DRILLING/COMPLETION AND TESTING OF GEOTHERMAL DISTRICT HEATING (GDH) DOUBLETS

Pierre Ungemach & Miklos Antics
GPC IP
95700 ROISSY CDG
France
pierre.ungemach@geoproduction.fr ; m.antics@geoproduction.fr
www.gpc-france.com

DRILLING OF GEOTHERMAL DISTRICT HEATING (GDH) DOUBLETS

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
  - Screens
  - Mud solids’control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

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
  - Screens
  - Mud solids’control
- 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.

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

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

footnote

(1) rhyolitic/andesitic/metamorphic

(2) Shale gas, source rock oil

(3) CHP targeted wells (Hydrothermal or EGS)

(4) Depth of tiber one will in the Golf of Mexico

(5) Total flow

(6) Shale gas

(7) Geothermal district heating

(8) Green house heating

(9) Standard. Exceptionally 13"$^{3/8}$ x 9"$^{5/8}$ / 10"$^{3/4}$ (s.l.) x 12"$^{1/4}$ (OH)

(10) Slotted x wire wrapped gravel packed screen assembly for sand control

(11) though tubing x packer x safety valve assembly (diesel filled annulus)

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

EUROPEAN DISTRICT HEATING LOCATIONS

EUROPEAN GEOTHERMAL DISTRICT HEATING (GDH) STATUS

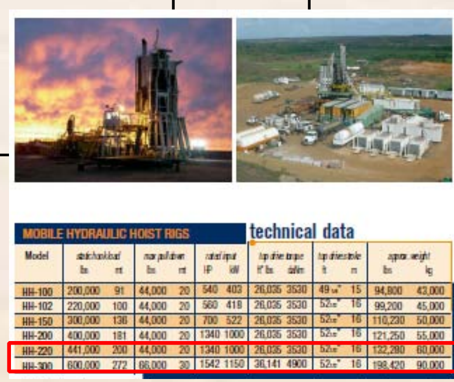
	Existing (@ 2011)	Commissioned (@ 2015)
GDH PLANTS		
Europe at large (*)	210	390
EU Member States	135	300
France	45	60
Paris Basin	35	45
INSTALLED CAPACITIES (MW_t)		
Europe at large (*)	3950	7000
EU Member States	1600	3500
France	310	
Paris Basin	290	
HEAT PRODUCTION (TJ/yr)		
Europe at large (*)	40000	
EU Member States	16500	
France	4050 (**)	
Paris Basin	3750 (**)	

(*) EU m.s. + Iceland & Macedona *(source : EGEC, 2011)*

(**) Including gas cogenerated base heat load (#1500 TJ/yr)

DEEP DRILLING CANDIDATE RIGS

Hook load	Mast	Nominal power	Tête d'injection motorisé (top drive, power swivel)	Pumps	Mud quarter	Miscellaneous
250 - 300 t dyn	Telescopic, Total height 26-31 m, Total clearance/stroke 16-18 m	1100 – 1500 kW	Torque = 3600-6000daNm Power = 375-500 kW Traction = 250-300 t Speed = 180-200 rpm Pressure = 350 bar	2 – 3 Triplex 1500-2000 kW 3600-5000 l/min 345 bar	3-4 tanks (1 mixing) 120-200 m^3 2 silos 1 hopper 2 transfer pumps 2 shale shaker desanders 2 transfer pumps desilter(s) mud degaser solids CONTROL : 2	Options : - connection to grid (PCR) - automatic pipe handling - hydrocyclones - BOP : standard + 1 rotating BOP



MOBILE HYDRAULIC HOIST RIGS technical data

Model	static hook load lbs	mt	max pulldown lbs	mt	rated input HP	kW	top drive torque ft*lbs	daNm	top drive stroke ft	m	approx. weight lbs	kg
HH-100	200,000	91	44,000	20	540	403	26,035	3530	49	15	94,800	43,000
HH-102	220,000	100	44,000	20	560	418	26,035	3530	52	16	99,200	45,000
HH-150	300,000	136	44,000	20	700	522	26,035	3530	52	16	110,230	50,000
HH-200	400,000	181	44,000	20	1340	1000	26,035	3530	52	16	121,250	55,000
HH-220	441,000	200	44,000	20	1340	1000	26,035	3530	52	16	132,280	60,000
HH-300	600,000	272	66,000	30	1542	1150	36,141	4900	52	16	198,420	90,000

UNIT EQUIVALENTS

US units		SF/Hybrid units
inch (in)	length	25.4 mm
in^2	area	6.45 cm^2
in^3	volume	16.4 cm^3
foot/feet (ft)	length	0.305 m
ft^2	area	0.093 m
ft^3	volume	28.3 l
gallon (gal)	volume	3.79 l
gallon per minute (gpm)	flowrate	3.79 l/mn
pound force (lbf)	force	0.445 daN
pound /sq.inch (psi)	pressure	6.89 kPa
pound/feet (lb/ft)	nominal weight	0.069 bar
pound feet (lb/ft)	torque	0.136 daN.m
horse power (Hp)	power	746 waHs

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

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
  - Screens
  - Mud solids’control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

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

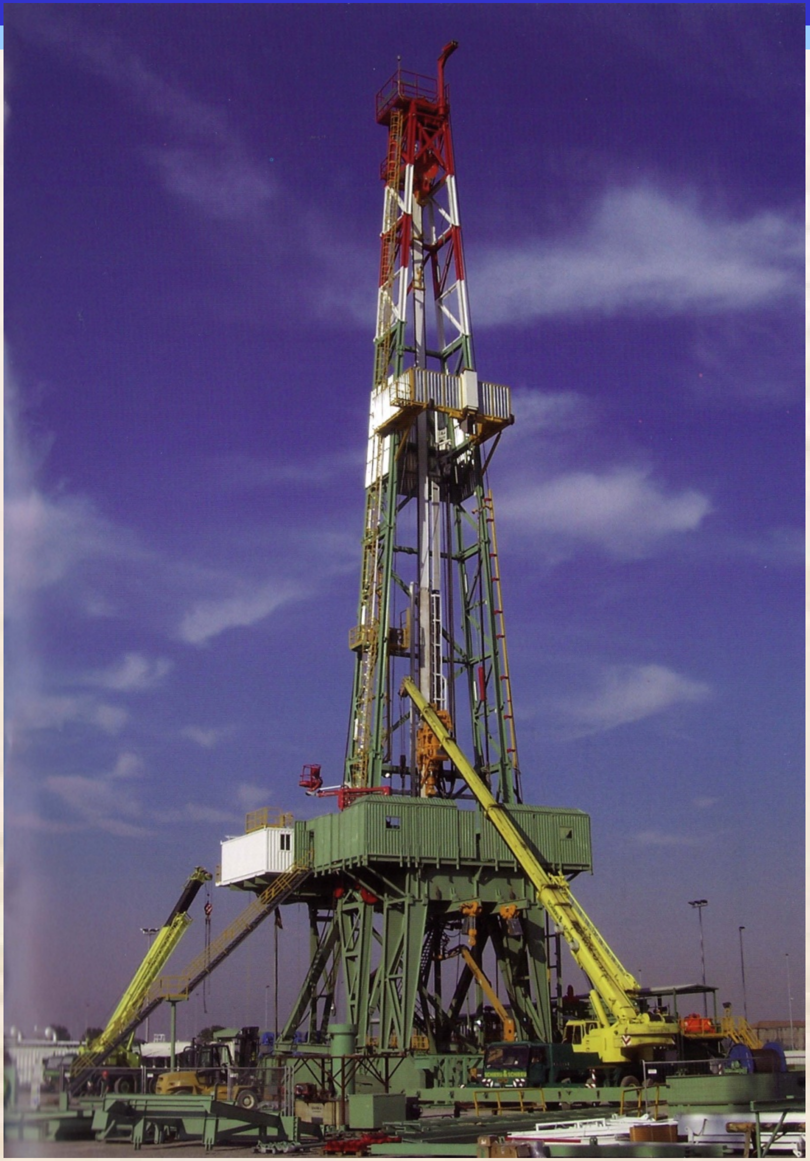
RIG SELECTION REQUIREMENTS

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.

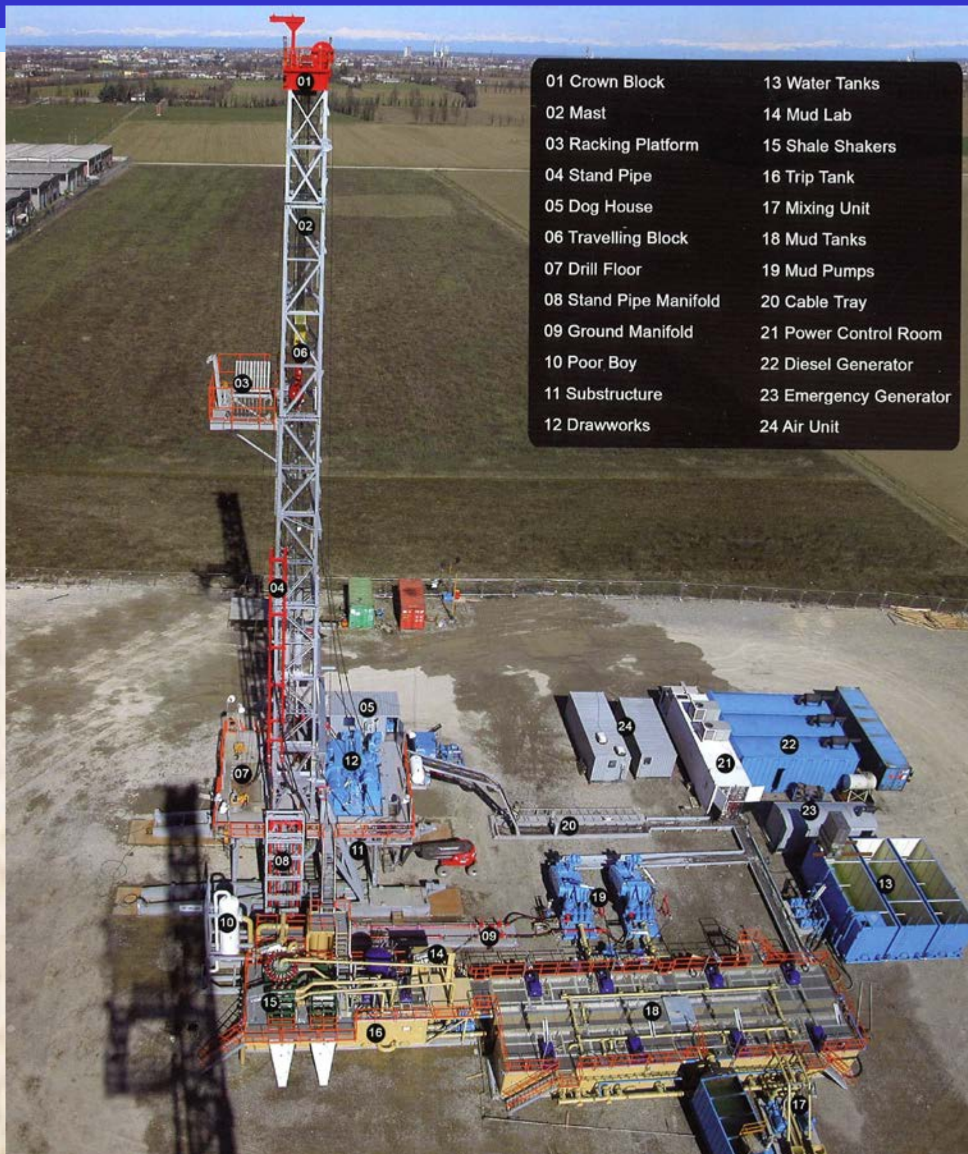
CONVENTIONAL RIG (200 T)

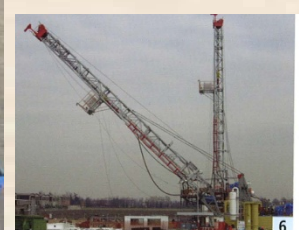
CONVENTIONAL HEAVY DUTY LAND RIG (600 T)



Source : DRILLMEC

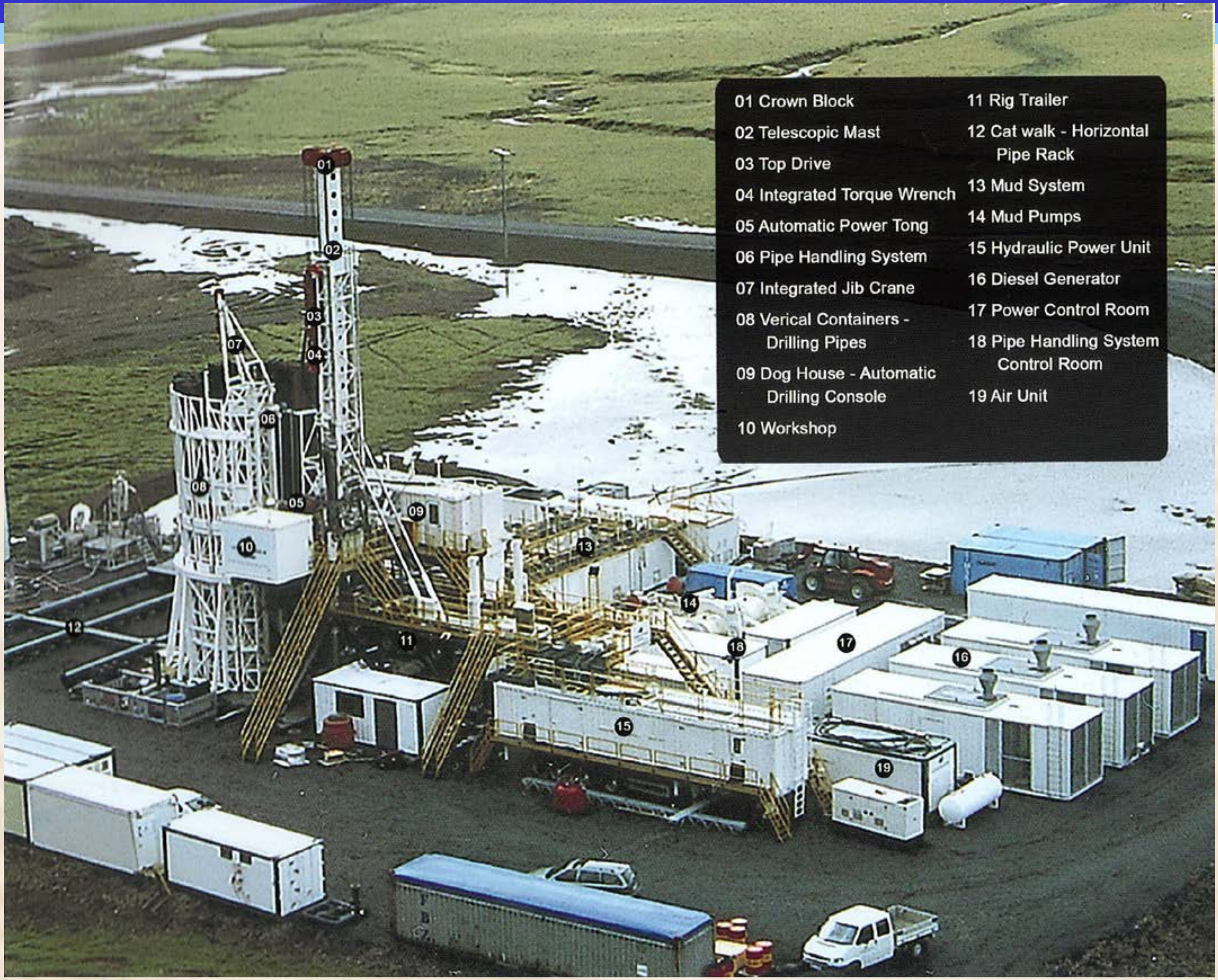
CONVENTIONAL HEAVY DUTY LAND RIG DESCRIPTION





Source : DRILLMEC

NOVEL DESIGN
HEAVY DUTY HYDRAULIC RIG



Source : DRILLMEC

INNOVATIVE RIG HYDRAULIC/ELECTRIC

FLEXIBLE AND FAST INSTALLATION ALSO IN REMOTE AREAS: DEEP DRILLING RIG TERRA INVADER 350/450 SLINGSHOT

Source : Herrenknecht Vertical GMBH)

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

RIG SELECTION

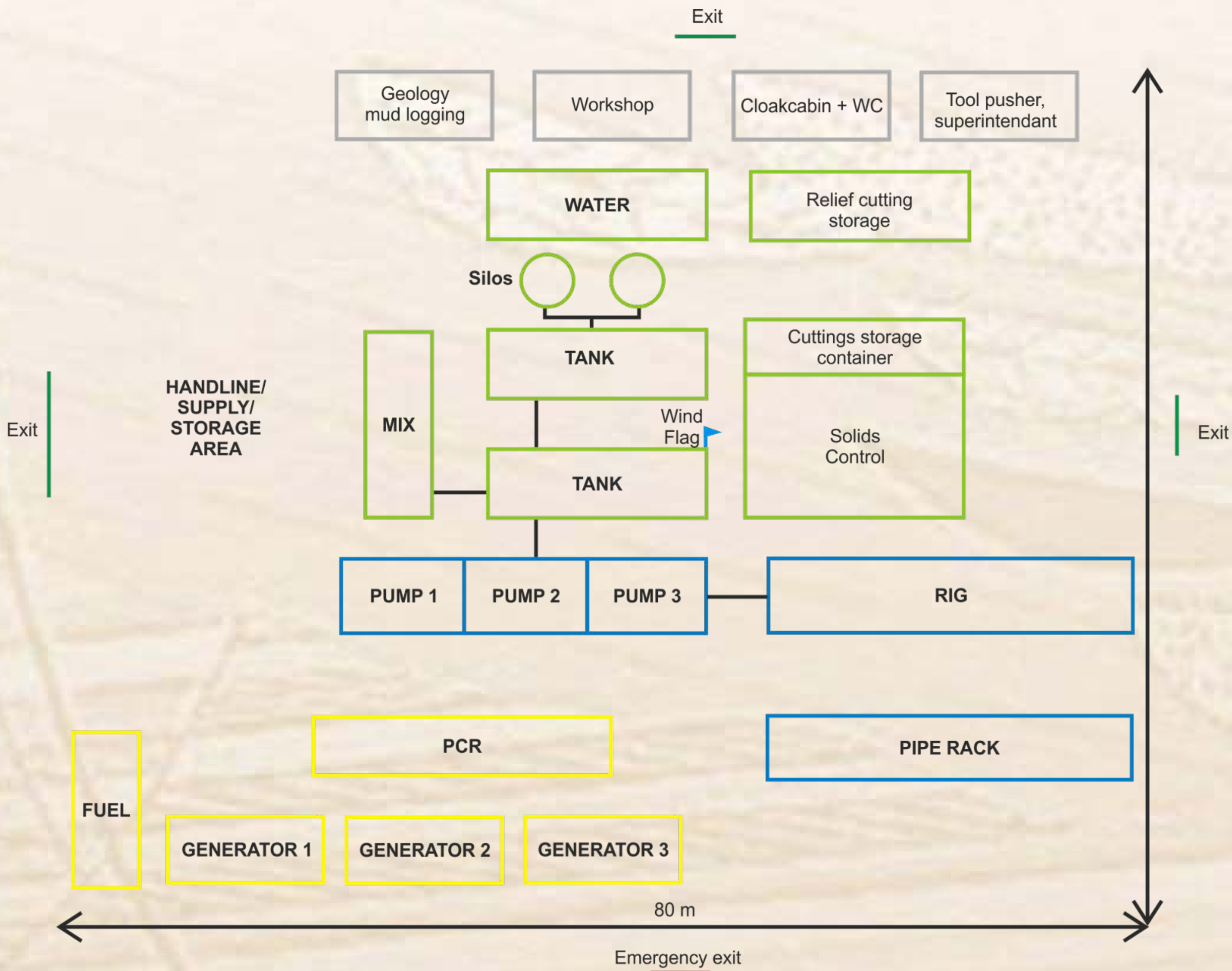
EXPERIENCE AND QUALIFICATION OF PERSONNEL & SUITABILITY EQUIPMENT EVALUATION SHEET

		Maximum Points Allocation
1.0	Evidence with similar projects carried out in home country and internationally for the last 10 years	15
2.0	Drilling Rig and Equipment	45
3.0	Qualifications and Experience of Personnel	35
4.0	Company Profile and Personnel Structure	5
TOTAL POINTS		100

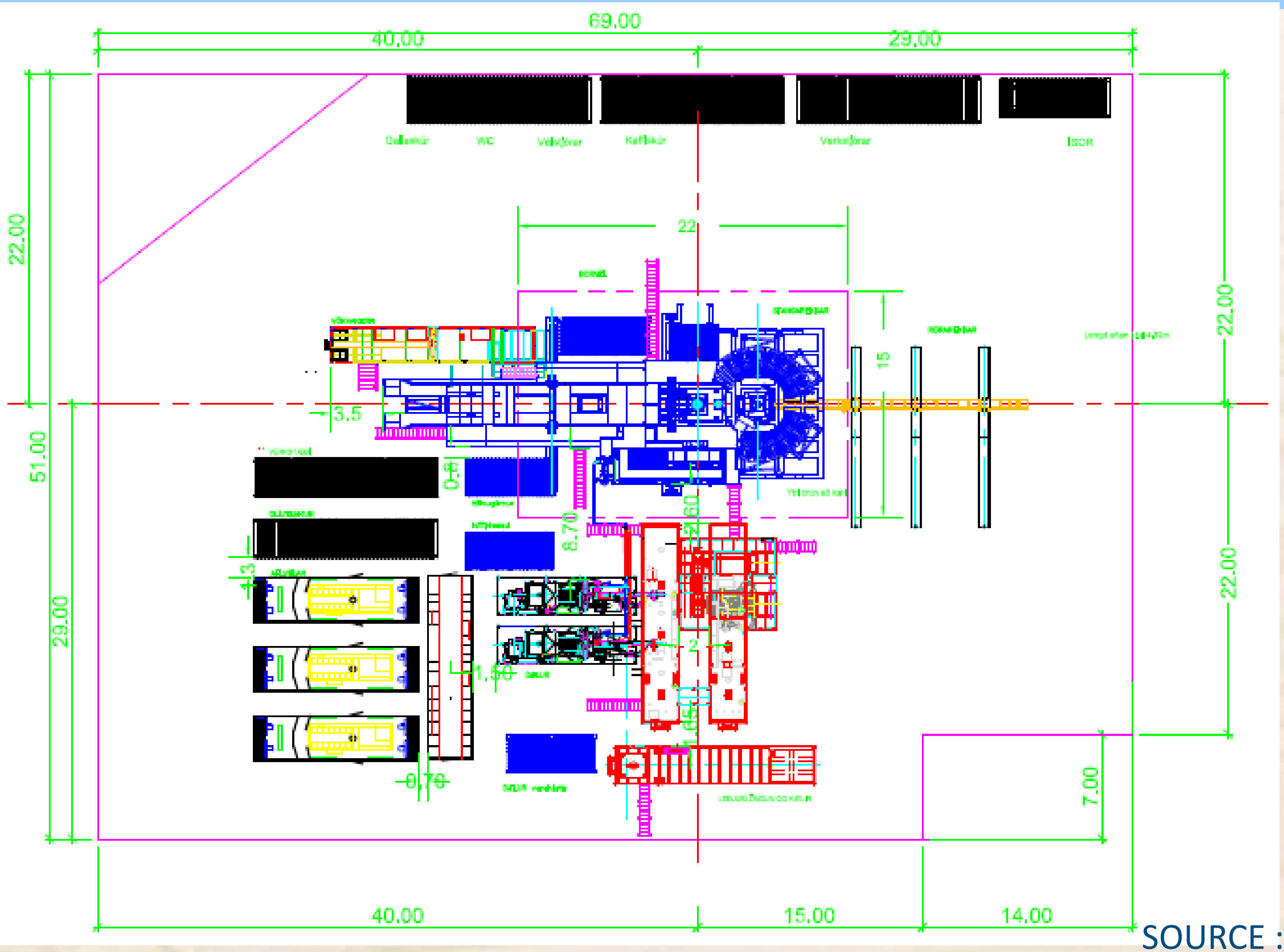
OUTLINE

- 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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

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

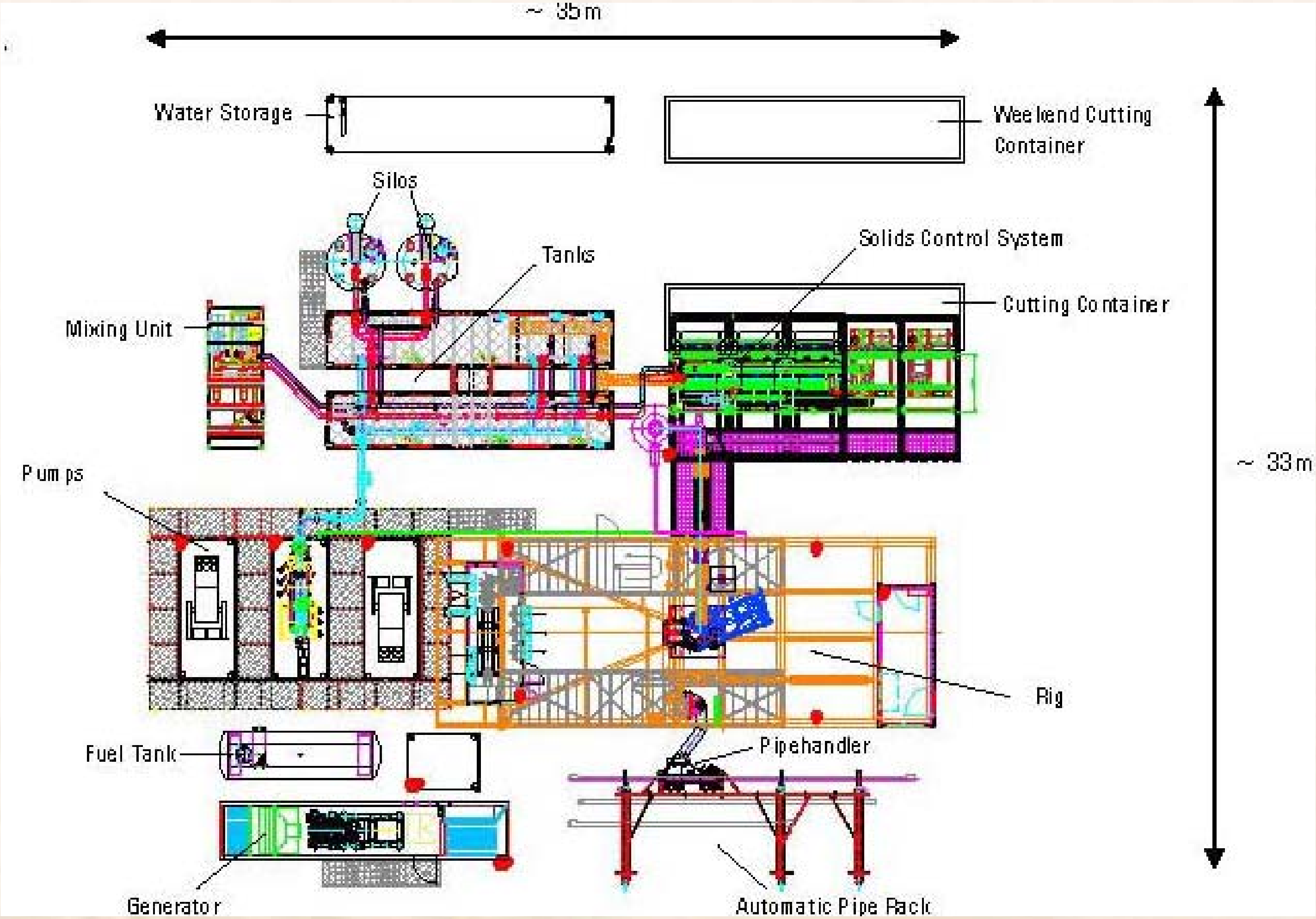


FOOT PRINT HH SERIES RIG



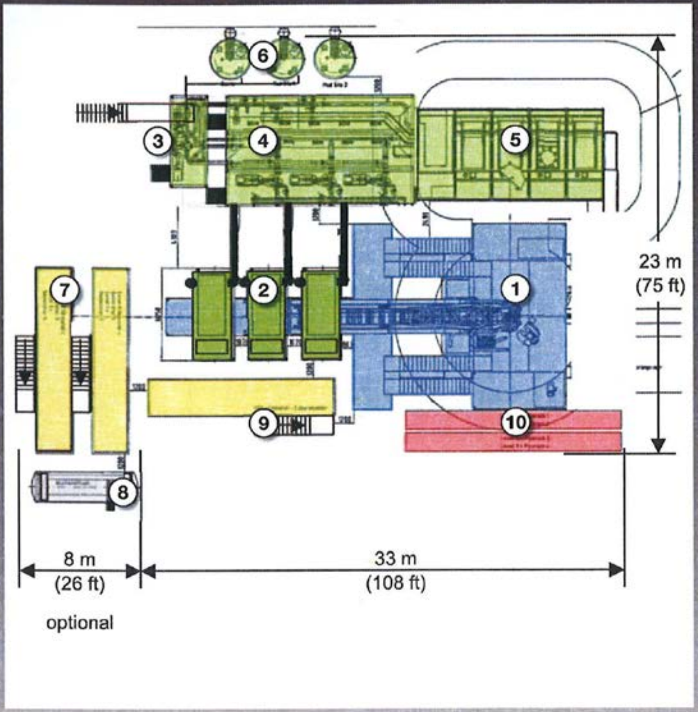
SOURCE : DRILLMEC

FOOT PRINT HEAVY DUTY RIG



SOURCE : DRILLTEC

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

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

DEEP WELL DRILLING
DRILLING/COMPLETION SEQUENCE

ITEM	PHASE	DC	CUS
1	Site preparation/rehabilitation		X
2	Move in/out ; rig-up/down	X	
3	Drilling	X	
4	Bits	X	
5	Drilling fluids	X	
6	Directional drilling	X	
7	Coring	X	
8	Logging		X
9	Casing, lining		X
10	Cementing	X	
11	Fishing	X	
12	Testing, sampling		X
13	Wellheads		X
14	Waste disposal/processing	X	
15	Engineering/supervision/reporting		X
16	Insurance		X
17	Contingencies		X

DC : drilling contractor
CUS : customer

OUTLINE

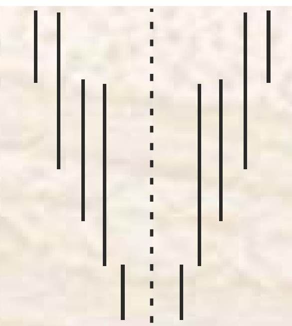
- SCOPE
- INTRODUCTION. GEOTHERMAL VS PETROLEUM
- **DEEP WELL DRILLING/COMPLETION FEATURES**
  - Rig selection
  - Site preparation. Rig footprint
  - Drilling
  - **Bits**
  - Drilling fluids
  - Directional drilling
  - Casing/lining
  - Cementing
  - Fishing
  - Waste disposal/processing
- CASE STUDY. 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
  - Screens
  - Mud solids’control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

BITS

IADC ROLLER BIT CLASSIFICATION TABLE
(IADC/SPE 23937, February, 1992)

	Formations	Series	Types	Standard roller bearing 1	Roller bearing air-cooled 2	Roller bearing gage protected 3	Sealed roller bearing 4	Sealed roller bearing gage protected 5	Sealed friction bearing 6	Sealed friction bearing gage protected 7	Features Available
Steel tooth bits	Soft formations with low compressive strength and high drillability	1	1								A Air application
			2								
			3								B Special bearing seal
			4								
	Medium to medium hard formations with high compressive strength	2	1								C Center jet
			2								
			3								D Deviation control
			4								
	Hard semi-abrasive and abrasive formations	3	1								E Extended jets (full length)
			2								
			3								G Gage/body protection (additional)
			4								
Insert bits	Soft formations with low compressive strength and high drillability	4	1								H Horizontal/steering applications
			2								
			3								J Jet deflection
			4								
	Soft to medium soft formations with low compressive strength	5	1								L Lug pads
			2								
			3								M Motor application
			4								
	Medium hard formations with high compressive strength	6	1								S Standard steel tooth model
			2								
			3								T Two cone bit
			4								
	Hard semi-abrasive and abrasive formations	7	1								W Enhanced cutting structure
			2								
			3								X Predominantely chisel tooth insert
			4								
	Extremely hard and abrasive formations	8	1								Y Conical tooth insert
			2								
			3								Z Other shape insert
			4								

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		

BITS

THREADS AND MAKE-UP TORQUES FOR DRILL BITS AND CORING BITS

(API RP 7G, January 1, 1995 – API Spec 7, April 1, 1994)

Rock bits

Bit size (in)	Bit thread
3 3/4 – 4 1/2	2 3/8 REG
4 5/8 – 5	2 7/8 REG
5 1/8 – 7 3/8	3 1/2 REG
7 1/2 – 9 3/8	4 1/2 REG
9 1/2 – 14 3/8	6 5/8 REG
14 1/2 – 18 1/2	6 5/8 or 7 5/8 REG
18 5/8 to 26	7 5/8 or 8 5/8 REG
27 and larger	8 5/8 REG

Bit thread	Make-up torque	
	(daN.m)	(ft.lb)
2 3/8 REG	400 – 480	3 000 – 3 500
2 7/8 REG	600 – 750	4 500 – 5 500
3 1/2 REG	950 – 1 200	7 000 – 9 000
4 1/2 REG	1 600 – 2 200	12 000 – 16 000
6 5/8 REG	3 800 – 4 300	28 000 – 32 000
7 5/8 REG	4 600 – 5 400	34 000 – 40 000
8 5/8 REG	5 400 – 8 100	40 000 – 60 000

Diamond and PDC bits

Bit size (in)	Bit thread identification	Maximum pin ID (in)	Bit sub OD (in)	Minimum make-up torque (1)	
				(daN.m)	(ft.lb)
3 11/16 – 4 1/2	2 3/8 REG	1	3 3 1/8 3 1/4	243 328 418	1 791 2 419 3 085
4 17/32 – 5	2 7/8 REG	1 1/4	3 1/2 3 3/4 3 7/8	417 626 632	3 078 4 617 4 658
5 1/32 – 7 3/8	3 1/2 REG	1 1/2	4 1/8 4 1/4 4 1/2	701 855 1 039	5 171 6 306 7 660
7 13/32 – 9 3/8	4 1/2 REG	2 1/4	5 1/2 5 3/4 6 6 1/4	1 688 2 234 2 380 2 408	12 451 16 476 17 551 17 757
9 13/32 – 14 1/2	6 5/8 REG	3 1/4	7 1/2 7 3/4 8 8 1/4	5 030 5 133 5 178 5 224	37 100 37 857 38 193 38 527
14 9/16 – 18 1/2	7 5/8 REG	3 3/4	8 1/2 8 3/4 9 9 1/4 9 1/2	6 548 7 824 8 130 8 200 8 256	48 296 57 704 59 966 60 480 60 895

(1) Normal torque range is tabulated value plus 10%.

