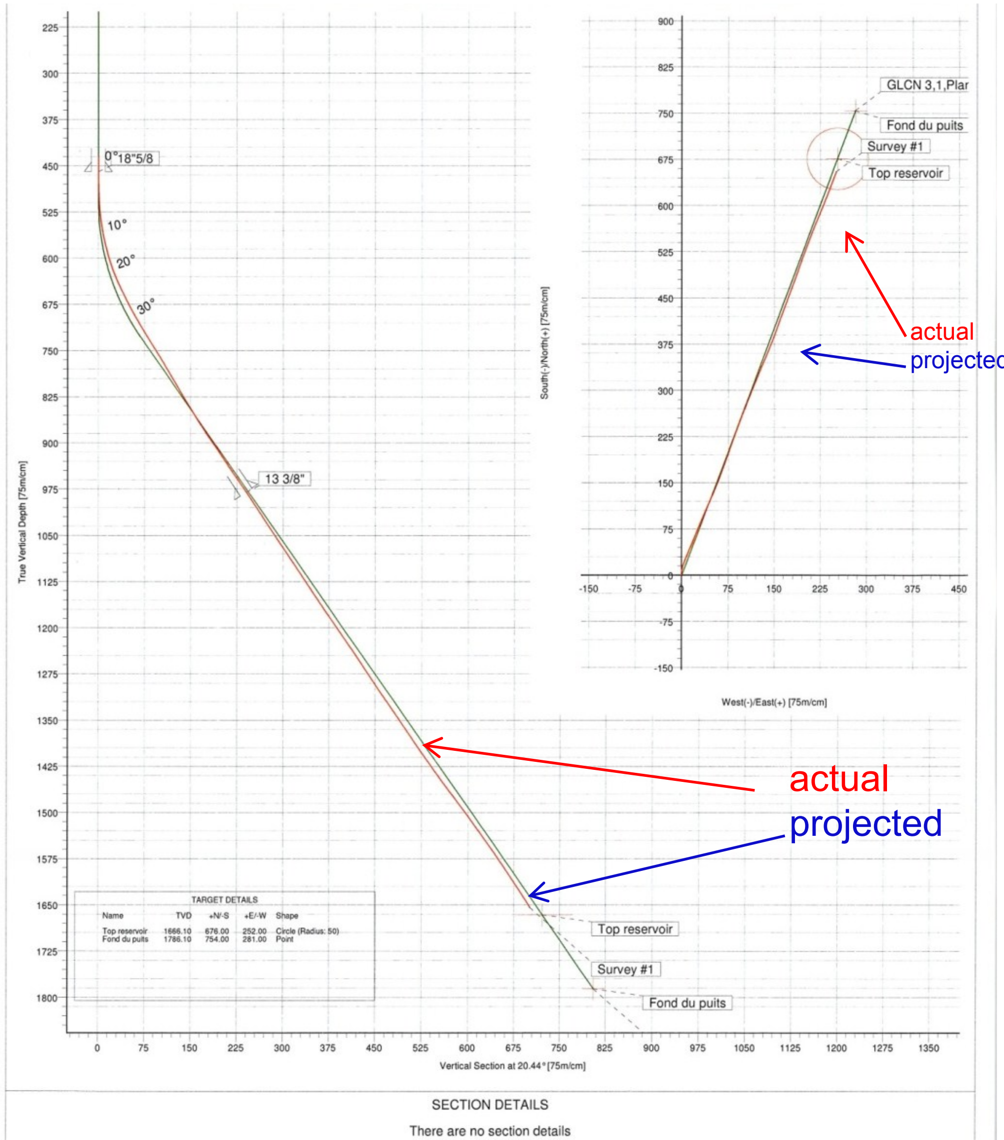
CASE STUDY
WIRELINE LOGGING PROGRAMME

TOOL(S)	DRILLING PHASE	INTERVAL (mbgl)	CASED PHASE	INTERVAL (mbgl)	REMARK(S)
A. STEEL/STEEL COMPLETION.					
GR/BGL	24	0-460			o BGL aims at refining cement volume estimates o HRT to be performed at the end of pressure build up o Pressure gauge and fluid sampler set 10 m below last casing shoe
GR/BGL	17 1/2	460-1050			
CBL-VDL/CIC			13 3/8	0-1048	
GR/BGL	12 1/4	1050-1880			
CBL-VDL/CIC			9 5/8	450-1878	
GR/LDL/BHC CAL/FMI	8 1/2	1880-2020			
FS/PLT/HRT	8 1/2	# 1890			
B. COMBINED STEEL CASING/FIBERGLASS LINING COMPLETION.					
GR/BGL	24	0-460			o Same as for completion A
GR/BGL	17 1/2	460-1050			
CBL-VDL/CIC			13 3/8	0-1880	
GR/LDL/BHC CAL/FMI	12 1/4	1880-2020			
FS/PLT/HRT	12 1/4	# 1890			

Nomenclature:

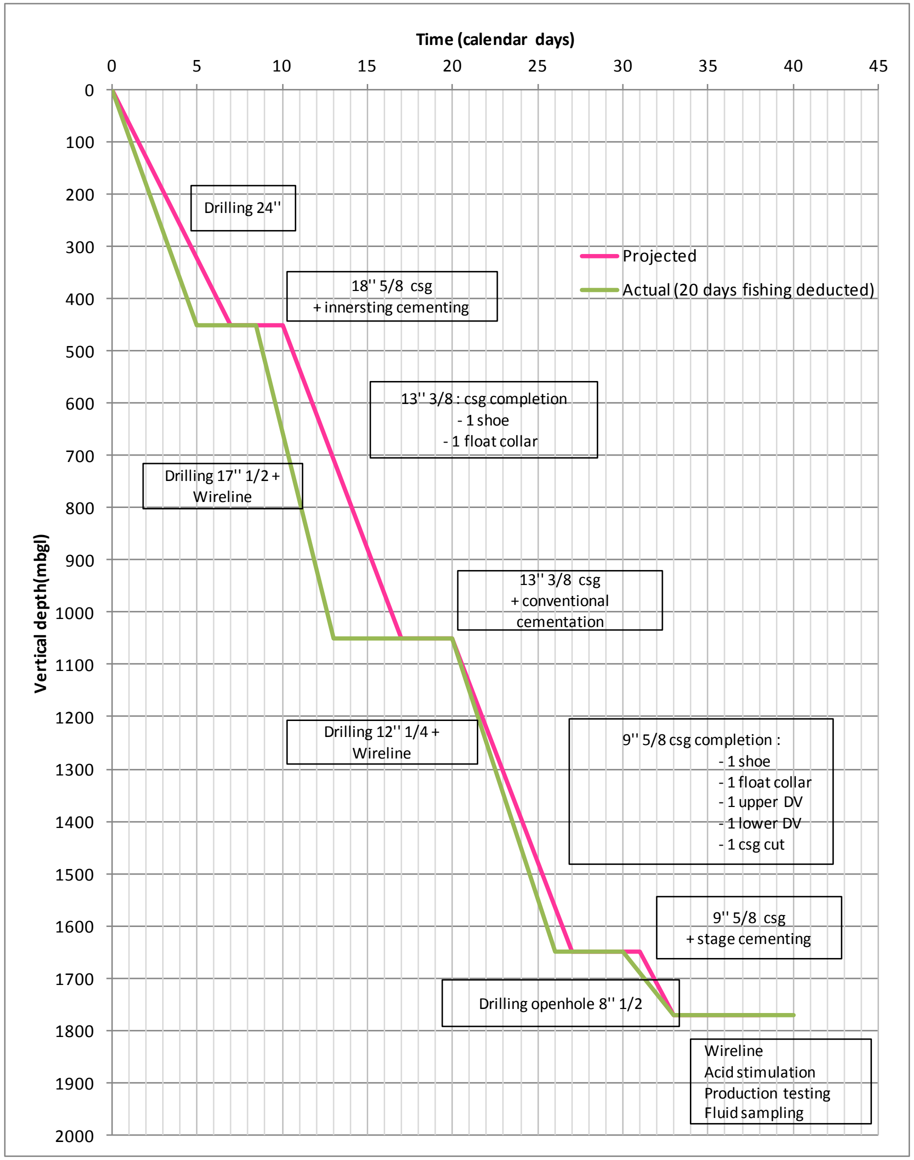
GR	= Gamma Ray
BGL	= Borehole Geometry Log
CBL-VDL	= Cement Bond Log - Variable Density Log
CIC	= Casing Inspection Caliper
CAL	= Caliper (OH)
LDL	= Lithodensity Log
BHC	= Borehole Compensated (Sonic)
FMI	= Formation Micro Imager
FS	= Fluid Sampler
PLT	= Production Logging Tools (flowmeter, pressure/temperature gauges)
HRT	=High Resolution Thermometer

CASE STUDY GLCN3
WELL TRAJECTORIES



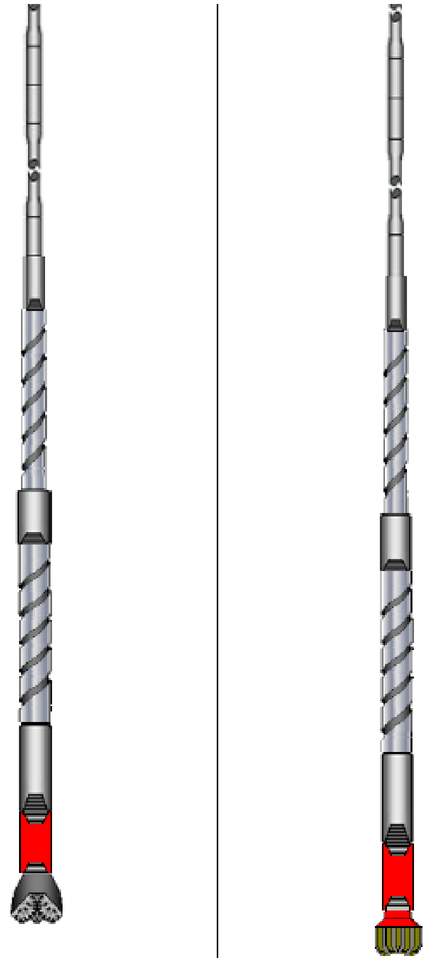
Source : WEATHERFORD

CASE STUDY
PROJECTED VS ACTUAL DRILLING TIME CHART



CASE STUDY GLCN3
DIRECTIONAL DRILLING BHAs

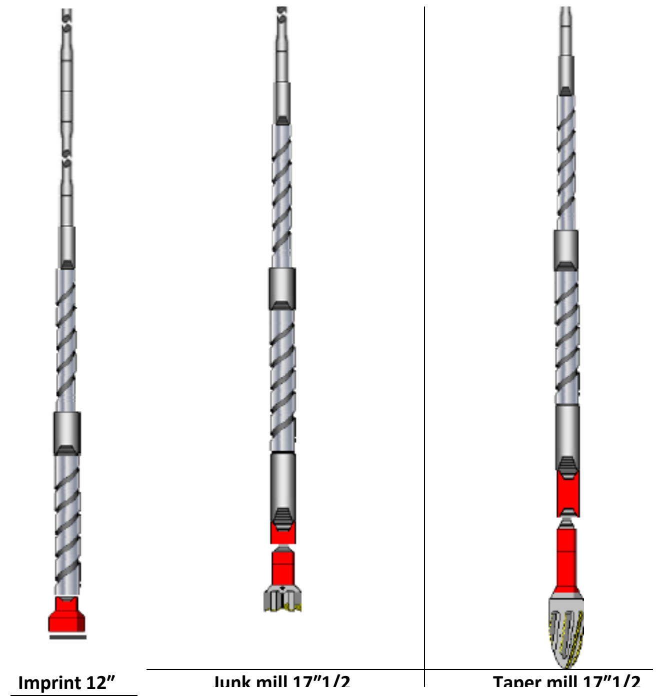
DIRECTIONAL DRILLING BHAs



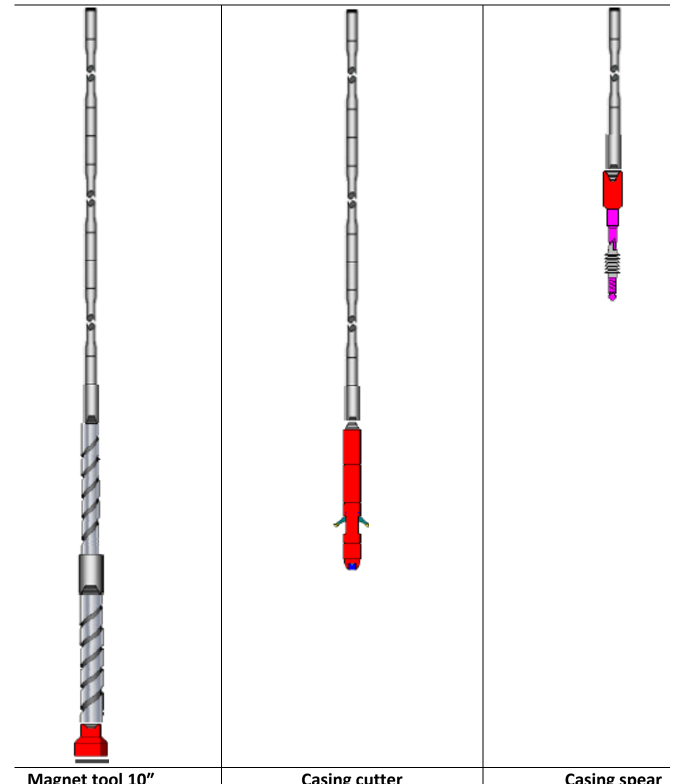
Directional drilling (drill bit 17"1/2)	**Directional drilling (PDC bit 12"1/4)**

Directional drilling (drill bit 17"1/2)	**Directional drilling (PDC bit 12"1/4)**
Drill bit 17"1/2	PDC bit 12"1/4
Motor pump	Motor pump
Float sub	MWD tool carrier
Measurement while drilling (MWD) tool carrier	MWD emetting sub
MWD emetting sub	NMDC 9"1/2
Non magnetic drill collars (NMDC) 9"1/2	2 x DC 8 "1/4
2 x Drill collars (DC) 8 "1/4	8 x DC 6"3/4
9 x DC 6"3/4	4 x HWDP 5"
4 x Heavy weight drill pipe (HWDP) 5"	Hydraulic jar
Hydraulic jar	9 x HWDP 5"
9 x HWDP 5"	DP 5"
Drill pipes (DP) 5"	

CASE STUDY GLCN3
FISHING BHAs



Imprint 12”	Junk mill 17”1/2	Taper mill 17”1/2
Imprint 12”	Junk mill 17”1/2	Taper mill 17”1/2
2 x DC 6”3/4	2 x DC 8 ”1/4	1 x DC 8 ”1/4
4 x HWDP 5”	9 x DC 6”3/4	Stabilyzer
Hydraulic jar	4 x HWDP 5”	1 x DC 8 ”1/4
9 x HWDP 5”	Hydraulic jar	2 x DC 6”3/4
DP 5”	9 x HWDP 5”	4 x HWDP 5”
	DP 5”	Hydraulic jar
		9 x HWDP 5”
		DP 5”



Magnet tool 10”	Casing cutter	Casing spear
Magnet tool 10”	Casing cutter	Casing spear
1 x DC 8 ”1/4	4 x HWDP 5”	DP 5”
Stabilyzer	Hydraulic jar	
1 x DC 8 ”1/4	9 x HWDP 5”	
2 x DC 6”3/4	DP 5”	
4 x HWDP 5”		
Hydraulic jar		
9 x HWDP 5”		
DP 5”		

CASE STUDY
STIMULATION – PRODUCTION TESTING – FLUID SAMPLING

(i) Acid stimulation :

- Run drill string to (9"5/8 or 13"3/8) casing shoe,
- Squeeze fresh water to reactivate the well,
- Shut in BOP,
- Pump 20 m3 of (passivated) HCl 15X,
- Fresh water flush (20 m3 + dp volume),
- Wait for acid reaction,
- Open BOP,
- Free gas bubble escape,
- Produce well in self-flowing mode via the flow line and waste fluid processing line and measure flowrates, pressure and temperatures at well head;

(ii) Downhole fluid sampling. Collect two samples @ 1890 mbgl depth (10 m below last casing shoe);

(iii) Production testing 1

Run flowmeter/temperature log through drill string to monitor reservoir producing zones, well (self) flowing

- Well shut in,
- POOH flowmeter/temperature tool and run downhole @ 1890 mbgl depth (10 m below last casing shoe) pressure temperature gauge;

(iv) Production testing 2 (pressure drawdown and buildup cycles)

- Flow the well, measure flowrates, pressures and temperatures at wellhead and record bottomhole pressures and temperatures (duration 8 hrs) (MDH interpretation),
- Shut in well,
- Record (duration 12 hrs) bottomhole pressure buildup (Horner interpretation).

PARIS BASIN GDH DOUBLET
TYPICAL COST BREAKDOWN (10^3€)

Ca 40% of CAPEX

CAPEX

Mining	min	max
Well drilling/completion	8500	9000
Primary (geothermal) loop	1200	1300
Geothermal heat exchanger	300	400
Total	10000	10700
Surface		
Secondary (grid) loop	600	700
Heat plant	800	900
Grid (piping)	8000	10000
Grid (substations)	2500	3000
Total	11900	14600
GRAND TOTAL	21900	25300

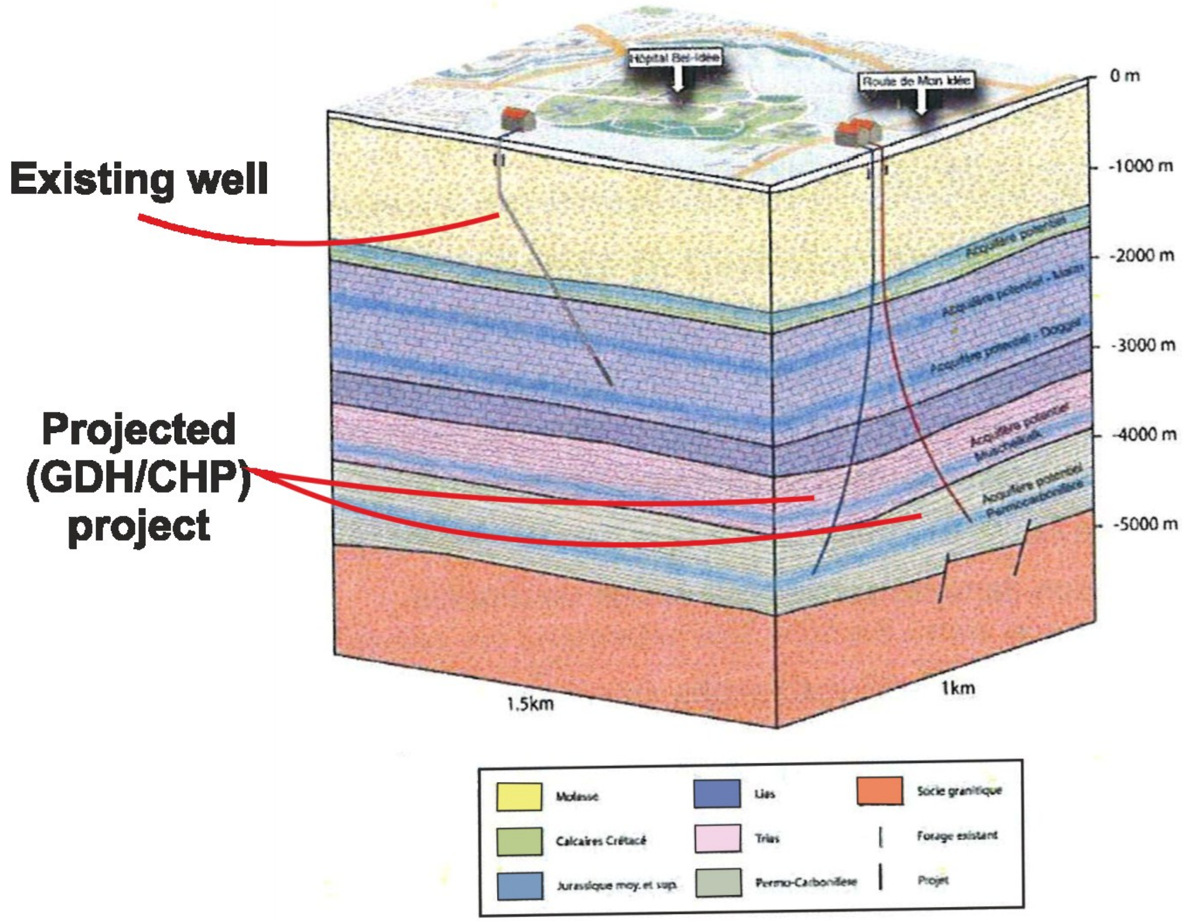
OPEX

Mining	min	max
P1 Power, chemicals, consummables	200	250
P2 Monitoring, light maintenance	75	90
Heavy duty maintenance, well workover, on duty call	250	300
Miscellaneous	30	50
Total	555	690
Surface		
P1 Power, chemicals	40	50
P2 Heat plant/grid monitoring/maintenance	400	450
P3 Provisions for depreciation	250	350
Miscellaneous	40	60
Total	730	910
GRAND TOTAL	1285	1600

	BREAKEVEN		SELLING COST
	WORST CASE	BEST CASE	MEDIUM CASE
CAPEX (10^3€)	25000	22000	23000
OPEX (10^3€/yr)	1600	1285	1400
SUBSIDY (% CAPEX)	0	35	25
BREAKEVEN (€/MWh_t)	**81**	**56**	**64**

DEEP DRILLING PROJECT

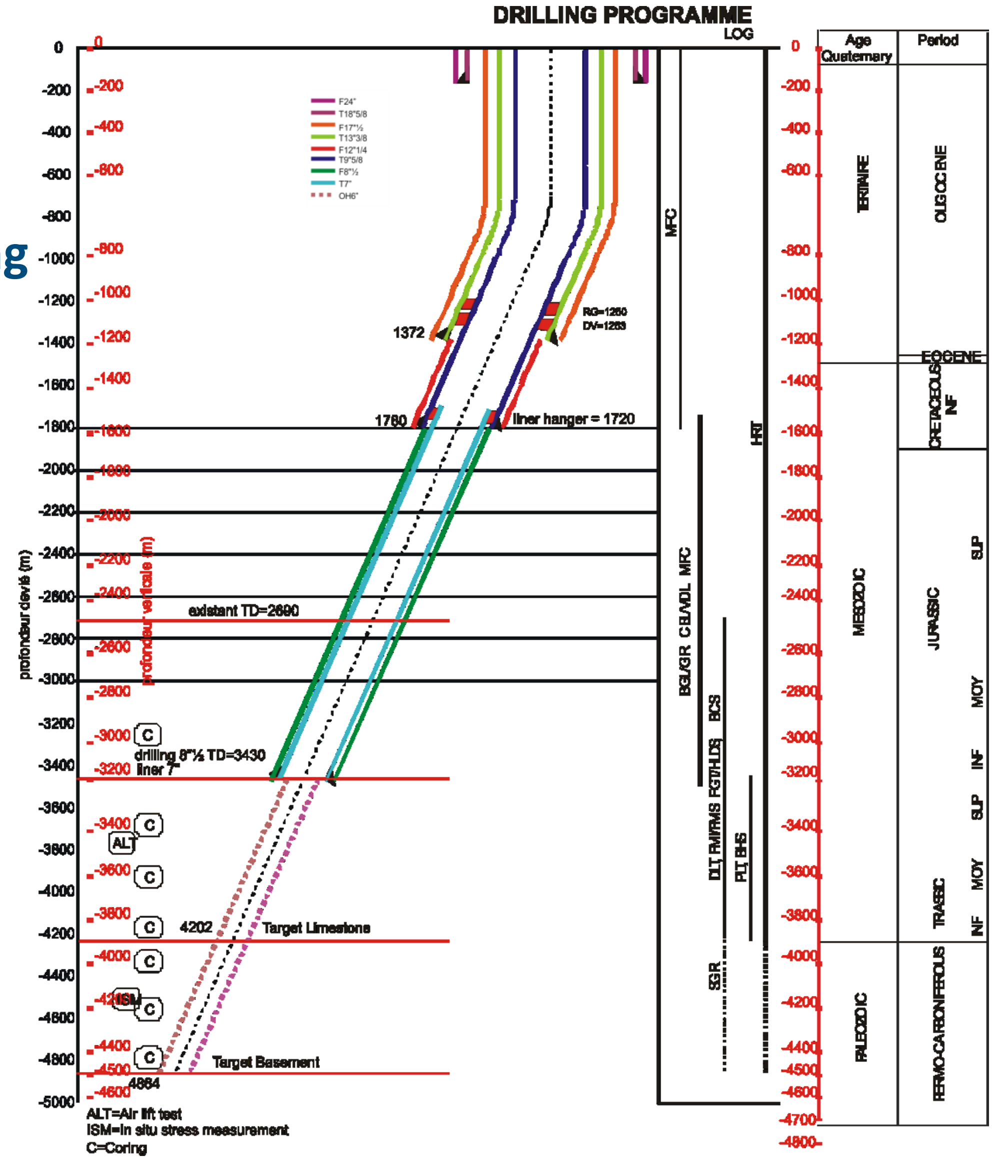
Medium enthalpy CHP EXPLO



Courtesy : SIG. Geneva.

DEEP (4-5 km) EXPLORATORY PROJECT DRILLING PROGRAMME

Medium Enthalpy (4-5km) Deep exploratory drilling

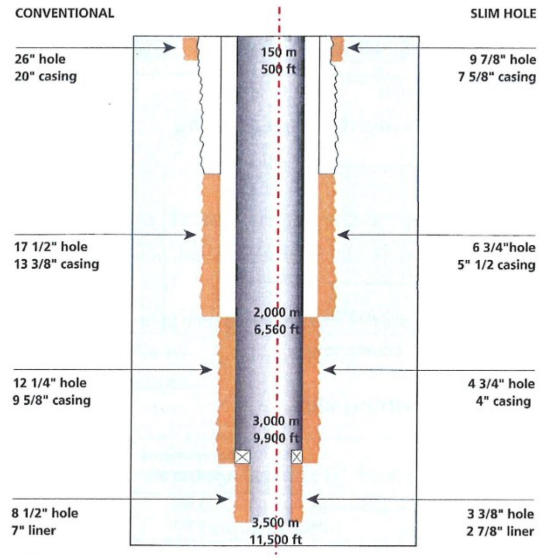


SLIMHOLE STRATEGY

Slimhole vs conventional drilling

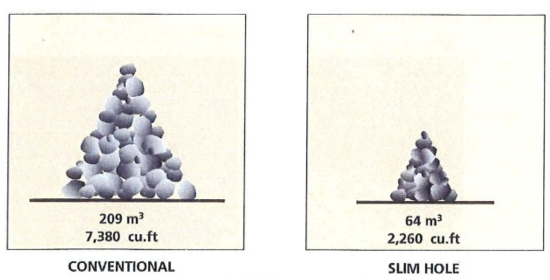
Technical advantages

Typical 3,500 m (11,500ft) well.
Slim hole versus conventional.