Coring bits

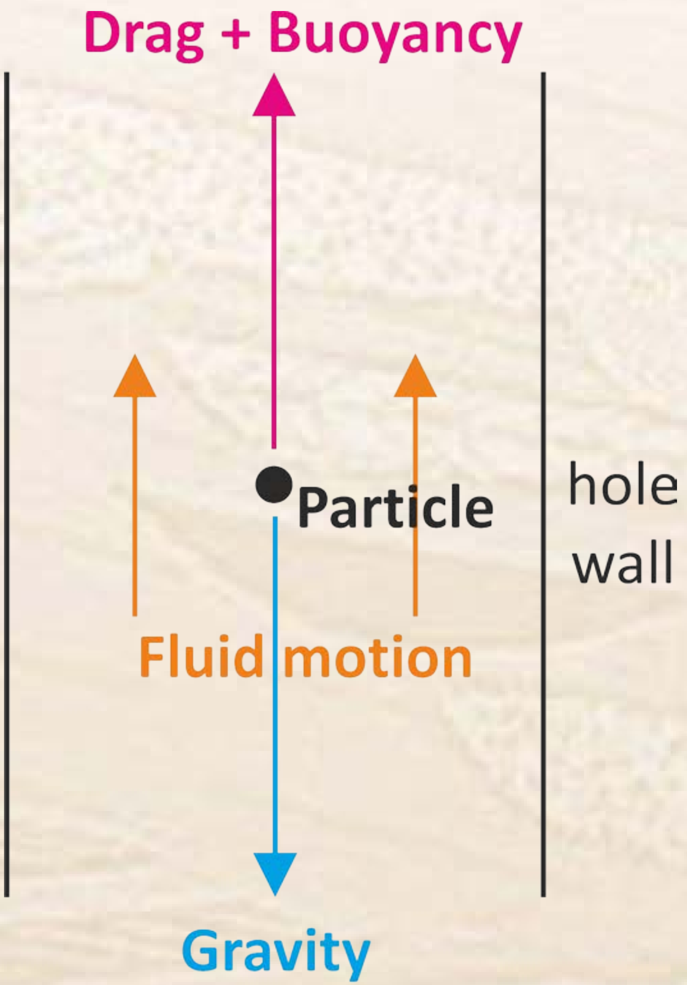
Core barrel size (in)	Make-up torque	
	(daN.m)	(ft.lb)
4 1/8	400 – 490	3 000 – 3 600
4 1/2	680 – 800	5 000 – 6 000
4 3/4	550 – 660	4 050 – 4 850
5 3/4	1 000 – 1 190	7 400 – 8 800
6 1/4 × 3	2 020 – 2 410	14 900 – 17 800
6 1/4 × 4	1 100 – 1 330	8 150 – 9 800
6 3/4	1 340 – 1 630	9 900 – 12 000
8	2 580 – 3 080	19 000 – 22 700

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

DRILLING FLUIDS

- Functions
- Properties/Rheology
- Balanced, under/over balanced
- Lost circulation
- Typical programmes
- Mud quarter equipment



FORCES INVOLVED

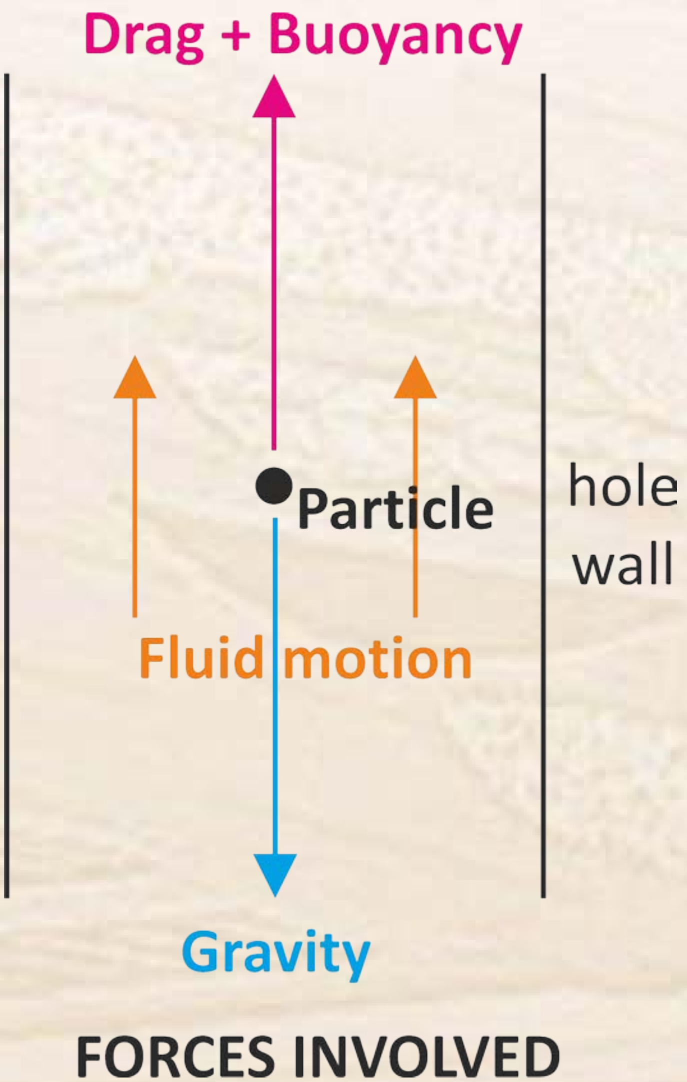
DRILLING FLUID FUNCTIONS

- Remove cuttings from Bit
- Recover cuttings at surface
- Cooling, lubrication of Bit and Drill String
- Hole & Formation Cooling
- Wall cake
- Lost circulation control
- Secure reservoir integrity

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



- 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

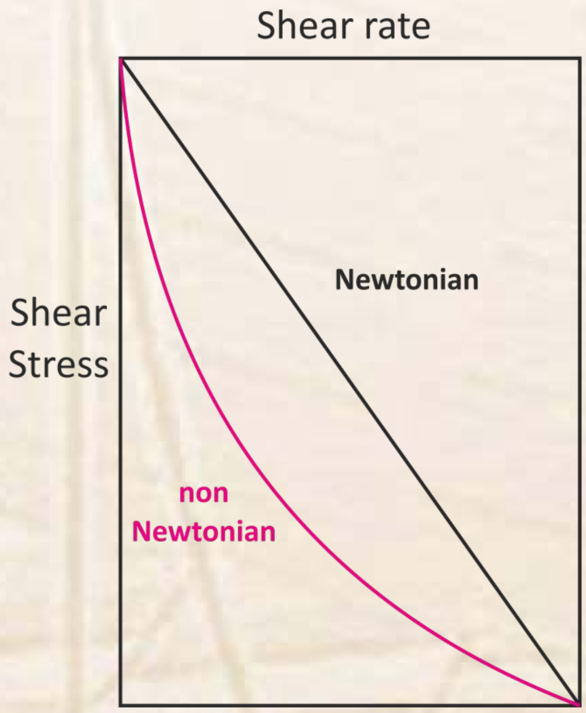
  - **Most drilling fluids and cement slurries are thixotropic**

Stationay fluid	viscosity increases
Non stationary fluid	viscosity decreases

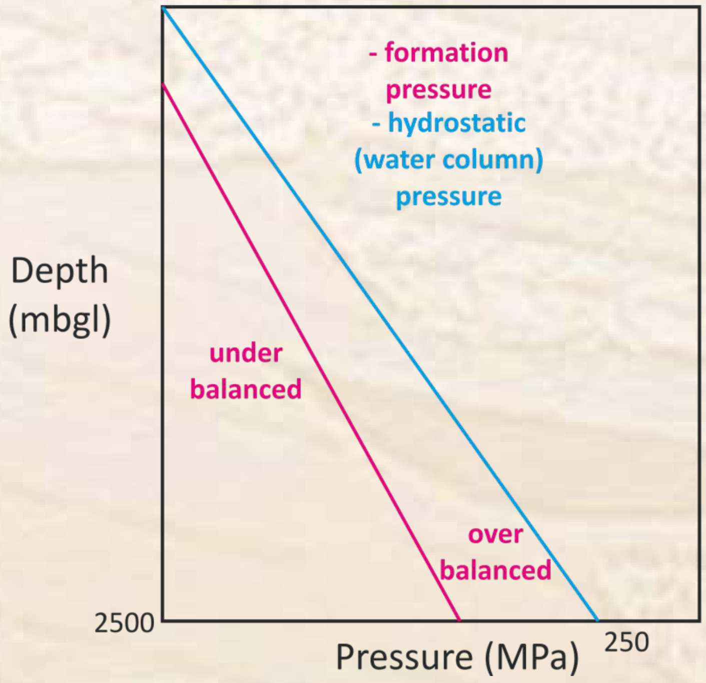
  - **Thixotropy allows to :**
- Keep solids in suspension when not circulating
- Release solids on shale shakers
- Build up a cake on hole wall

- 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

GRAPHICS



Thixotropy
Gel Strength



Under vs
Overbalanced
drilling

- 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)

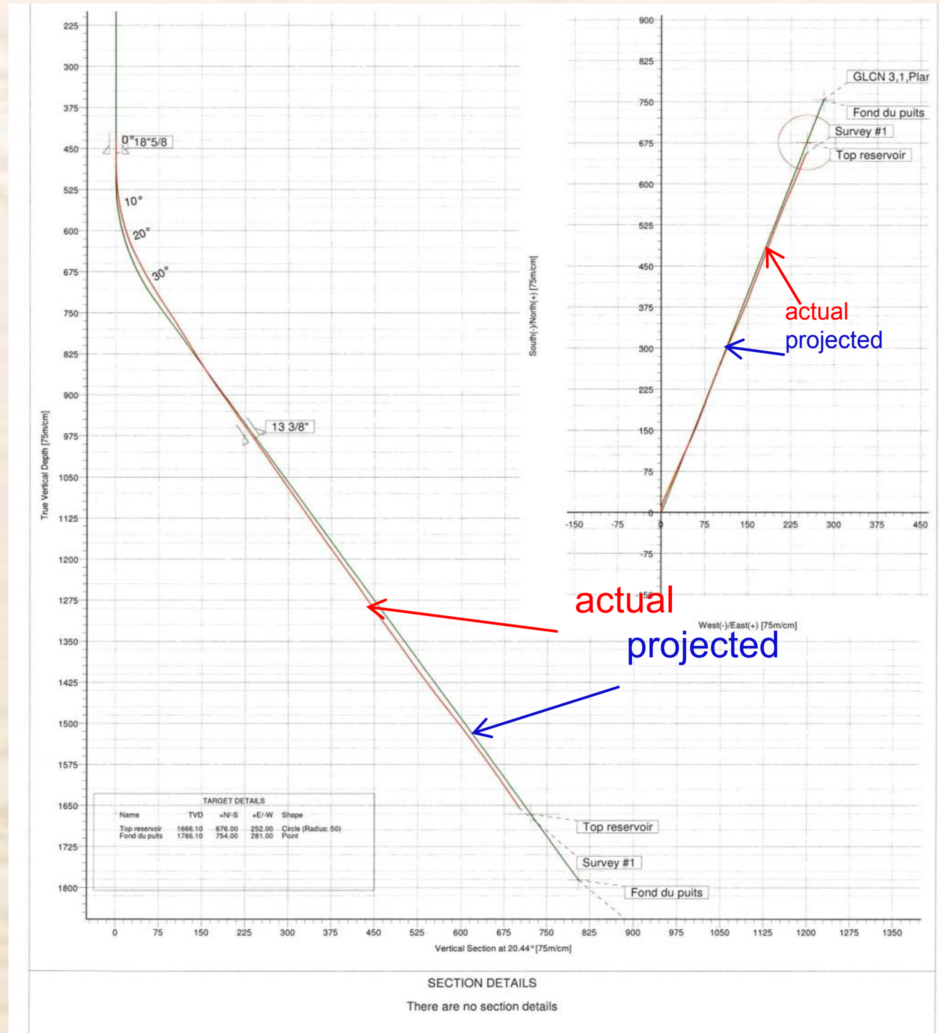
  - **Conclusion :**
    keep as close as possible to balance drilling conditions unless otherwith dictated (blow out control)

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

DIRECTIONAL DRILLING

- OBJECTIVES
- CLUSTERS
- CANDIDATE (J/S SHAPED) TRAJECTORIES
- PLANNING LIMITATIONS
- TYPICAL WELL PROFILES
- BHAs



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)

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)

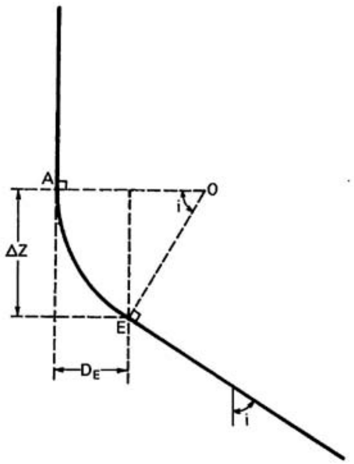
in general $\frac{\Delta i}{\Delta L}$ is kept as constant as possible during kickoff (constant radius of curvature)

Hence:

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

$D_E = R(1 - \cos i)$ (m)

$\Delta Z = R \sin i$ (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

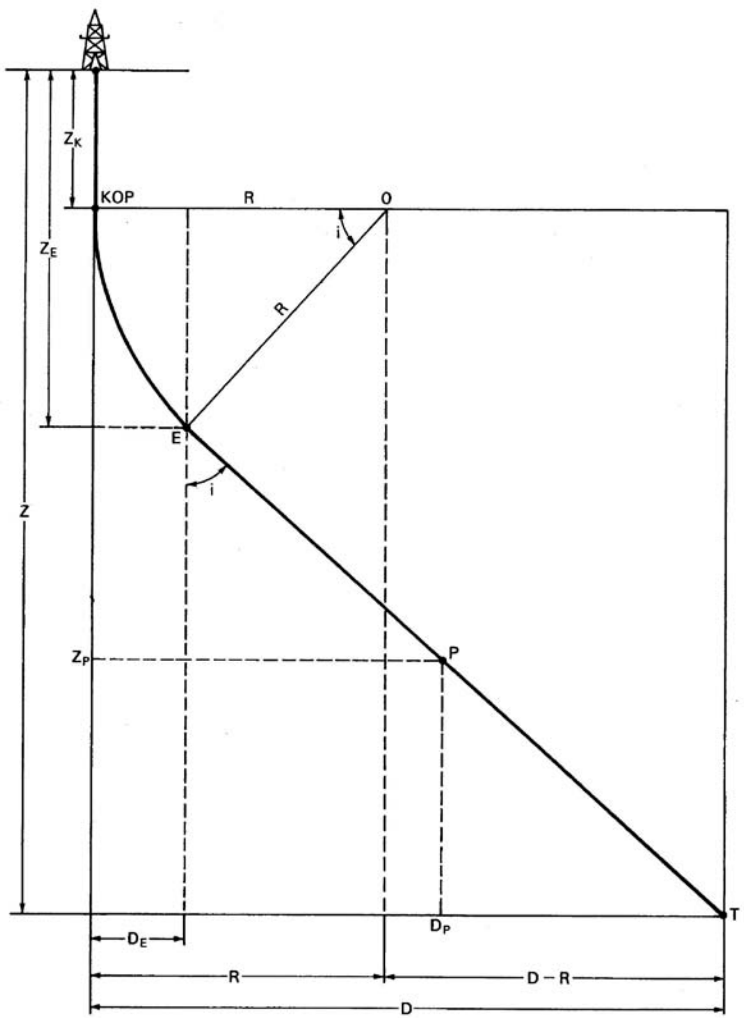
m × 3.28 = ft °/10 m × 3.048 = °/100 ft

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*:

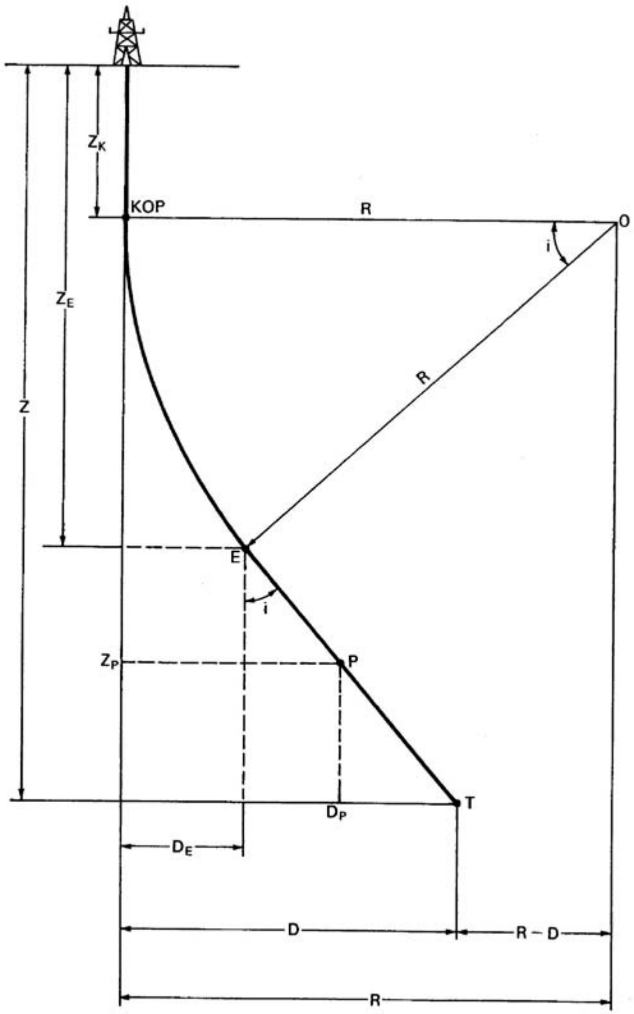
$$Z_P = Z_K + \frac{573}{gbu} \sin i + \left(L_P - Z_K - \frac{10 i}{gbu}\right) \cos i$$

Source : IFP/TECHNIP

J SHAPED HOLE (2)

CALCULATION OF CHARACTERISTIC POINTS OF THE THEORETICAL VERTICAL PROFILE

J* hole: *D* < *R



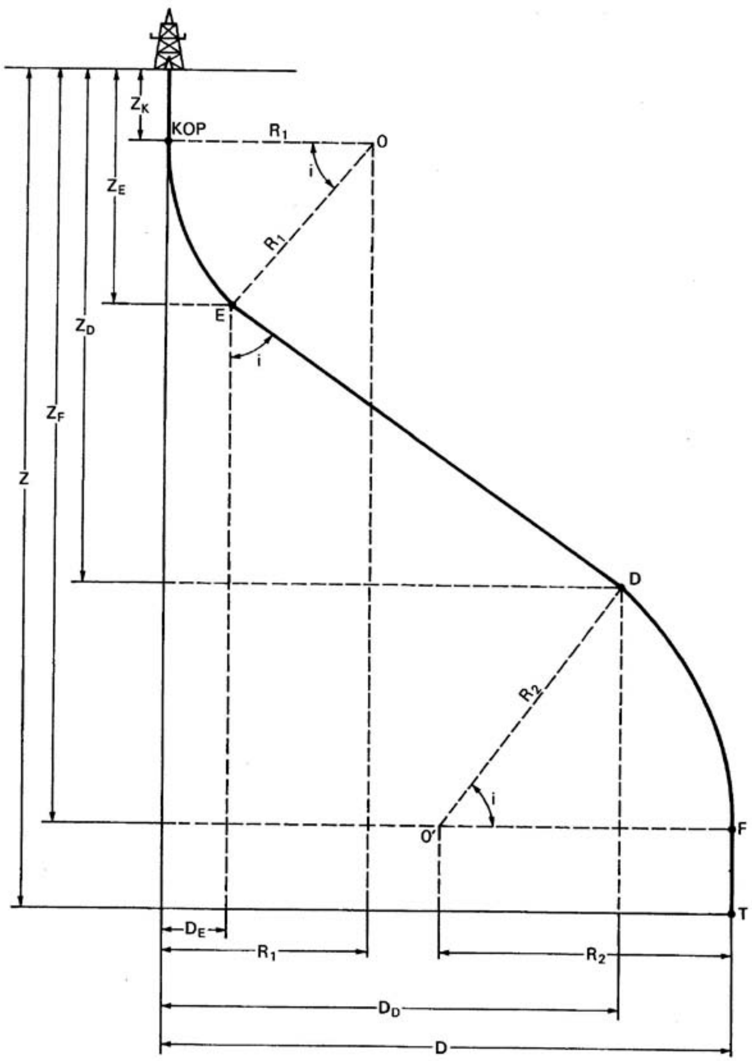
	Measured depth *L* (TMD)	Vertical depth *Z* (TVD)	Inclination	Displacement
Kickoff point (*K*)	Z_K	Z_K	0	0
End of deviation (*E*)	$L_E = Z_K + \frac{\Pi i R}{180}$	$Z_E = Z_K + R \sin i$	i	$D_E = R(1 - \cos i)$
Target (*T*)	$L_T = Z_K + \frac{\Pi i R}{180} + \frac{Z - Z_K - R \sin i}{\cos i}$	Z	i	D

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

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:

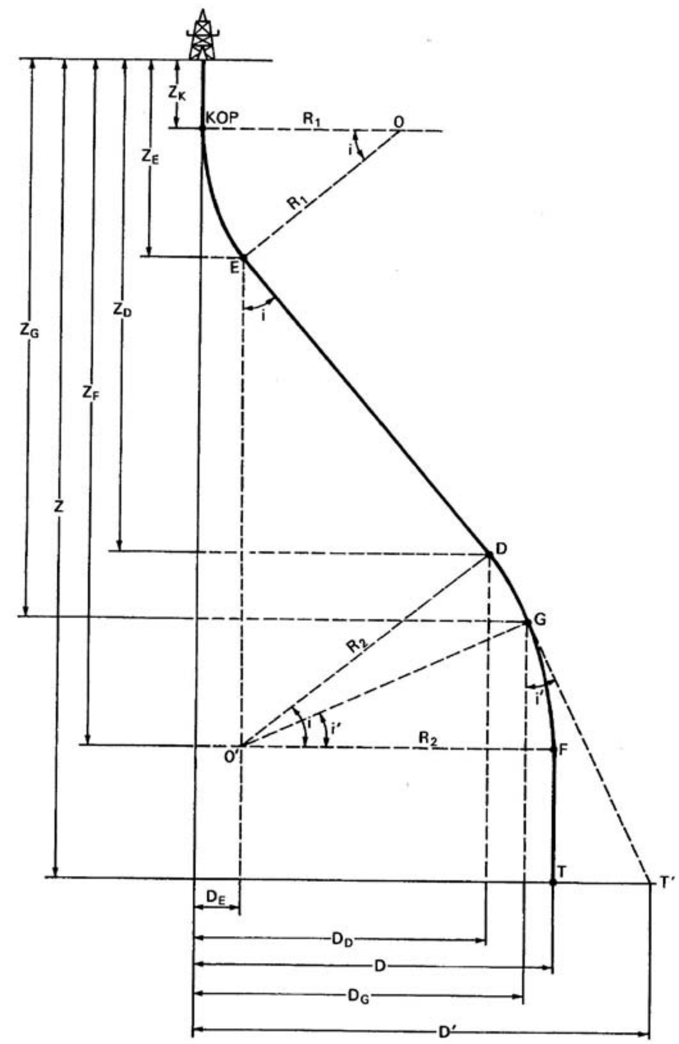
$$L_F = L_D + \frac{\Pi i R_2}{180}$$

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

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:

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

The remaining calculations are unchanged (see J 9).

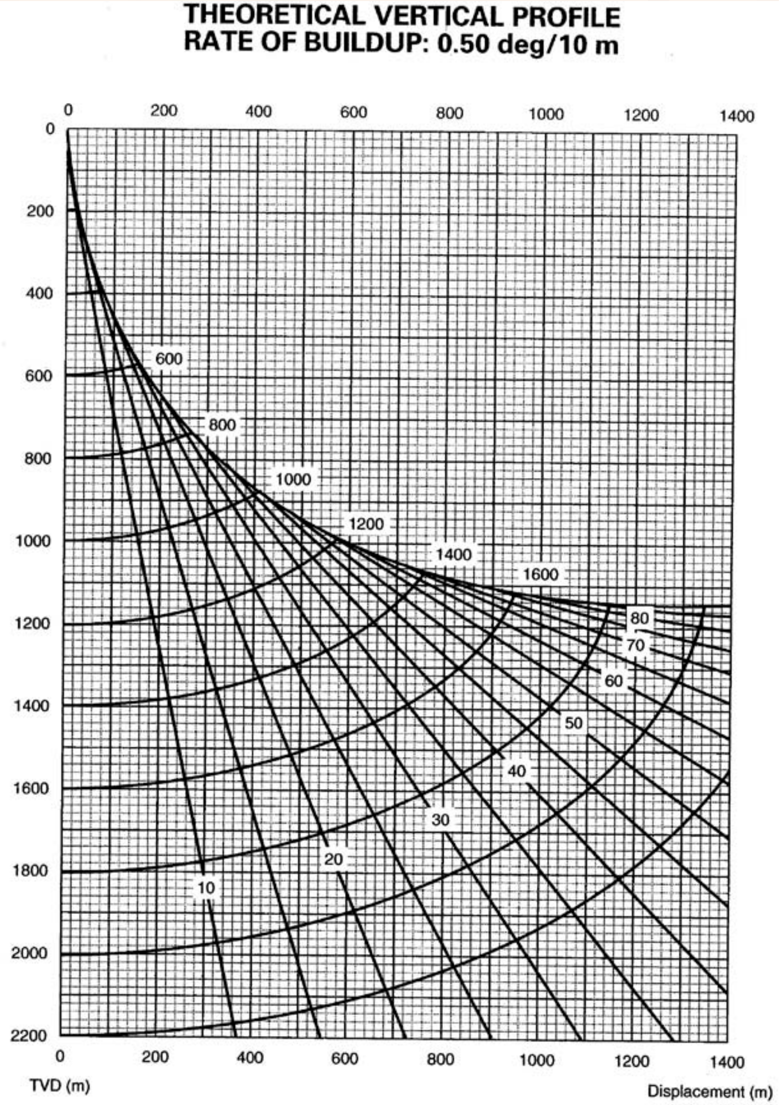
If the well does not return to the vertical, the displacement at T' from point G becomes:

$$D' = D_G + (Z - Z_G) \tan i'$$

$$L_{T'} = L_G + \frac{(Z - Z_G)}{\cos i'}$$

Source : IFP/TECHNIP

Build up rate = 10/10 m



Source : IFP/TECHNIP

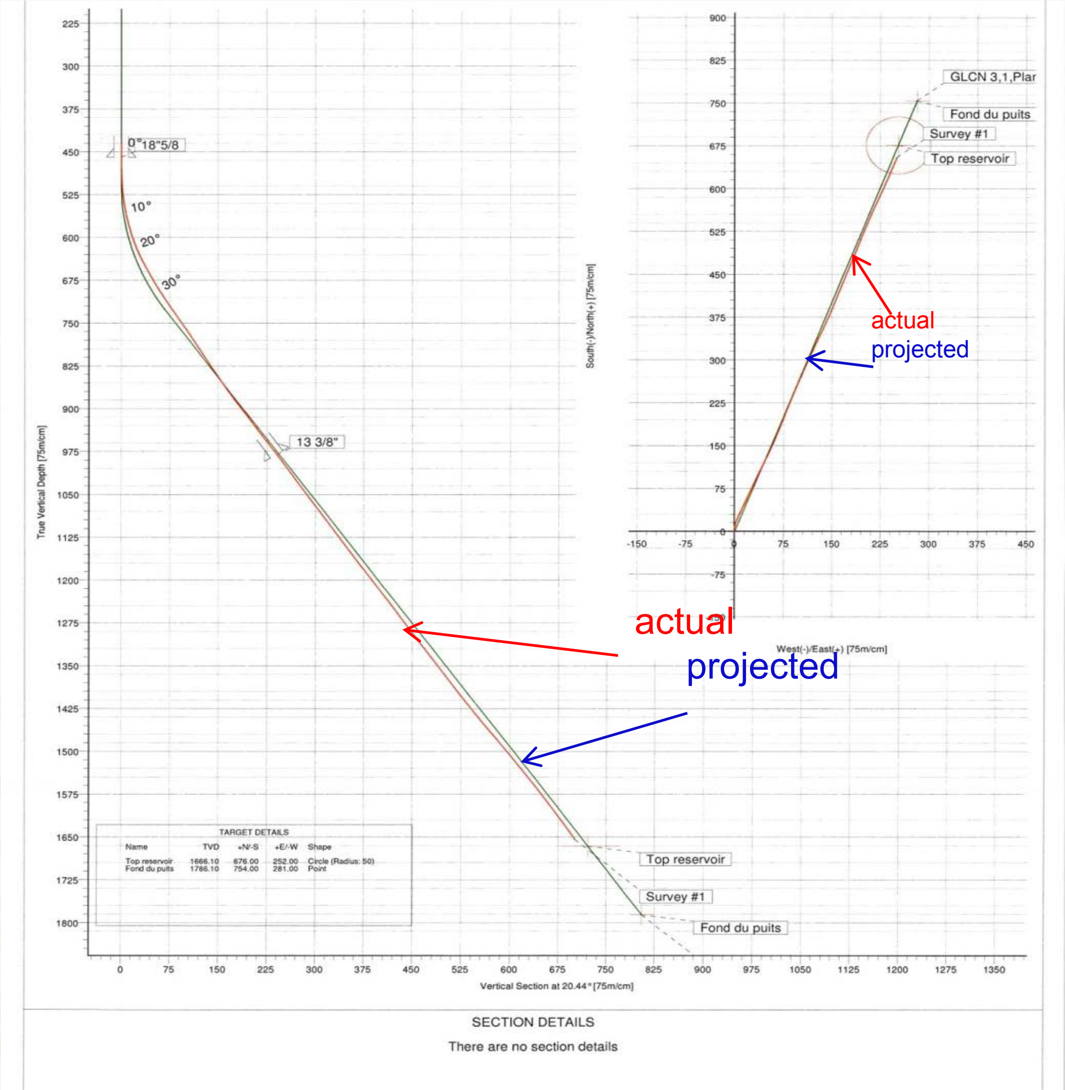
DIRECTIONAL DRILLING SURVEY REPORT

Company:	GPC / SMP	**Date:**	9/26/2011	**Time:** 08:37:53	**Page:** 2
Field:	Bassin Parisien	**Co-ordinate(NE) Reference:**	Well: GLCN 3, Grid North		
Site:	GLCN	**Vertical (TVD) Reference:**	SITE 43.1		
Well:	GLCN 3	**Section (VS) Reference:**	Well (0.00N,0.00E,20.44Azi)		
Wellpath:	1	**Survey Calculation Method:**	Minimum Curvature	**Db:** Sybase	

Survey: Survey #1

MD m	Incl deg	Azim deg	TVD m	+N/-S m	+E/-W m	VS m	DLS deg/30m	Build deg/30m	Turn deg/30m	Tool/Comment
669.00	26.81	22.73	662.13	41.08	11.73	42.59	1.258	0.833	2.100	EM MWD
679.00	26.81	22.48	671.06	45.24	13.46	47.09	0.338	0.000	-0.750	EM MWD
688.00	27.69	22.60	679.06	49.05	15.04	51.21	2.939	2.933	0.400	EM MWD
698.00	28.81	22.23	687.87	53.42	16.85	55.94	3.401	3.360	-1.110	EM MWD
707.00	30.22	21.98	695.70	57.53	18.51	60.37	4.718	4.700	-0.833	EM MWD
716.00	30.94	22.23	703.45	61.77	20.24	64.95	2.437	2.400	0.833	EM MWD
725.00	30.69	21.60	711.18	66.05	21.96	69.56	1.361	-0.833	-2.100	EM MWD
735.00	30.81	22.48	719.77	70.79	23.88	74.67	1.397	0.360	2.640	EM MWD
745.00	31.81	22.73	728.31	75.59	25.87	79.86	3.025	3.000	0.750	EM MWD
754.00	32.25	22.35	735.94	79.99	27.70	84.63	1.613	1.467	-1.267	EM MWD
763.00	32.38	22.35	743.55	84.44	29.53	89.44	0.433	0.433	0.000	EM MWD
773.00	31.44	22.98	752.04	89.32	31.57	94.72	2.992	-2.820	1.890	EM MWD
782.00	31.06	23.23	759.73	93.62	33.40	99.39	1.338	-1.267	0.833	EM MWD
792.00	30.75	23.35	768.31	98.33	35.43	104.52	0.948	-0.930	0.360	EM MWD
802.00	30.56	23.48	776.92	103.01	37.46	109.61	0.604	-0.570	0.390	EM MWD
811.00	30.88	22.35	784.65	107.25	39.25	114.20	2.200	1.067	-3.767	EM MWD
821.00	31.38	22.98	793.21	112.02	41.24	119.37	1.790	1.500	1.890	EM MWD
830.00	31.06	23.23	800.91	116.31	43.07	124.03	1.151	-1.067	0.833	EM MWD
840.00	30.31	23.73	809.51	120.99	45.10	129.12	2.377	-2.250	1.500	EM MWD
849.00	30.38	23.48	817.28	125.16	46.92	133.66	0.481	0.233	-0.833	EM MWD
859.00	30.94	22.48	825.88	129.85	48.92	138.76	2.272	1.680	-3.000	EM MWD
869.00	31.50	22.35	834.43	134.64	50.89	143.94	1.692	1.680	-0.390	EM MWD
878.00	31.06	21.85	842.12	138.97	52.65	148.61	1.703	-1.467	-1.667	EM MWD
888.00	31.31	22.48	850.68	143.77	54.60	153.78	1.233	0.750	1.890	EM MWD
897.00	31.94	21.98	858.34	148.14	56.39	158.50	2.275	2.100	-1.667	EM MWD
907.00	32.69	20.60	866.79	153.12	58.33	163.85	3.156	2.250	-4.140	EM MWD
916.00	33.06	20.60	874.35	157.69	60.05	168.73	1.233	1.233	0.000	EM MWD
928.00	33.50	20.73	884.38	163.85	62.37	175.32	1.114	1.100	0.325	EM MWD
938.00	34.00	20.10	892.70	169.06	64.31	180.87	1.831	1.500	-1.890	EM MWD
947.00	34.44	20.35	900.14	173.81	66.06	185.93	1.540	1.467	0.833	EM MWD
957.00	34.06	20.60	908.41	179.08	68.03	191.56	1.216	-1.140	0.750	EM MWD
966.00	33.25	20.10	915.90	183.75	69.76	196.55	2.854	-2.700	-1.667	EM MWD
975.00	33.13	19.35	923.43	188.39	71.43	201.47	1.426	-0.400	-2.500	EM MWD
985.00	33.38	19.10	931.79	193.57	73.23	206.96	0.855	0.750	-0.750	EM MWD
995.00	34.13	18.23	940.11	198.83	75.01	212.51	2.677	2.250	-2.610	EM MWD
1004.00	34.81	19.23	947.53	203.66	76.64	217.60	2.949	2.267	3.333	EM MWD
1014.00	34.62	19.19	955.75	209.04	78.52	223.30	0.574	-0.570	-0.120	EM MWD
1024.00	34.44	19.98	963.98	214.38	80.42	228.96	1.448	-0.540	2.370	EM MWD
1034.00	34.35	19.67	972.24	219.69	82.33	234.61	0.591	-0.270	-0.930	EM MWD
1064.00	33.13	20.60	997.18	235.34	88.07	251.27	1.325	-1.220	0.930	EM MWD
1074.00	32.94	20.60	1005.57	240.44	89.99	256.73	0.570	-0.570	0.000	EM MWD
1083.00	32.94	20.35	1013.12	245.02	91.70	261.62	0.453	0.000	-0.833	EM MWD
1092.00	33.18	20.74	1020.66	249.62	93.42	266.53	1.069	0.800	1.300	EM MWD
1102.00	33.44	20.85	1029.02	254.75	95.37	272.02	0.801	0.780	0.330	EM MWD
1111.00	33.38	21.23	1036.53	259.38	97.15	276.98	0.726	-0.200	1.267	EM MWD
1121.00	33.25	21.35	1044.89	264.50	99.14	282.47	0.437	-0.390	0.360	EM MWD
1130.00	33.31	22.10	1052.41	269.08	100.97	287.40	1.386	0.200	2.500	EM MWD
1141.00	33.81	21.48	1061.58	274.73	103.23	293.48	1.653	1.364	-1.691	EM MWD
1150.00	33.69	20.73	1069.06	279.40	105.03	298.48	1.445	-0.400	-2.500	EM MWD
1160.00	33.69	21.10	1077.38	284.58	107.01	304.03	0.616	0.000	1.110	EM MWD
1169.00	33.75	21.23	1084.87	289.24	108.81	309.03	0.313	0.200	0.433	EM MWD
1179.00	34.19	21.10	1093.16	294.45	110.83	314.61	1.338	1.320	-0.390	EM MWD
1188.00	34.06	21.60	1100.61	299.15	112.67	319.66	1.031	-0.433	1.667	EM MWD

DIRECTIONAL DRILLING TYPICAL DEVIATED WELL PROFILES TRAJECTORIES DISPLAYS



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"	

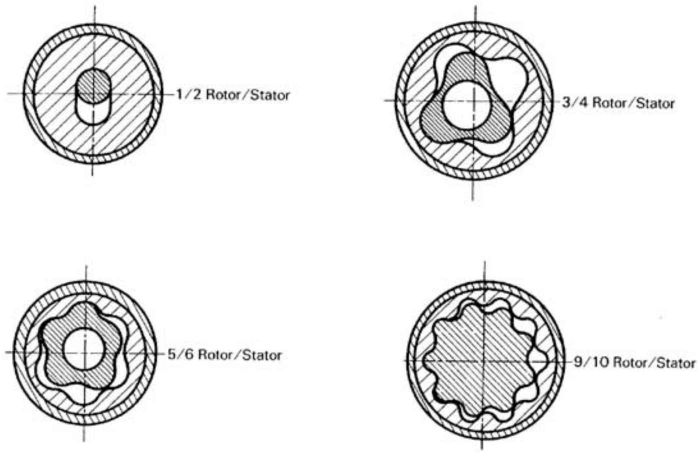
POSITIVE DISPLACEMENT MOTORS

I SPECIFICATIONS OF POSITIVE DISPLACEMENT MOTORS

Positive displacement motors are identified by:

(a) Outside diameter of the body

(b) Ratio of the shaft lobes (rotor) to the sleeve (stator) which may vary from 1/2 to 9/10:



(c) Number of stages

(d) Length and weight.

The hydraulic characteristics are indicated by:

(a) Minimum and maximum flow rates

(b) Minimum and maximum rotary speeds

(c) Maximum pressure drop across the motor

(d) Maximum torque supplied

(e) Maximum mechanical horsepower output supplied

(f) Maximum efficiency.

II VARIATIONS IN SPECIFICATIONS

The specifications are given by the manufacturers for a specific gravity of 1.20 (10 ppg):

- The **rotary speed** is directly proportional to the flow rate:

$$N_2 = N_1 \frac{Q_2}{Q_1}$$

The higher the number of shaft lobes, the lower the rotary speed.

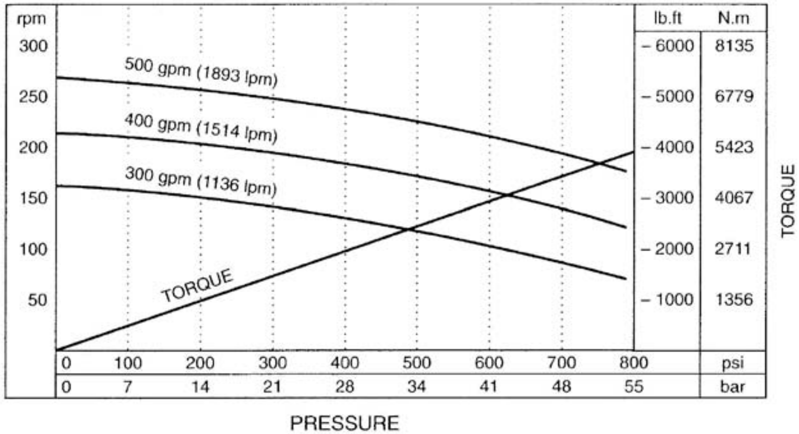
It varies only slightly with torque and pressure drop.