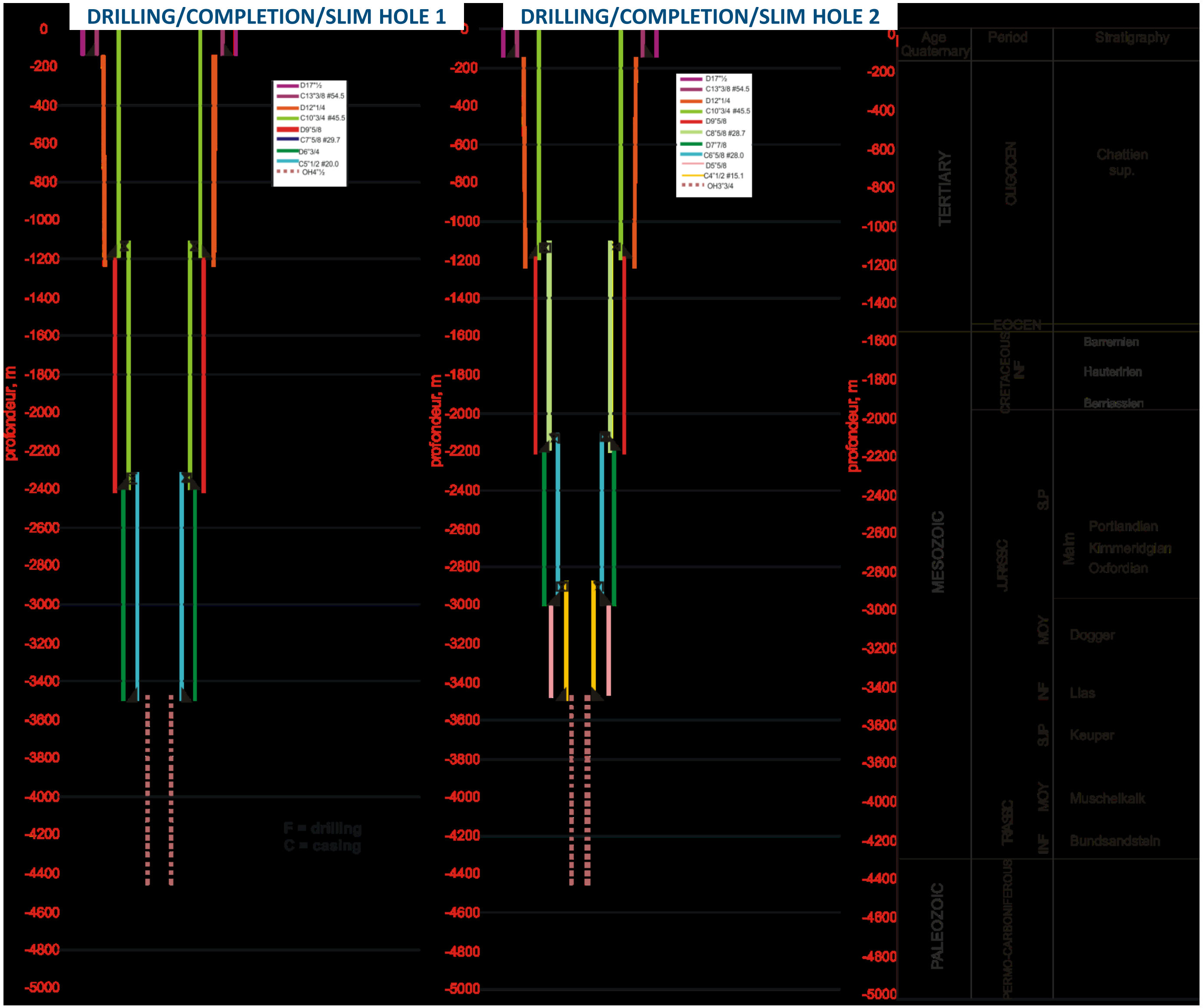
Tangible facts:

1 - Rocks drilled



SOURCE : FORASOL/FORASLIM

SLIMHOLE OPTIONS



SLIMHOLE CONFIGURATION 1

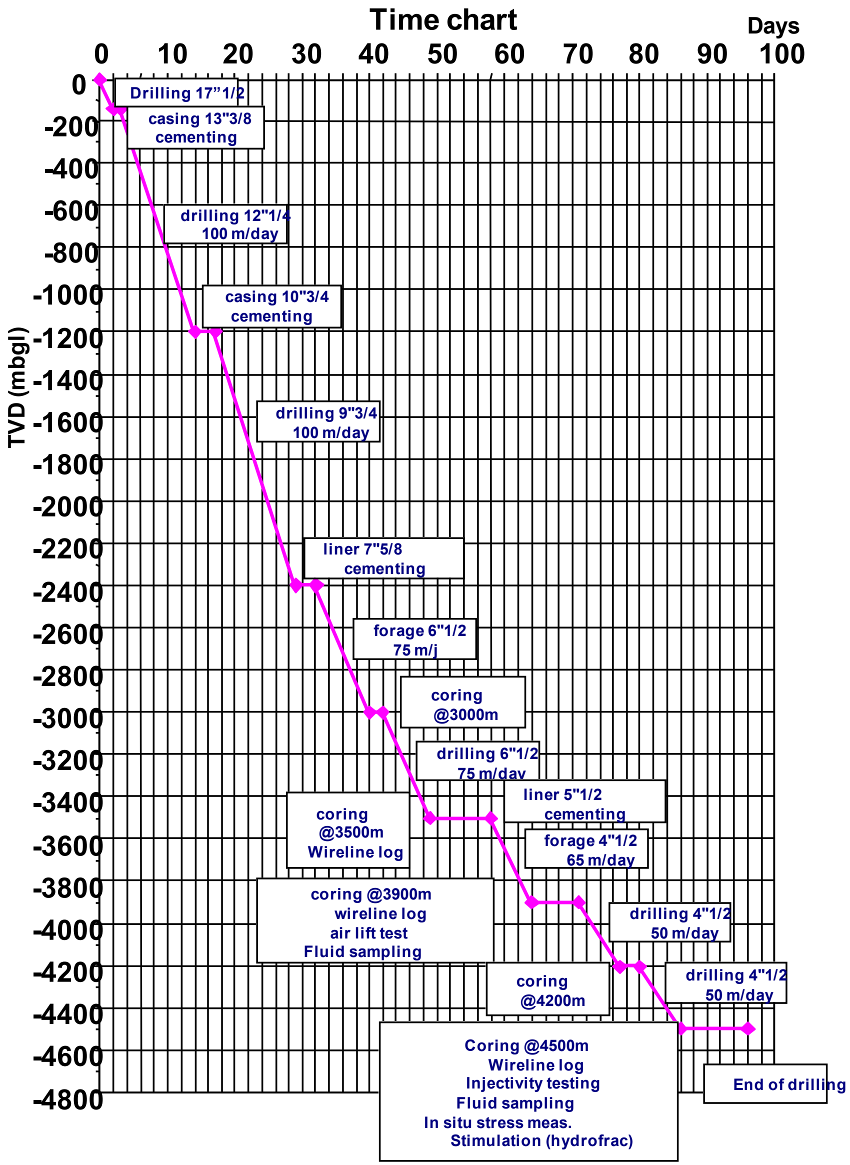
Casing programme

Diameter (OD)"	13 3/8	10 3/4	8 5/8	5 1/2
Interval (mbgl)	0-146	0-1200	1100-2400	2400-3500
Steel grade	K55	K55	K55	K55
Linear weight (lbs/ft)	54.5	45.5	29.7	20
Thread	API	BTC	BTC	BTC
Remark		Float collar @1180 mbgl	Liner hanger (LH) @#2380 mbgl Float valve @#2300 mbgl	Liner hanger (LH) @#2300 mbgl Float valve @#3480 mbgl

Cementing characteristics

Casing	13 3/8	10 3/4	8 5/8	5 1/2
Interval (mbgl)	0-146	0-1200	1100-2400	2400-3500
Slurry	G, POZZ MIX	G, POZZ MIX	G, POZZ MIX	G, POZZ MIX
Density	1,6-1,65	1,6	1,65	1,6
Volume (m3)	10.4	23.1	25	9.5
Weight (tons)	9.5	21.1	22.8	8.6

SLIMHOLE CONFIGURATION 1

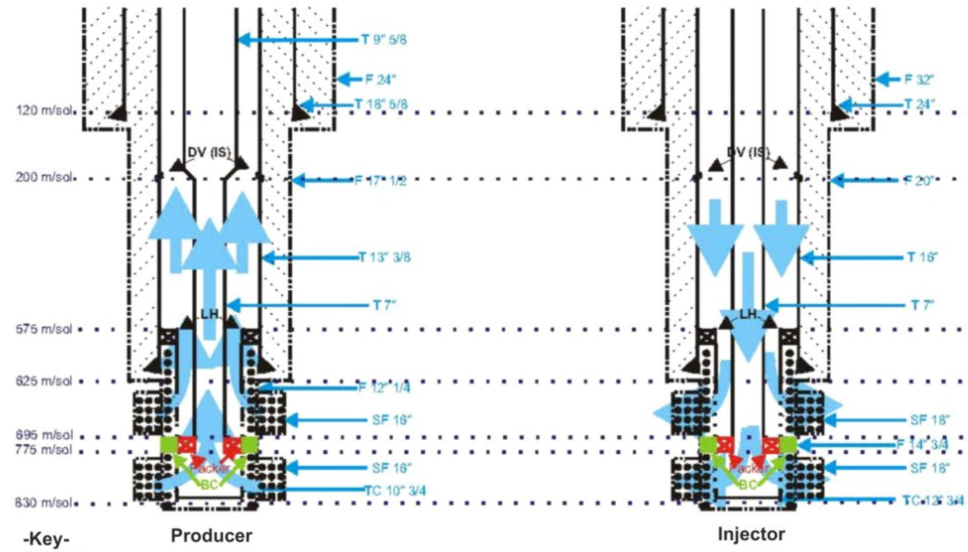


DUAL COMPLETIONS
GEOTHERMAL DISTRICT HEATING & COOLING (GDHC)

Medium depth seated reservoirs

Depth			N°	Thickners (m)	Transmissivity (m^2/s)
625	0 12,5	Albo-Aptien 1	1	25	$5\ 10^{-3}$
	35	Aquitard	2	20	k_v = 15 mD
695	57,5	Albo-Aptien 2	1	25	$5\ 10^{-3}$
	110	Aquitard (Barremien)	3	80	k_v = 0.1 mD
	157,5	Néocomien 1	4	15	$3{,}5\ 10^{-3}$
775	175	Aquitard	5	20	k_v = 5 mD
825	192,5 200	Néocomien 2	4	15	$3{,}5\ 10^{-3}$

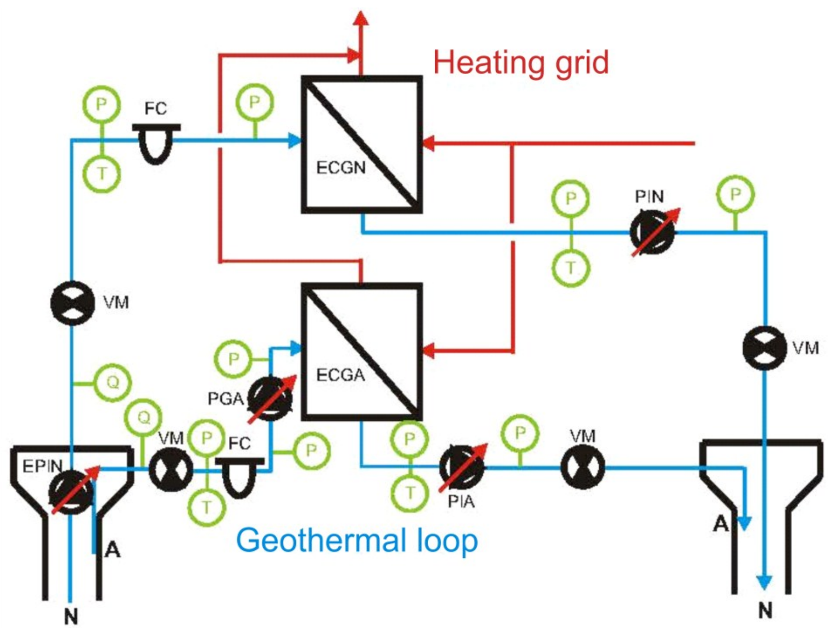
AQUIFER SYSTEM



-Key-
F : drilling
T : casing
TC : screen
SF : underreaming
BC : sealing gel plug
GP : gravel pack
DV : diverting valve (innestring option)
LH : liner hanger

GDHC DOUBLET COMPLETION

DUAL COMPLETIONS
GDHC GEOTHERMAL LOOPS

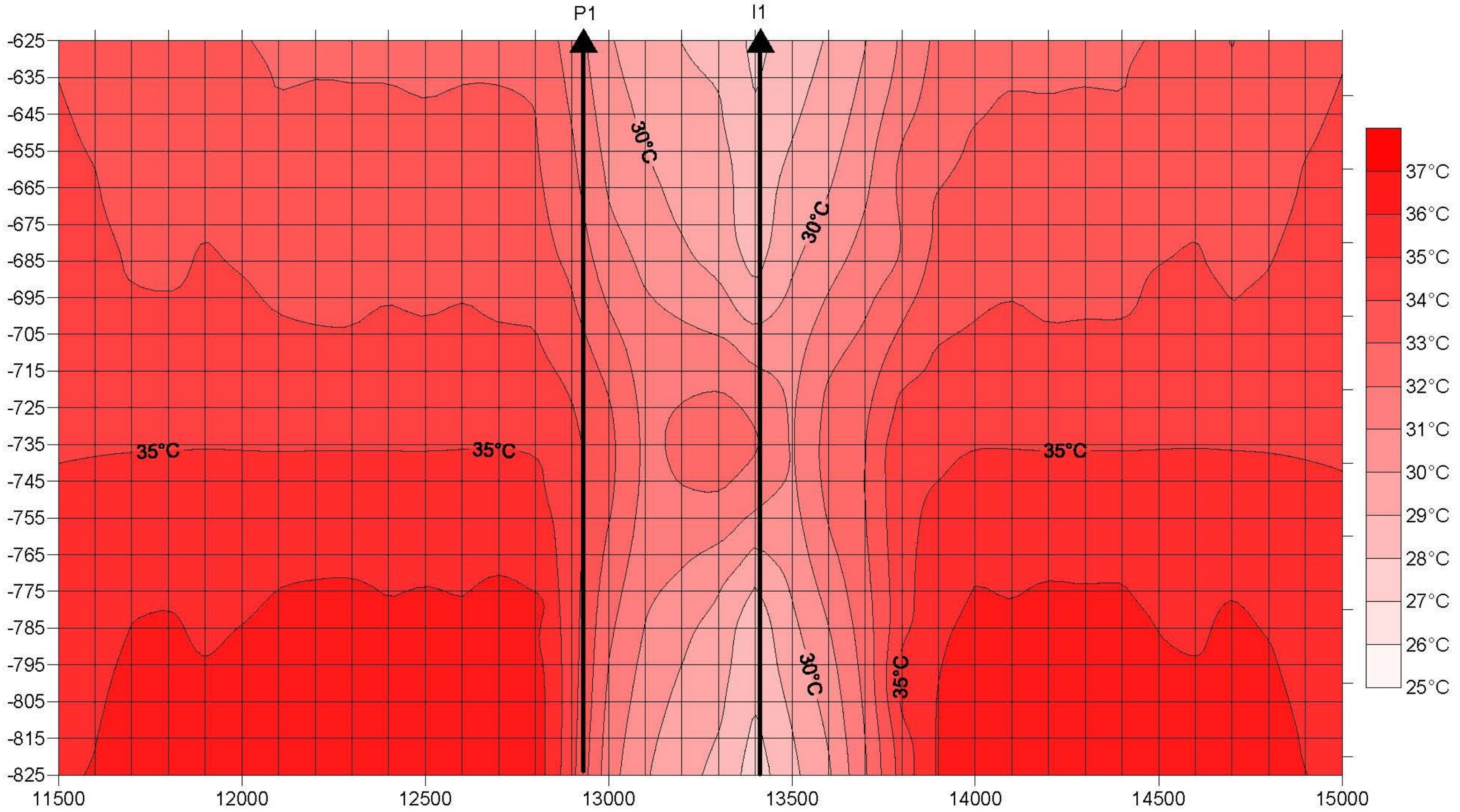


OPTION 3

-Key-

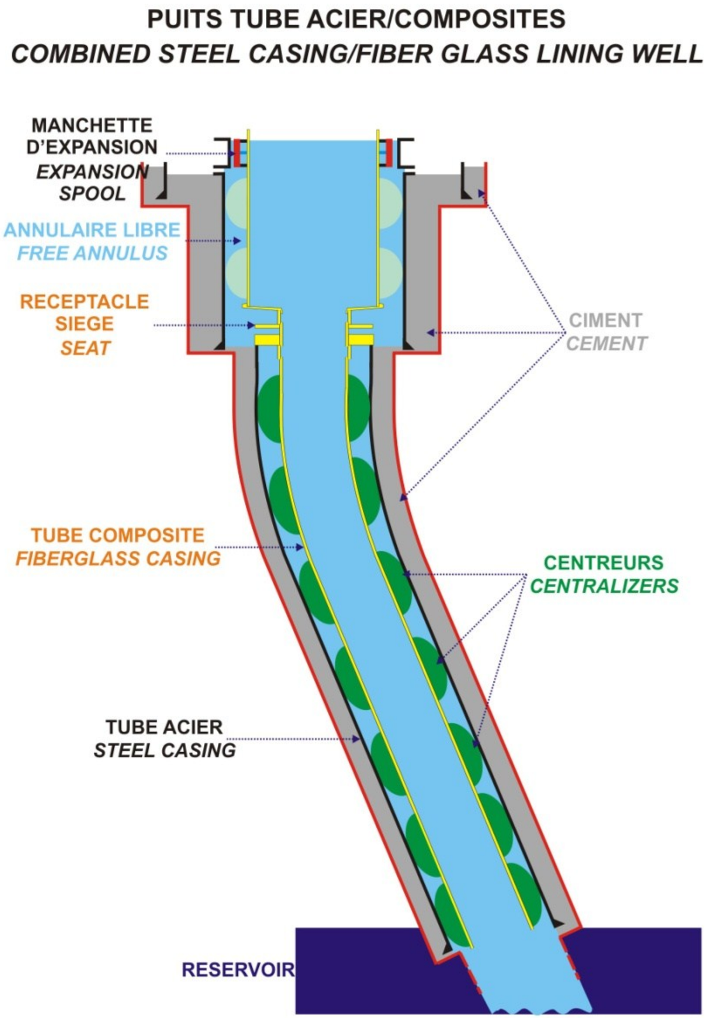
ECGA : geothermal heat exchanger Albian
ECGN : geothermal heat exchanger Neocomian
EPIA : ESP (Albian)
EPIN : ESP (Neocomian)
FC : cartridge filter
I : injector well
PGA : surface boost pump (Albian)
PIA : injection pump (Albian)
PIN : injection pump (Neocomian)
P/Q/T : pressure/flowrate/temperature
VM : master valve

DUAL COMPLETIONS
MODELLING OF THE GDHC DOUBLET



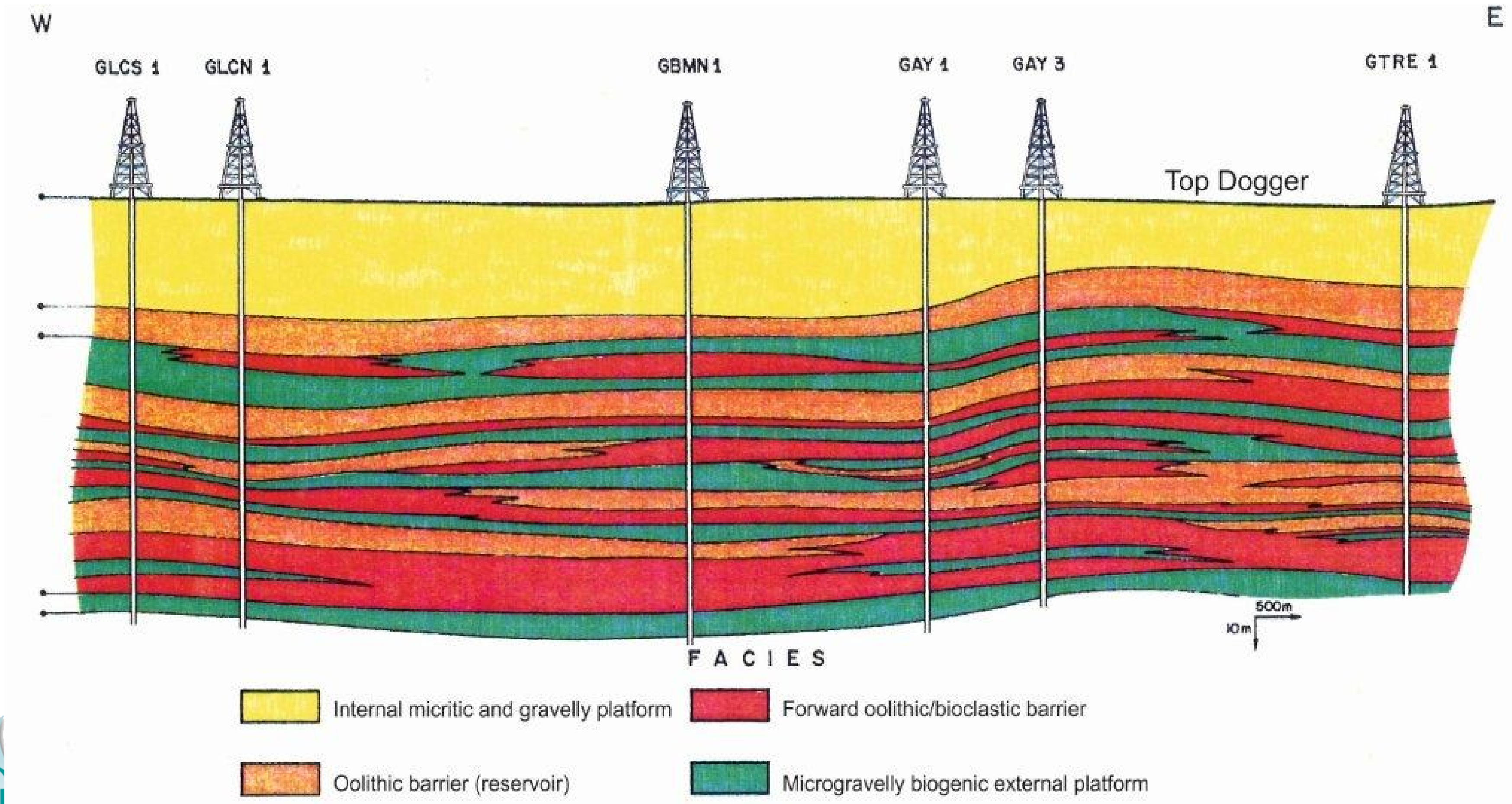
VERTICAL TEMPERATURE DISPLAY (YEAR 2030)

ANTI-CORROSION WELL COMPLETION



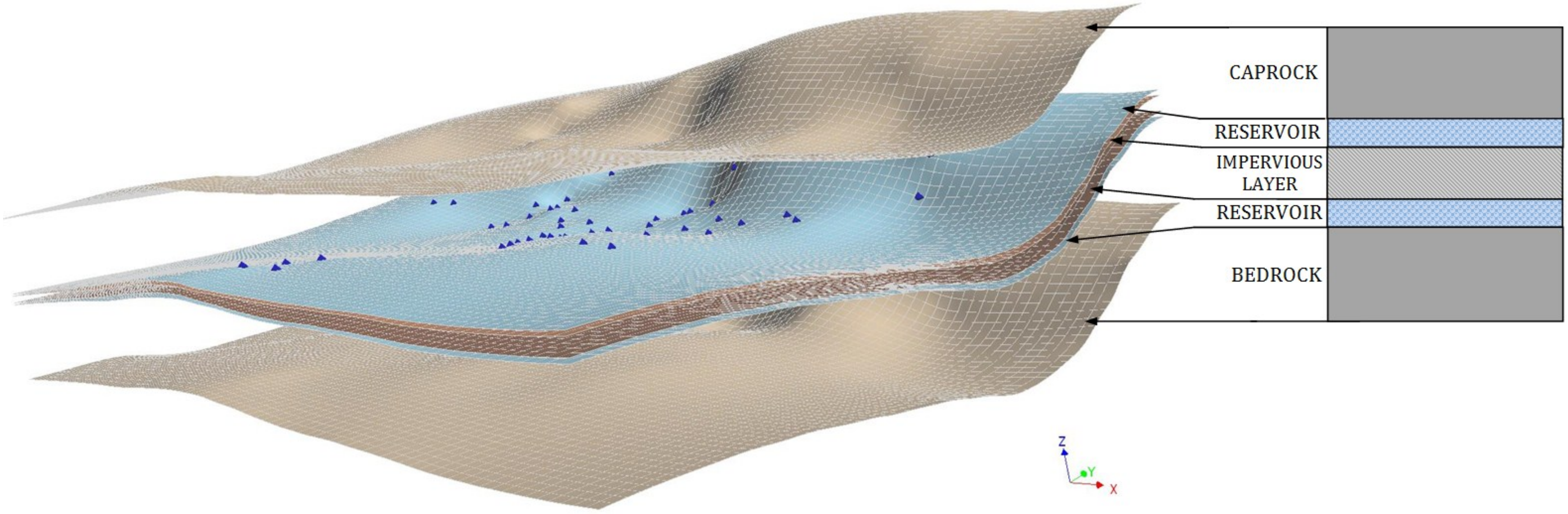
(SUB)HORIZONTAL GDH WELL DESIGNS

MULTILAYERED RESERVOIR STRUCTURE
TENTATIVE FACIES CORRELATIONS. NORTHERN AREA
(ROJAS ET AL, 1989)