DOWNHOLE MOTORS

PERFORMANCE CURVES OF POSITIVE DISPLACEMENT MOTORS FOR DIFFERENT FLOW RATES *Q*

Example of a 6 3/4" – 4/5 lobe Performance Curves:

Motor start pressure 100 psi (7 bar)



POSITIVE DISPLACEMENT MOTORS
(continued)

- The **torque** is directly proportional to the pressure drop across the motor:

$$T_2 = T_1 \frac{\Delta p_2}{\Delta p_1}$$

- The **mechanical horsepower output** transmitted to the rotor is the product of the rotary speed multiplied by the torque:

$$P_m = \frac{TN}{9550}$$

- The **hydraulic horsepower** is the product of the pressure drop multiplied by the flow rate:

$$P_h = \frac{\Delta p Q}{60\,000}$$

where:

T = torque (in N.m)
N = rotary speed (in rpm)
Δp = pressure drop in the motor (in kPa)
Q = mud flow rate (in l/min)
P_h = hydraulic horsepower (in kW)
P_m = mechanical horsepower output at rotor (in kW)

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

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

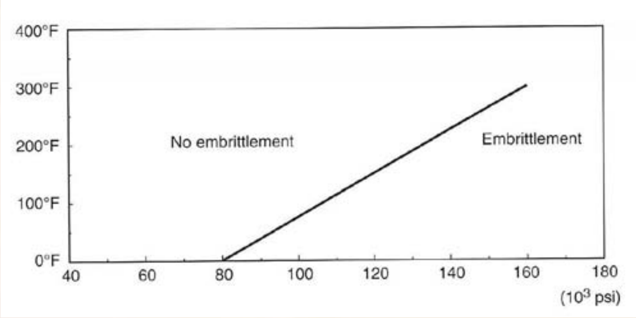
Standard steel strength

Grade	Yield strength				Tensile strength		Hardness
	Minimum		Maximum		Minimum		Maximum
	psi	MPa	psi	MPa	psi	MPa	HRC
C75	75,000	517	90,000	620	95,000	655	22
L80	80,000	552	95,000	655	95,000	655	23
C90	90,000	620	105,000	724	100,000	690	25.4
C95	95,000	655	110,000	758	105,000	723	

High strength steels

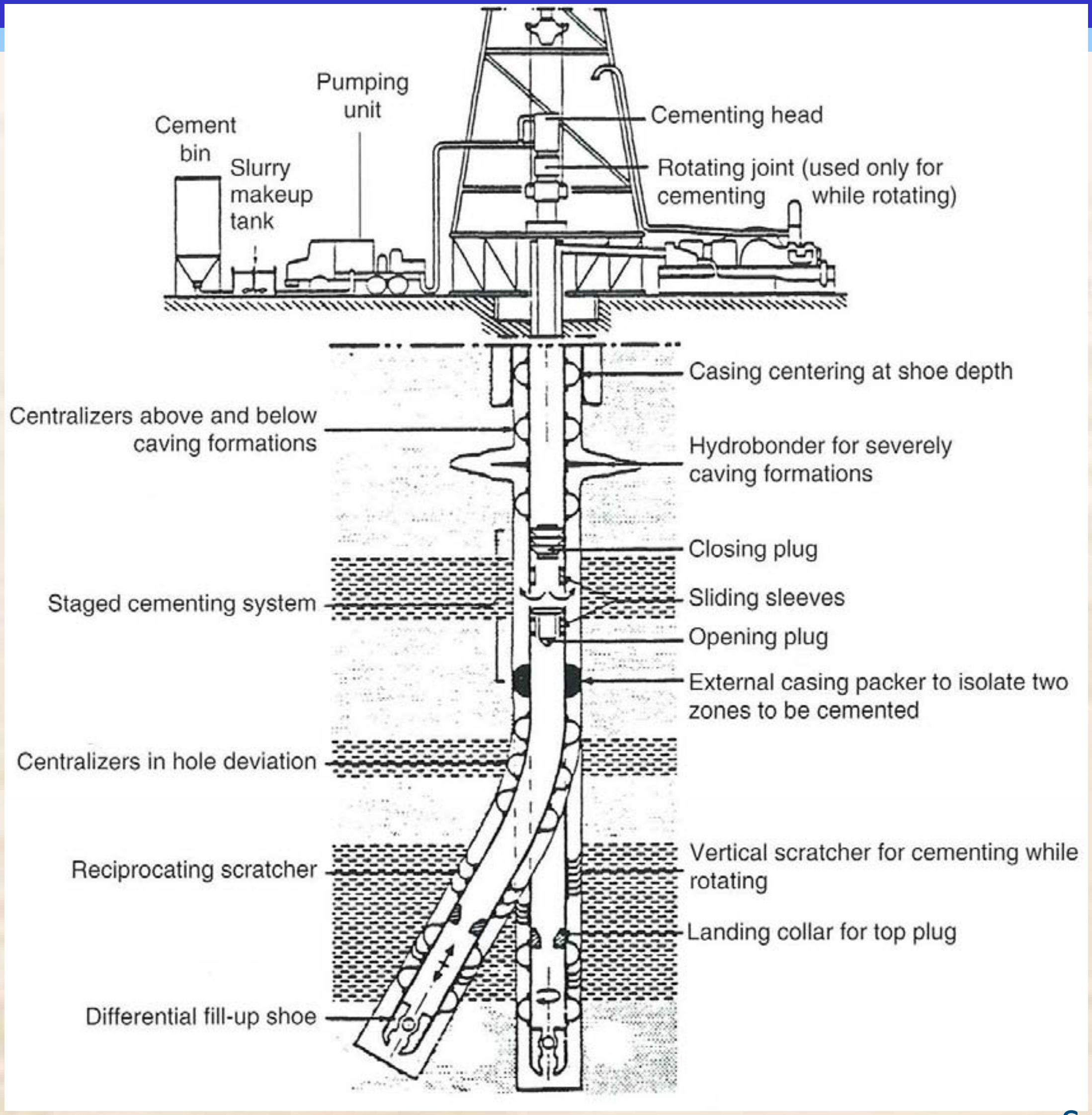
Grade	Yield strength				Tensile strength	
	Minimum		Maximum		Minimum	
	psi	MPa	psi	MPa	psi	MPa
P105	105,000	724	135,000	931	120,000	827
P110	110,000	758	140,000	965	125,000	827
Q125	125,000	862	155,000	1069	135,000	931
V150	150,000	1034			160,000	1104

H2S embrittlement



Source : J.P. NGUYEN

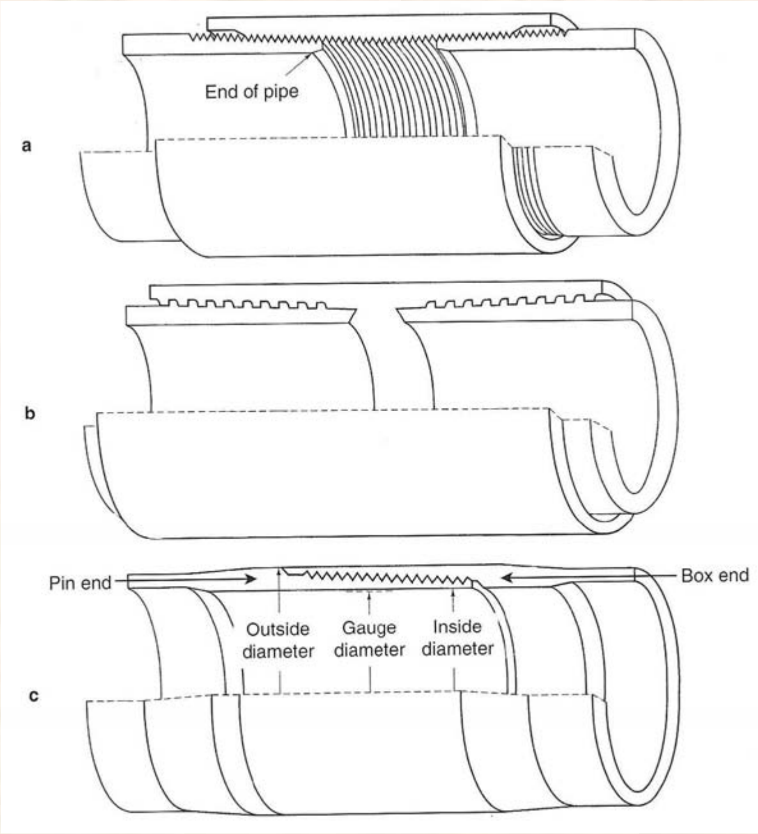
CASING/LINING
RUNNING CASING STRING



Source : Gaz de France

CASING/LINING

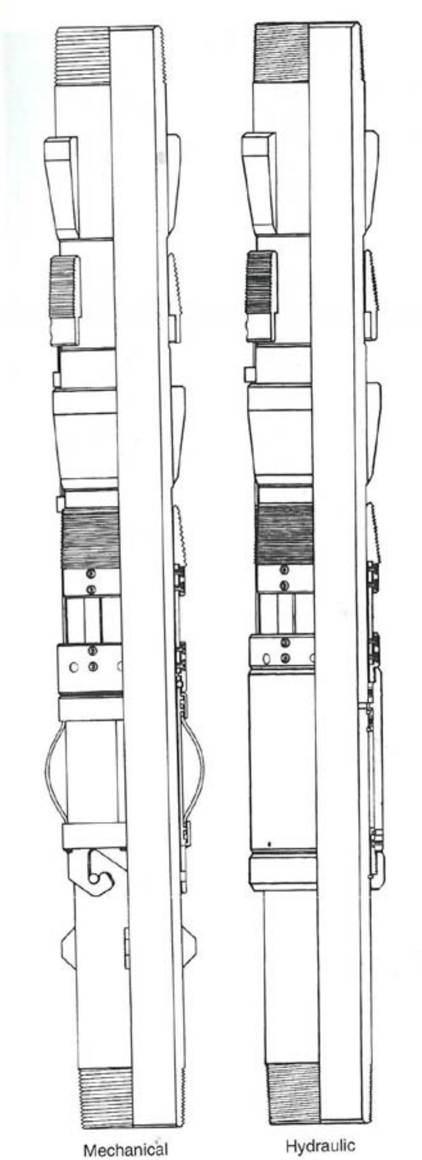
Pipe couplings



a. API round
b. VAM
c. Extreme line

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

CASING/LINING
LINER HANGERS



Source : Baker

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

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.
G	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 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

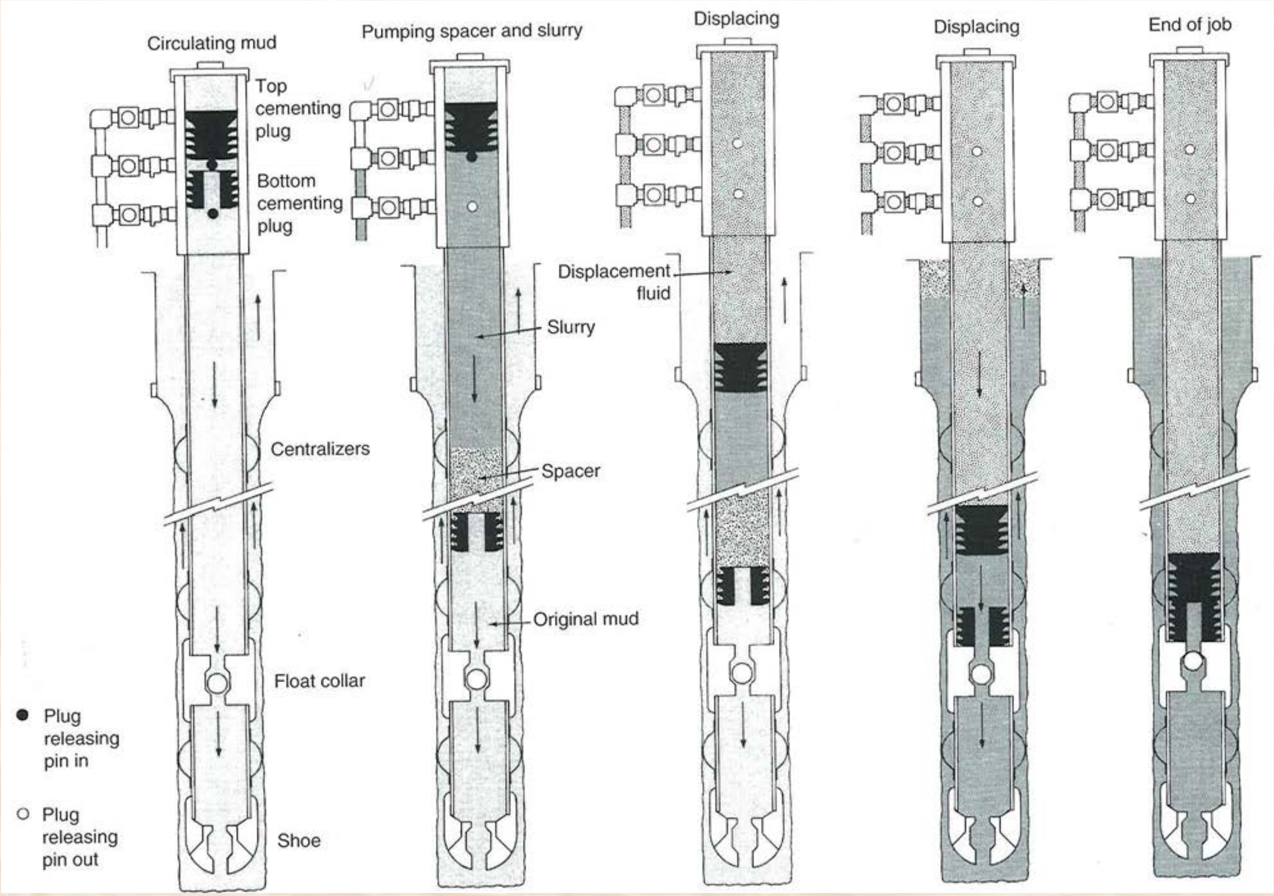
CEMENTING
CEMENT ADDITIVE CHARATERISTICS

Cement Characteristics	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

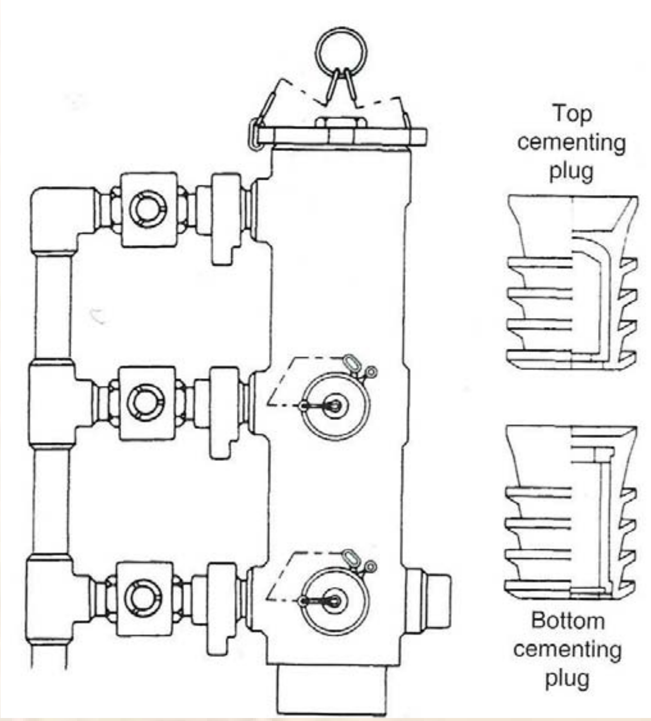
Source : Drilling Data Handbook, Editions Technip & Dowell Schlumberger

Primary casing cementing sequence



Source : Dowell Schlumberger

CEMENTING
TWIN-PLUG CEMENTING HEAD



HEAD

PLUGS

Top **Bottom**

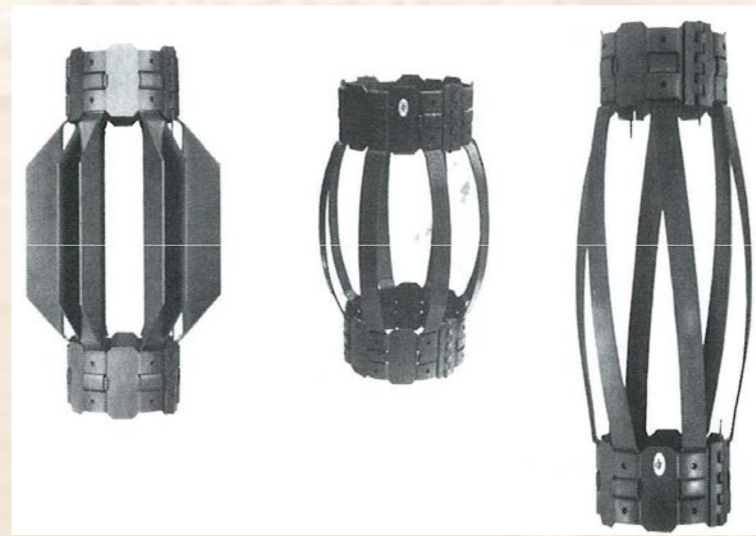
Source : Weatherford

CEMENTING COMPONENTS

Shoes **Landing float collar**

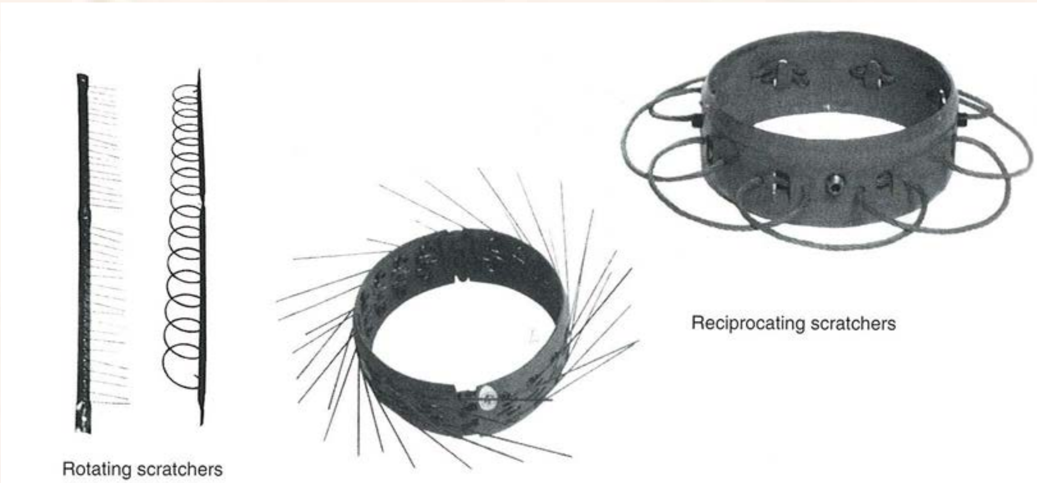
Source : Halliburton

CENTRALIZERS



Source : Weatherford

CEMENTING ACCESSORIES

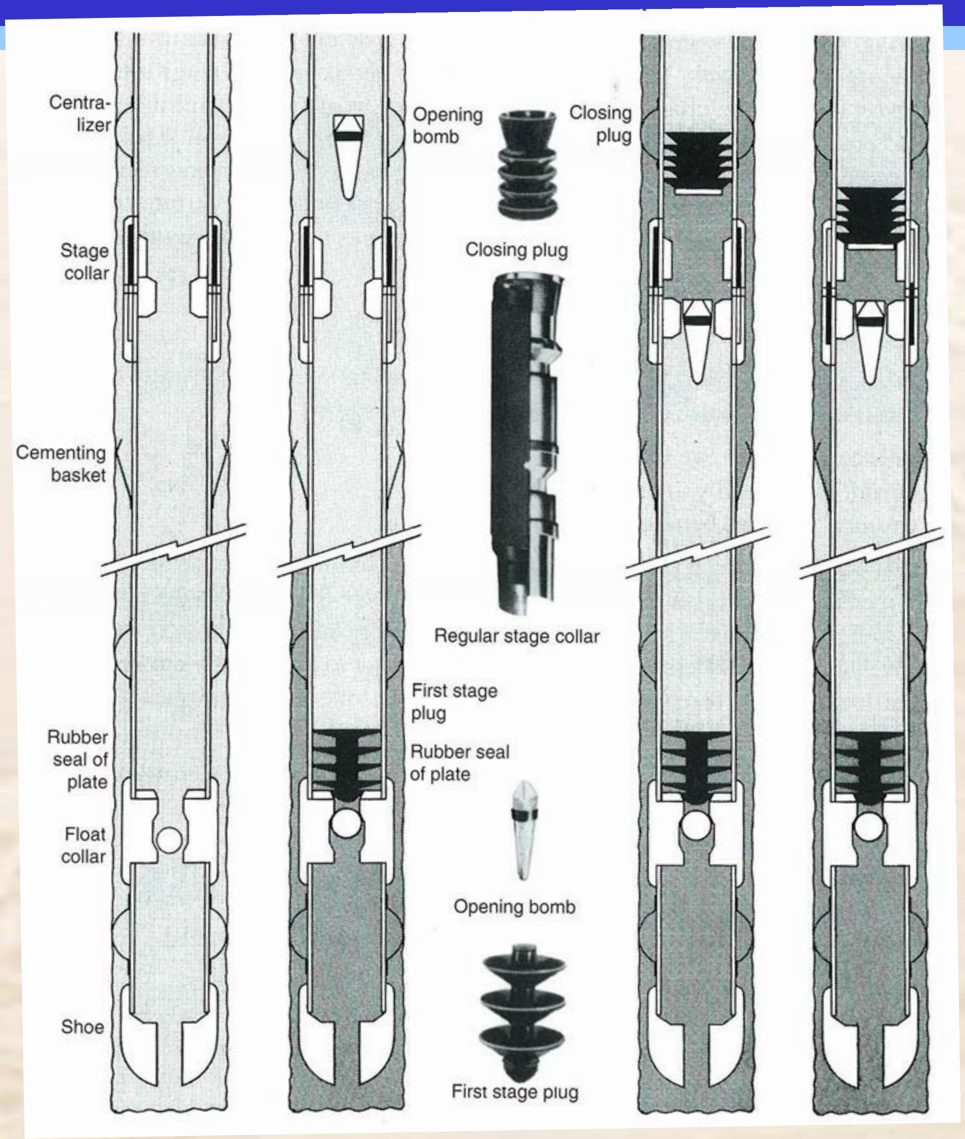


Scratchers

Hydrobonder

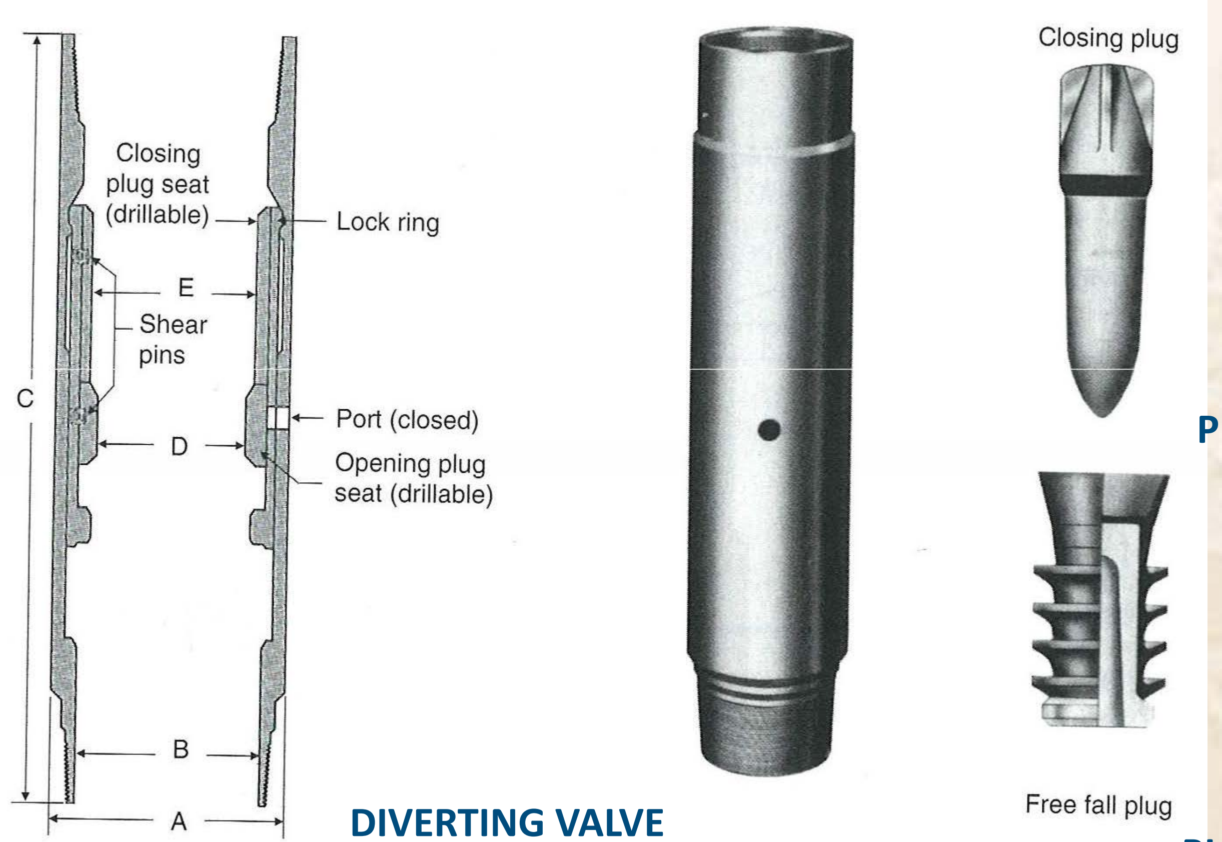
Source : Halliburton

CEMENTING
TWO-STAGE CEMENTING SEQUENCE



Source : Weatherford

CEMENTING
TWO-STAGE CEMENTING EQUIPMENT



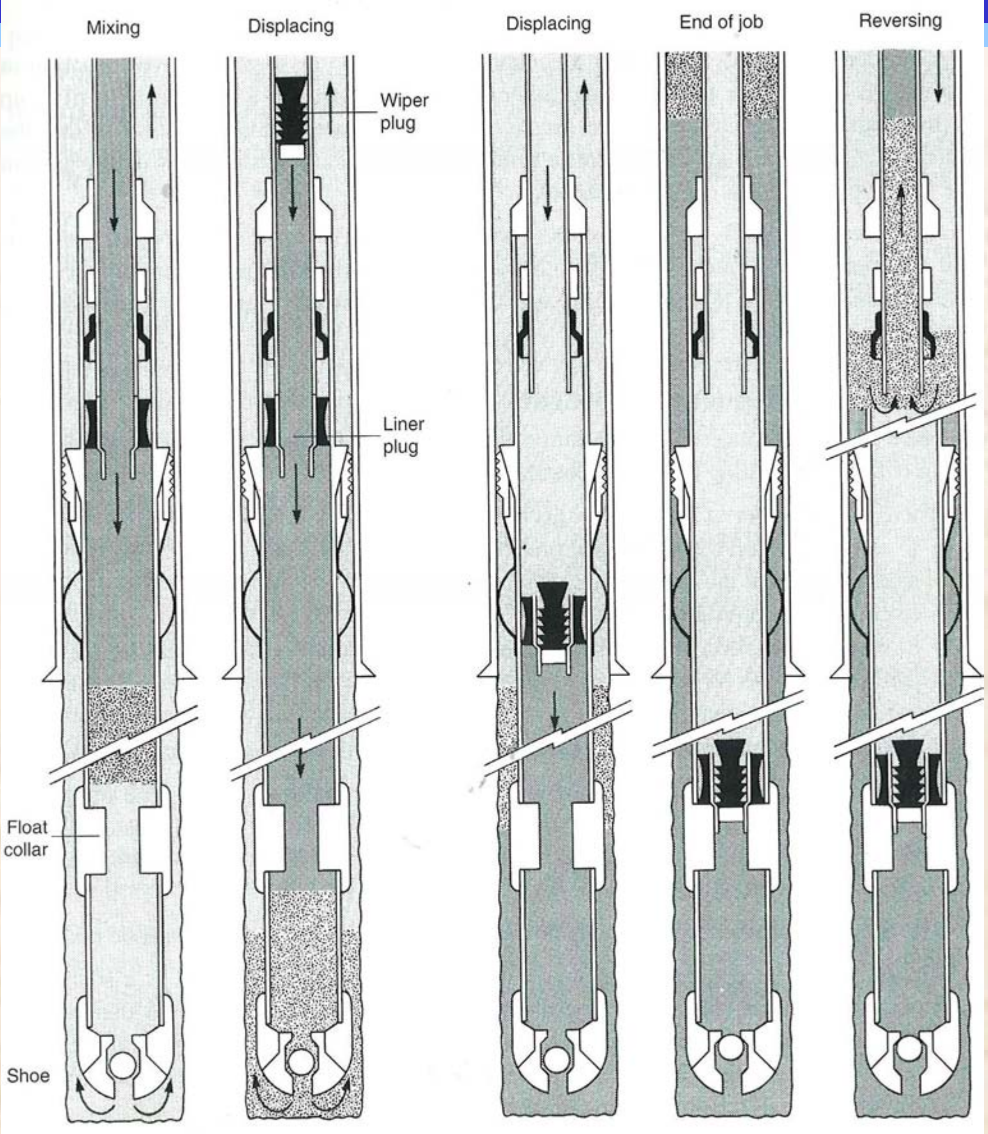
DIVERTING VALVE

PLUG

PLUGS

Source : BJ Hughes

CEMENTING
LINER CEMENTING SEQUENCE



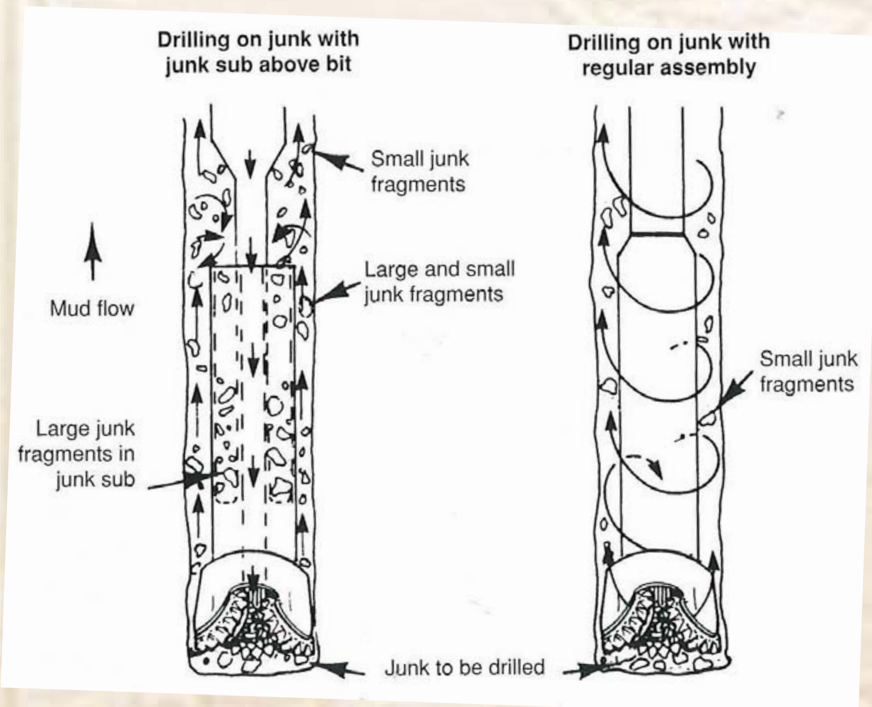
LINER

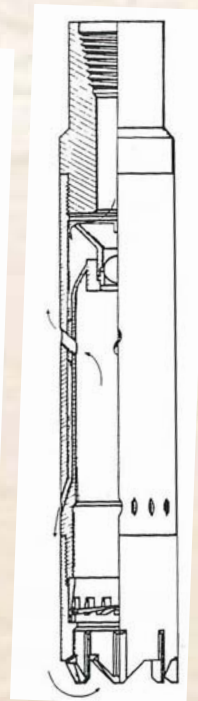
Source : Weatherford

LINER CEMENTING SEQUENCE

CEMENTING
LINER CEMENTING SEQUENCE

FISHING BASKETS



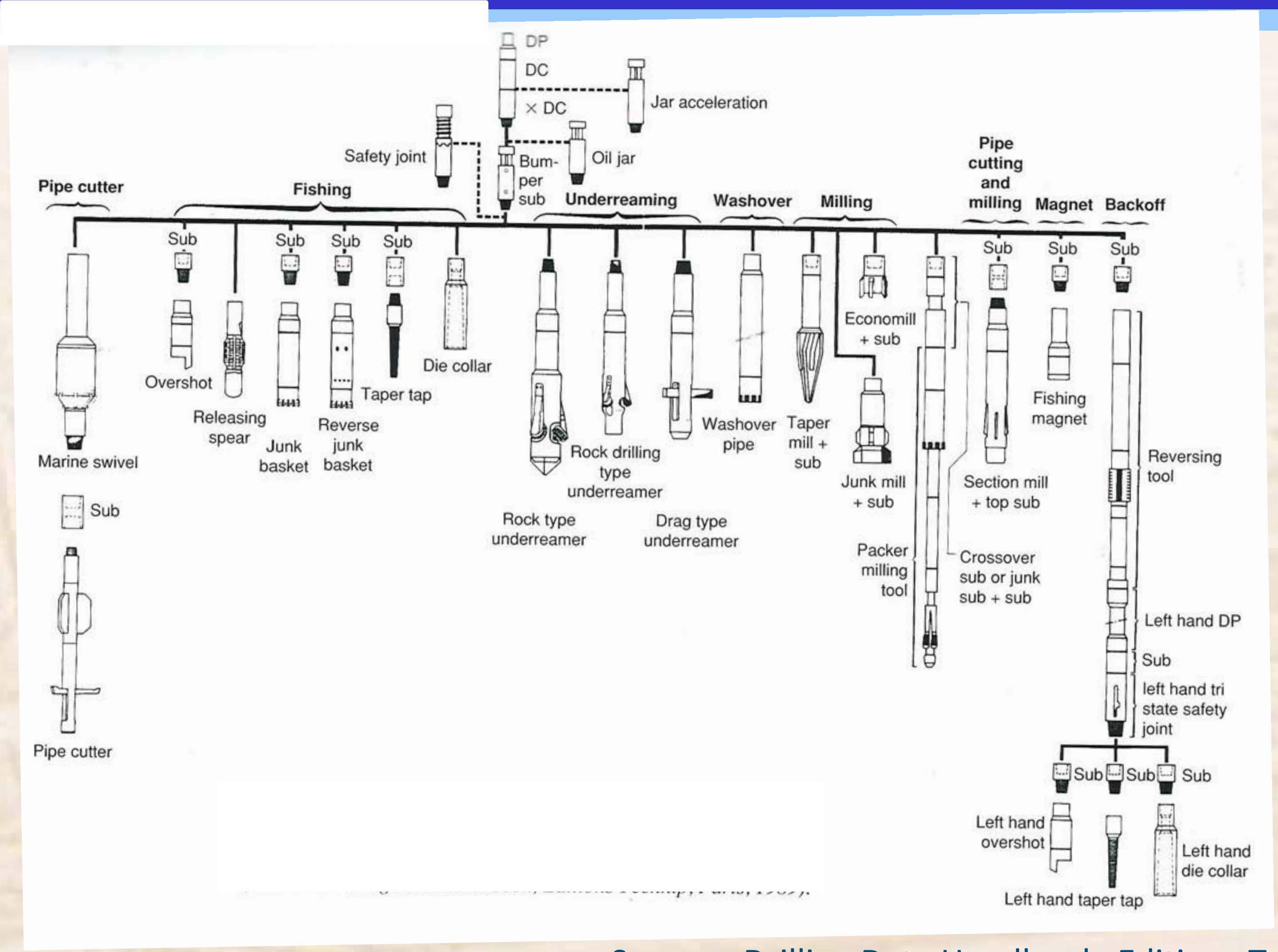


Source : J.P. NGUYEN

OUTLINE

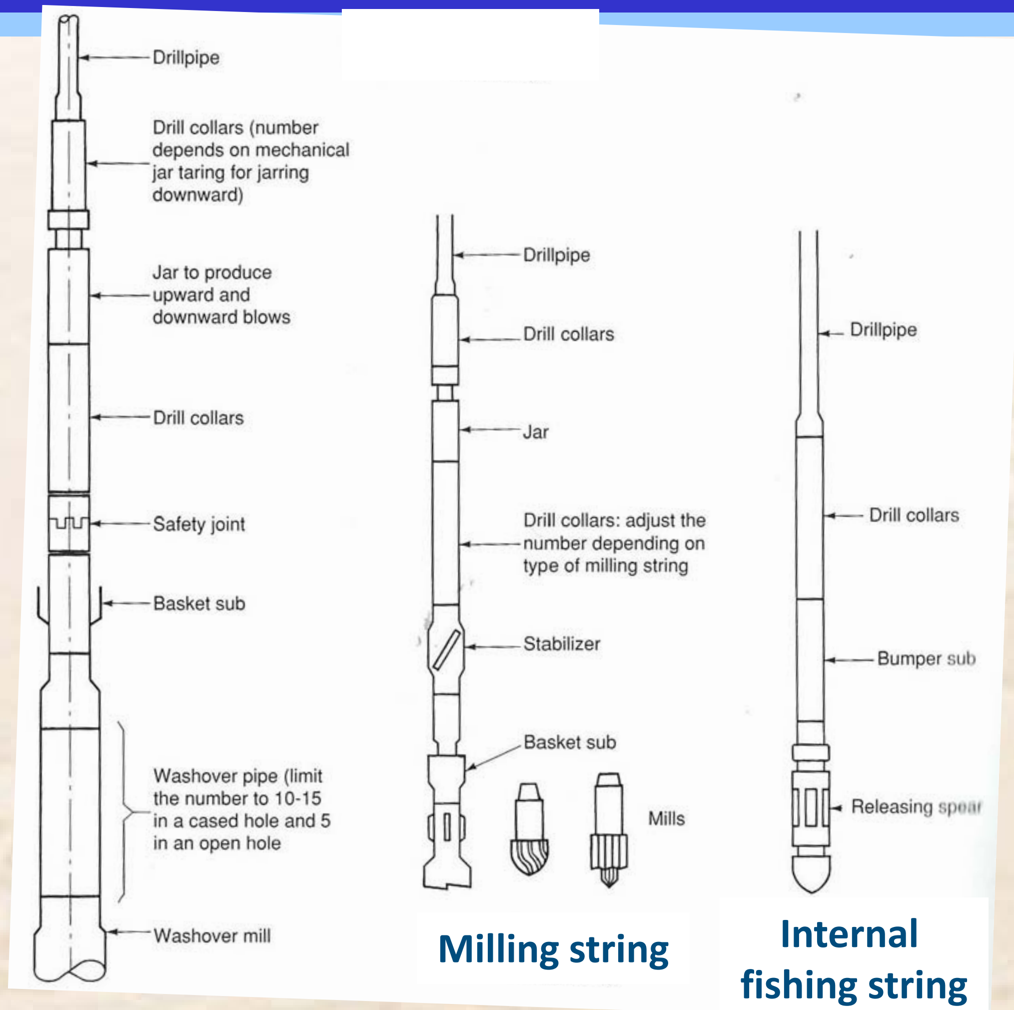
- SCOPE
- INTRODUCTION. GEOTHERMAL VS PETROLEUM
- **DEEP WELL DRILLING/COMPLETION FEATURES**
  - Rig selection
  - Site preparation. Rig footprint
  - Drilling
  - Bits
  - Drilling fluids
  - Directional drilling
  - Casing/lining
  - Cementing
  - **Fishing**
  - Waste disposal/processing
- CASE STUDY. 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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

FISHING
TYPICAL FISHING, MILLING AND BACK OFF STRINGS



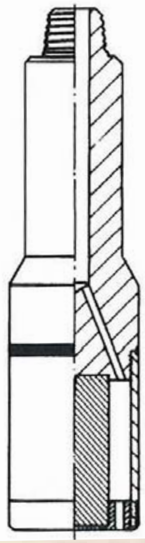
Source : Drilling Data Handbook, Editions Technip, Paris)

WASHOVER ASSEMBLY



Source : J.P. NGUYEN

FISHING
MAGNET & JUNK MILL



Hole diameter (in)	Outside diameter of fish (in)	Thread API reg (in)
6	5	2 7/8
8 1/2	7	4 1/2
12 1/4	11 1/2	6 5/8
17 1/2	16	7 5/8