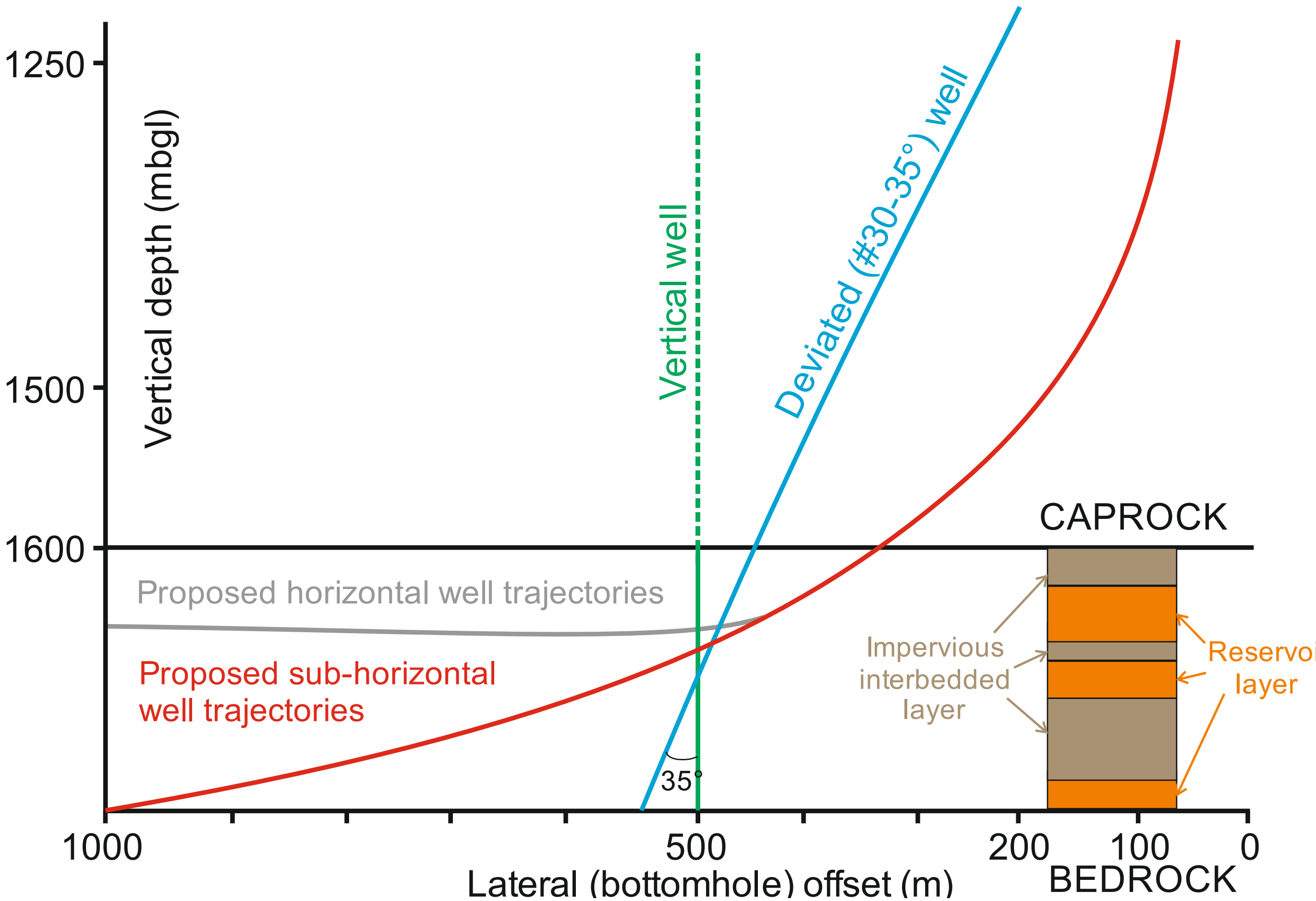
(SUB)HORIZONTAL GDH WELL DESIGNS

GOCAD 3D VIEW OF THE SANDWICH HETEROGENEOUS RESERVOIR STRUCTURE



(SUB)HORIZONTAL WELL DESIGNS

CANDIDATE WELL TRAJECTORIES
MULTILAYERED RESERVOIR
CONVENTIONAL (VERTICAL, DEVIATED)
AND SUGGESTED [(SUB)HORIZONTAL] WELL TRAJECTORIES



(SUB)HORIZONTAL WELL DESIGNS

CANDIDATE WELL TRAJECTORIES
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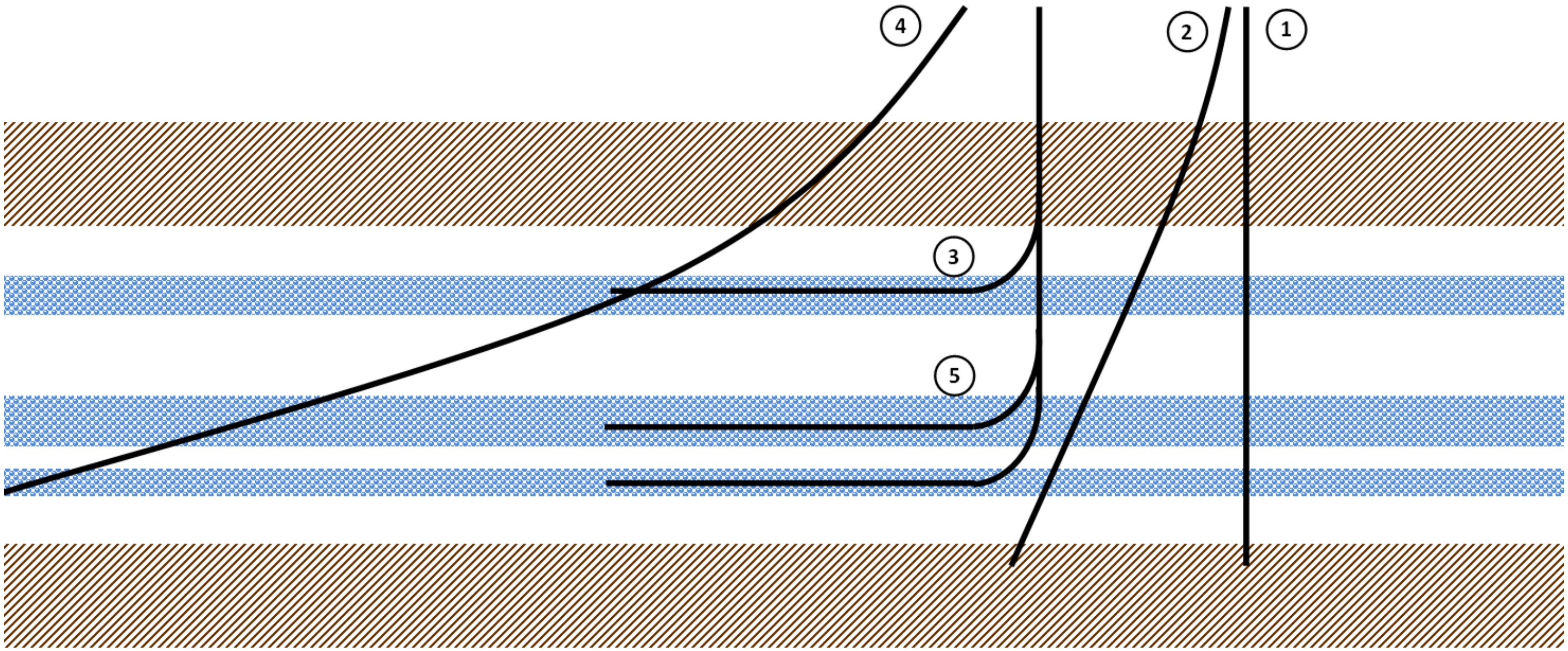


1 Vertical well

2 Deviated well (≠ 30-35°)

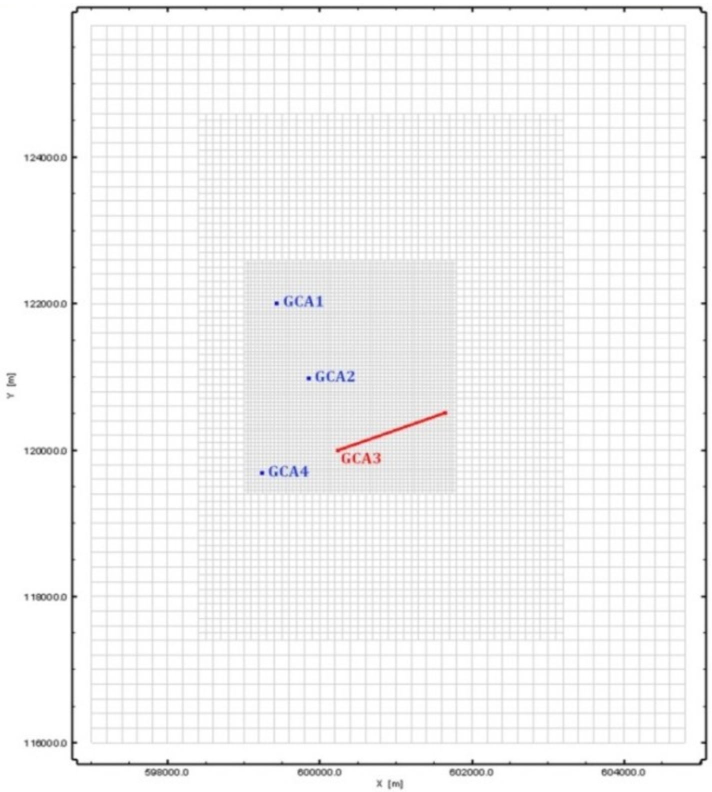
3 Horizontal drain intersecting one layer

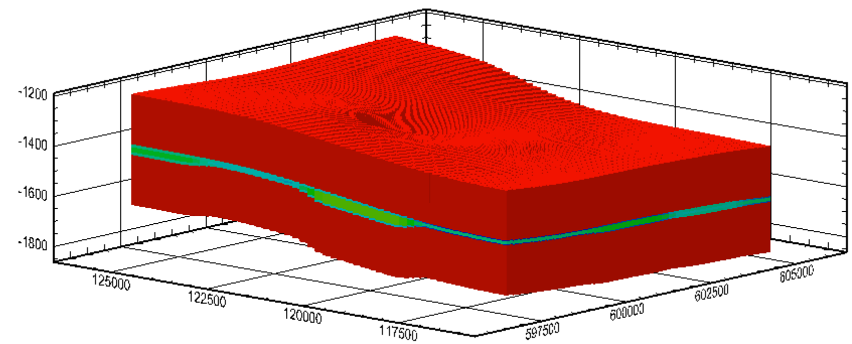
4 Subhorizontal well (≠80-85°) intersecting all the producing layers

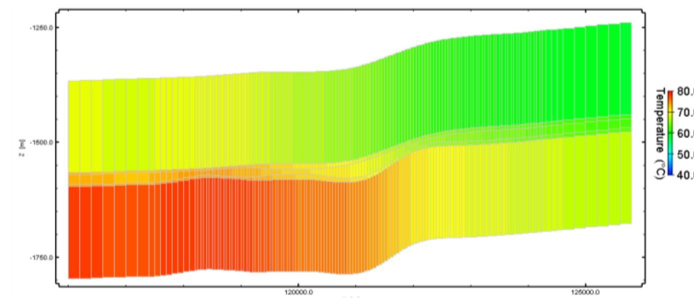
5 Multilateral well, horizontal drains intersecting all the producing layers

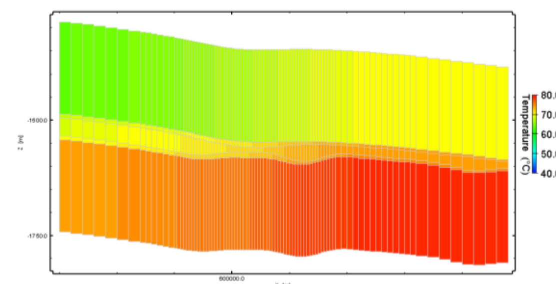
(SUB)HORIZONTAL WELL MODELLING

DISCRETISATION GRID





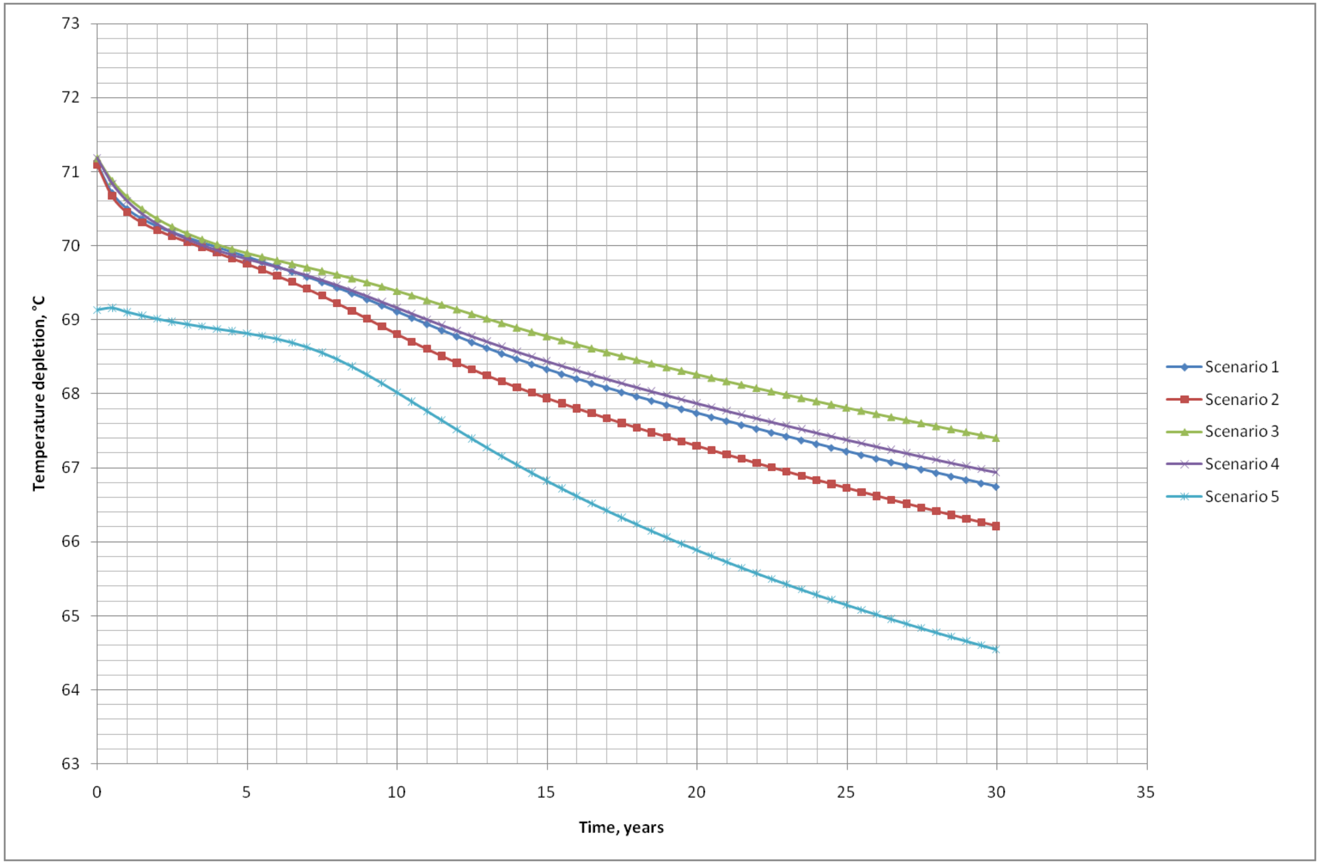




(SUB)HORIZONTAL WELL MODELLING

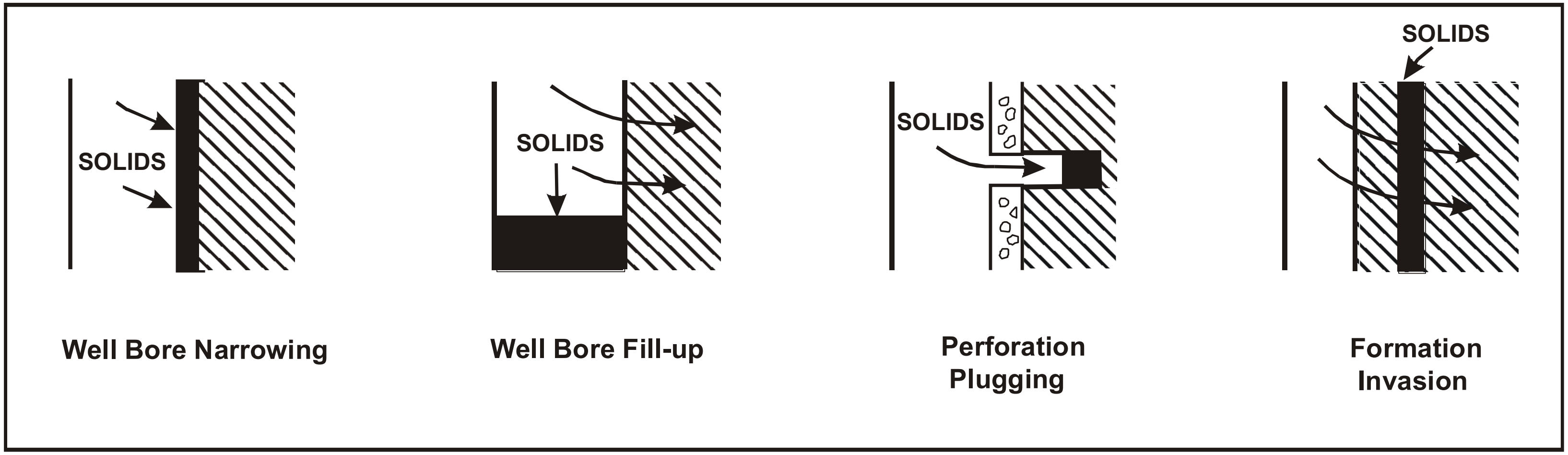
COOLING KINETICS

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Well length (meter)	1000	1000	1500	1500	Vertical
Flow rate (m^3/h)	300	350	300	350	300
Injection temperature (°C)	40	40	40	40	40



WATER INJECTION

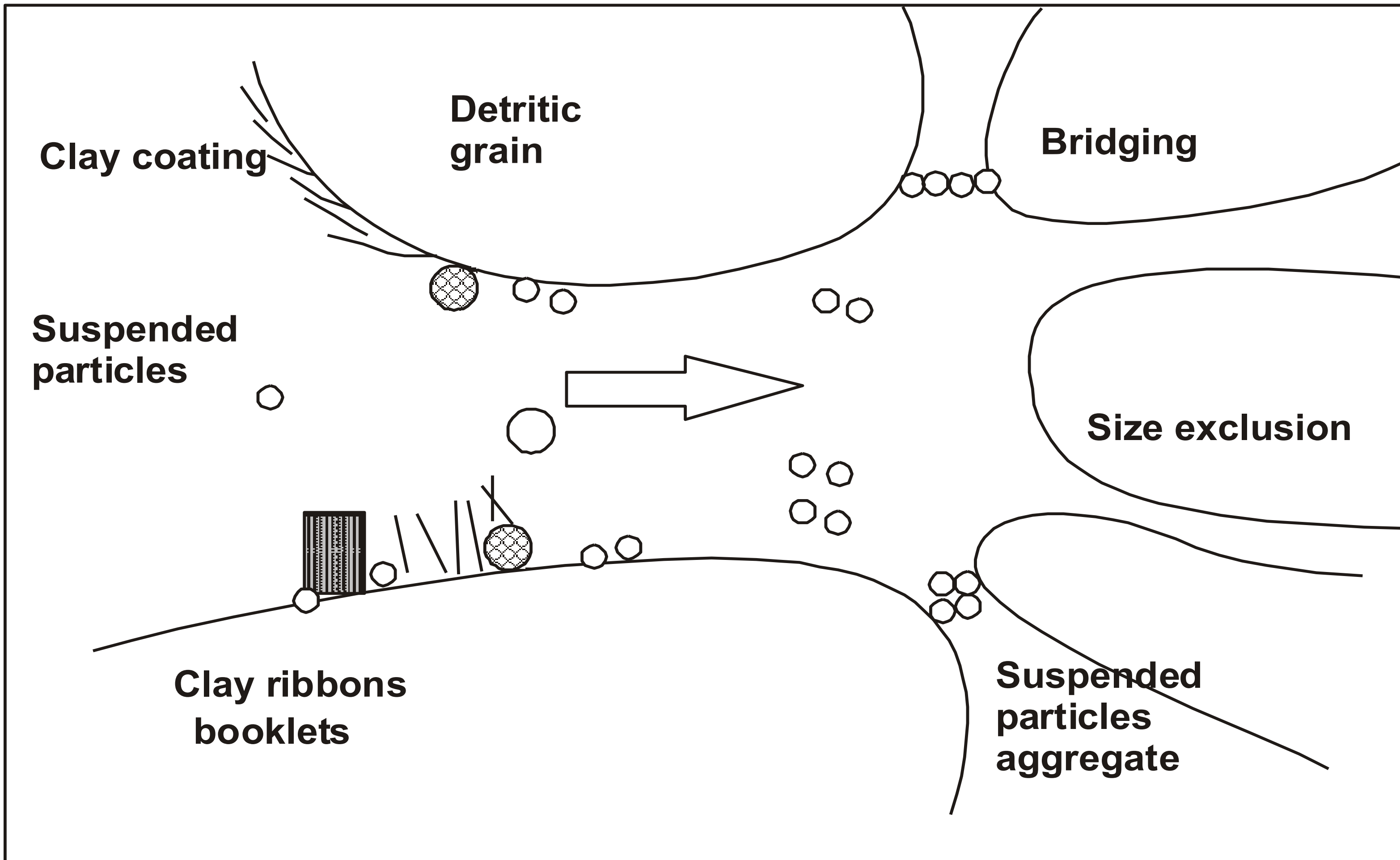
PARTICLE INDUCED DAMAGE MECHANISMS



Source : Barkman Davidson
in Ungemach 2003

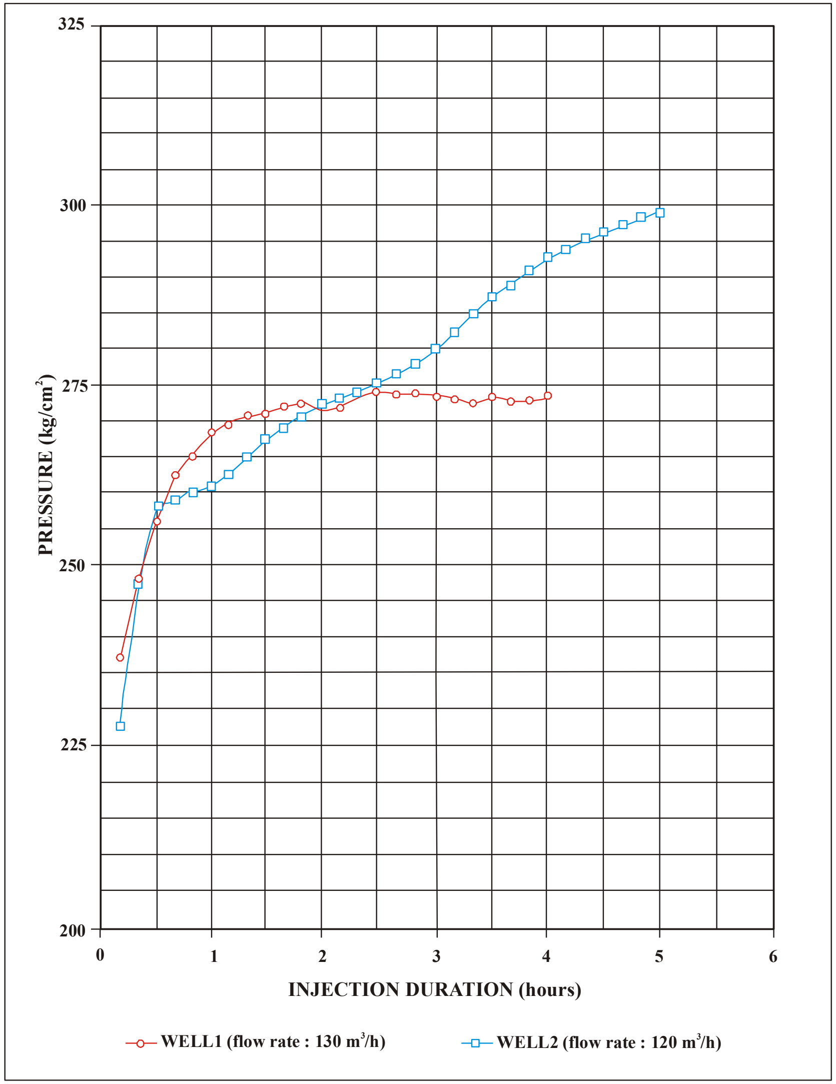
WATER INJECTION

PARTICLE INDUCED DAMAGE MECHANISMS



WATER INJECTION

PARTICLE INDUCED DAMAGE

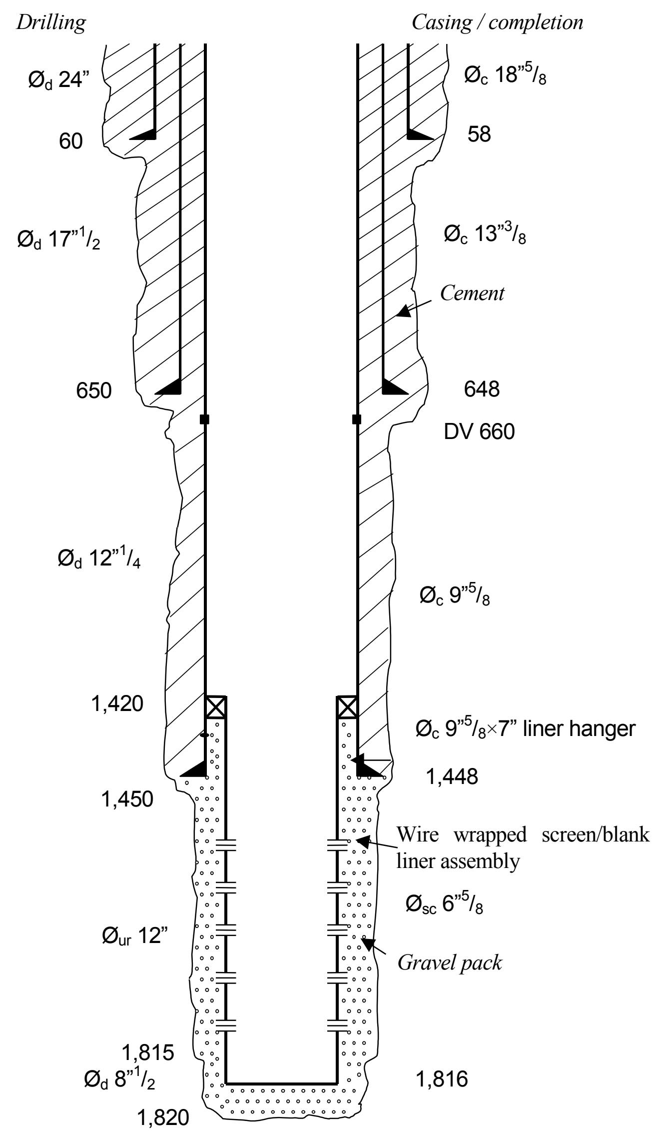


WATER INJECTION IN CLASTIC SEDIMENTS

WELL COMPLETION REQUIREMENTS

PROJECTED WELL / RESERVOIR PERFORMANCE

- Top reservoir depth .... 1,500 m
- Static WHP .... -5 bars
- Total pay .... 400 m
- Net pay (h) .... 110 m
- Effective porosity ($Ø_e$) 0.2
- Permeability (k) .... 100 mD
- Transmissivity (kh) .... 11,000 mDm
- Skin factor (S) .... -2
- Formation temperature 90ºC
- Average injection temperature 35ºC
- Fluid (eq. NaCl) salinity .... 2.5 g/l
- Fluid dynamic viscosity (production) (μp) .... 0.32 cp
- Fluid dynamic viscosity (injection) (μi) .... 0.73 cp
- Total compressibility factor (c_t) .... 10^{-4} $bars^{-1}$
- Fluid density (ρ_p) at 90ºC .... 965.34 kg/m^3
- Fluid density (ρ_i) at 35ºC .... 994.06 kg/m^3
- Target injection rate (Q) .... 150 m^3/hr
- WHP (150 m^3/hr, 35ºC) .... 20.5 bars
- Sandface velocity (v_{sf}) .... 0.23 cm/s
- Velocity at completion outlet (v_c) .... 0.61 cm/s