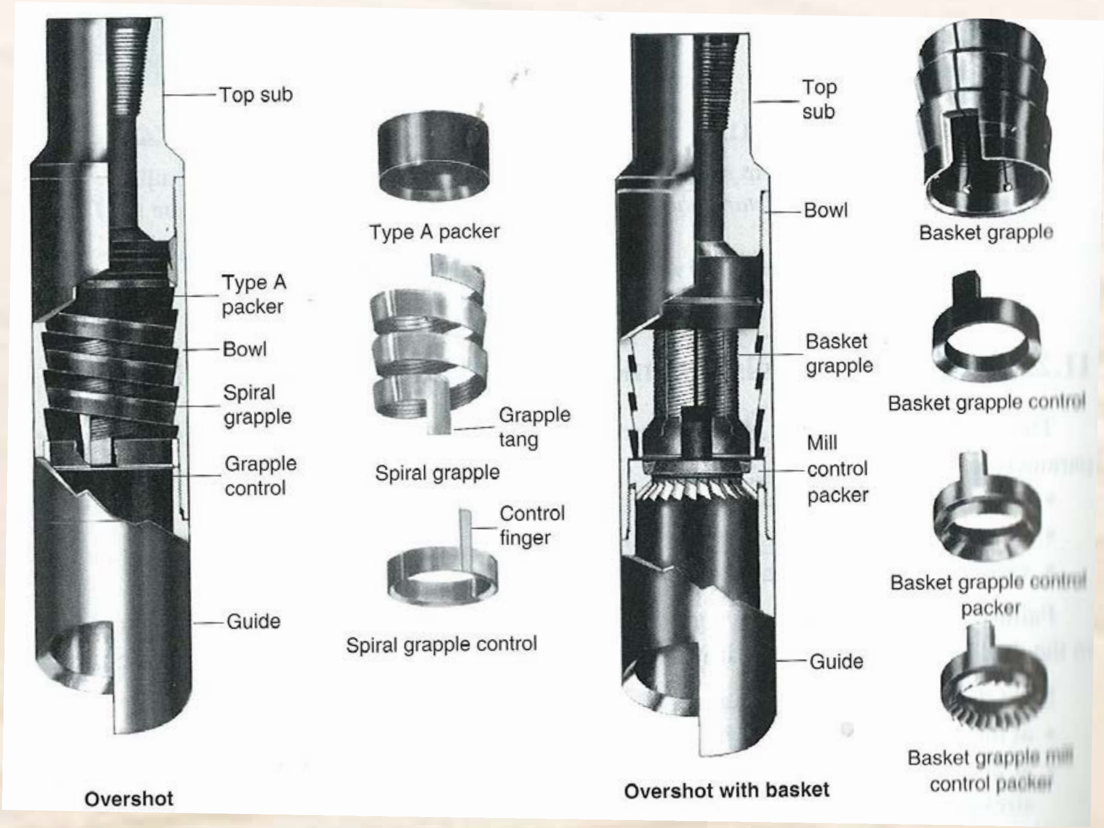
Permanent magnet

Junk mill

Source : Drillstar Industries

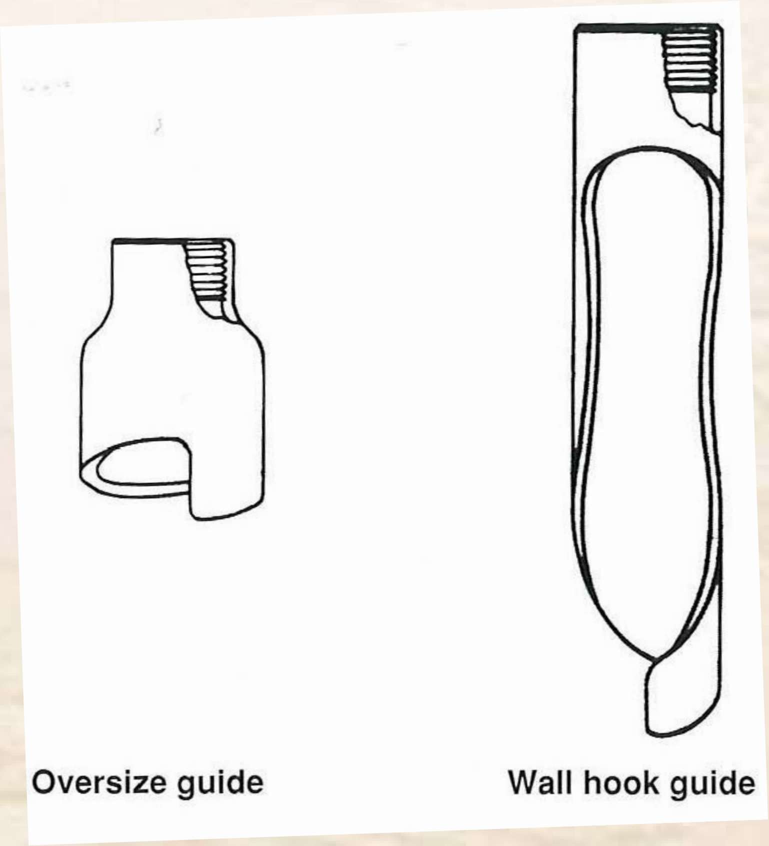
Source : Tristate Oil Tool

FISHING
OVERSHOT & GRAPPLES



Source : Bowen

FISHING
OVERSHOT GUIDES

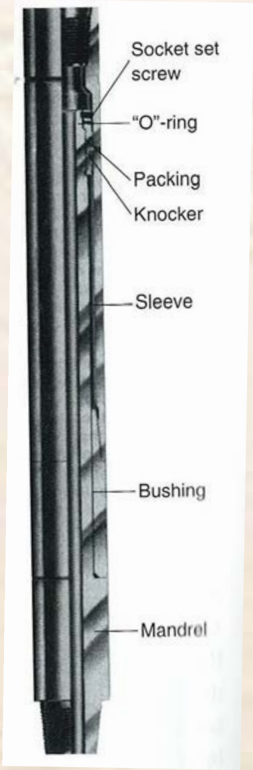


Source : Drillsatr Industries

FISHING
BUMPER SUBS

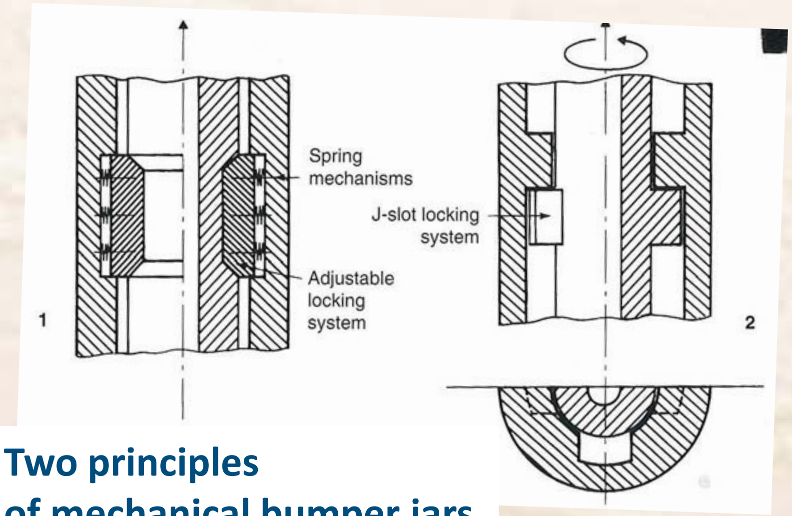
Mechanical bumper sub

Source : N.L. MacCullough



Bumper sub

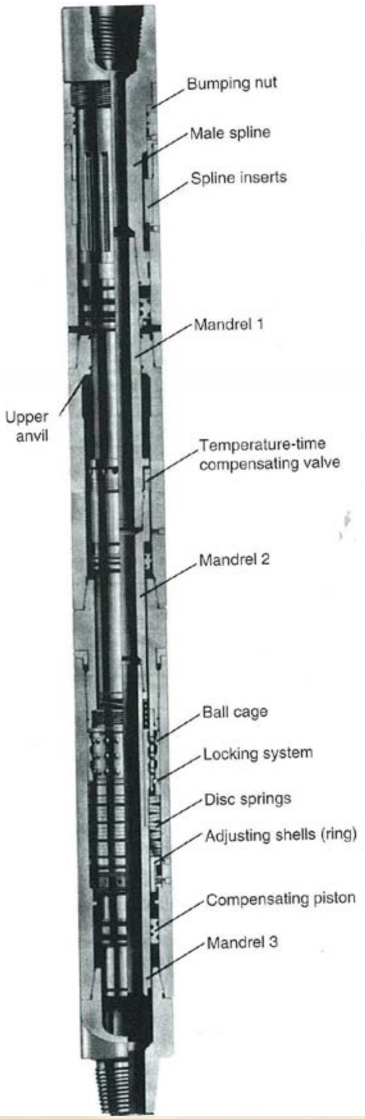
Source : AZ

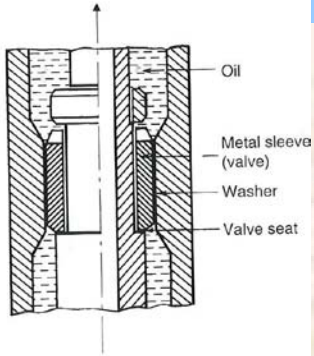


Two principles of mechanical bumper jars

Source : Eastman Christensen

FISHING
HYDRAULIC BUMPER SUB



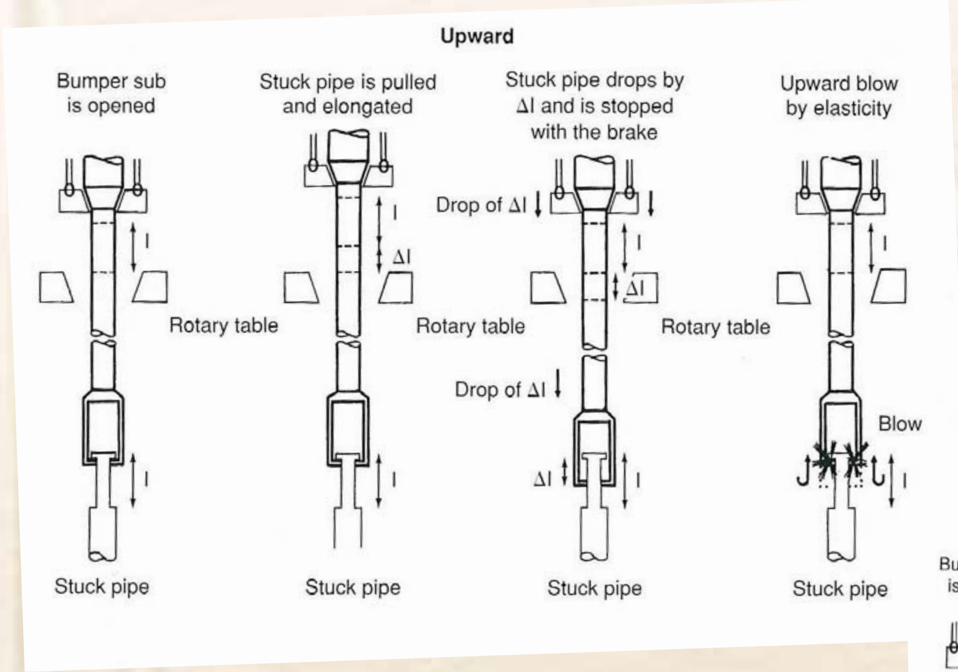


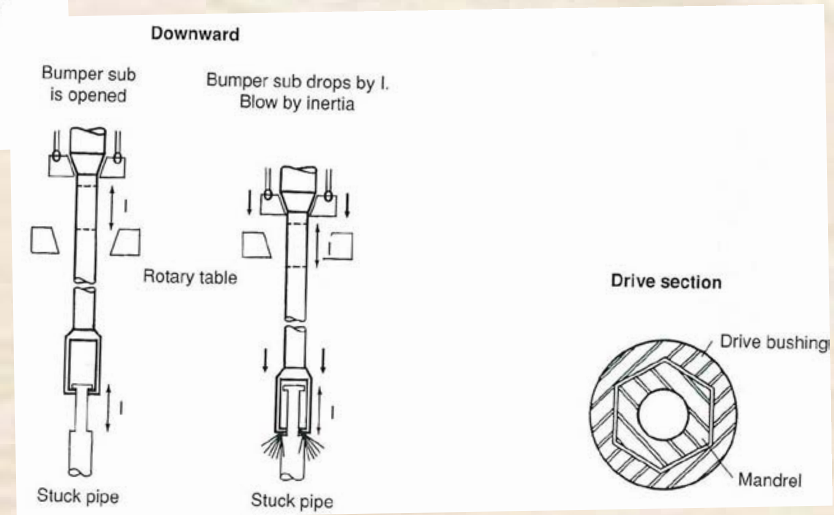
Principle of the piston

Fig. 11.11

Source : Eastman Christensen

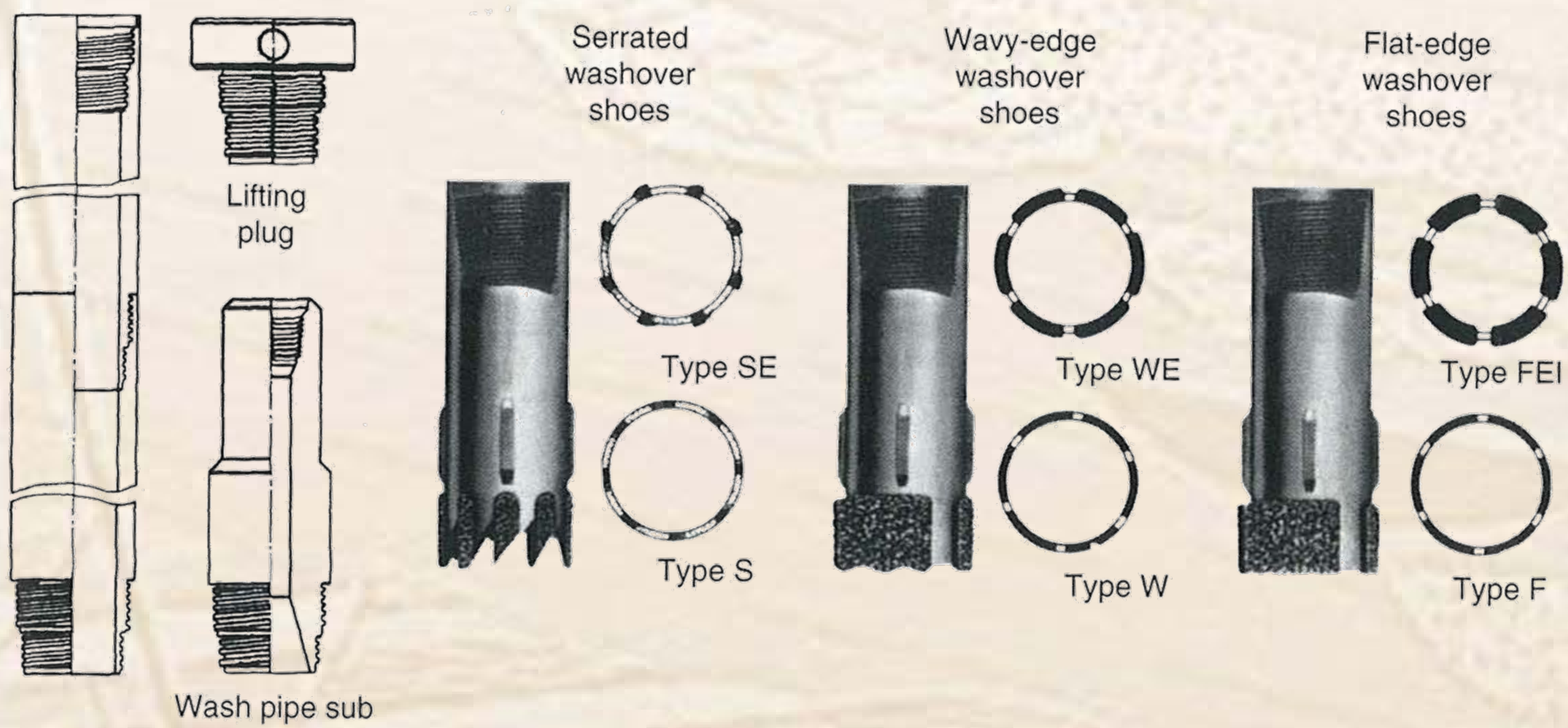
FISHING
UPWARD & DOWNWARD JARRING





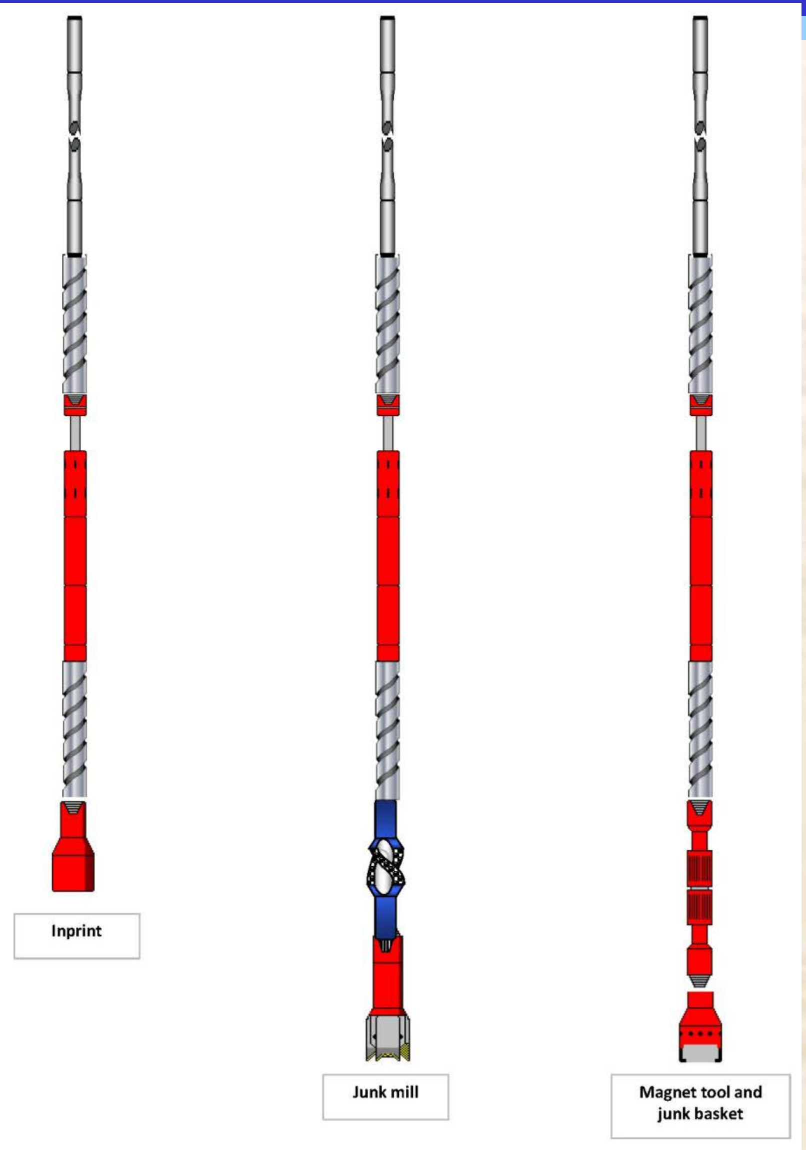
Source : J.P. NGUYEN

FISHING
WASHOVER ASSEMBLY COMPONENTS



Source : Drillstar Industries

FISHING
TYPICAL FISHING BHAS

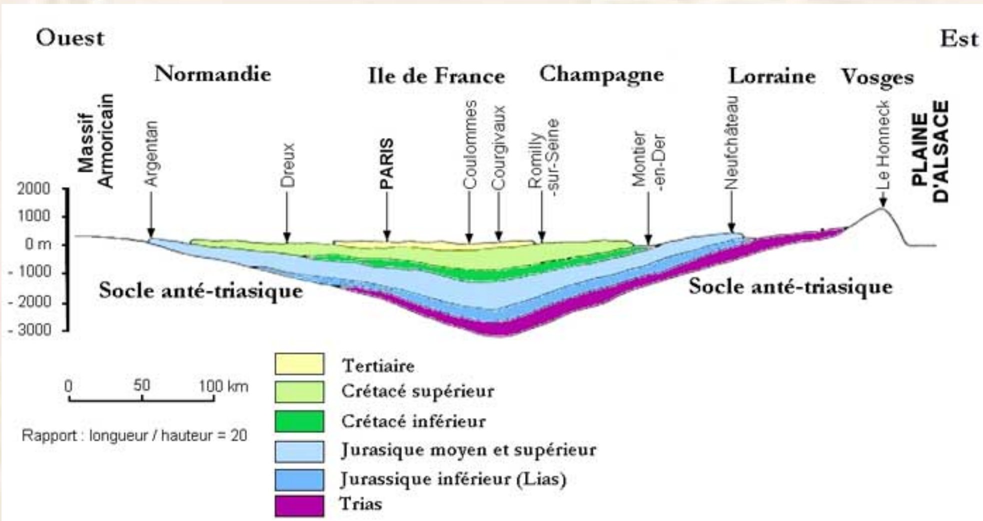


OUTLINE

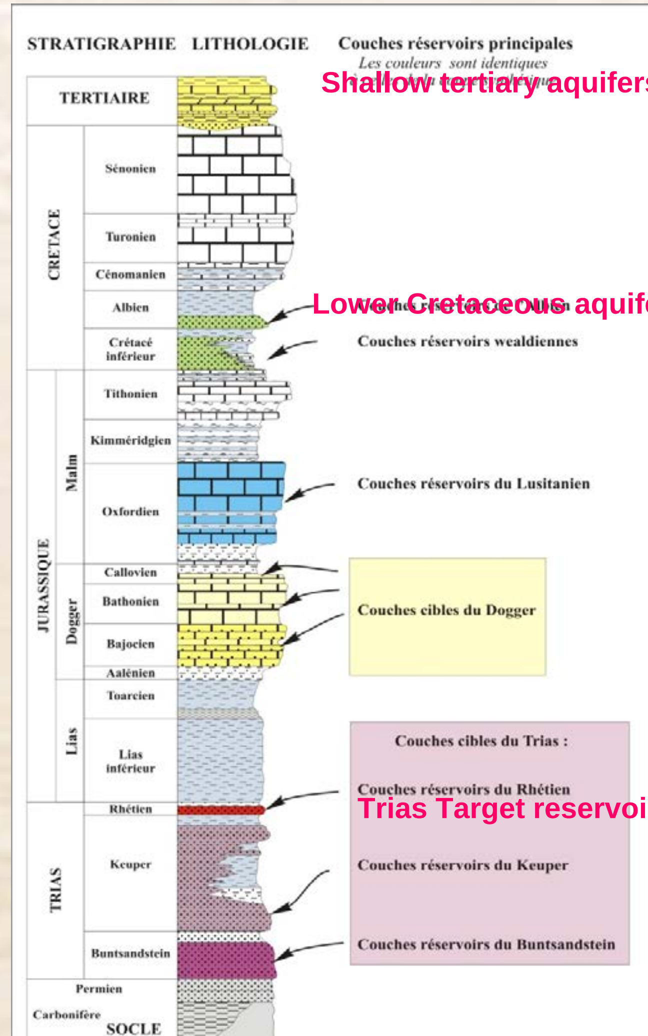
- SCOPE
- INTRODUCTION. GEOTHERMAL VS PETROLEUM
- DEEP WELL DRILLING/COMPLETION FEATURES
  - Rig selection
  - Site preparation. Rig footprint
  - Drilling
  - Bits
  - Drilling fluids
  - Directional drilling
  - Casing/lining
  - Cementing
  - Fishing
  - Waste disposal/processing
- **CASE STUDY. PARIS 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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

CASE STUDY
PARIS BASIN. GEOLOGICAL SKETCHES

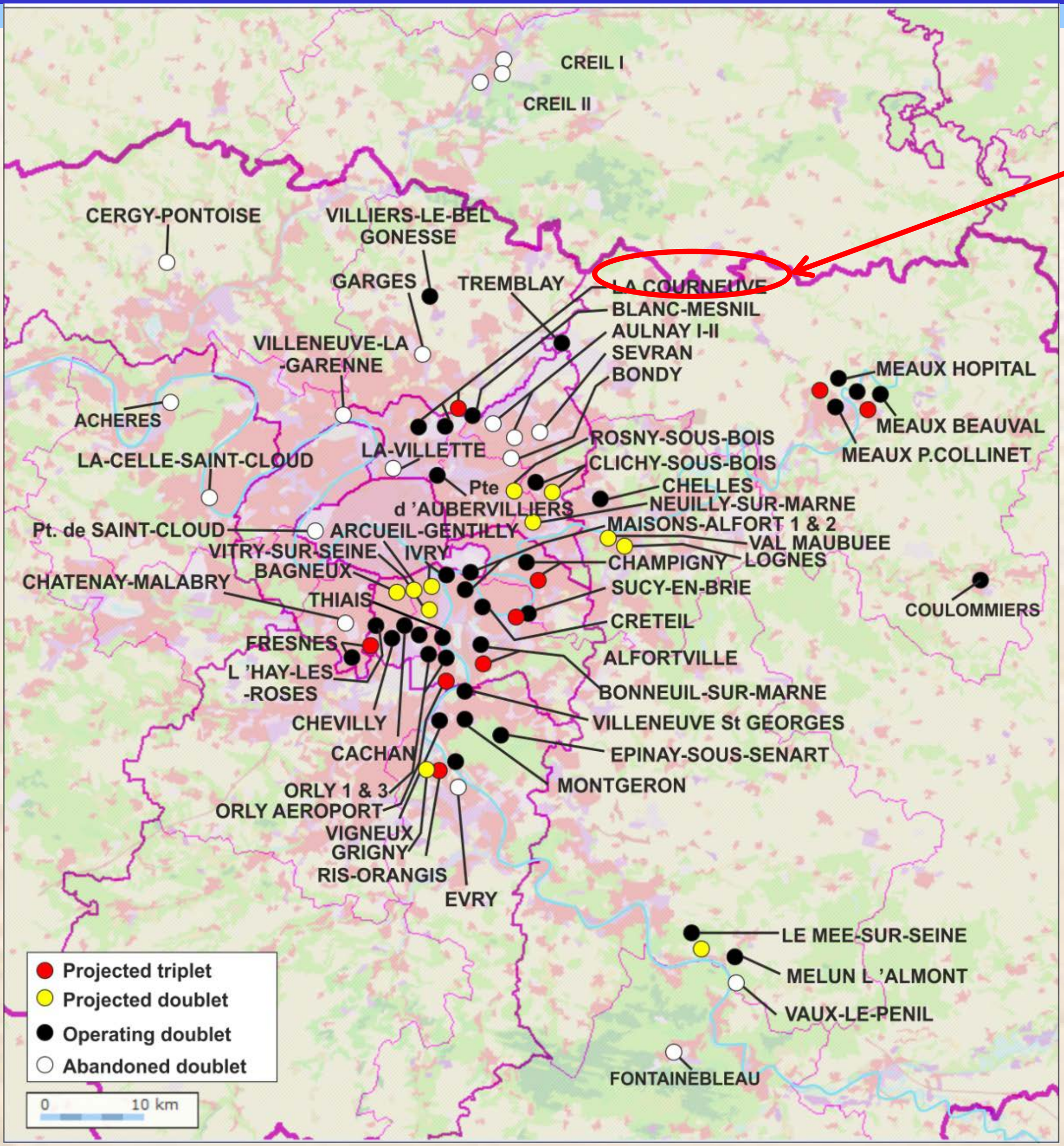
West East Cross Section



Lithostratigraphic column
and target reservoir horizons

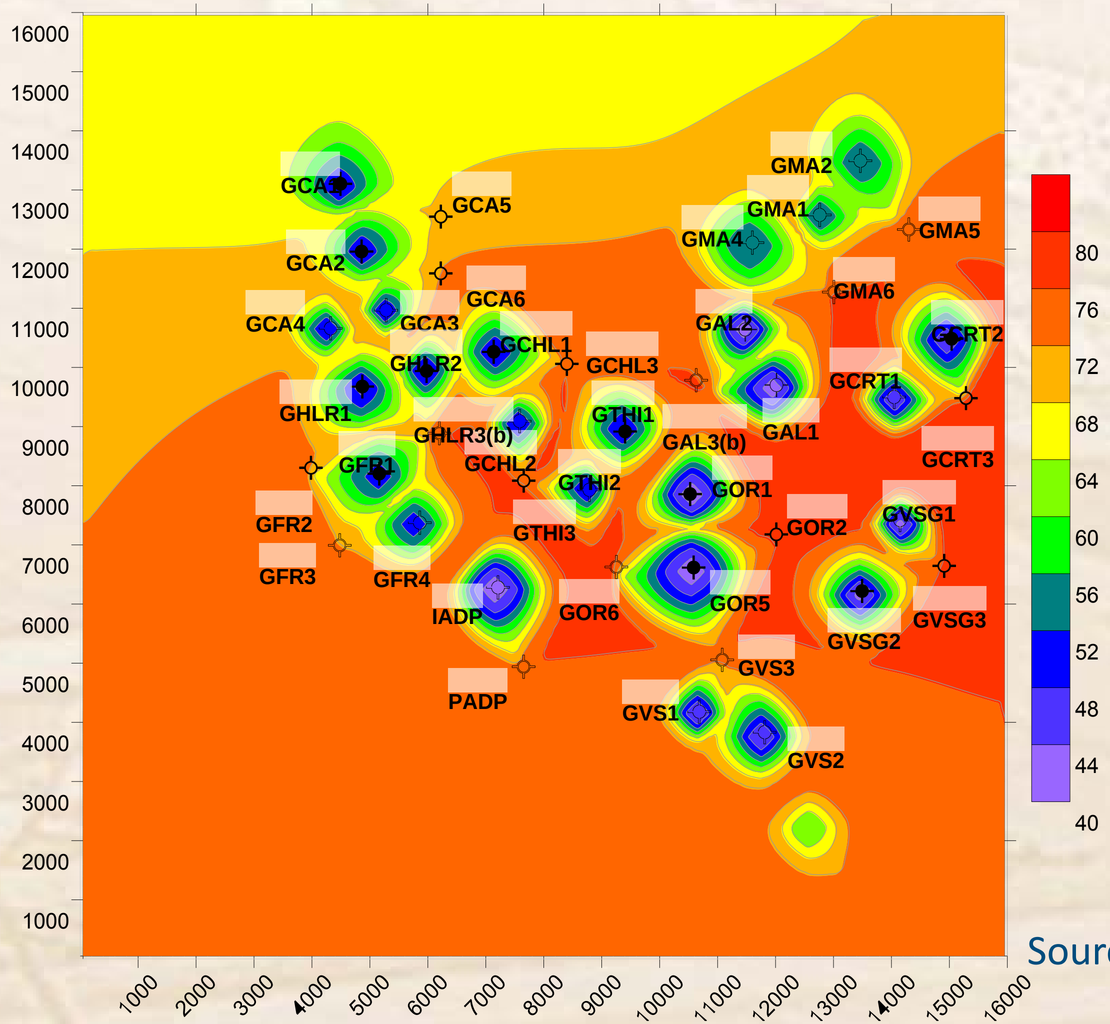


CASE STUDY
PARIS BASIN GDH STATUS (@ JAN. 2012)



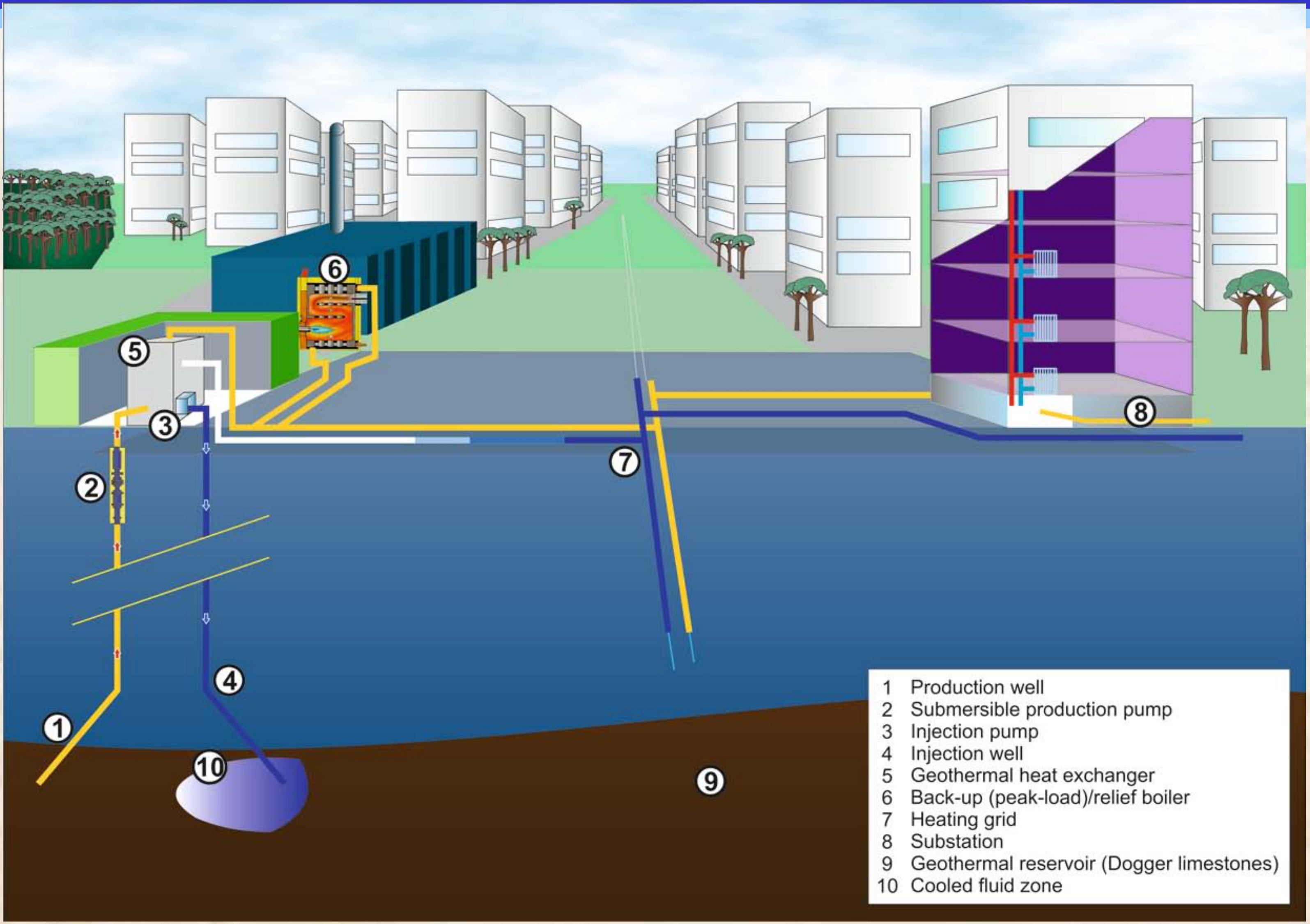
CASE STUDY

PARIS BASIN GDH EXPLOTATION STATUS (PARIS SOUTH)

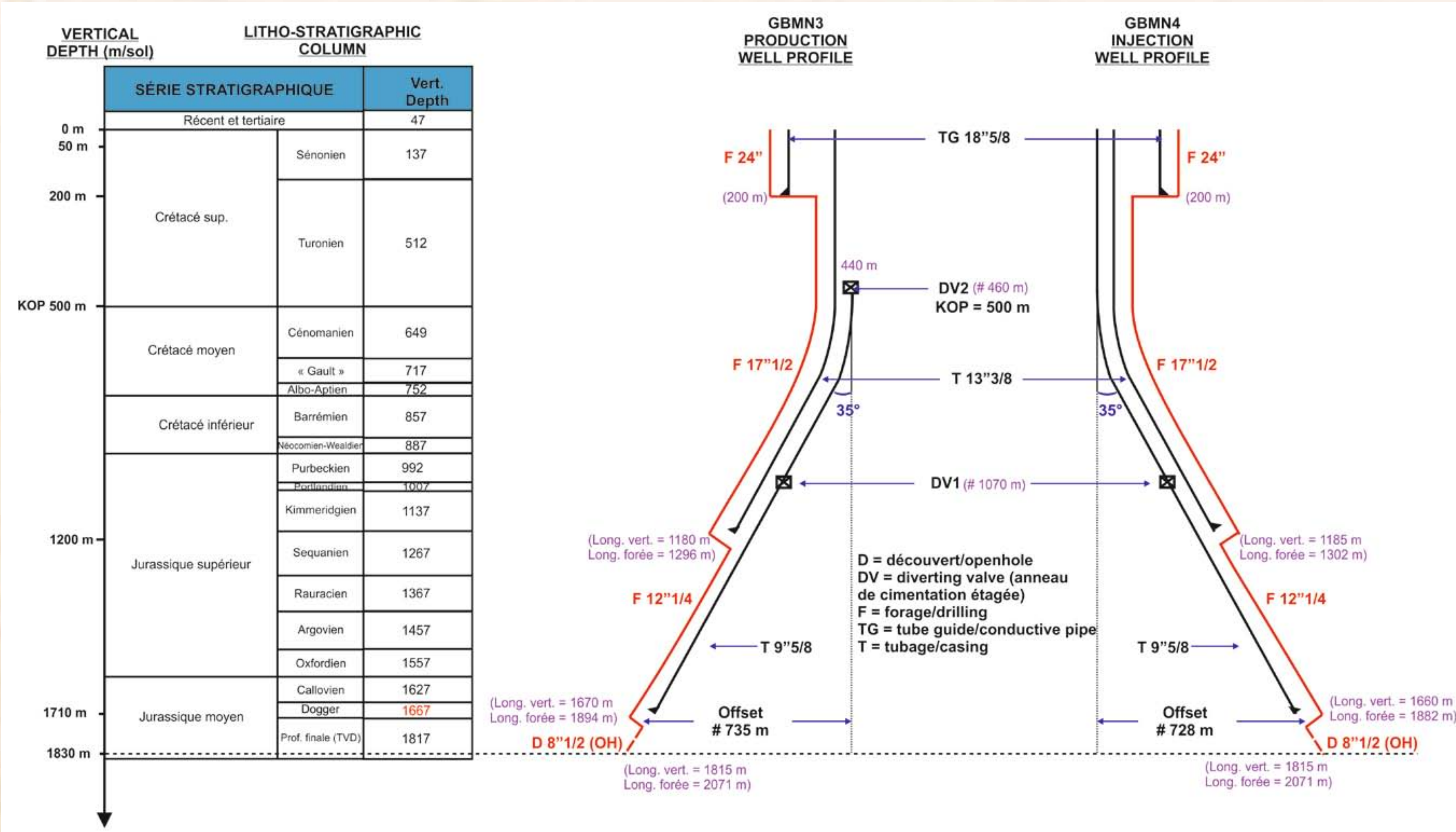


Source : Maria Papachristou

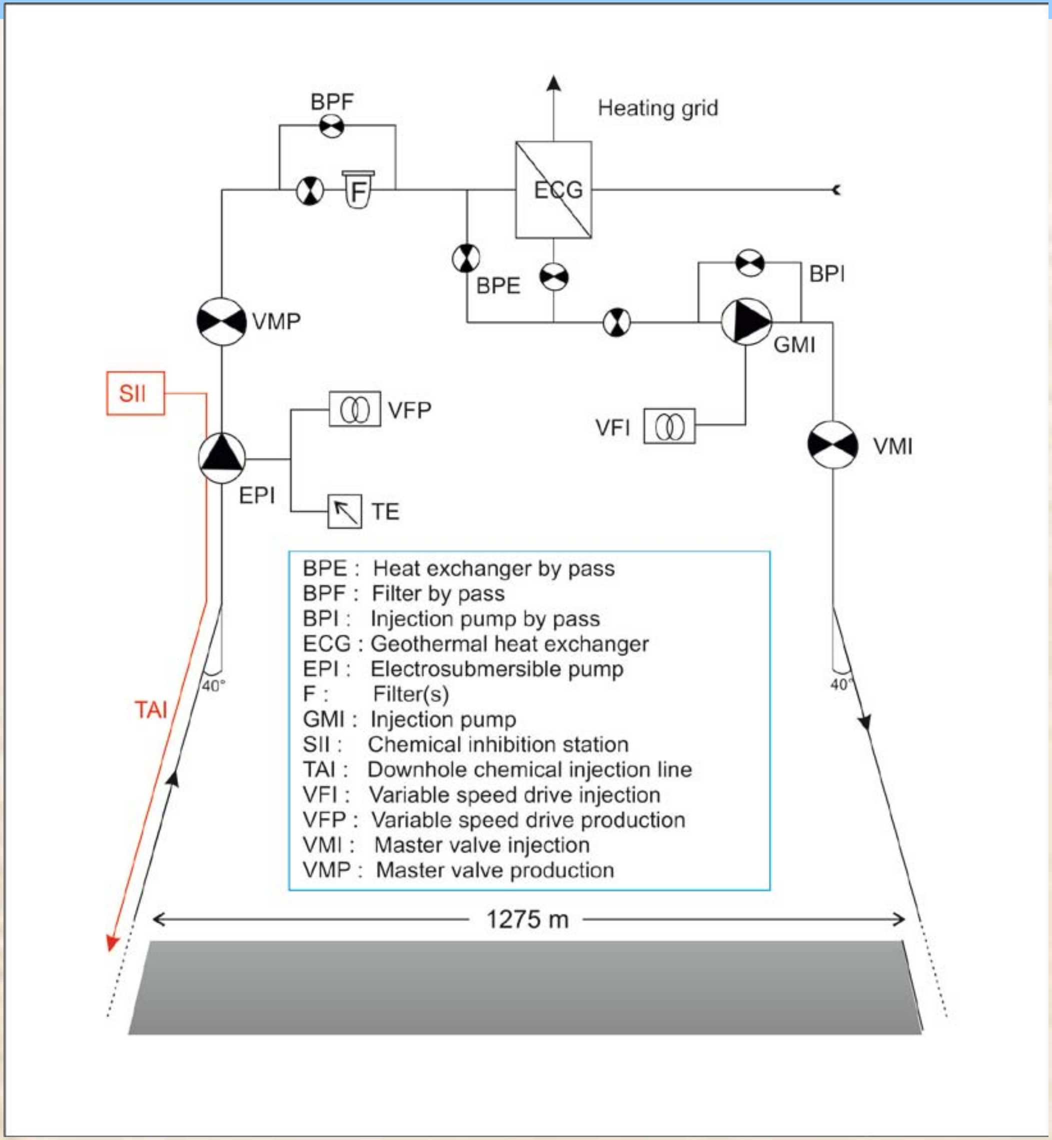
CASE STUDY
PARIS BASIN GDH SCHEME



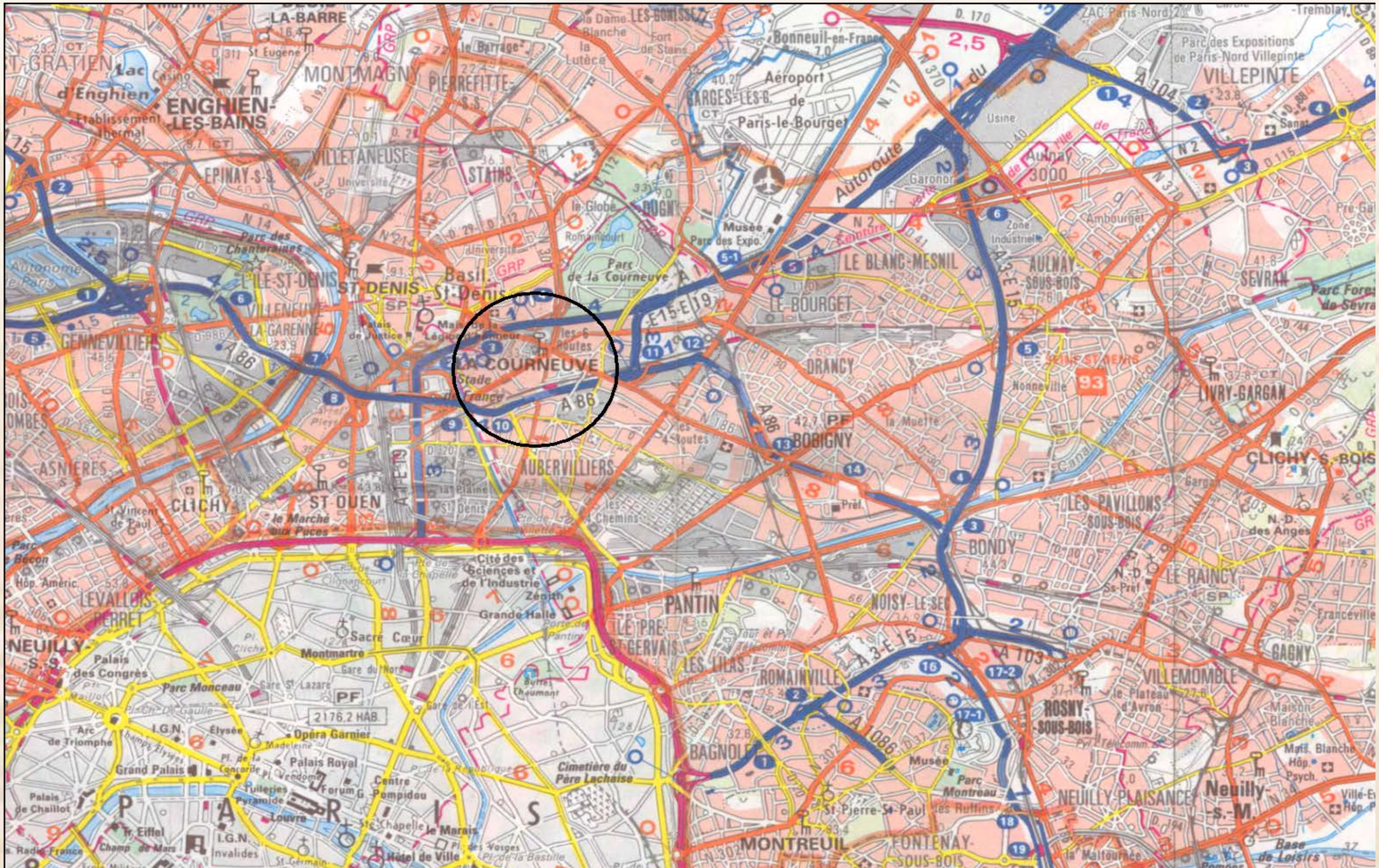
CASE STUDY
TYPICAL GDH WELL ARCHITECTURES