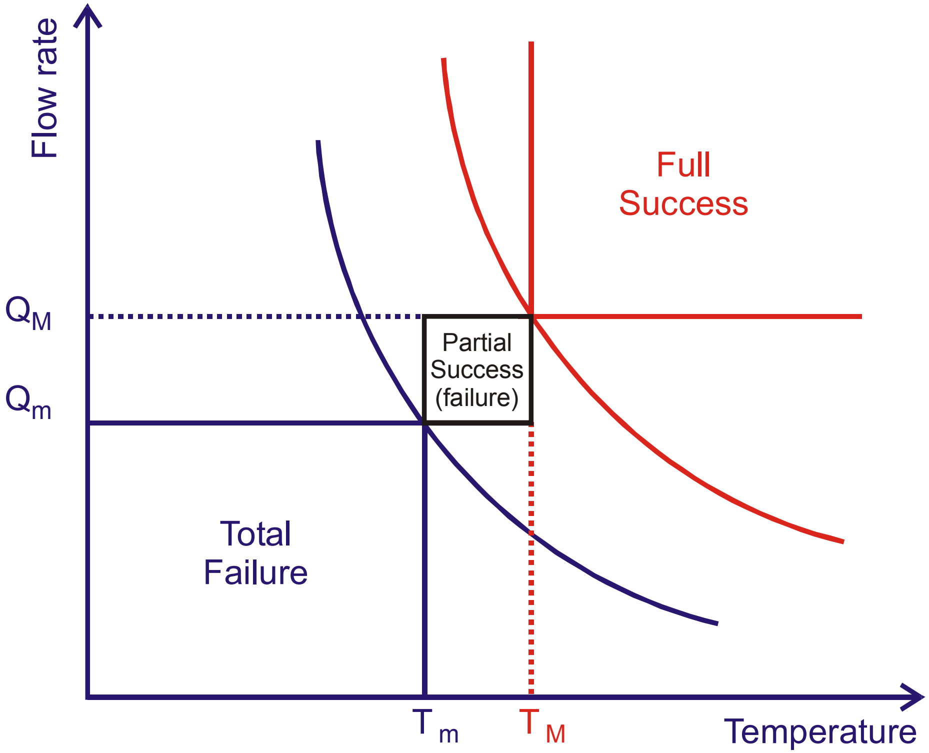


TECHNICAL RISK MATRIX

Cause Consequence	Unsufficient hook load	Inadequate BHAs	Odd cementin g	Loose geological control	Odd drilling fluid formulation	Lost BHA, dp
Drilling time	X	X		X	X	X
Dog legs	X	X		X		X
Diameter reduction	X					X
Drilling/completion costs	X		X	X	X	X
Well life			X			
Well loss						X

MINING RISK INSURANCE

RISK ASSESSMENT
SUCCESS/FAILURE CRITERIA (1)



Full success:

$$Q(T_{wh} - T_i) = \frac{1}{1.161 \cdot nh \cdot c}\left[A \cdot INV + OMC + \frac{INV}{n}\right]$$

Total failure:

$$Q'(T_{wh} - T_i) = \frac{1}{1.161 \cdot nh \cdot c}\left[A' \cdot INV + OMC + \frac{INV}{n}\right]$$

Where:

Q, Q' = flowrate (yearly average) (m^3/h)

T_{wh} = production wellhead temperature (°C)

T_i = injection temperature (yearly average) (°C)

$$A = \frac{r(1+r)^n}{(1+r)^n - 1}$$

$$A' = \frac{r'(1+r')^n}{(1+r')^n - 1}$$

INV = capital investment (€)

OMC = operation and maintenance costs (€/yr)

c=heat selling price (€/MWh_t)

n = project lifetime (years)

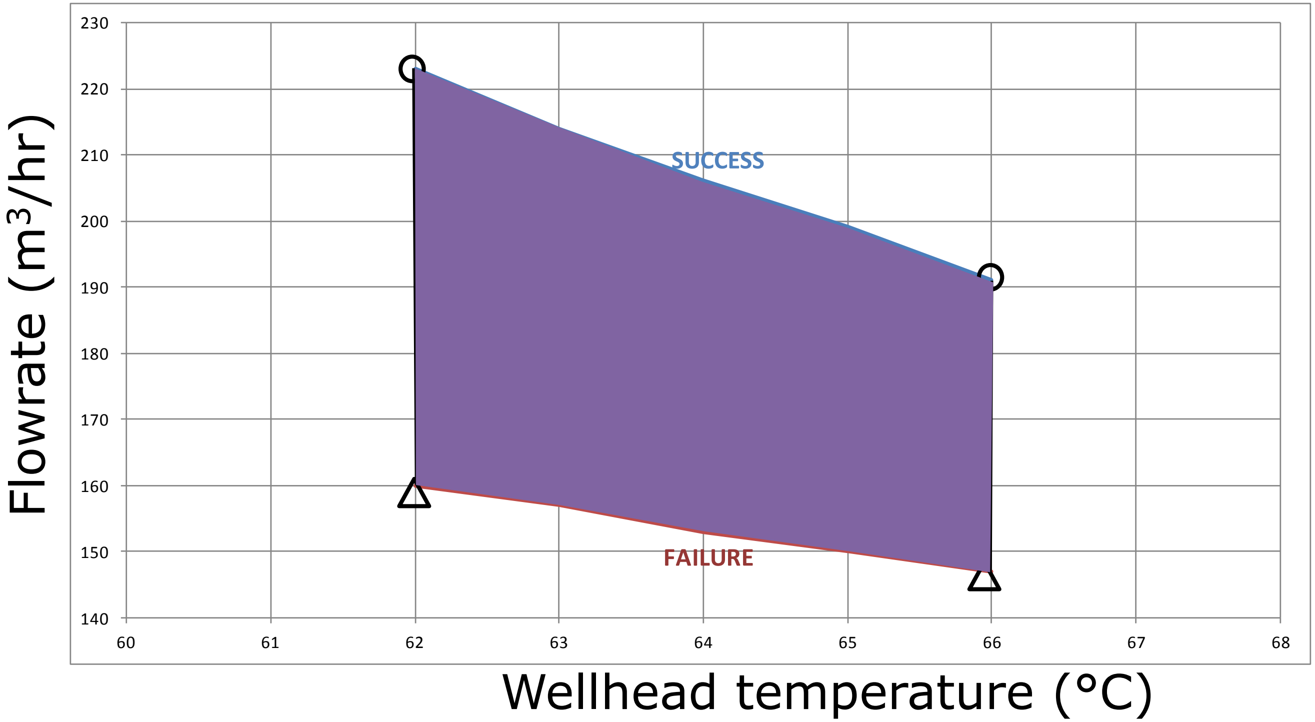
nh = number of operating hours per year

r, r' = discount rates

*OMC = OPEX
* INV = CAPEX

MINING RISK INSURANCE

RISK ASSESSMENT
SUCCESS/FAILURE CRITERIA (2)



Numerical application:

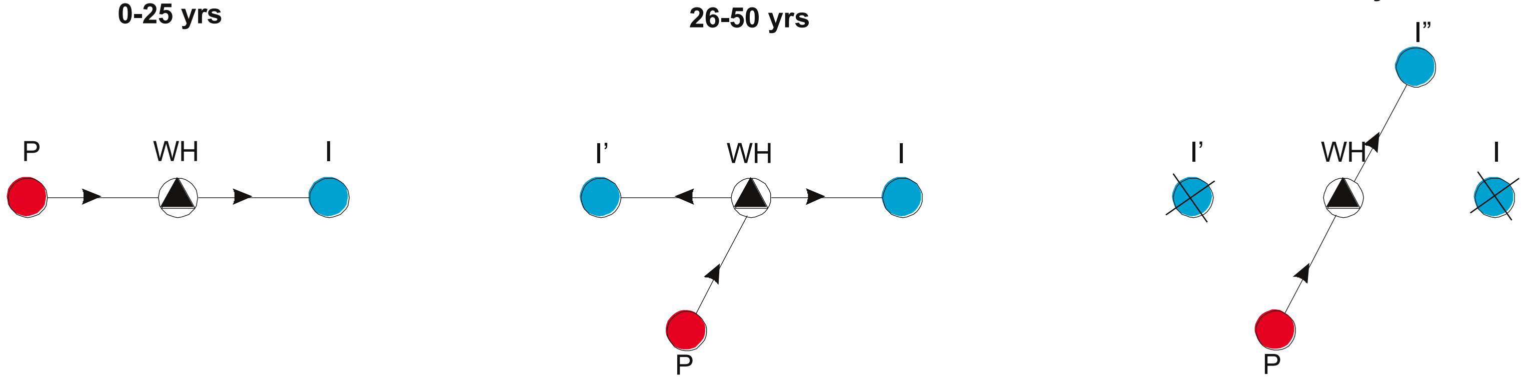
CAPEX=12 10^6 €
OPEX= 5 10^5 €
n=20 years
nh=8256 hr/yr
r=5% (total failure)

r=10% (total success)
Full equity (no debt)
Subsidies=0 ; 25% CAPEX
c=35 ; 40 ; 45 €/MWht
T_i=40 ; 45 ; 50°C

SUSTAINABLE GDH RESERVOIR MANAGEMENT

SUSTAINABILITY
MINING SCHEMES

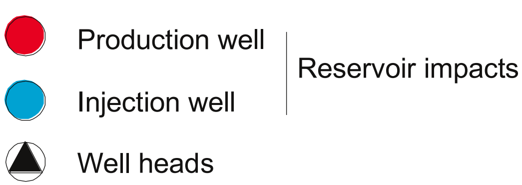
INITIAL DOUBLET 0-25 yrs | **INTERMEDIATE TRIPLET ARRAY 26-50 yrs** | **NEW DOUBLET 51-75 yrs**



Initial cased wells
9"5/8 casings

Former doublet wells
lined (7") as injector wells
New anti-corrosion production well