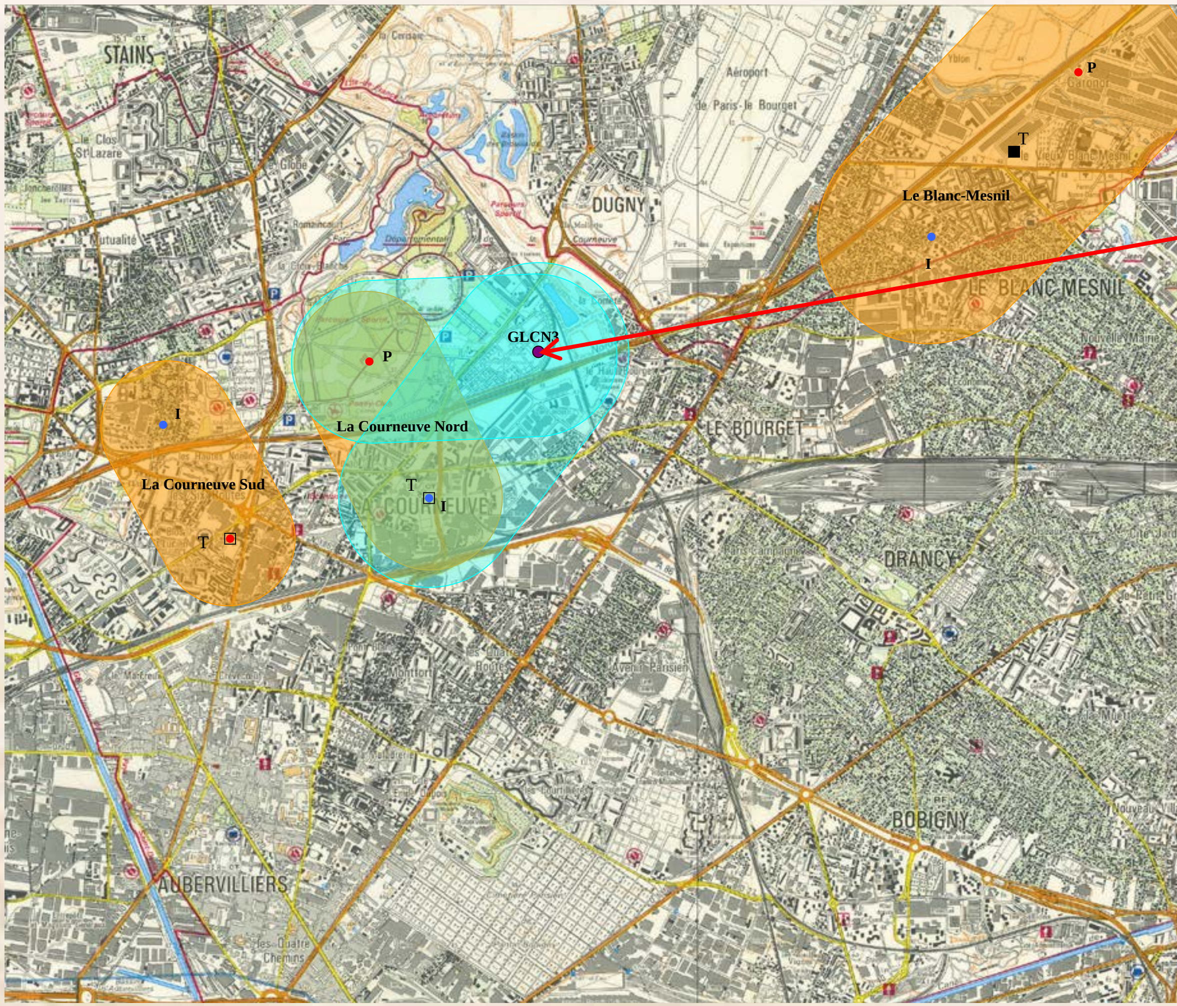
CASE STUDY
GEOTHERMAL LOOP DESIGN



CASE STUDY GLCN3 WELL LOCATION MAP



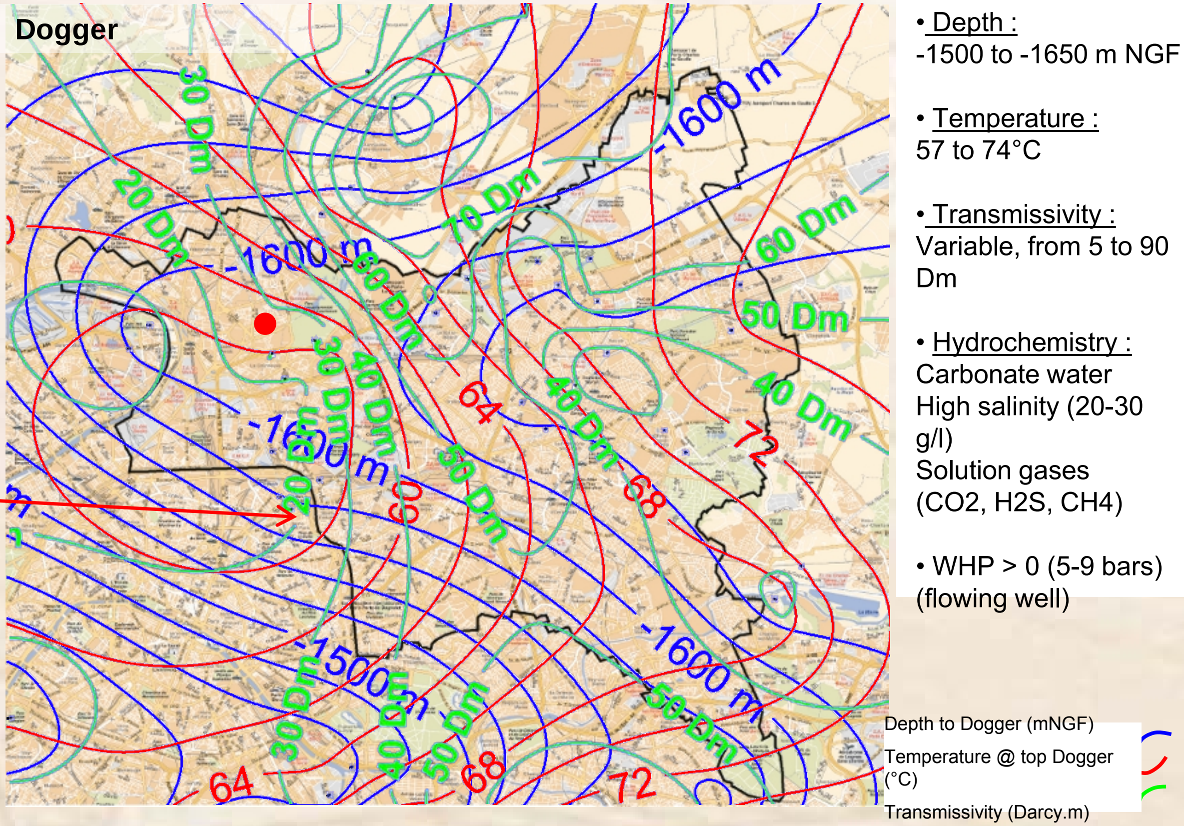
EXPLORATION/EXPLOITATIONPERIMETERS OF EXISTING AND FUTURE (TRIPLET/DOUBLET) GDH SYSTEMS



NEW TRIPLET PRODUCTION WELL

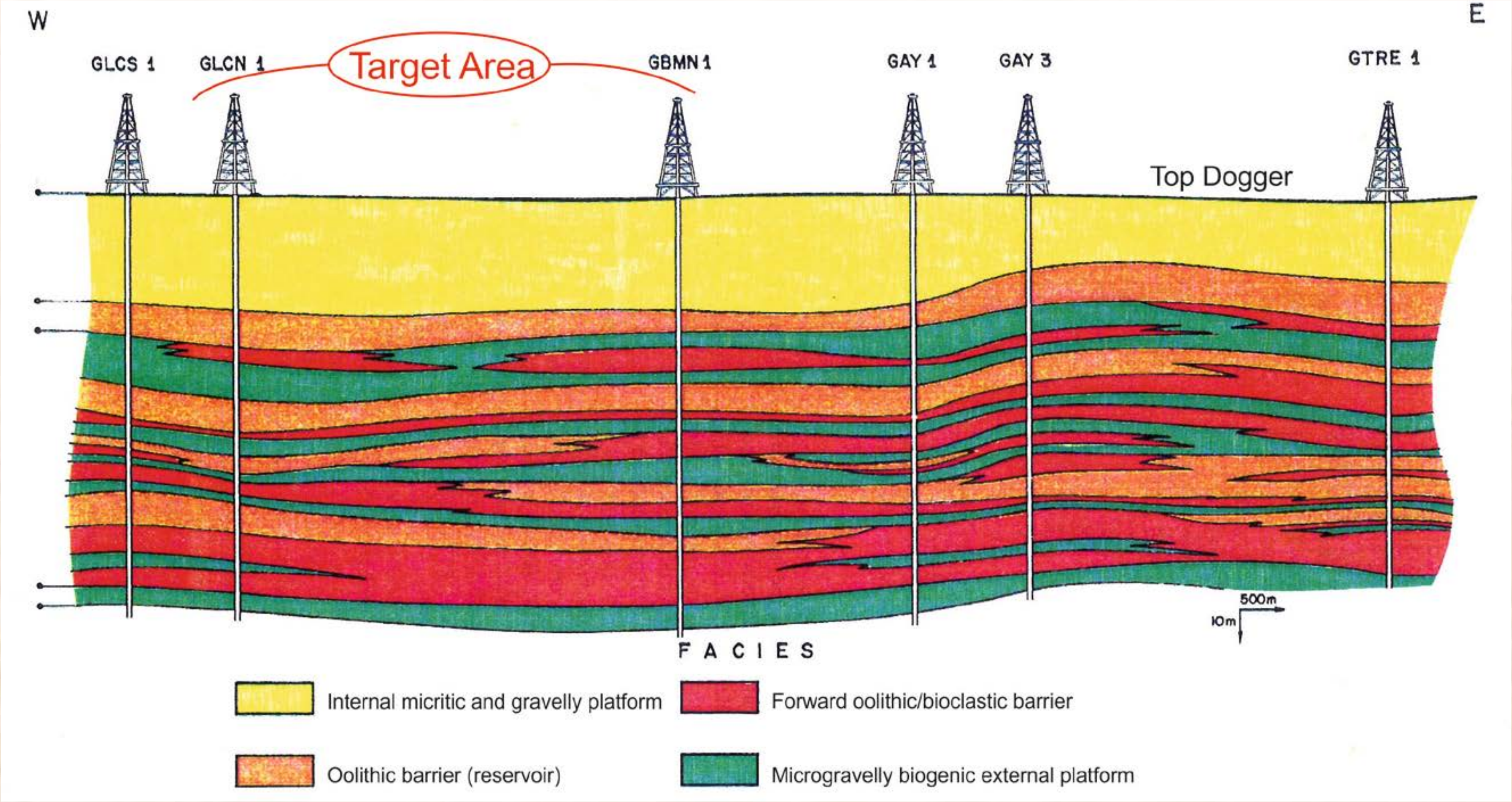
CASE STUDY GLCN3
DOGGER RESERVOIR CHARACTERISTICS. PARIS NORTH

GLCN 3

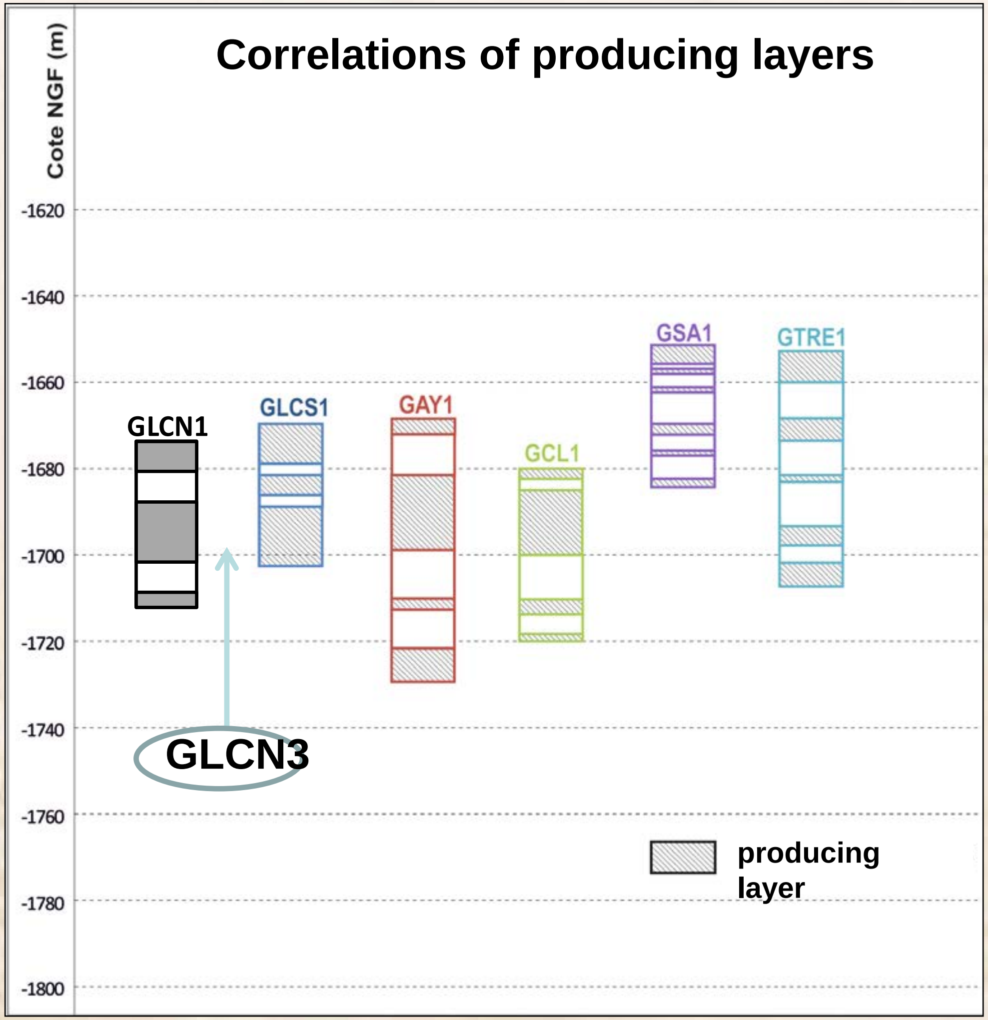


- Depth : -1500 to -1650 m NGF
- Temperature : 57 to 74°C
- Transmissivity : Variable, from 5 to 90 Dm
- Hydrochemistry : Carbonate water High salinity (20-30 g/l) Solution gases (CO_2, H_2S, CH_4)
- WHP > 0 (5-9 bars) (flowing well)

CASE STUDY GLCN3
RESERVOIR ASSESSMENT TENTATIVE FACIES CORRELATIONS. PARIS NORTH

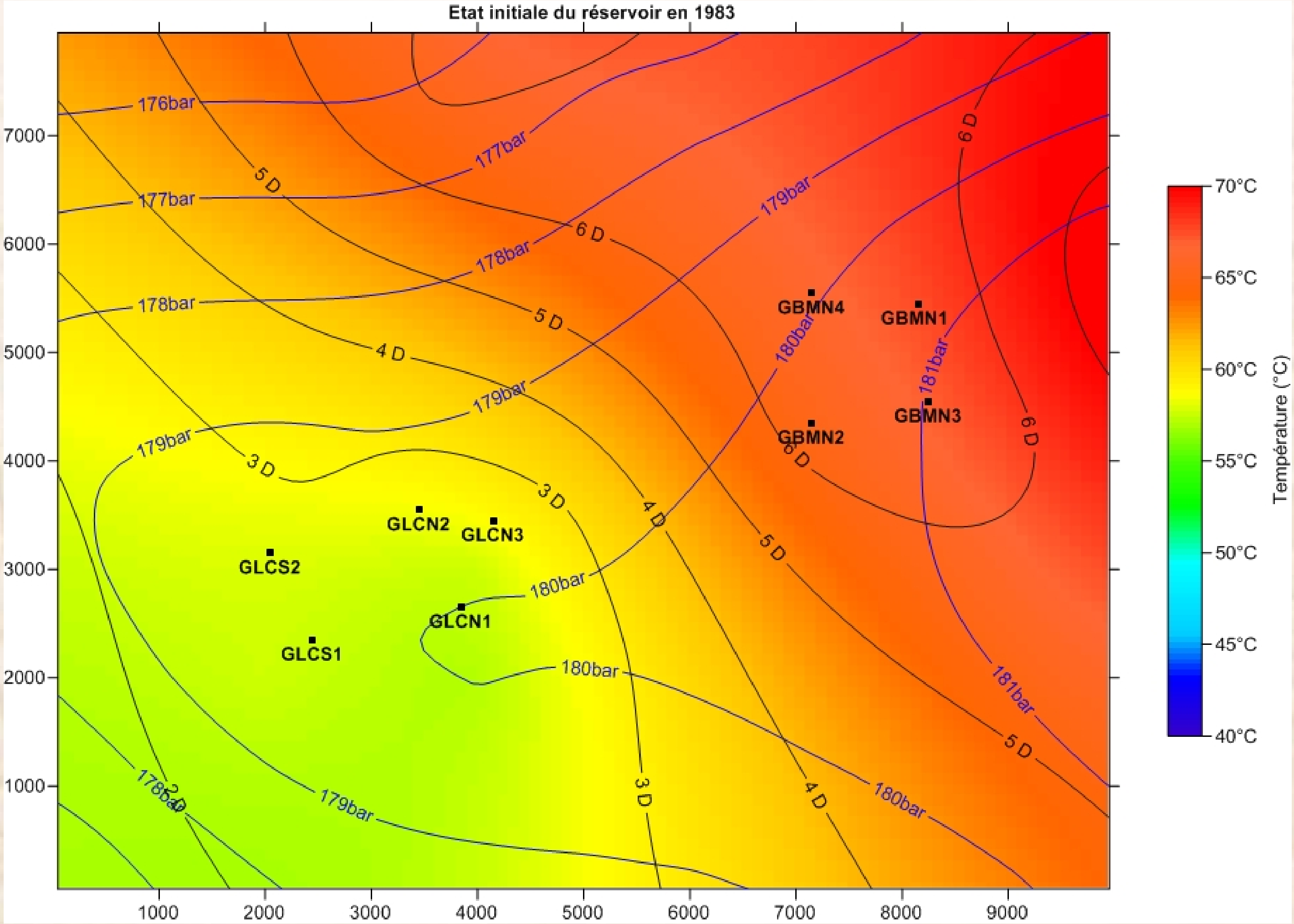


CASE STUDY GLCN3
RESERVOIR ASSESSMENT CORRELATION OF PRODUCING LAYERS

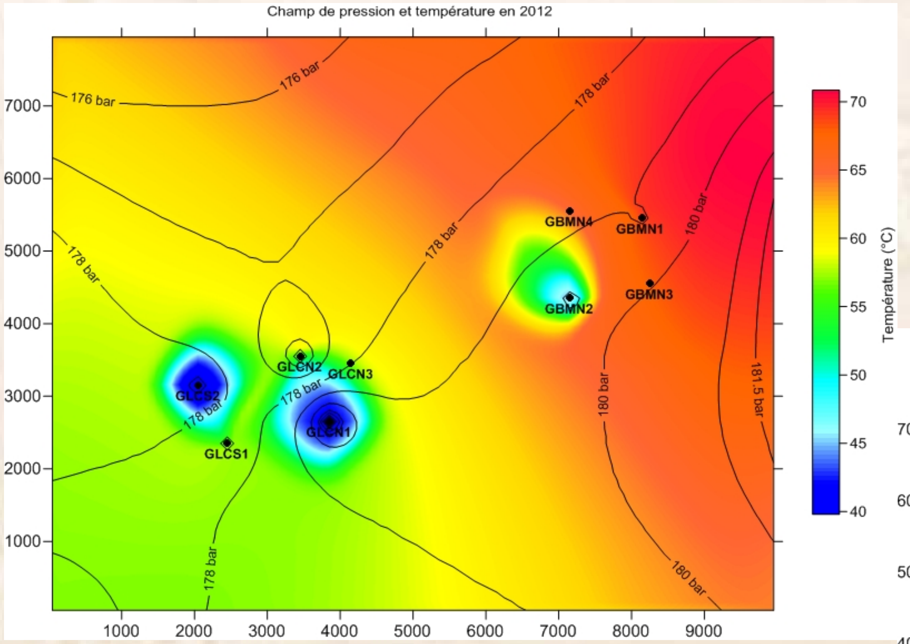


CASE STUDY GLCN3. RESERVOIR SIMULATION
INITIAL PRESSURE, TEMPERATURE & PERMEABILITY STATE

(@ YEAR 1982)

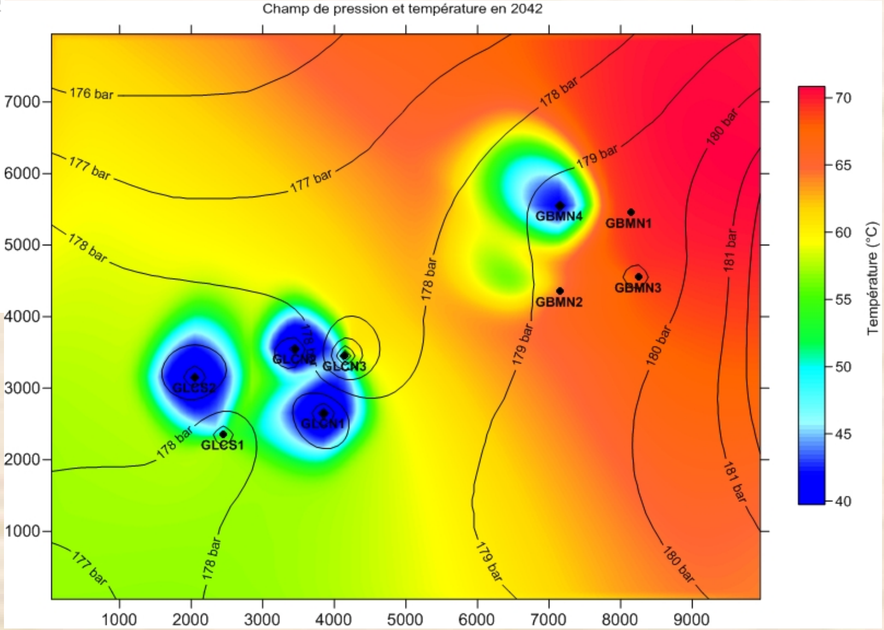


CASE STUDY GLCN3
RESERVOIR SIMULATION. BHP & BHT FIELDS (1982-2042)



2012

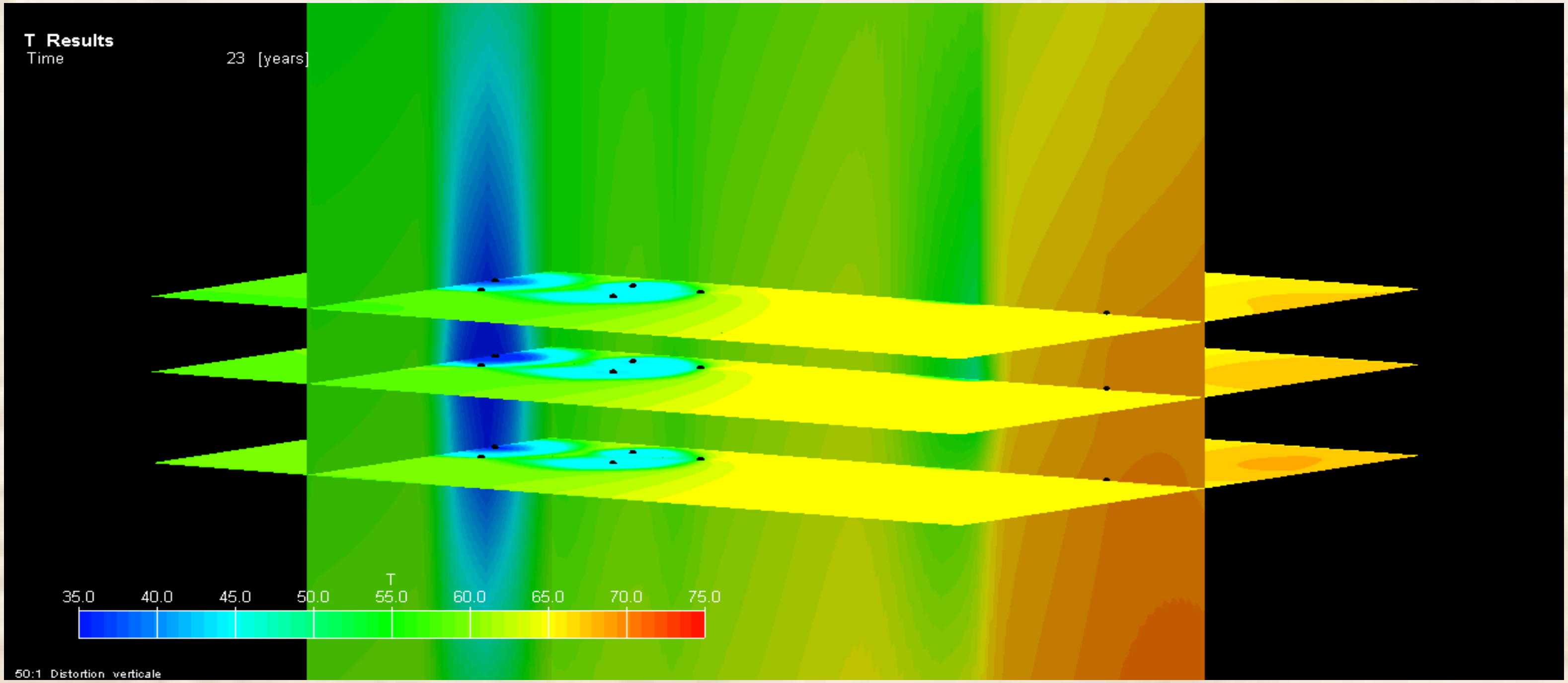
2042



CASE STUDY
RESERVOIR SIMULATION

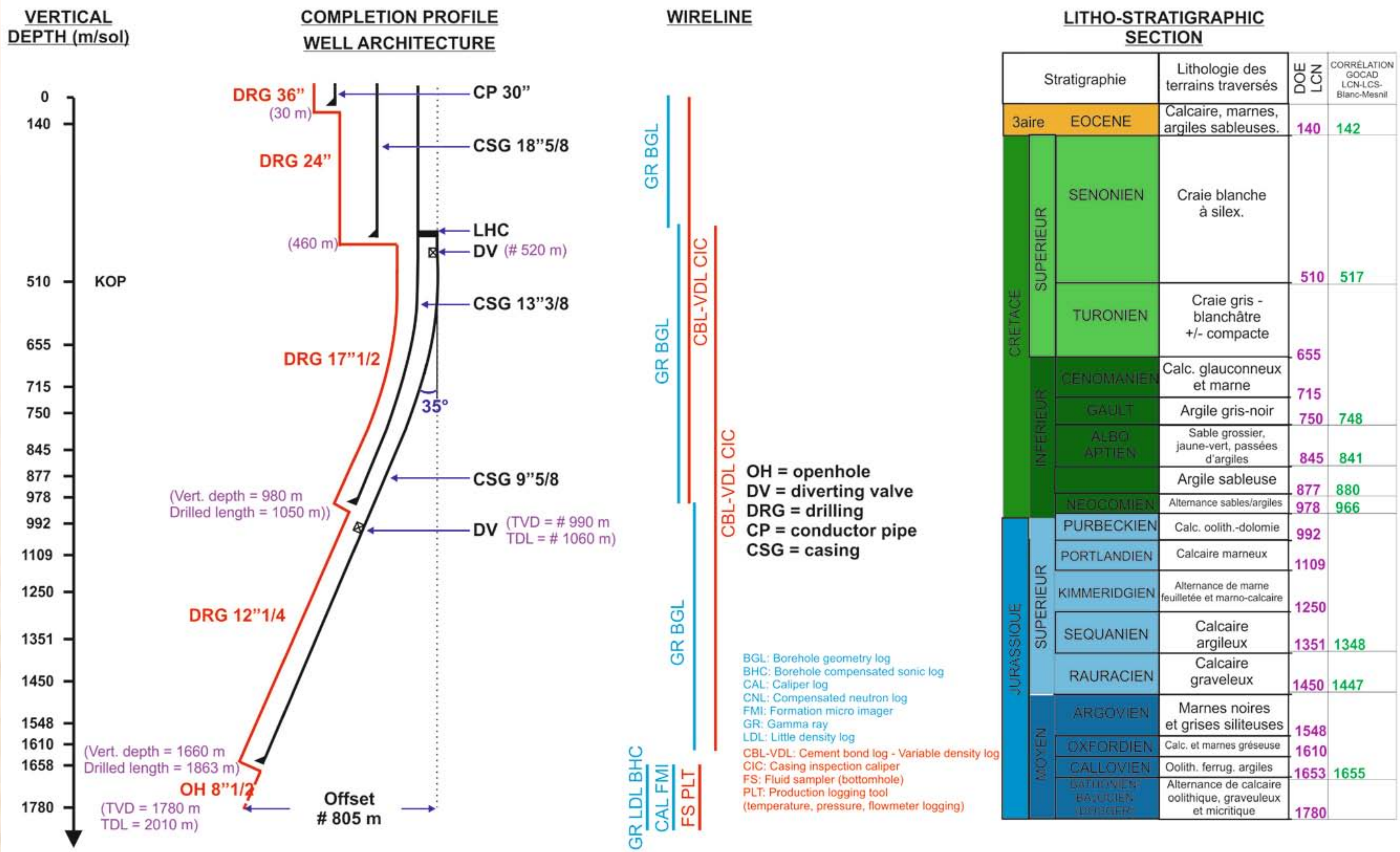
3D display of cooling kinetics (year 2035)
(280 m^3/hr)

Qnom = 280 m3/h



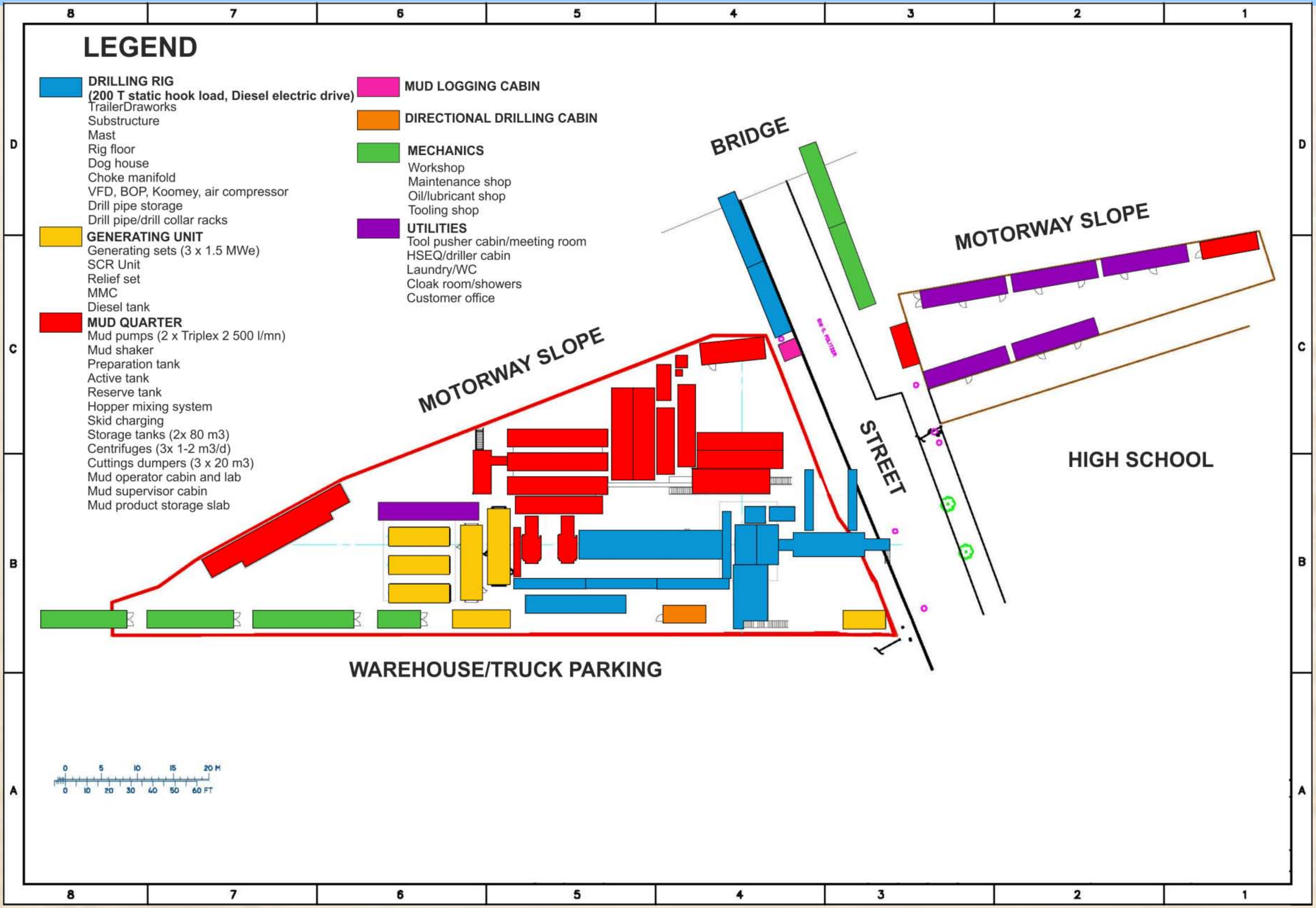
CASE STUDY
AEREAL VIEW OF GLCN3 DRILL SITE

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						REMARKS
Diameter (")	Drilled interv (mbgl)	Diameter (")	Depths (mbgl) and lengths (m) drilled	Range	Material/grade	Unit weight (lbs/ft)	Thread	
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						
⦰ 24- 0-460	1.15	60-80		25-30	3/15	BBS[3]
⦰ 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
⦰ 12 1/4 655-1880	"	"	"	"	"	"
⦰ 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						
⦰ 24 0-460	1.15	60-80		25-30	3/15	BBS[3]
⦰ 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
⦰ 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 rhéology

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

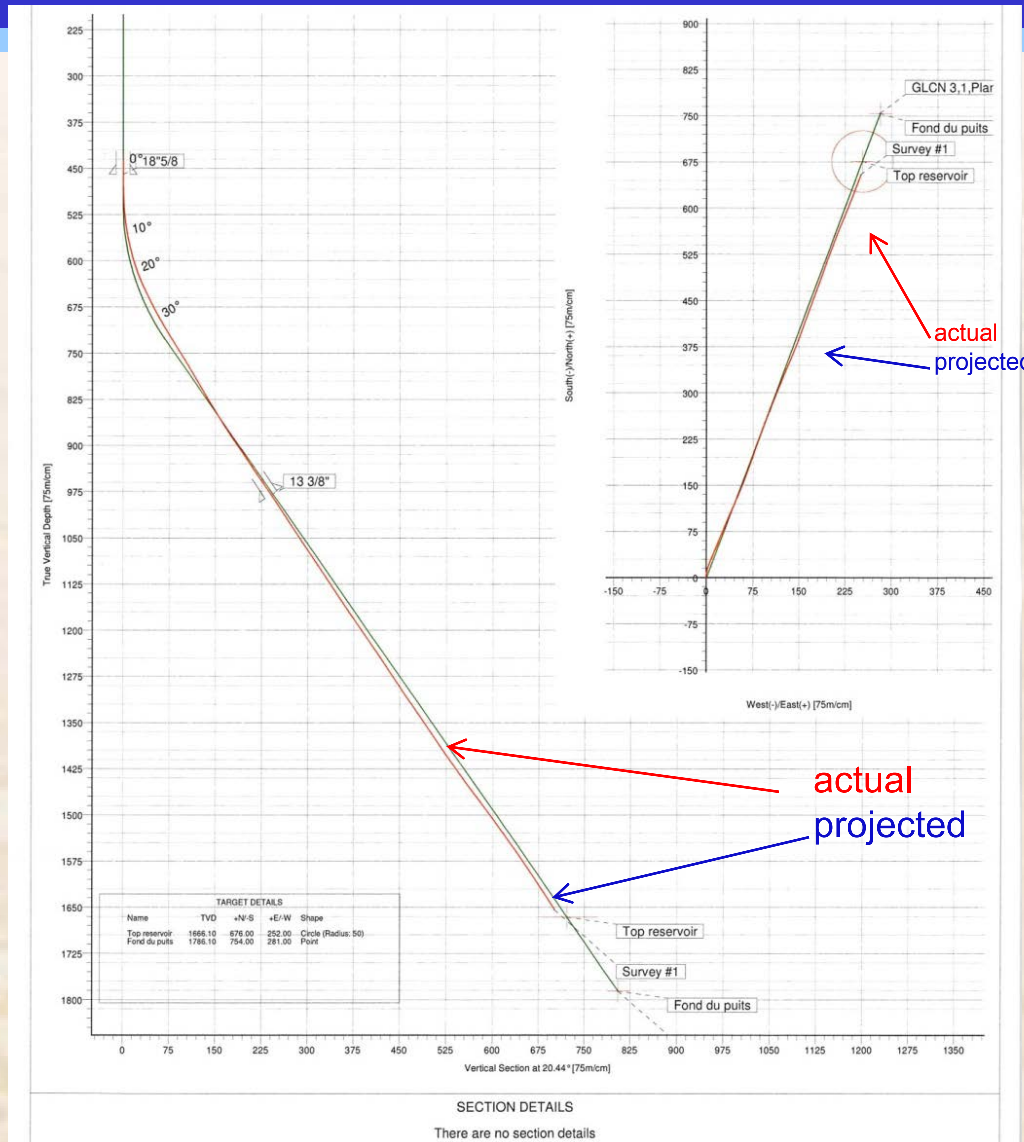
CASE STUDY
WIRELINE LOGGING PROGRAMME

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

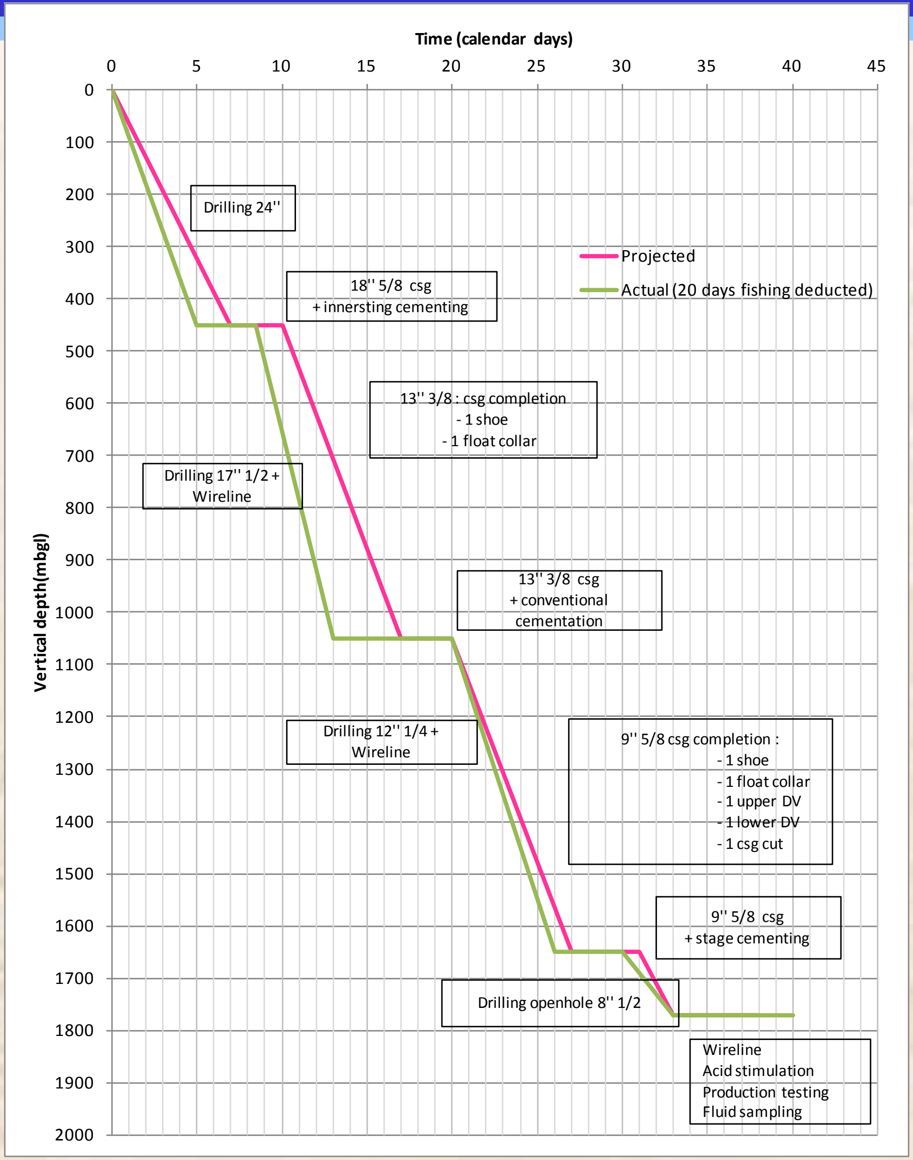
GR	= Gamma Ray	CAL	= Caliper (OH)	FS	= Fluid Sampler
BGL	= Borehole Geometry Log	LDL	= Lithodensity Log	PLT	= Production Logging Tools (flowmeter, pressure/temperature gauges)
CBL-VDL	= Cement Bond Log - Variable Density Log	BHC	= Borehole Compensated (Sonic)		
CIC	= Casing Inspection Caliper	FMI	= Formation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

CASE STUDY GLCN3
WELL TRAJECTORIES



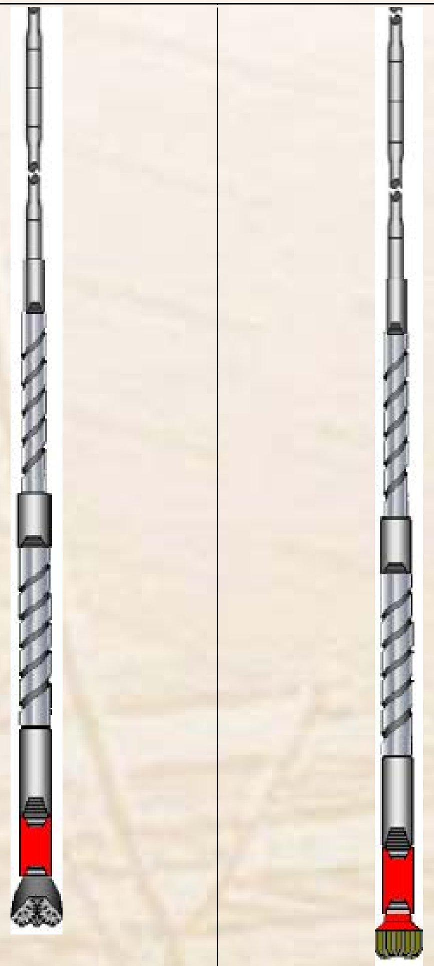
Source : WEATHERFORD

CASE STUDY
PROJECTED VS ACTUAL DRILLING TIME CHART



CASE STUDY GLCN3
DIRECTIONAL DRILLING BHAs

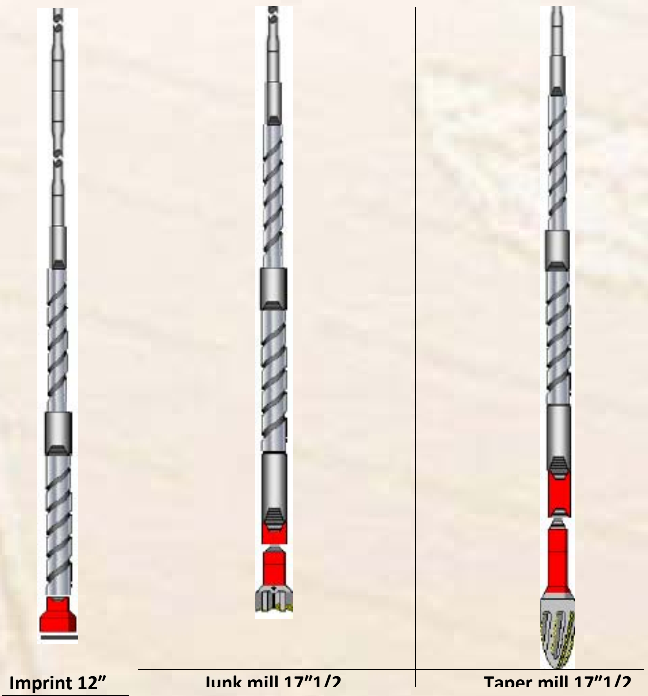
DIRECTIONAL DRILLING BHAs



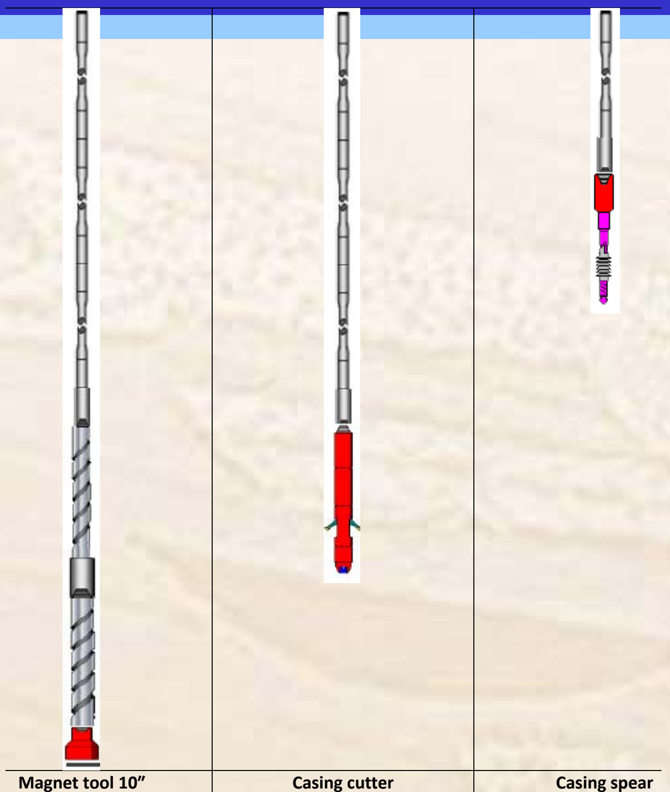
Directional drilling (drill bit 17"1/2) | Directional drilling (PDC bit 12"1/4)

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

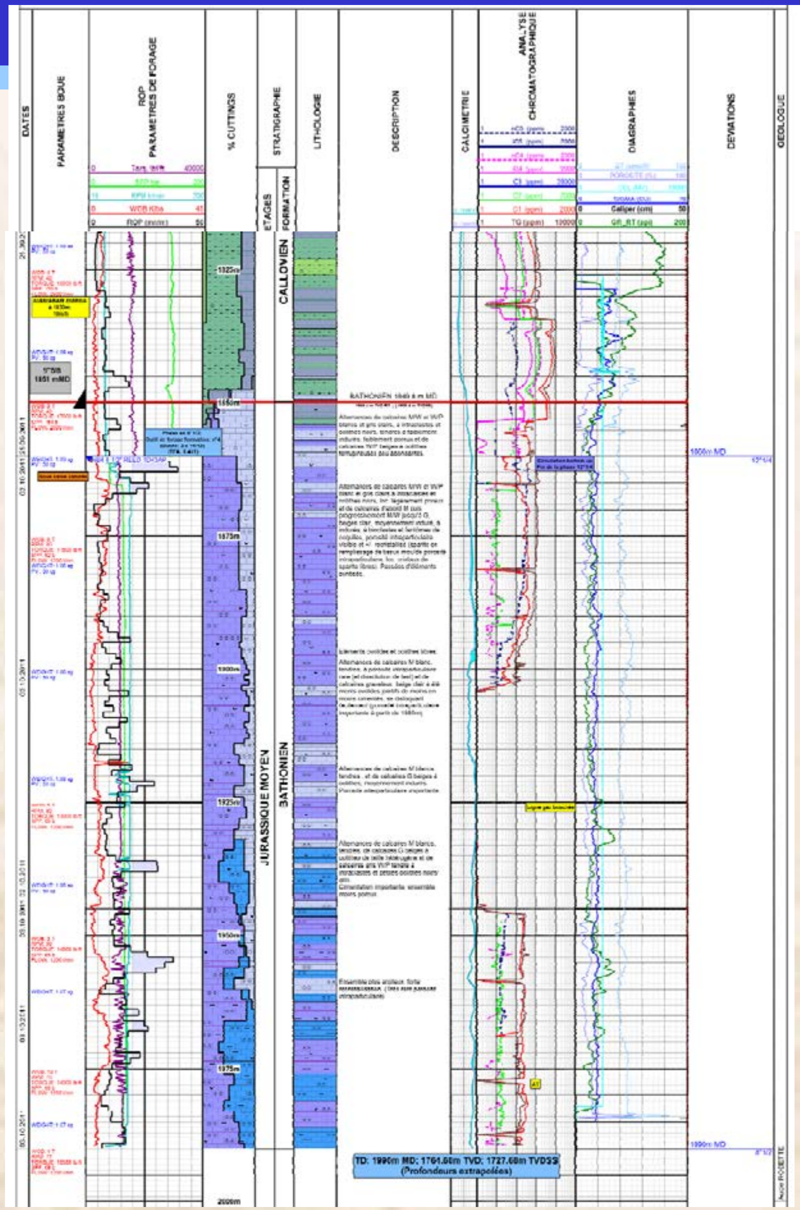


Imprint 12”	Junk mill 17”1/2	Taper mill 17”1/2
Imprint 12”	Junk mill 17”1/2	Taper mill 17”1/2
2 x DC 6”3/4	2 x DC 8 ”1/4	1 x DC 8 ”1/4
4 x HWDP 5”	9 x DC 6”3/4	Stabilyzer
Hydraulic jar	4 x HWDP 5”	1 x DC 8 ”1/4
9 x HWDP 5”	Hydraulic jar	2 x DC 6”3/4
DP 5”	9 x HWDP 5”	4 x HWDP 5”
	DP 5”	Hydraulic jar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

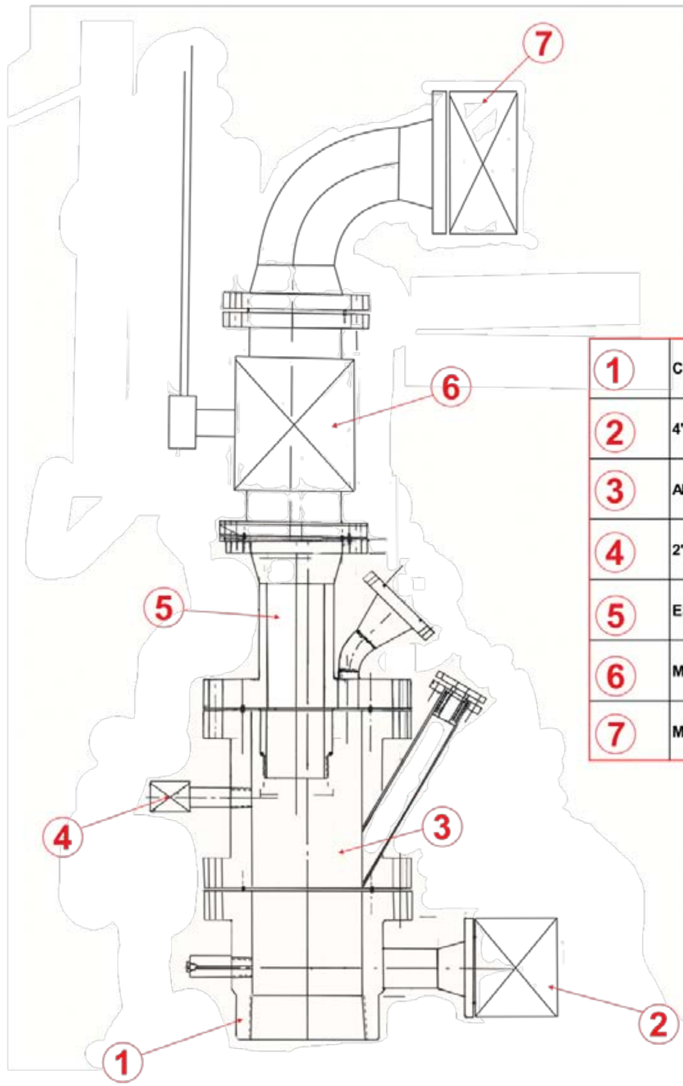


Magnet tool 10”	Casing cutter	Casing spear
Magnet tool 10”	Casing cutter	Casing spear
1 x DC 8 ”1/4	4 x HWDP 5”	DP 5”
Stabilyzer	Hydraulic jar	
1 x DC 8 ”1/4	9 x HWDP 5”	
2 x DC 6”3/4	DP 5”	
4 x HWDP 5”		
Hydraulic jar		
9 x HWDP 5”		
DP 5”		

CASE STUDY GLCN3
MUD LOGGING: WELL COMPOSITE LOG OF RESERVOIR SECTION



CASE STUDY GLCN3
PRODUCTION WELL HEAD DESIGN



1	Casing head 13" 5/8
2	4" wing valve
3	AIT* suspension spool
4	2" wing valve
5	ESP* tubing suspension spool
6	Master valve (hand remote control)
7	Motorised butterfly control valve

*AIT = Auxiliary Injection Tubing (downhole chemical injection line)
*ESP = Electro submersible pump

(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**

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

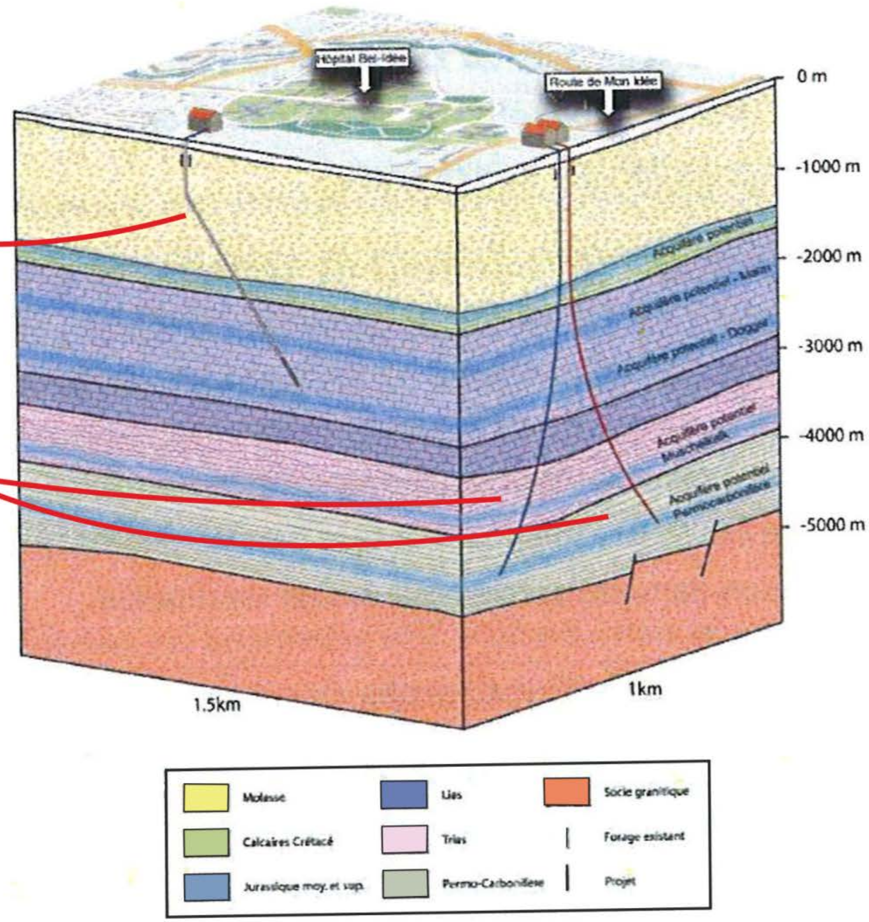
OUTLINE

- 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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

Medium enthalpy CHP EXPLO

Existing well

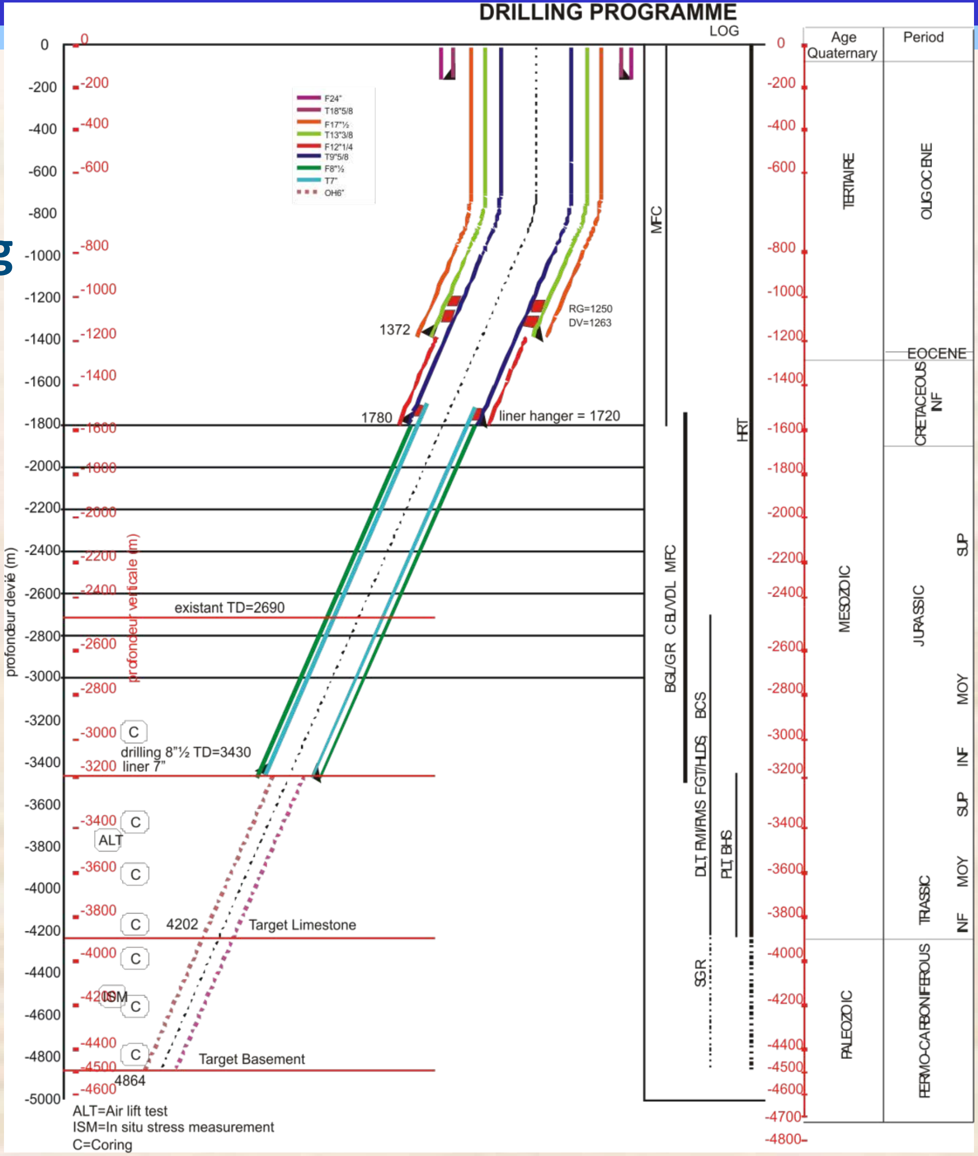
Projected (GDH/CHP) project



Courtesy : SIG. Geneva.

DEEP (4-5 km) EXPLORATORY PROJECT DRILLING PROGRAMME

Medium Enthalpy (4-5km) Deep exploratory drilling

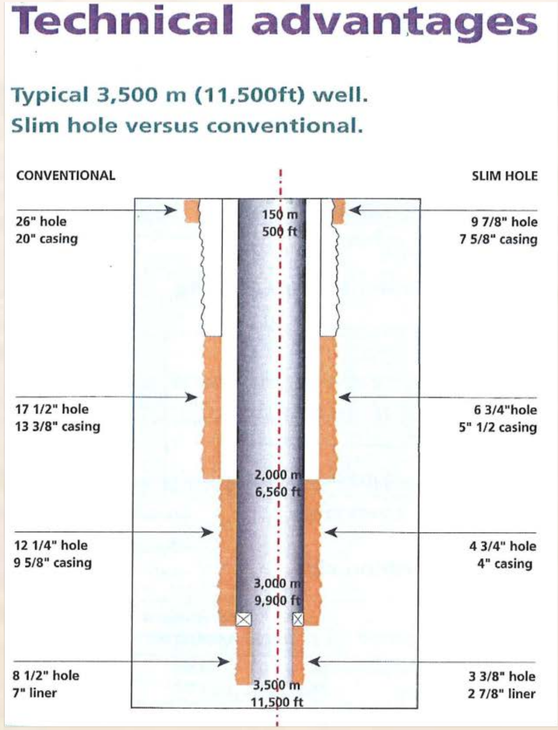


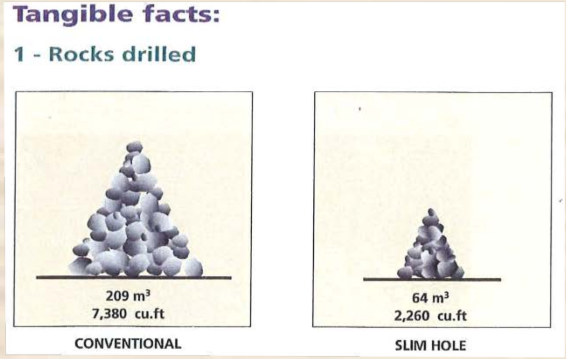
OUTLINE

- 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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

SLIMHOLE STRATEGY

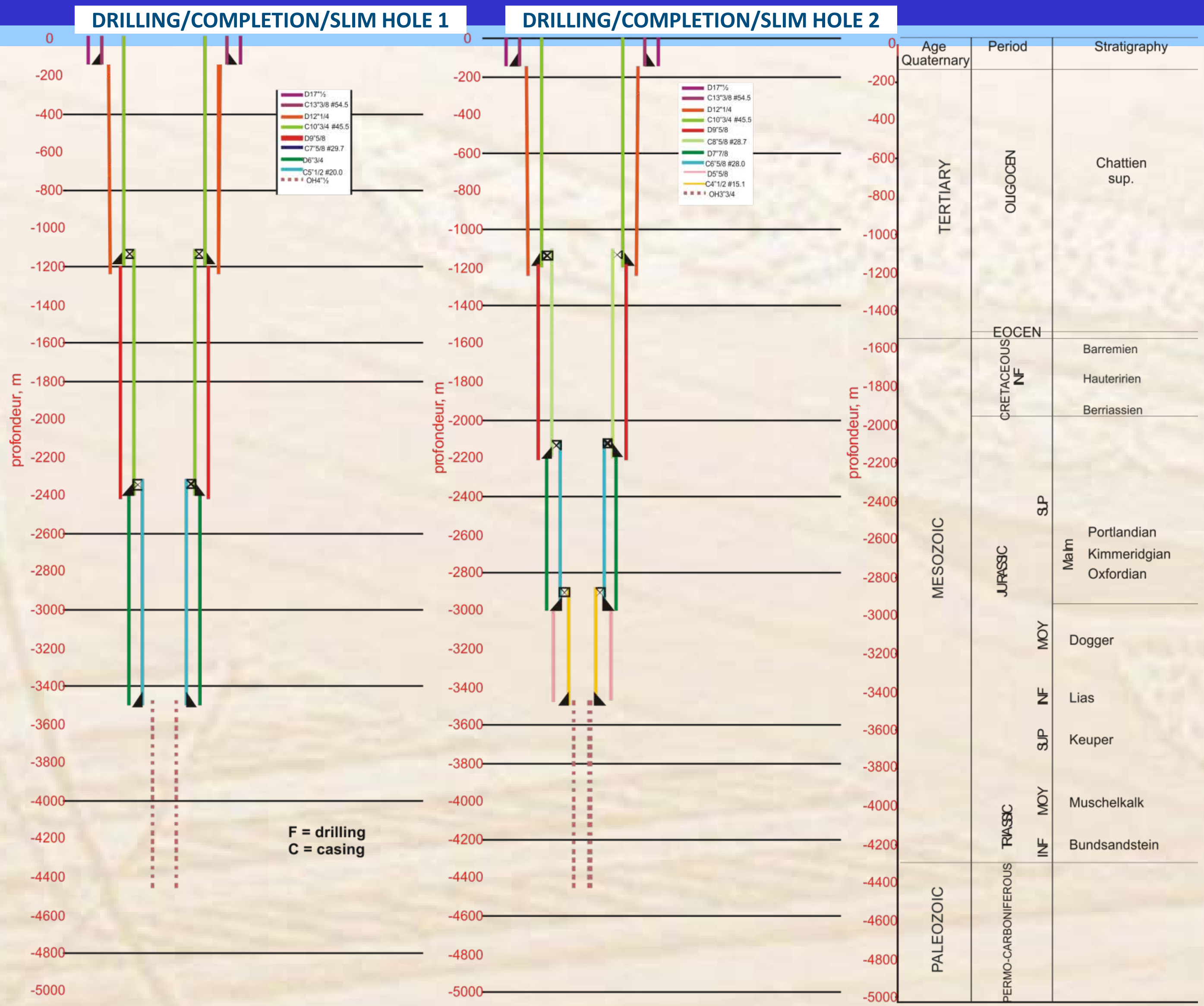
Slimhole vs conventional drilling





SOURCE : FORASOL/FORASLIM

SLIMHOLE OPTIONS



SLIMHOLE CONFIGURATION 1

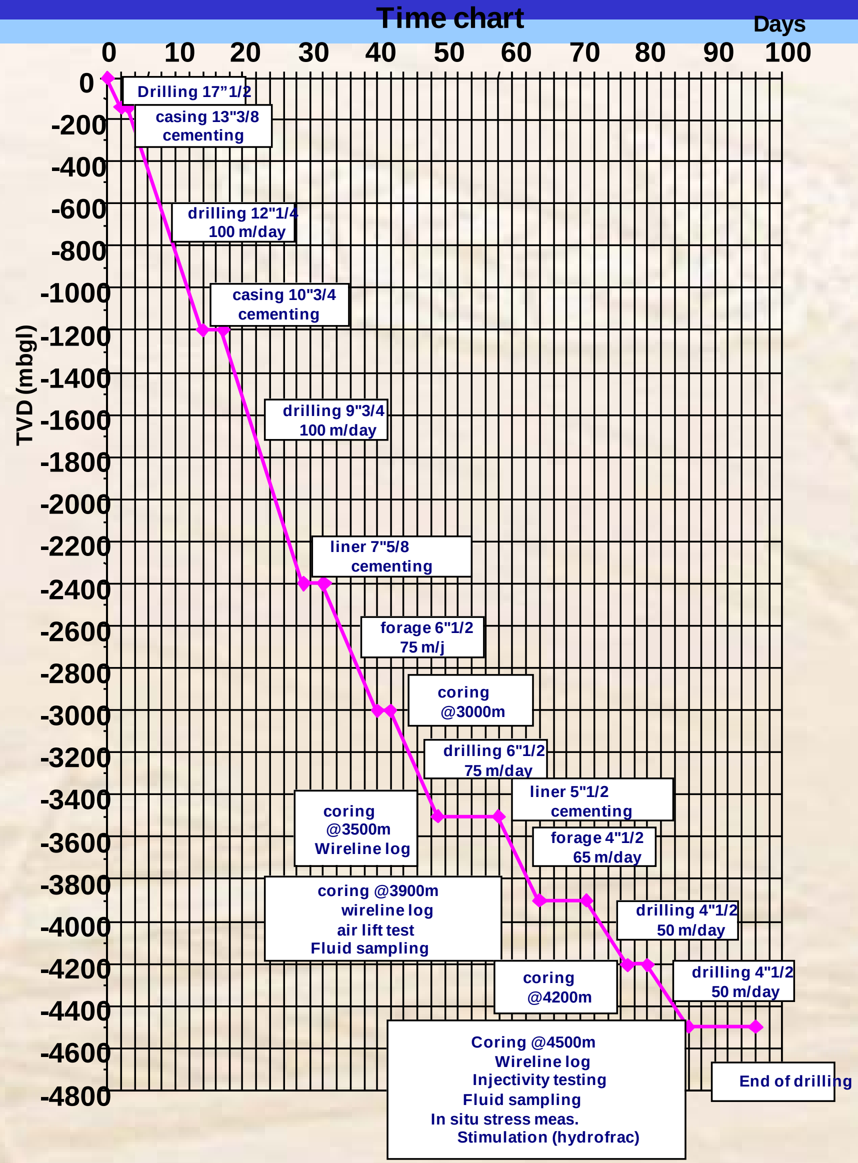
Casing programme

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



SLIMHOLE CONFIGURATION 2

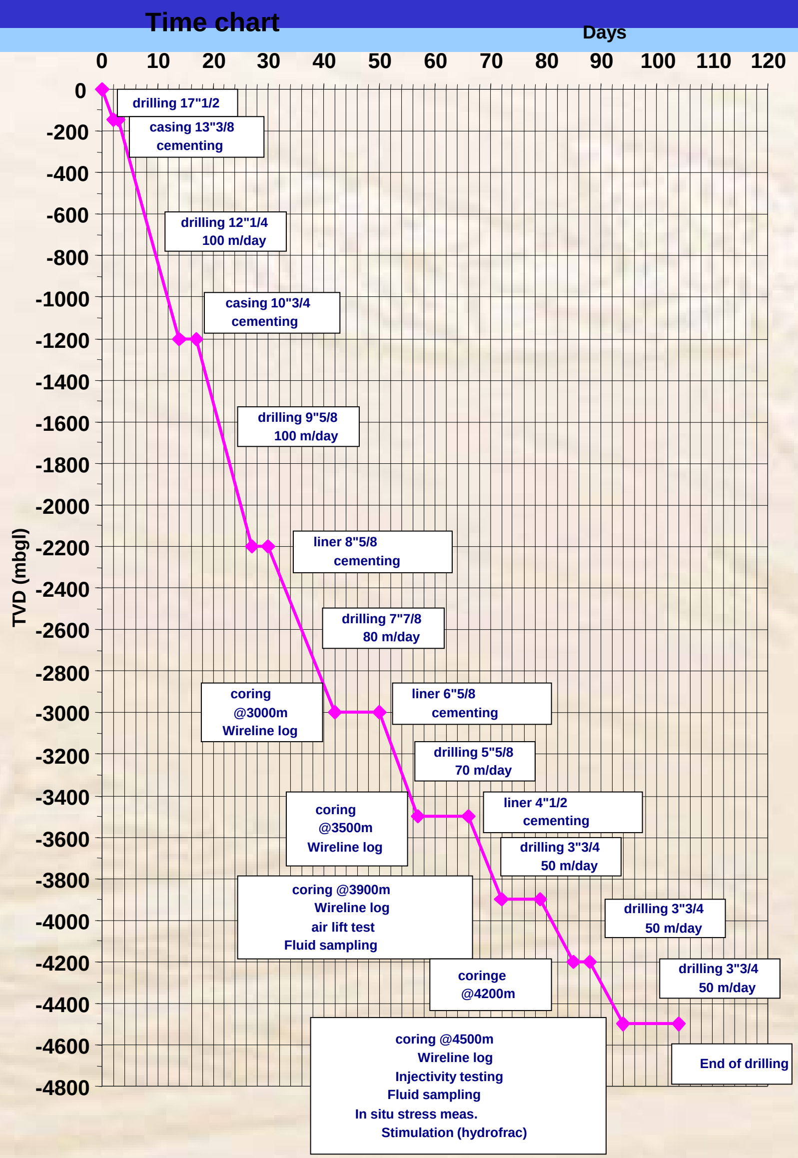
Casing programme

Diameter (OD)"	13 3/8	10 3/4	8 5/8	6 5/8	4"1/2
Interval (mbgl)	0-146	0-1200	1100-2200	2100-3000	3000-3500
Steel grade	K55	K55	K55	K55	K55
Linear weight (lbs/ft)	54.5	45.5	28.7	28	15.10
Thread	API	BTC	BTC	BTC	
Remark		Float collar @1200 mbgl	Liner hanger (LH) @#2400 mbgl Float valve @#2300 mbgl	Liner hanger (LH) @#2100 mbgl Float valve @#3800 mbgl	Liner hanger (LH) @#2100 mbgl Float valve @#3800 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 2



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
  - Screens
  - Mud solids’control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

OUTLINE

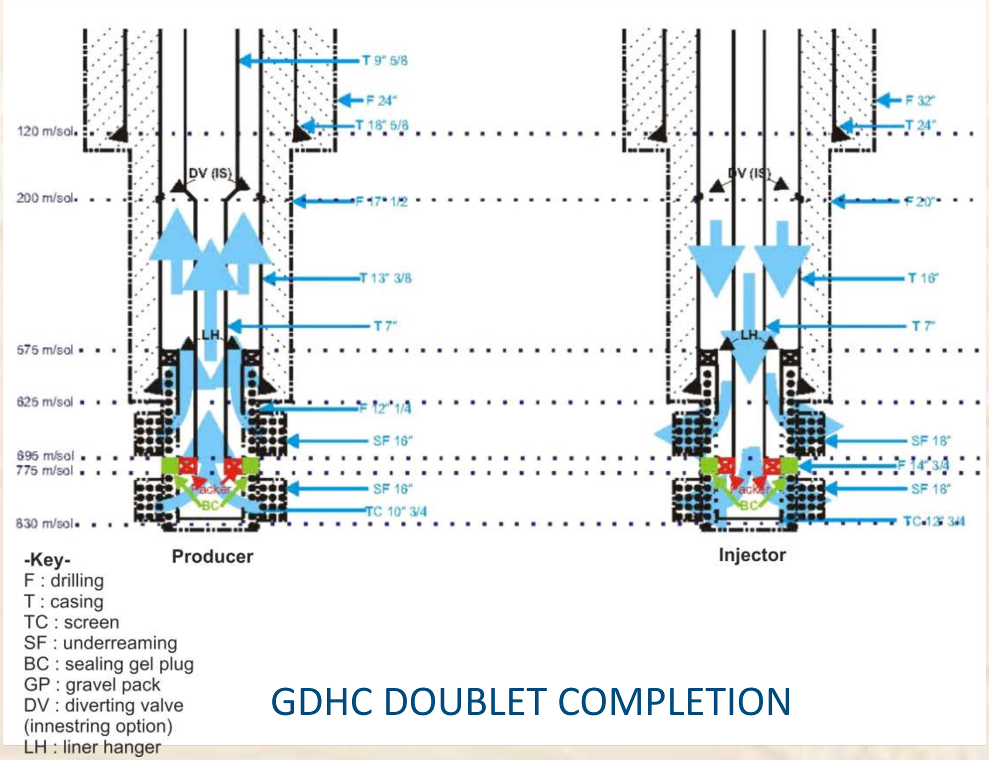
- SCOPE
- INTRODUCTION. GEOTHERMAL VS PETROLEUM
- DEEP WELL DRILLING/COMPLETION FEATURES
  - Rig selection
  - Site preparation. Rig footprint
  - Drilling
  - Bits
  - Drilling fluids
  - Directional drilling
  - Casing/lining
  - Cementing
  - Fishing
  - Waste disposal/processing
- CASE STUDY. PARIS 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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