Former injector wells abandoned
New anti-corrosion injection well

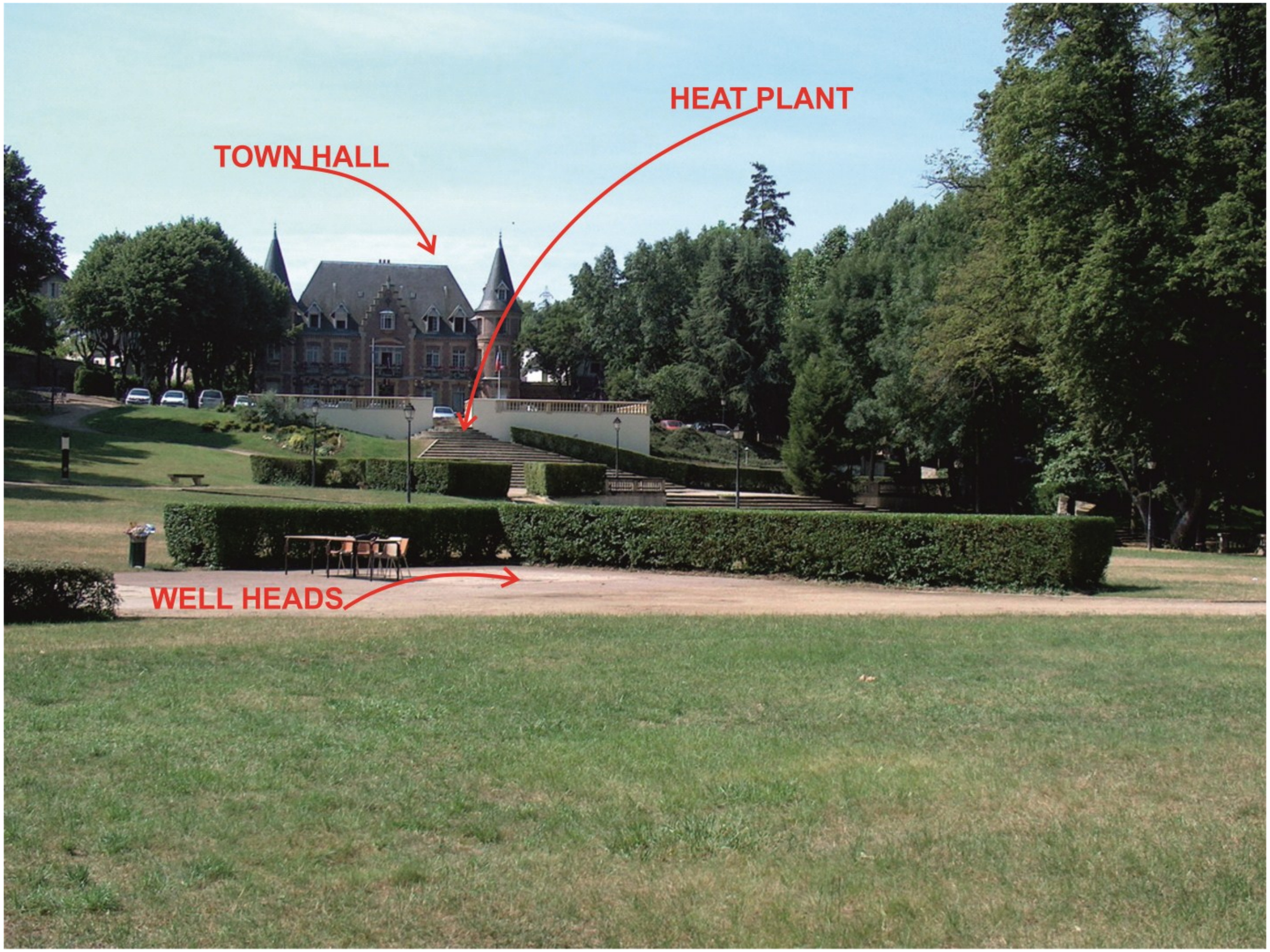


Sustaining 75 yrs

System life

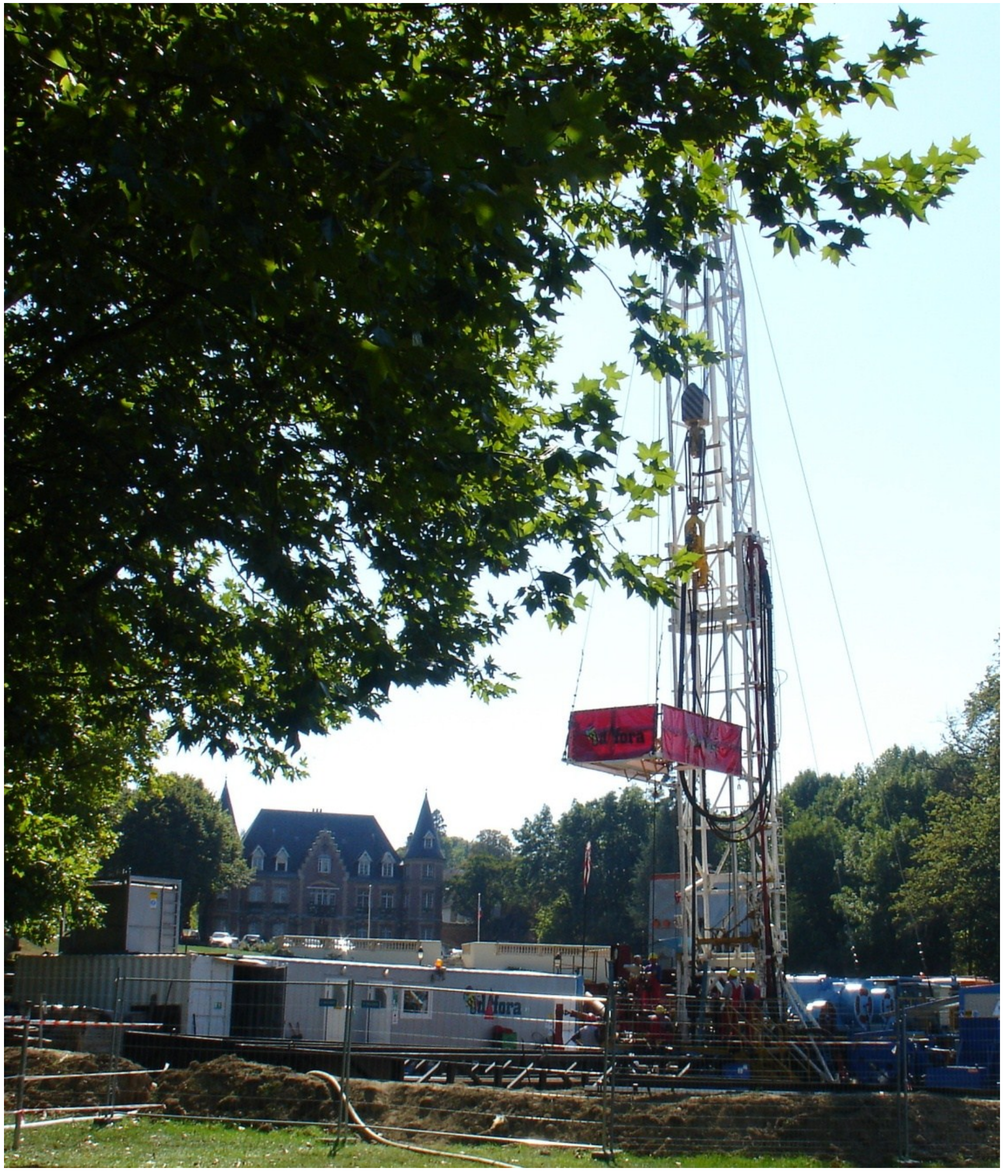
A FRIENDLY GDH ENVIRONMENT

EPINAY-SOUS-SENART
AN ENVIRONMENTALLY FRIENDLY SET UP



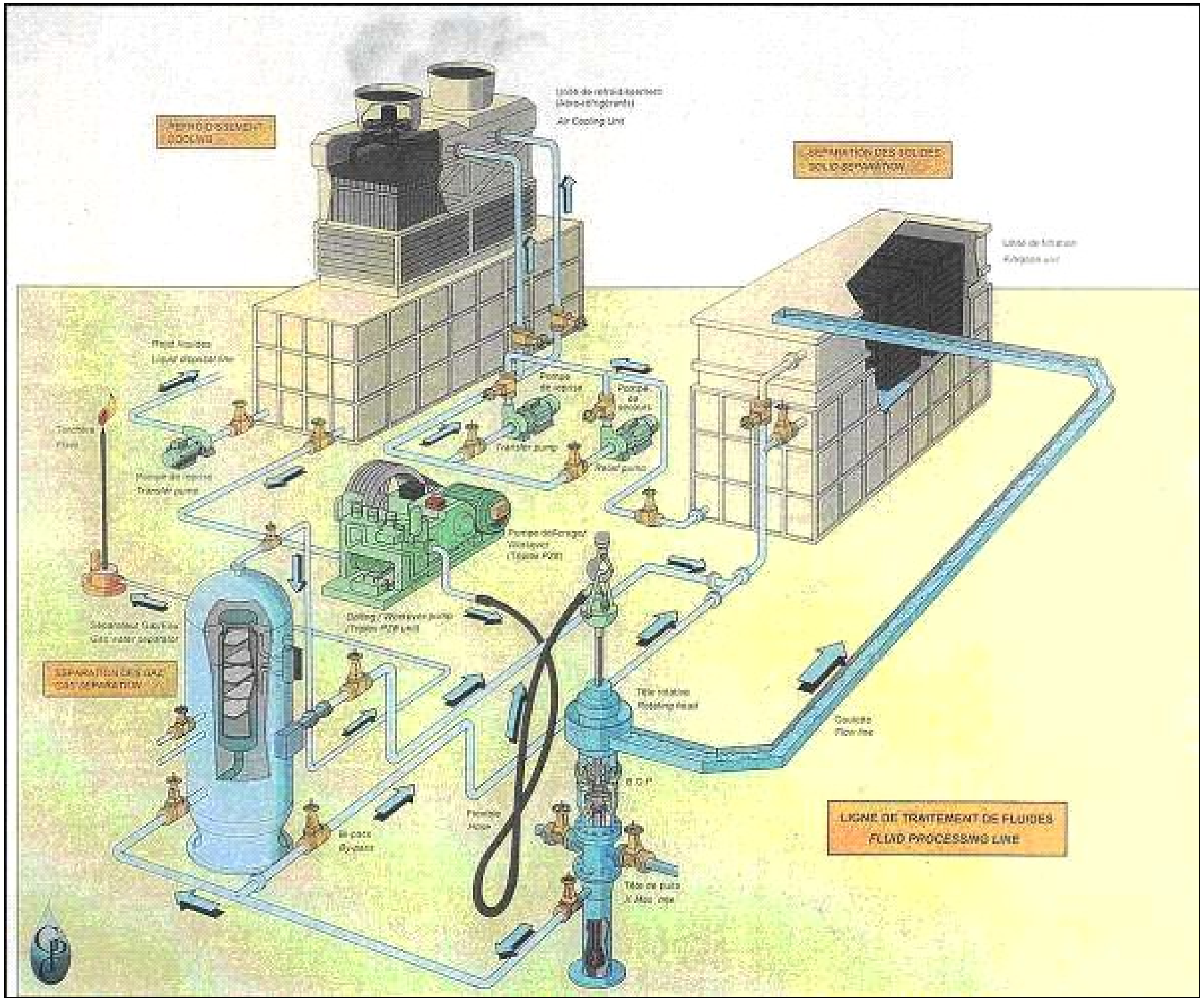
A FRIENDLY GDH ENVIRONMENT

WORKOVER SETUP



GAS ABATEMENT LINE

WORKOVER WASTE PROCESSING LINE



DRILLING CONTRACTS

Either TURNKEY, METER RATE OR UNIT TIME RATE contracts

TURNKEY	Contractor takes the risk
METER RATE	Both Contractor and Customer share the risk (and costs)
UNIT TIME RATE	Customer takes the risk and cots and responsability

LOW RISK	Turnkey and meter rate may apply
HIGH RISK	Unit time rate applies

A combinaison of unit time and meter rate may also be contemplated.

CONTRACT
ITEMIZED DRILLING & COMPLETION SEQUENCE (Adapted from Hagen Hole)

- Reservoir engineering & Well Targeting (customer)
- Well design and specification (customer)
- Materials specification & procurement (customer)
- Well pad & access road civil design and engineering (customer)
- Water supply design & engineering (customer)
- Civil construction supervision (customer)
- Well drilling engineering and supervision
- Provision of drilling rig and equipment (contractor)
- Provision of drilling personnel (contractor)
- Provision of top drive equipment & personnel (contractor)
- Provision of cementing equipment, personnel & services (contractor)
- Provision of directional drilling equipment & personnel (contractor)
- Provision of mud engineering personnel (contractor)
- Provision of aerated drilling equipment and personnel (optional, contractor)
- Provision of mud logging / geology equipment & personnel (contractor or customer)
- Drilling tool rental or purchase (contractor)
- Drill pipe inspection & hard-banding (customer)
- Provision of well measurements equipment and personnel (customer subcontractor or contractor)

CONTRACTING
HYPOTHETICAL EXAMPLE

An Owner has with its own 'in-house' resources:-
- Geoscientific and engineering capability
  (or contracts these from Consultants)
- Reservoir engineering & well targeting
- Well design, materials specification & procurement
- Drilling pad & access road design & supervision
- Drilling engineering & supervision

Drilling services contract would typically be simple unit time rate contract
- Owner simply renting equipment & personnel to operate equipment

- Owner fully responsible to issue all day-to-day instructions for every step of every operation

Owner carries all the operational responsibility and all operational risk
- if there are drilling problems - Owner continues to pay day rate.

Source : Hagen Hole

CONTRACTING
ALTERNATIVE MODEL

Owner may decide that operational responsibility and control is to lie with Contractor
The extreme of this concept is the 'Pure Turnkey' Contract

Owners instruction could be – "Drill me a well into this reservoir at this location – come back and tell me when it is completed"

Owner may have no 'in-house technical capability or necessary managerial resources
- Contractor totally responsible, has full control
- But!!! Carries all of the operational risk

Source : Hagen Hole

RIG CREW & SUPERVISION STAFF

RIG CREW	
Rig Manager	(1)
Tool pushers	(2)
Drillers	(3)
Assistant driller	(3)
Derrickman(*)	(3)
Roughnecks	(6-9)
Chief mechanics	(2)
Mechanics	(2-3)
Chief electrician	(2)
Electrician	(2-3)
Rig secretary	(1)
Safety manager	(1-2)
CUSTOMER SUPERVISION STAFF	
Drilling/production Engineer	(1)
Drilling supervisor	(1)
Drilling superintendant (2)	
Completion supervisor(**)	(1)
Log Analyst/Testing supervisor	(1)

(*) if no top drive
(**) optional

Hydraulic electrically powered rigs have been shown to reduce rig crew and mob/demob/rig up/rig down operations

Source : ISOR, ICELAND DRILLING

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The Sun Rises at El Tatio
But Never Sets on Geothermal Energy