DUAL COMPLETIONS
GEOTHERMAL DISTRICT HEATING & COOLING (GDHC)

Medium depth seated reservoirs

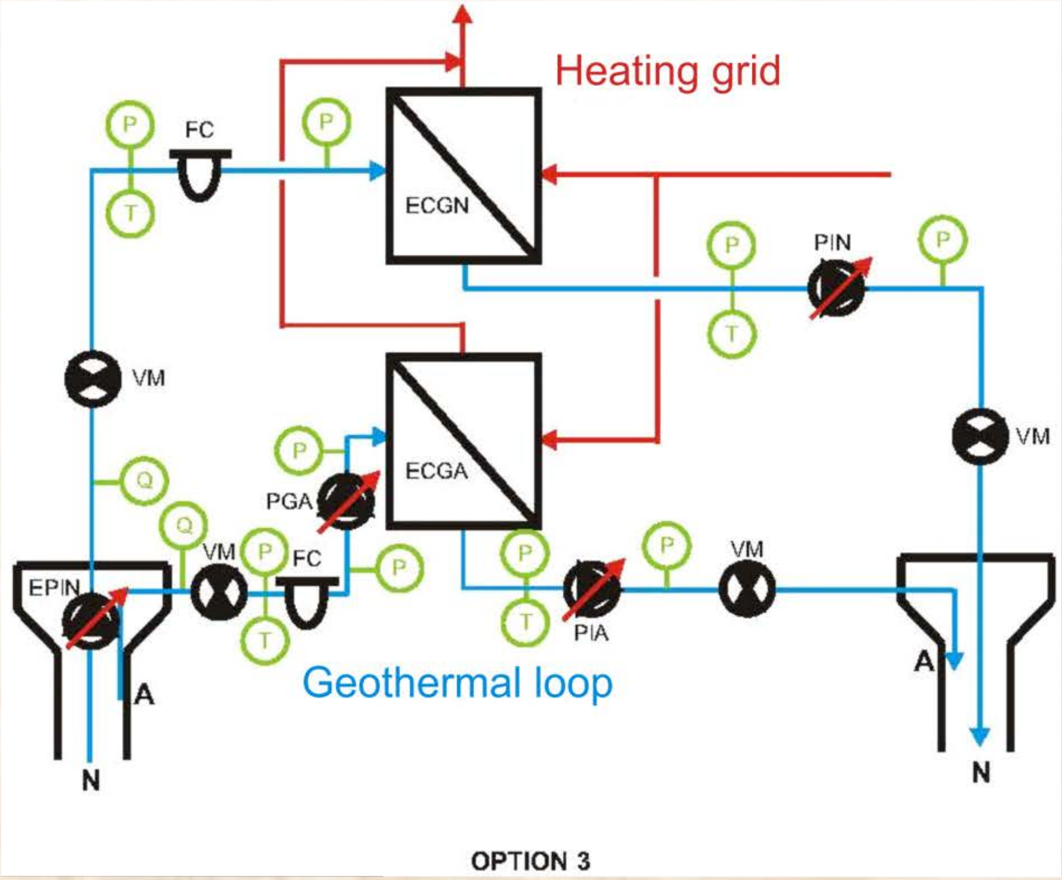
Depth			N°	Thickners (m)	Transmissivity (m^2/s)
625	0 – 12,5	Albo-Aptien 1	1	25	$5\ 10^{-3}$
	35	Aquitard	2	20	k_v = 15 mD
695	57,5	Albo-Aptien 2	1	25	$5\ 10^{-3}$
	110	Aquitard (Barremien)	3	80	k_v = 0.1 mD
	157,5	Néocomien 1	4	15	$3{,}5\ 10^{-3}$
775	175	Aquitard	5	20	k_v = 5 mD
825	192,5 – 200	Néocomien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

AQUIFER SYSTEM



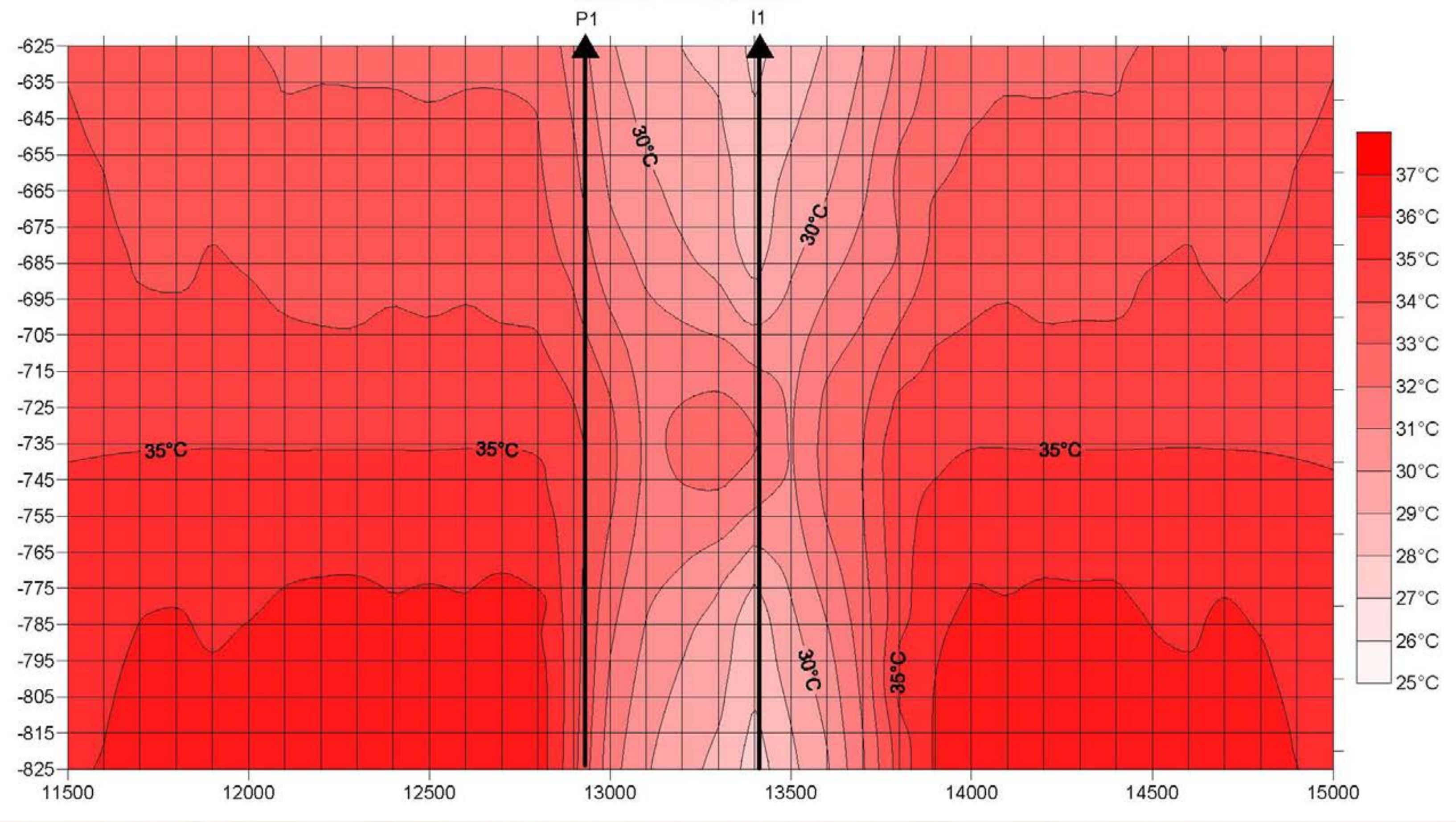
GDHC DOUBLET COMPLETION

DUAL COMPLETIONS
GDHC GEOTHERMAL LOOPS



-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

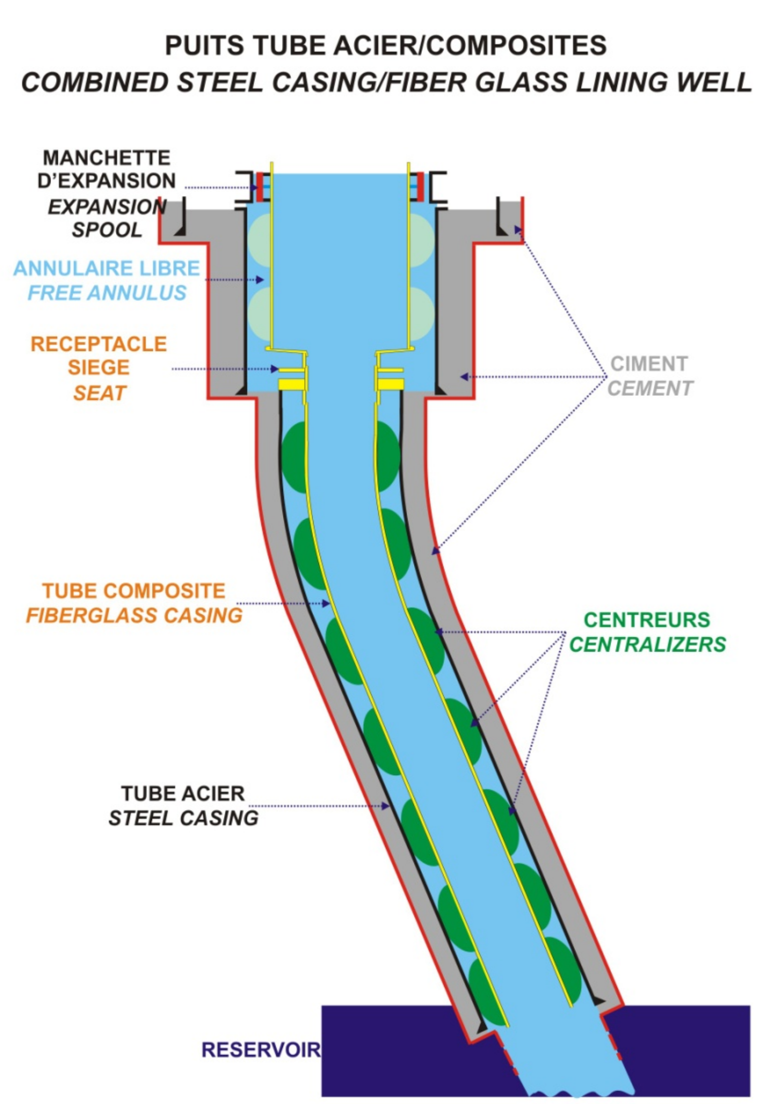


VERTICAL TEMPERATURE DISPLAY (YEAR 2030)

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

ANTI-CORROSION WELL COMPLETION



FIBERGLASS CASING/LINER RATINGS (ACT COUPLINGS)

SIZE	Nominal (")	9"5/8 (*)	13"3/8 (**)
TEMPERATURE	Maximum (°C)	93	93
BURST PRESSURE	Rating (bar)	130	140
	STAR Ultimate (bar)	199	182
	Safety margin	1.5	1.3
	Ultimate (ASTM D-1599)	312	280
	Safety margin	2.4	2
TENSILE	Rating (tons)	57	100
	STAR Ultimate (tons)	74	120
	Safety margin	1.3	1.2
COLLAPSE PRESSURE	Rating (tons)	165	140
	STAR Ultimate (ASTM D-2924)	350	280
	Safety margin	2.1	2
NOMINAL DIMENSIONS	ID (mm)	196.6	301.1
	Minimum drift (mm)	192.6	299.3
	OD (mm)	229.9	338.3
	Wall thickness (mm)	16.7	18.6
	Unit mass (daN/m)	24.4	41.8
	Length	9.15 m nominal API range 2, (8.55 to 9.75 m)	
JOINING SYSTEM	Collar OD (mm)	302.26	431.8
	Upset OD (mm)	245.11	355.6
	Thread size (mm)	244.48	339.73
	Thread type	API 8RD	API 8RD
ELASTICITY MODUL	Hoop (10^5 bar)	345	350
	Axial (10^5 bar)	207	210
	Poisson ratio (minimum)	0.25	0.24
PHYSICAL PROPERTIES	Density (kg/m^3)	196	
	F (W/mK)	0.4	
	Specific heat (Kj/kgK)	1.005	
	Axial expension (mm/mm/°C)	15.7	
HYDRAULIC PROPERTIES	Rugosity (absolute) (mm)	0.0053	
	Hazen Williams coefficient (C)	150	

(*) standard

(**) non standard, customised design

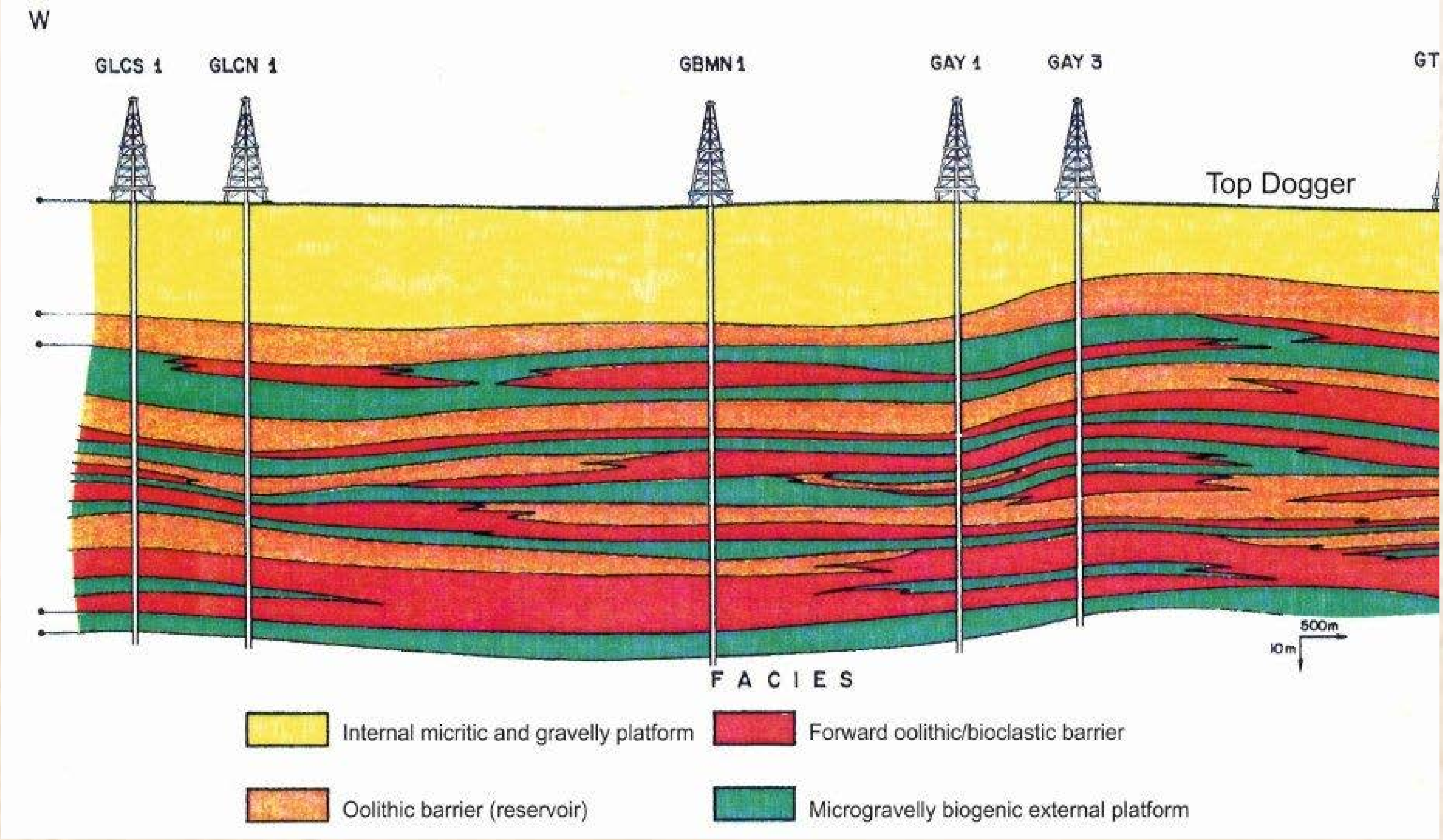
Source : STAR FIBERGLASS SYSTEMS

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

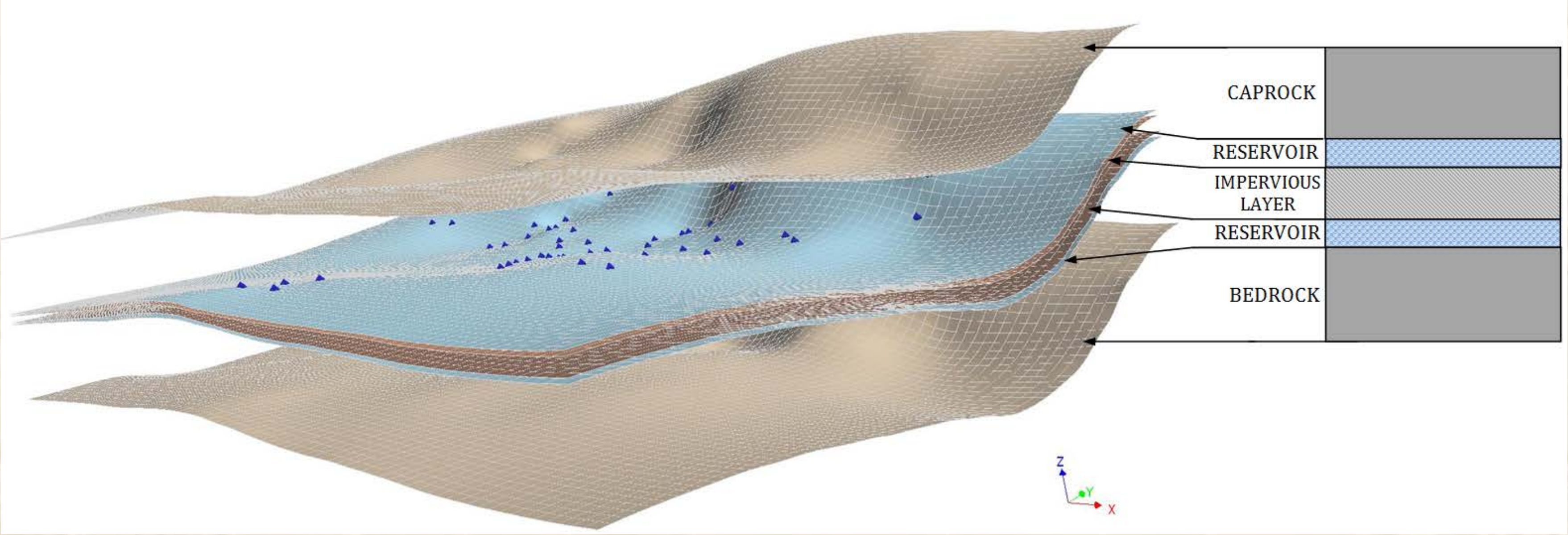
(SUB)HORIZONTAL GDH WELL DESIGNS

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



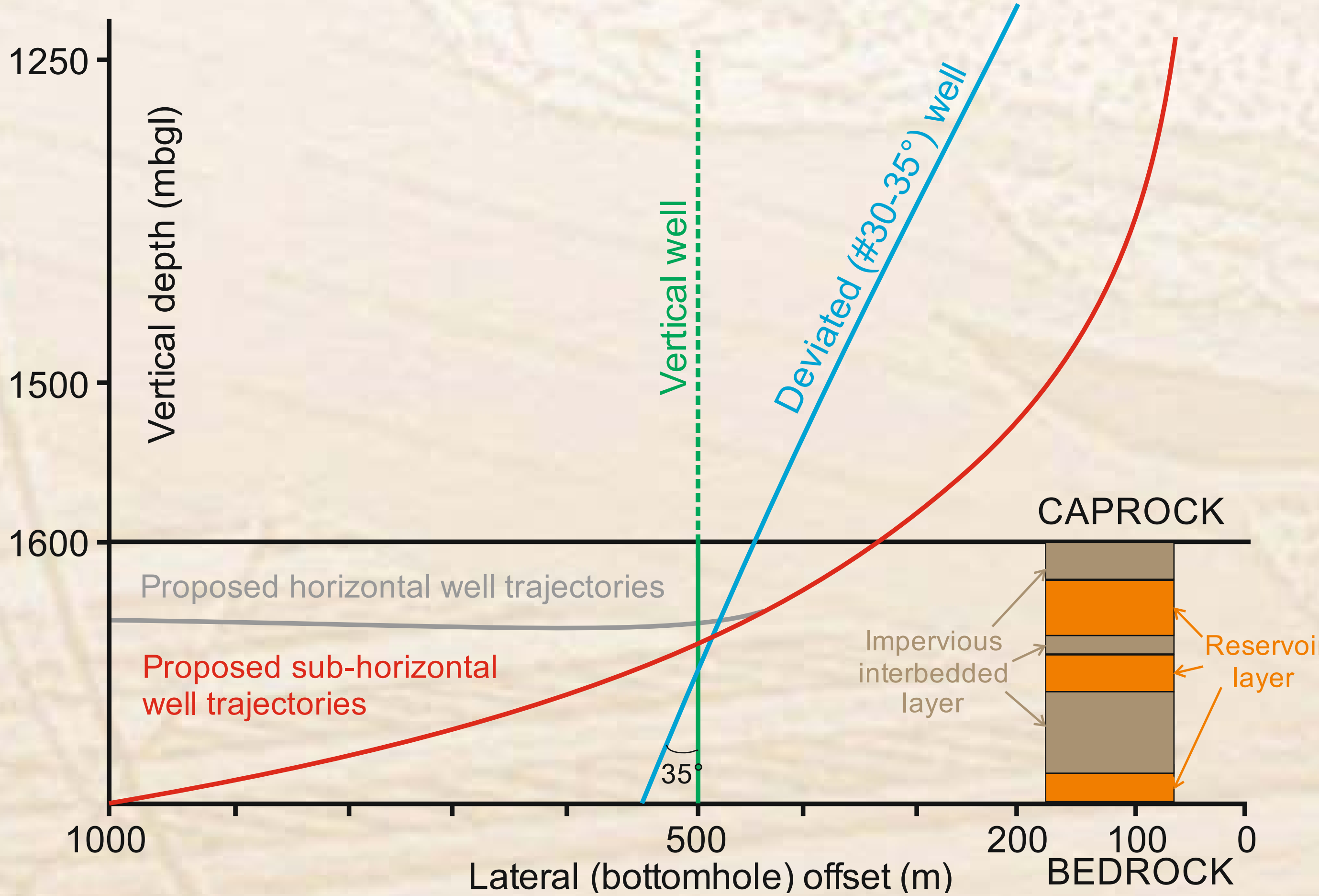
(SUB)HORIZONTAL GDH WELL DESIGNS

GOCAD 3D VIEW OF THE SANDWICH HETEROGENEOUS RESERVOIR STRUCTURE



(SUB)HORIZONTAL WELL DESIGNS

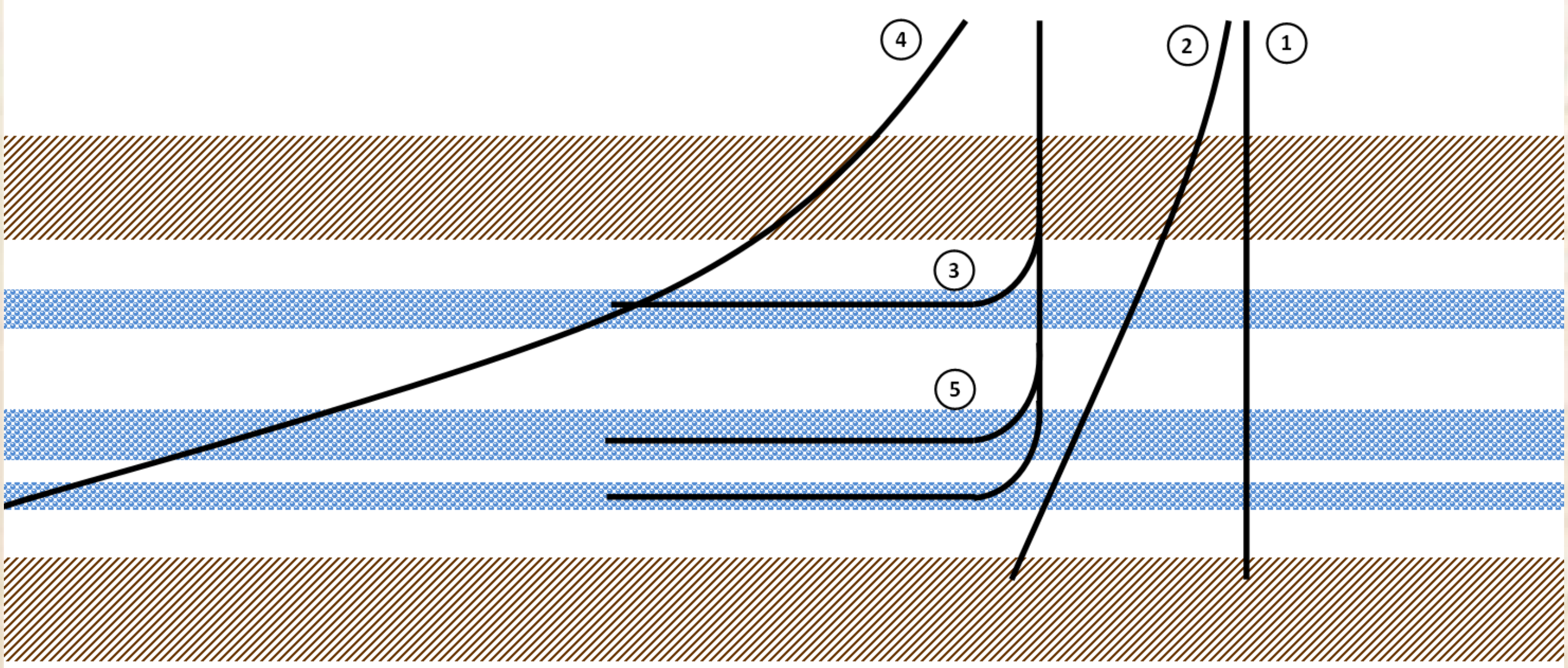
CANDIDATE WELL TRAJECTORIES
MULTILAYERED RESERVOIR
CONVENTIONAL (VERTICAL, DEVIATED)
AND SUGGESTED [(SUB)HORIZONTAL] WELL TRAJECTORIES



Ungemach & Antics, 2012

(SUB)HORIZONTAL WELL DESIGNS

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



1 Vertical well

2 Deviated well (≠ 30-35°)

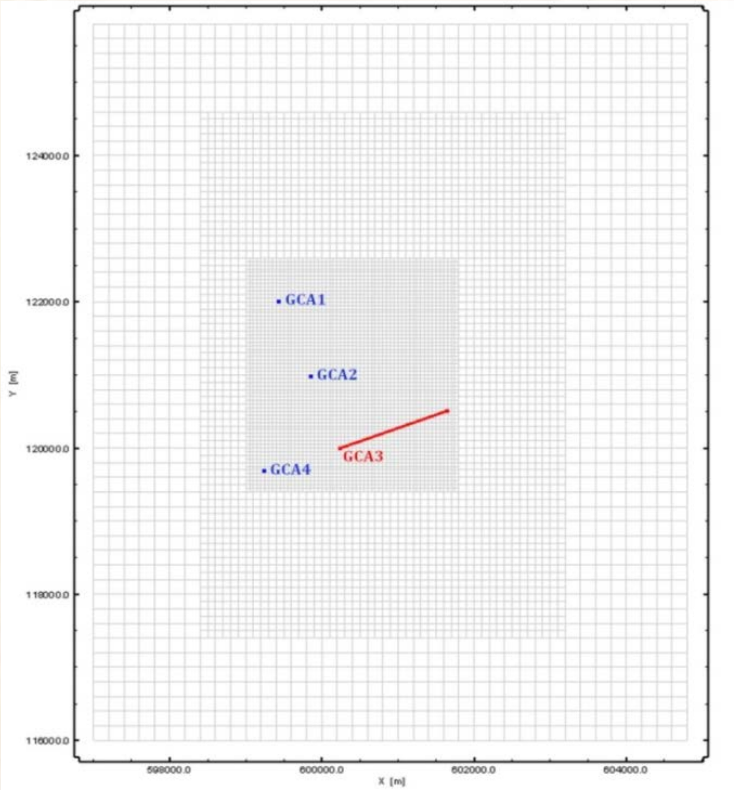
3 Horizontal drain intersecting one layer

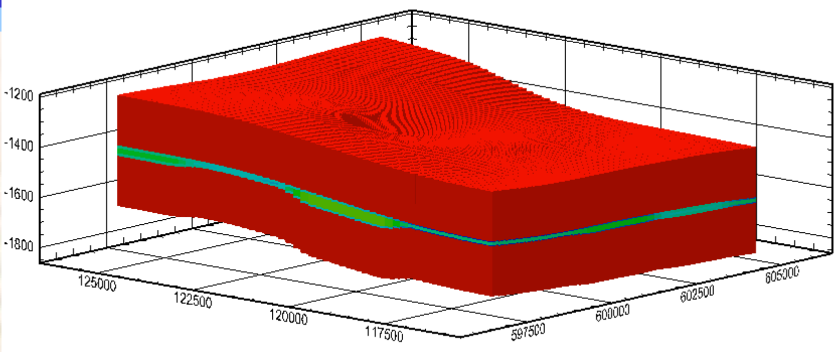
4 Subhorizontal well (≠80-85°) intersecting all the producing layers

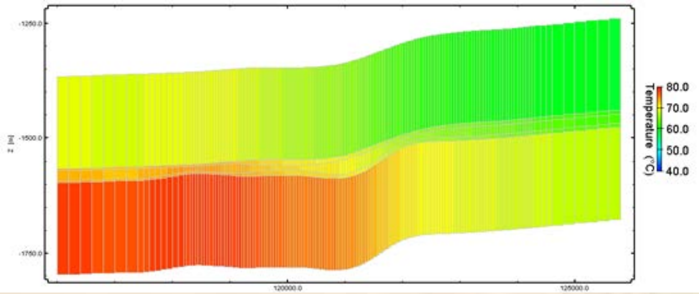
5 Multilateral well, horizontal drains intersecting all the producing layers

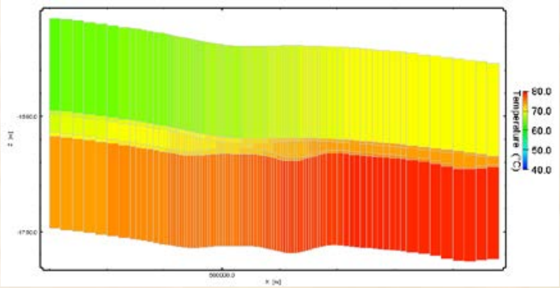
(SUB)HORIZONTAL WELL MODELLING

DISCRETISATION GRID





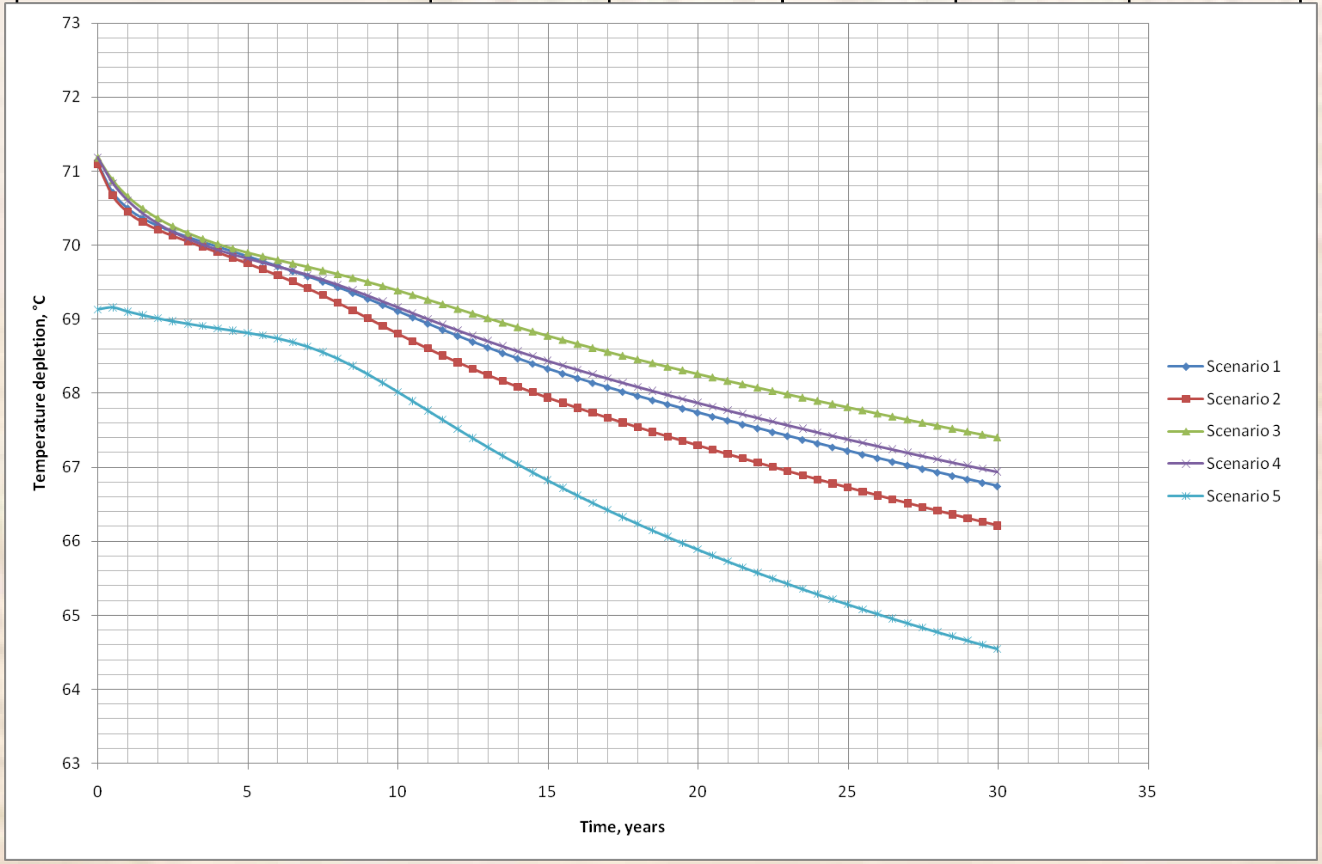




(SUB)HORIZONTAL WELL MODELLING

COOLING KINETICS

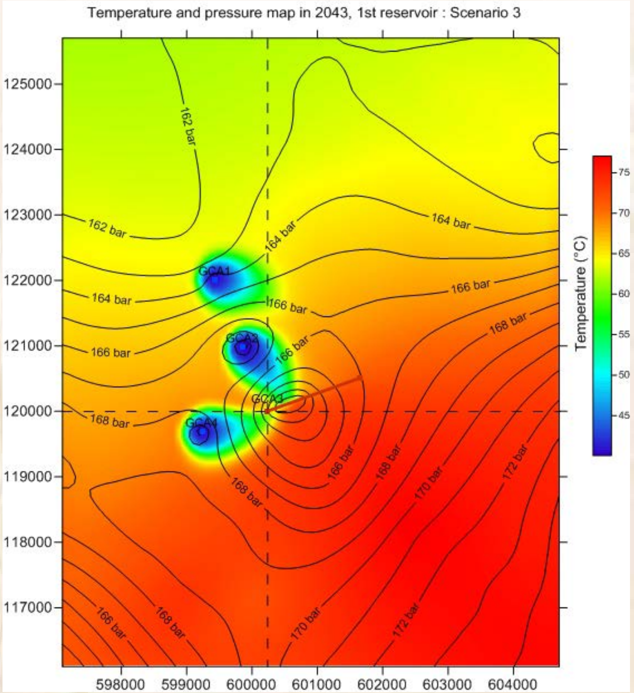
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Well length (meter)	1000	1000	1500	1500	Vertical
Flow rate (m^3/h)	300	350	300	350	300
Injection temperature (°C)	40	40	40	40	40

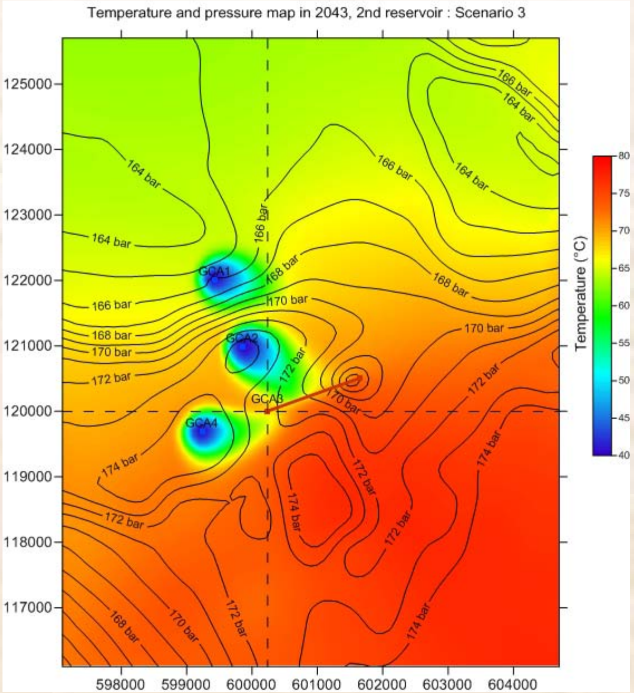


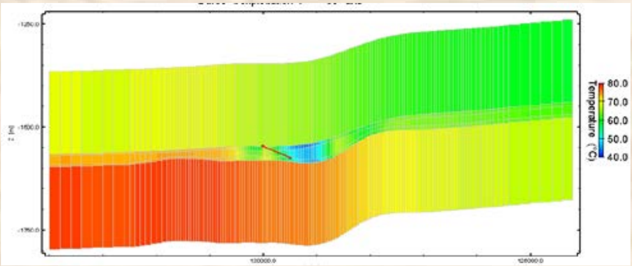
(SUB)HORIZONTAL WELL MODELLING

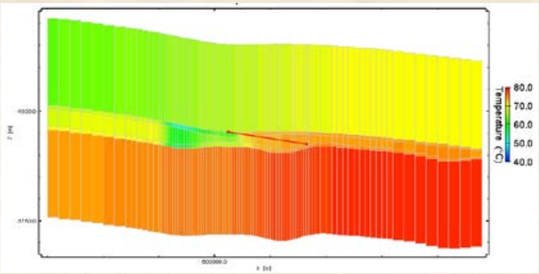
PRESSURE/TEMPERATURE DISPLAYS (YEAR 2043)

SCENARIO 3









(SUB)HORIZONTAL WELL DESIGNS

CONCLUSIONS

(Sub)Horizontal well designs, preferably intersecting the whole pay interbedded sequence, is suggested as a reliable alternative (improved productivities/injectivities and thermal life) to conventional well architectures.

OUTLINE

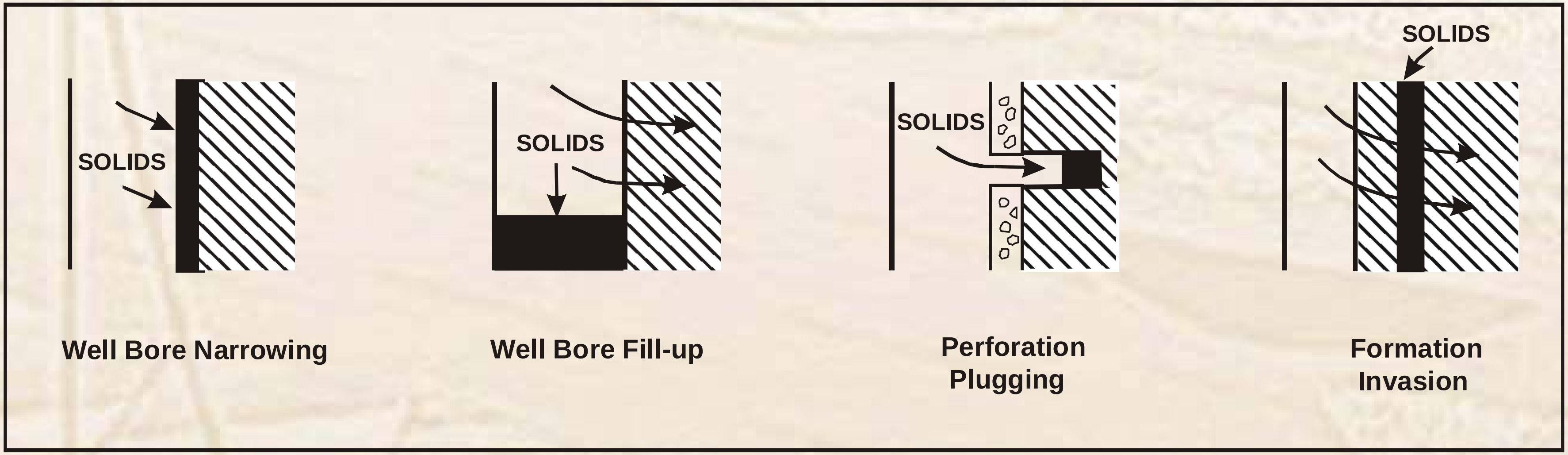
- SCOPE
- INTRODUCTION. GEOTHERMAL VS PETROLEUM
- DEEP WELL DRILLING/COMPLETION FEATURES
  - Rig selection
  - Site preparation. Rig footprint
  - Drilling
  - Bits
  - Drilling fluids
  - Directional drilling
  - Casing/lining
  - Cementing
  - Fishing
  - Waste disposal/processing
- CASE STUDY. PARIS 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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

WATER INJECTION

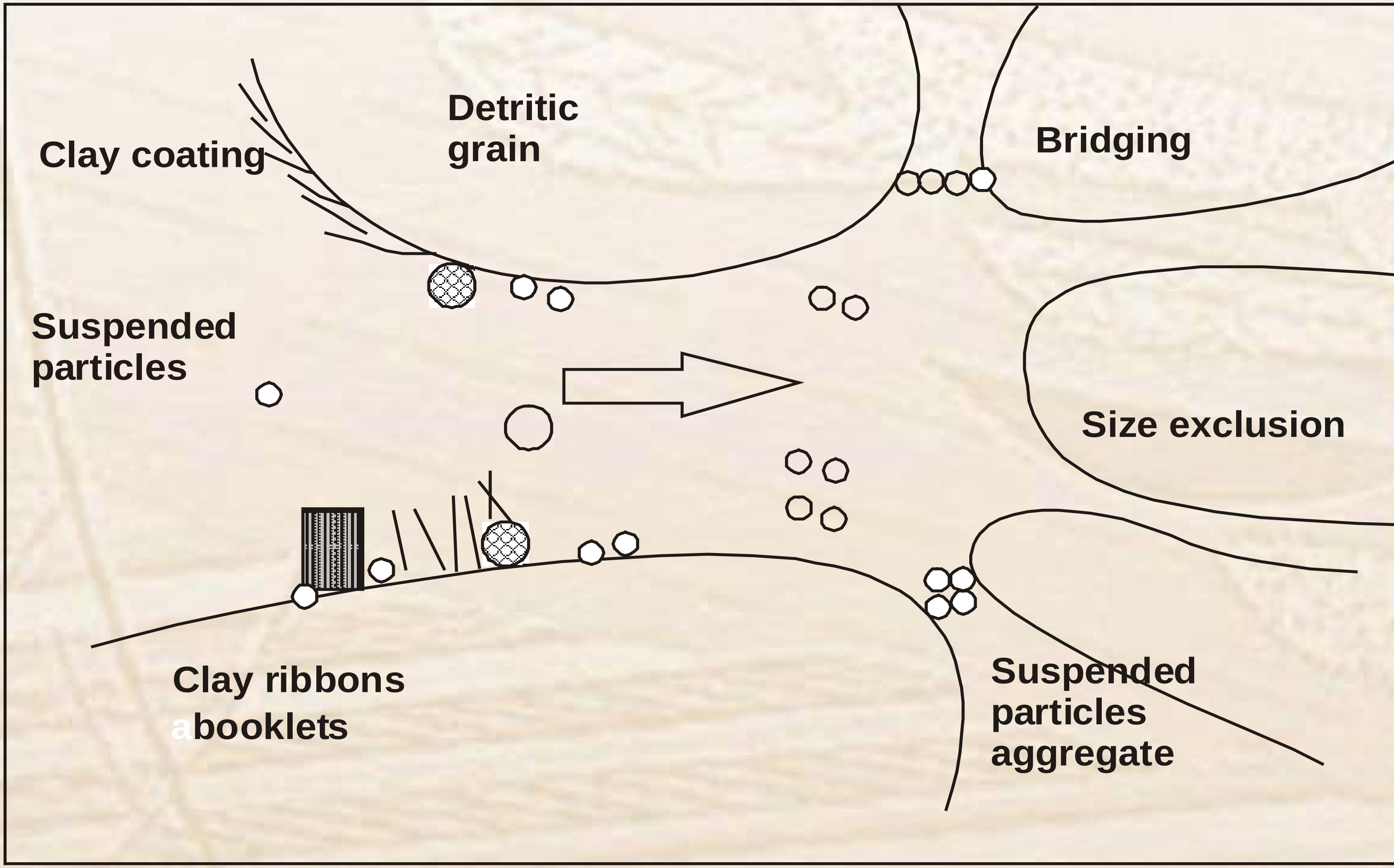
PARTICLE INDUCED DAMAGE MECHANISMS



Source : Barkman Davidson
in Ungemach 2003

WATER INJECTION

PARTICLE INDUCED DAMAGE MECHANISMS



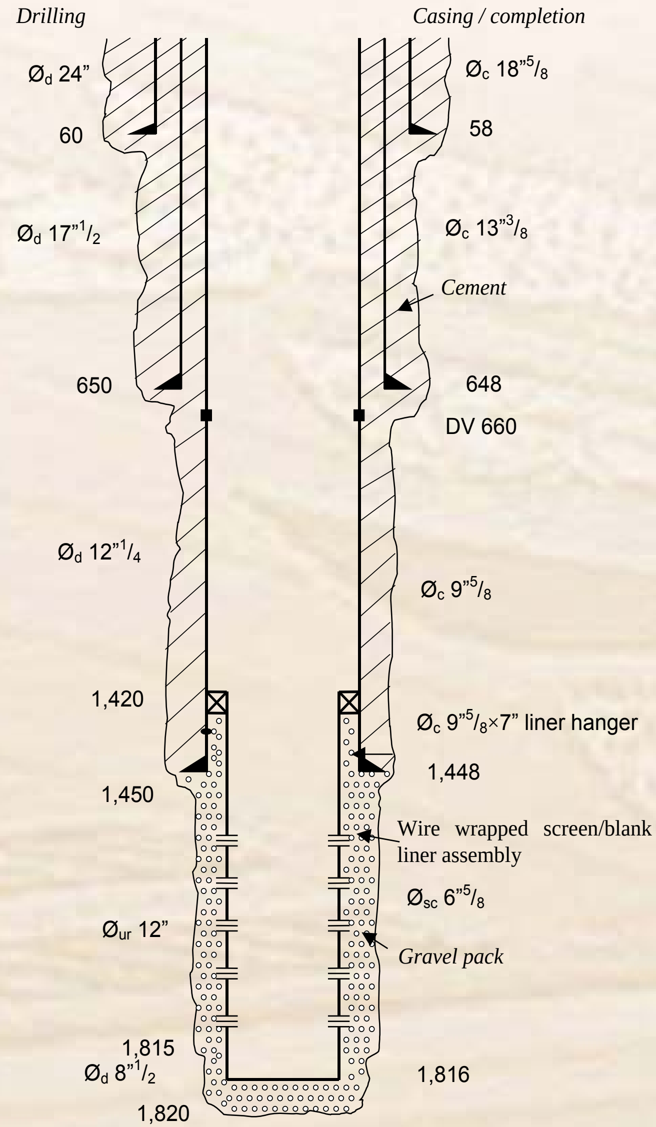
WATER INJECTION

PARTICLE INDUCED DAMAGE

WELL COMPLETION REQUIREMENTS

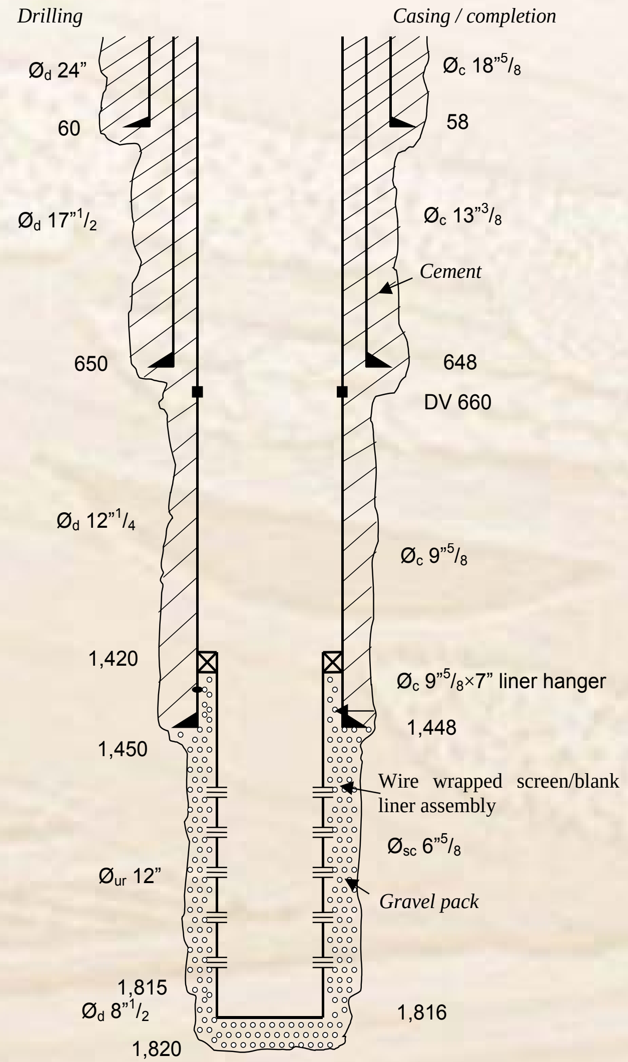
PROJECTED
WELL /
RESERVOIR
PERFORMANCE

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 (ρp) at 90ºC	965.34 kg/m^3
Fluid density (ρi) 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



WATER INJECTION IN CLASTIC SEDIMENTS CONCLUSIONS/RECOMMENDATIONS

- **Water injection is merely site specific**
- **Thorough experimental investigations required**
  - petrographic, chemical, turbidity assessments
  - laboratory testing on cores
  - design of brine handling facilities
  - field testing
- **Last but not least sound well completion design**



OUTLINE

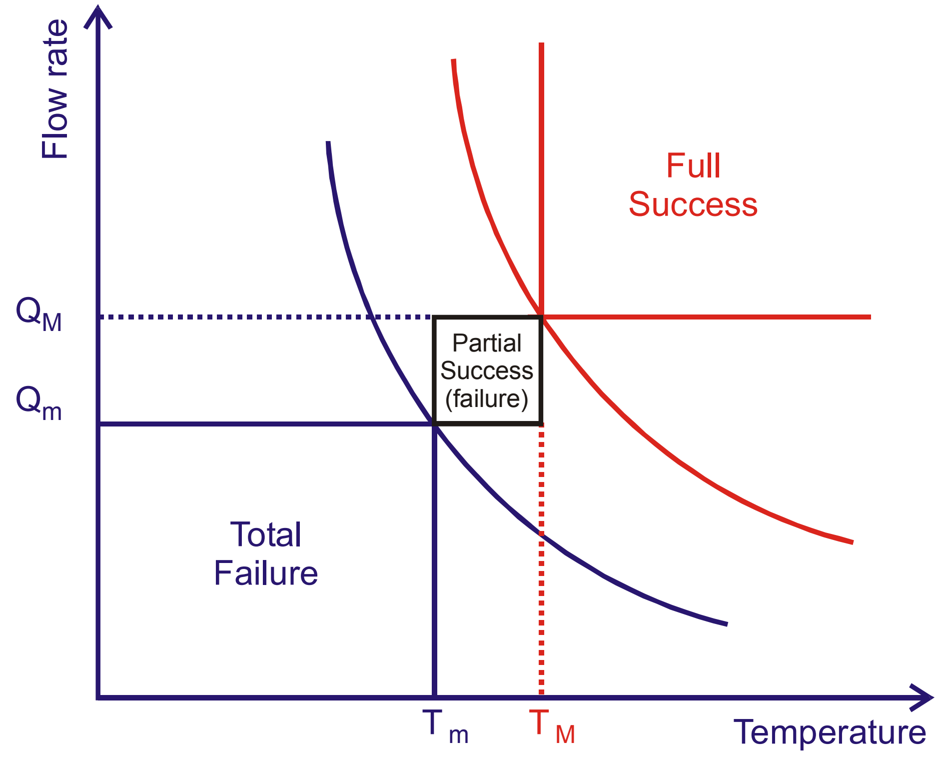
- SCOPE
- INTRODUCTION. GEOTHERMAL VS PETROLEUM
- DEEP WELL DRILLING/COMPLETION FEATURES
  - Rig selection
  - Site preparation. Rig footprint
  - Drilling
  - Bits
  - Drilling fluids
  - Directional drilling
  - Casing/lining
  - Cementing
  - Fishing
  - Waste disposal/processing
- CASE STUDY. PARIS 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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

TECHNICAL RISK MATRIX

Cause Consequence	Unsufficient hook load	Inadequate BHAs	Odd cementing	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:

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

Total failure:

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

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)

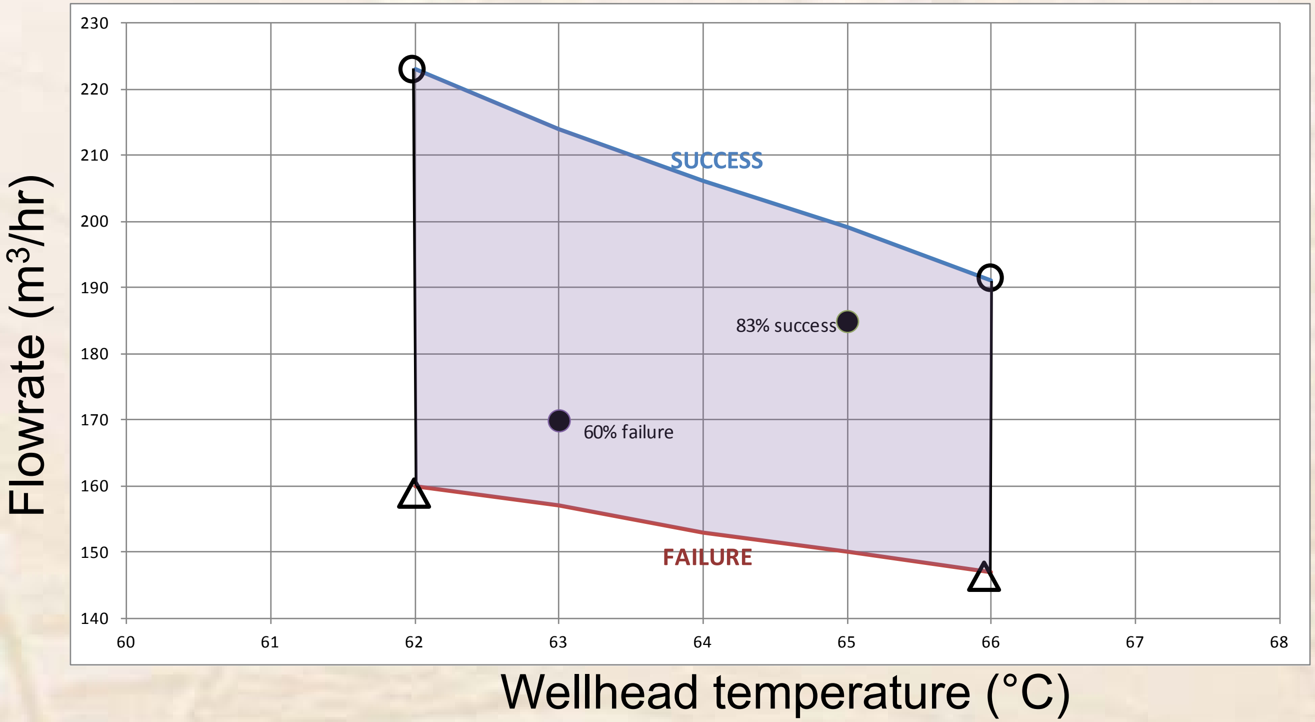
nh = number of operating hours per year

r, r' = discount rates

*OMC = OPEX

* INV = CAPEX

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

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

SUSTAINABILITY

SUSTAINABLE HEAT EXTRACTION SCENARIOS

Given that GE is renewable and exhaustible

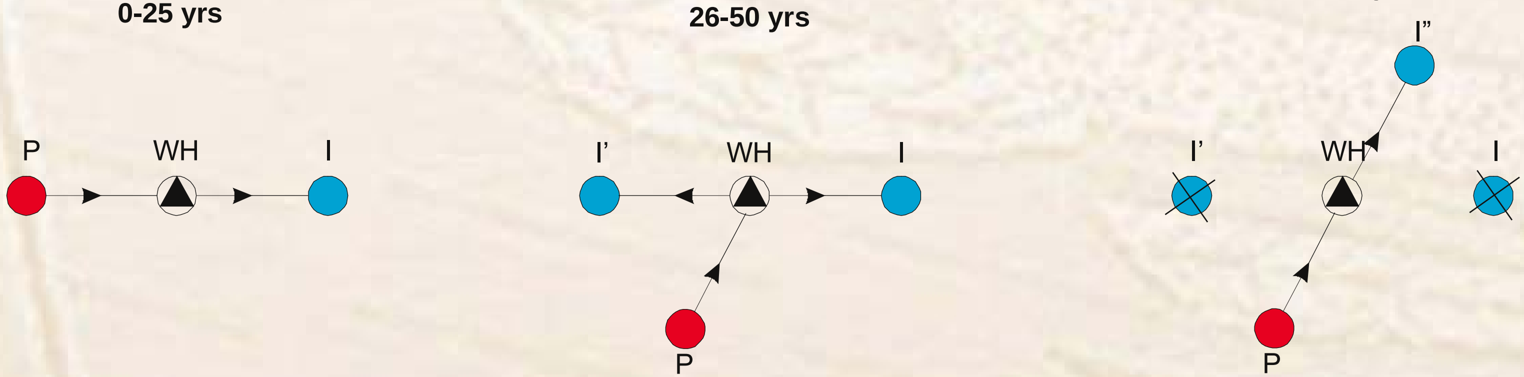
- OBJECTIVE
  - Secure well longevities and reservoir life up to 75/100 years
- PREREQUISITE
  - (Re)Injection of the heat depleted brine into (preferably) the source reservoir
- CONSTRAINTS
  - Project life = 25 years
  - Well life expectation = 20-25 years
  - Target thermal breakthrough = 20 years
- IS THERE A LIFE AFTER ???
  - YES, provided adequate heat mining schemes be designed

SUSTAINABILITY MINING SCHEMES

INITIAL DOUBLET
0-25 yrs

INTERMEDIATE TRIPLET ARRAY
26-50 yrs

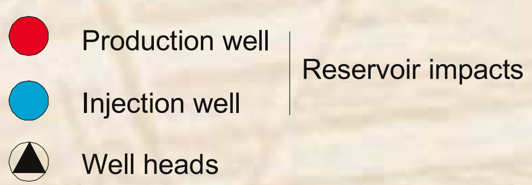
NEW DOUBLET
51-75 yrs



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

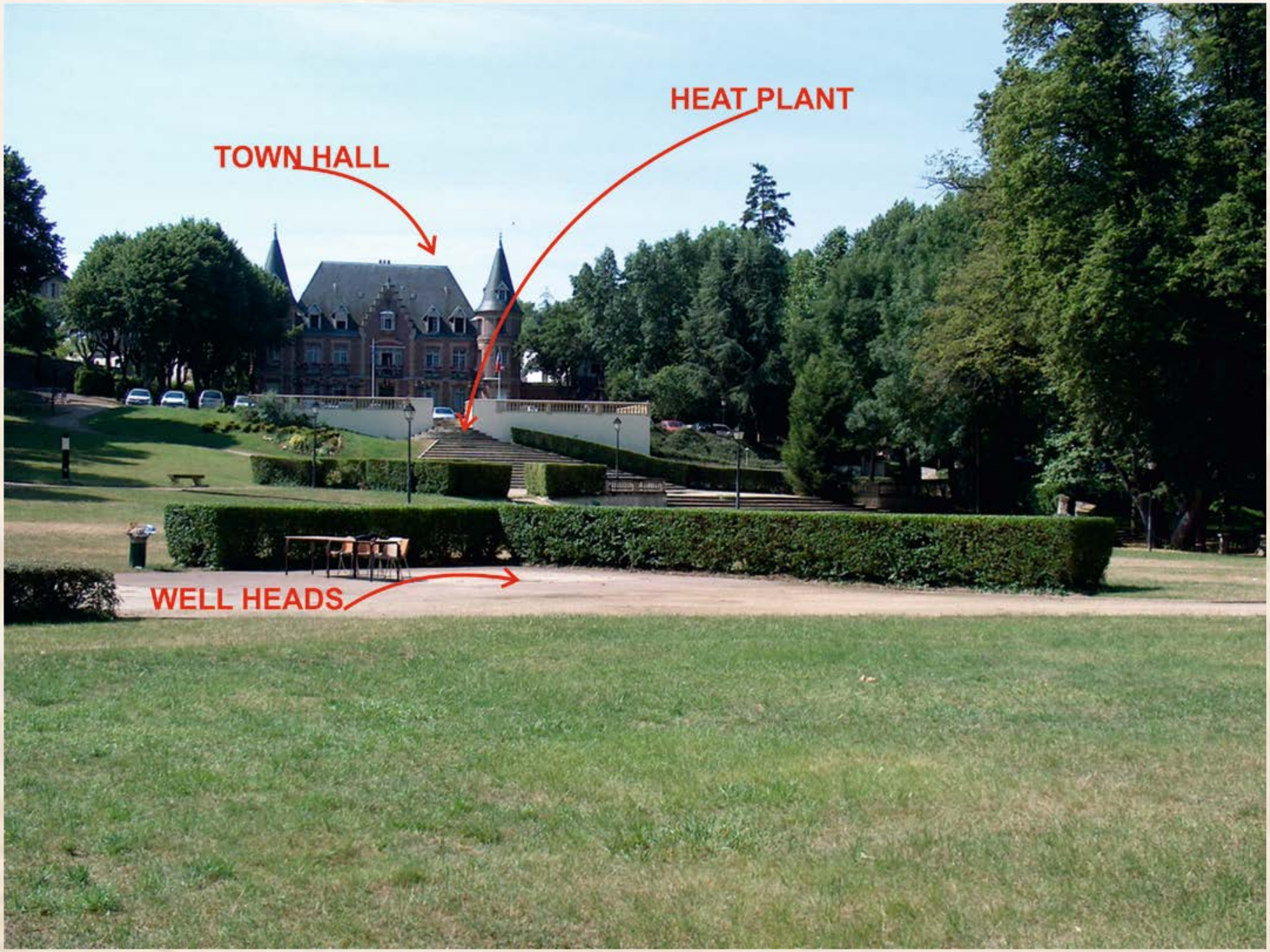
System life

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
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

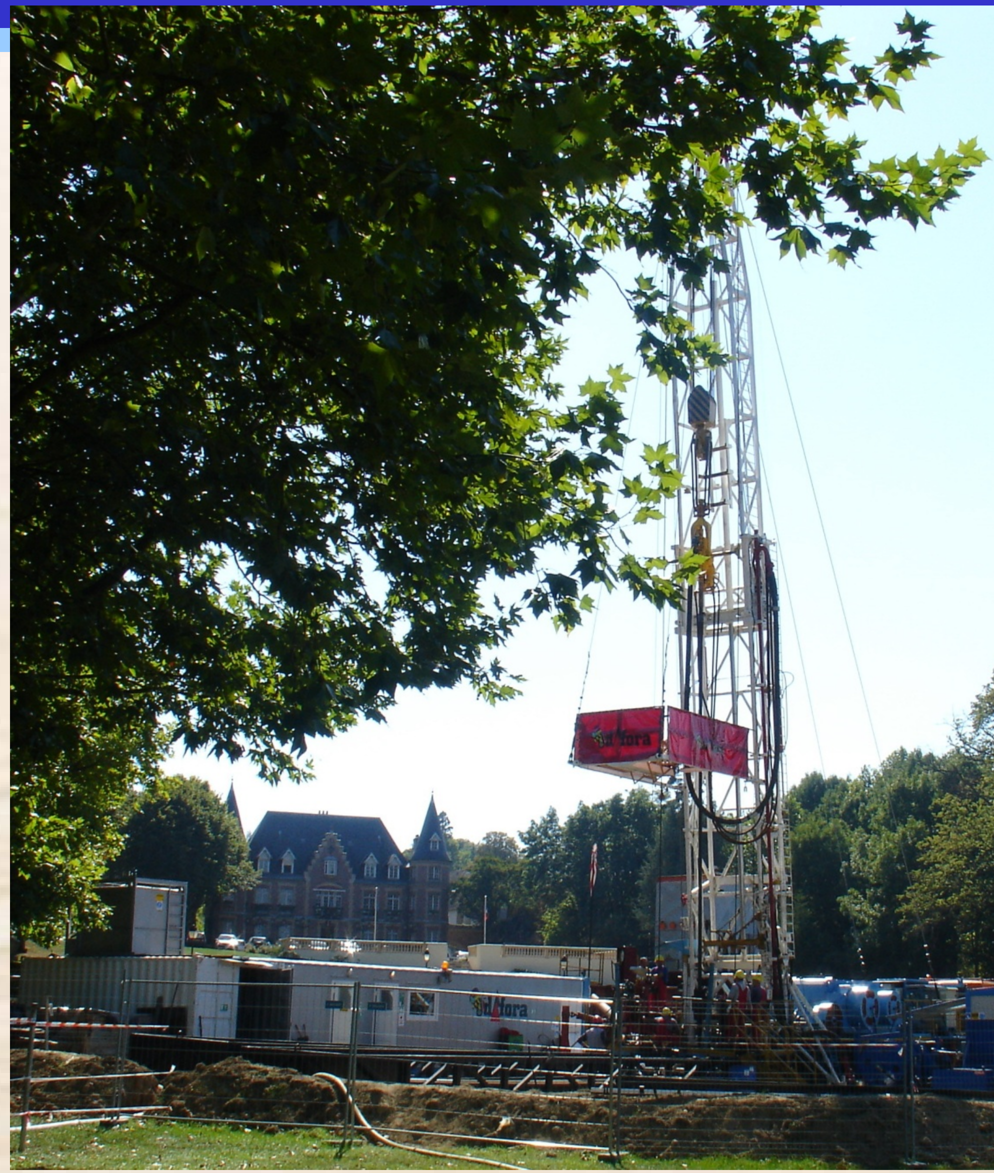
A FRIENDLY GDH ENVIRONMENT

EPINAY-SOUS-SENART
AN ENVIRONMENTALLY FRIENDLY SET UP



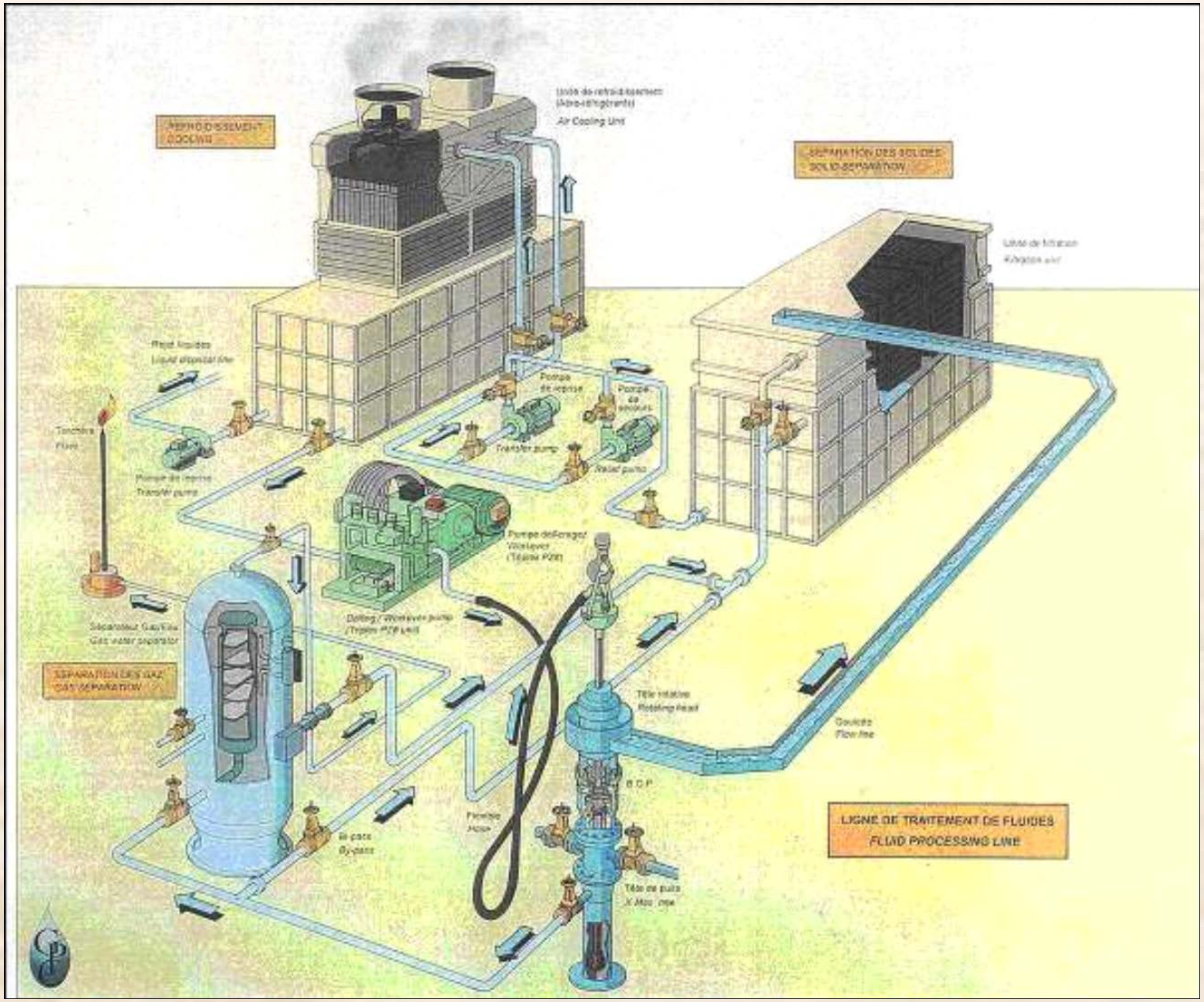
A FRIENDLY GDH ENVIRONMENT

WORKOVER SETUP



GAS ABATEMENT LINE

WORKOVER WASTE PROCESSING LINE



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**
  - Screens
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

MISCELLANEOUS ISSUES

TYPICAL GEOTHERMAL WELL WORKOVER PROGRAMME

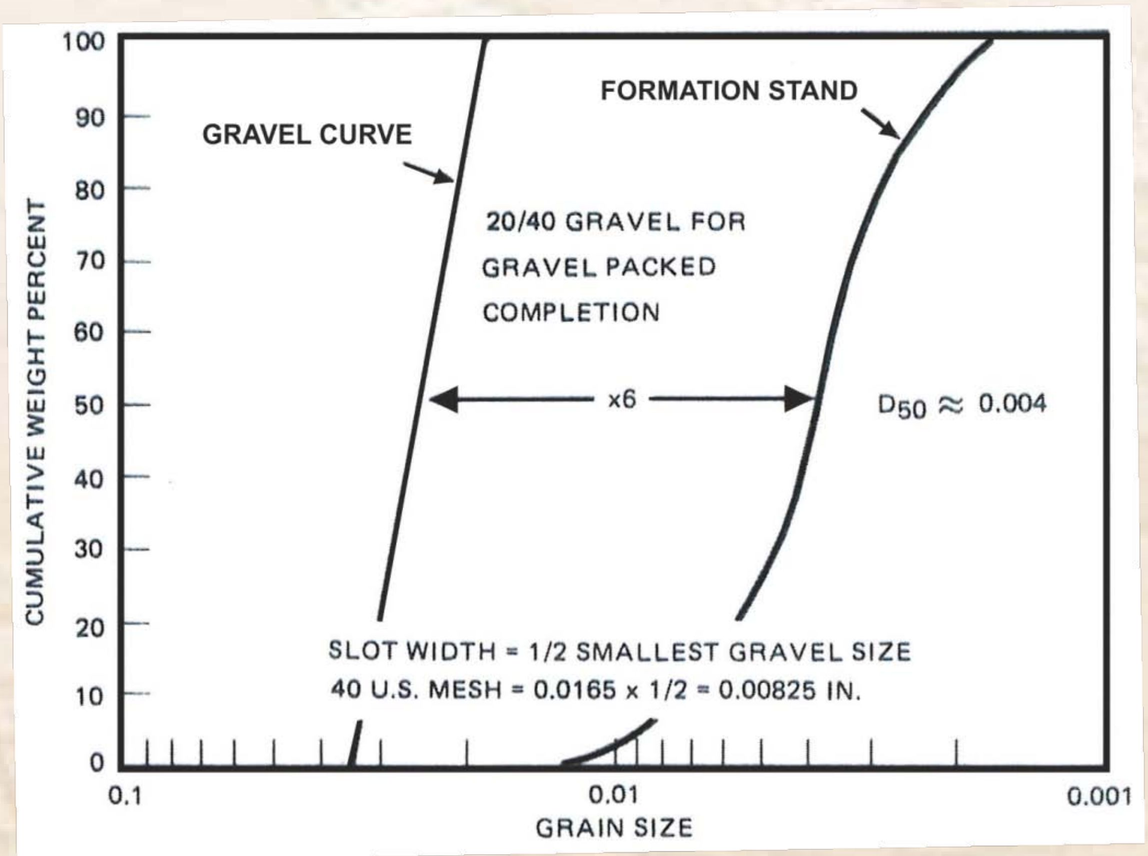
1) Rig mobilisation
2) AIT (or equivalent) fishing
3) Jetting
4) Leak detection logging
   a. Casing inspection caliper (CIC) (*)
   b. Flowmeter / temperature (**)
5) Mechanical leak detection
   Packer leak off tests
6) Leak sealing: squeeze cement
7) Relining
8) Logging:
   a. CIC
   b. CBL/VDI(Cement Boud Control)
   c. ABI (Acoustic Borehole Imager)
9) Acid stimulation
10) Well test
11) Rig de-mobilisation
12) Site rehabilitation

(*) Auxiliary Injection Tubing (Downhole control chemical injection line)
(**) in combination with cold water injection

OUTLINE

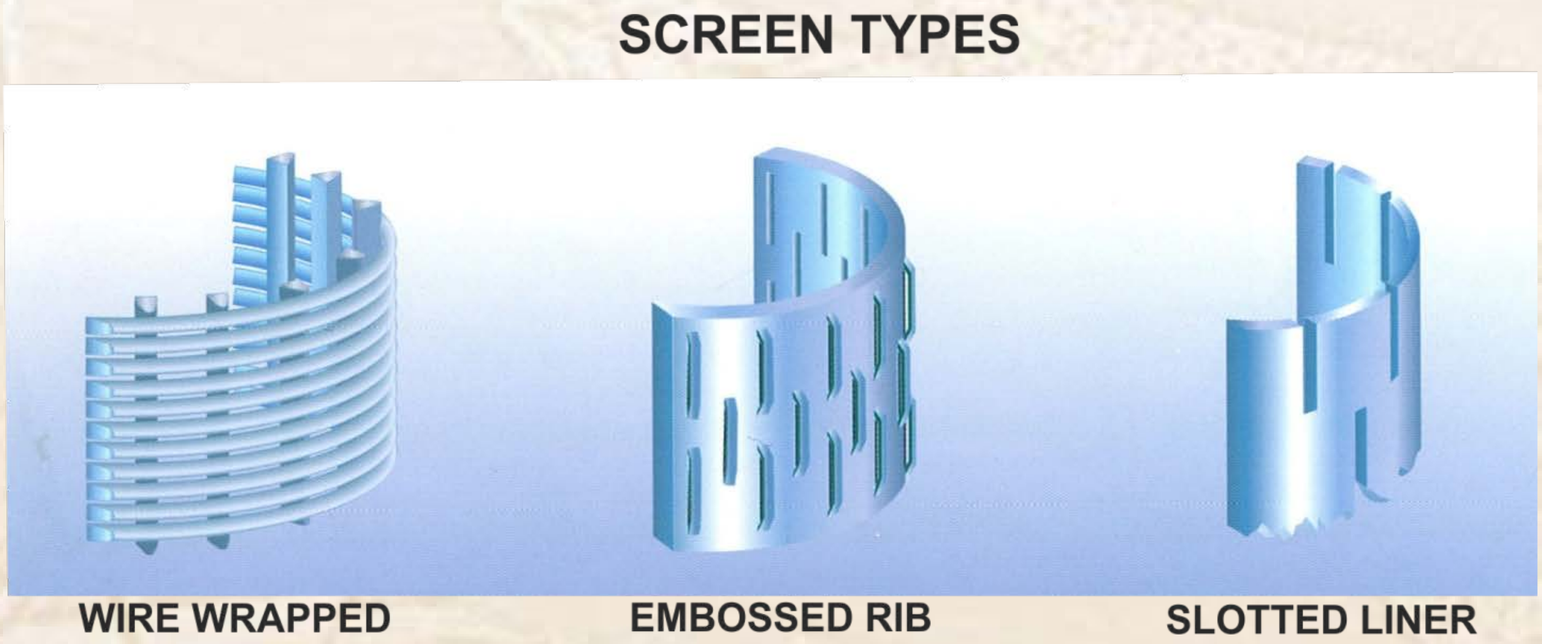
- SCOPE
- INTRODUCTION. GEOTHERMAL VS PETROLEUM
- DEEP WELL DRILLING/COMPLETION FEATURES
  - Rig selection
  - Site preparation. Rig footprint
  - Drilling
  - Bits
  - Drilling fluids
  - Directional drilling
  - Casing/lining
  - Cementing
  - Fishing
  - Waste disposal/processing
- CASE STUDY. PARIS 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
  - **Screens**
  - Mud solids'control
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

GRAVEL PACK DESIGN



Source : H.P. well screen

SCREENS
SCREEN TYPES



Source : Johnson screens

SCREENS
WIRE WRAPPED SCREENS

WIRE WRAPPED SCREENS

STANDARD

REIFORCED

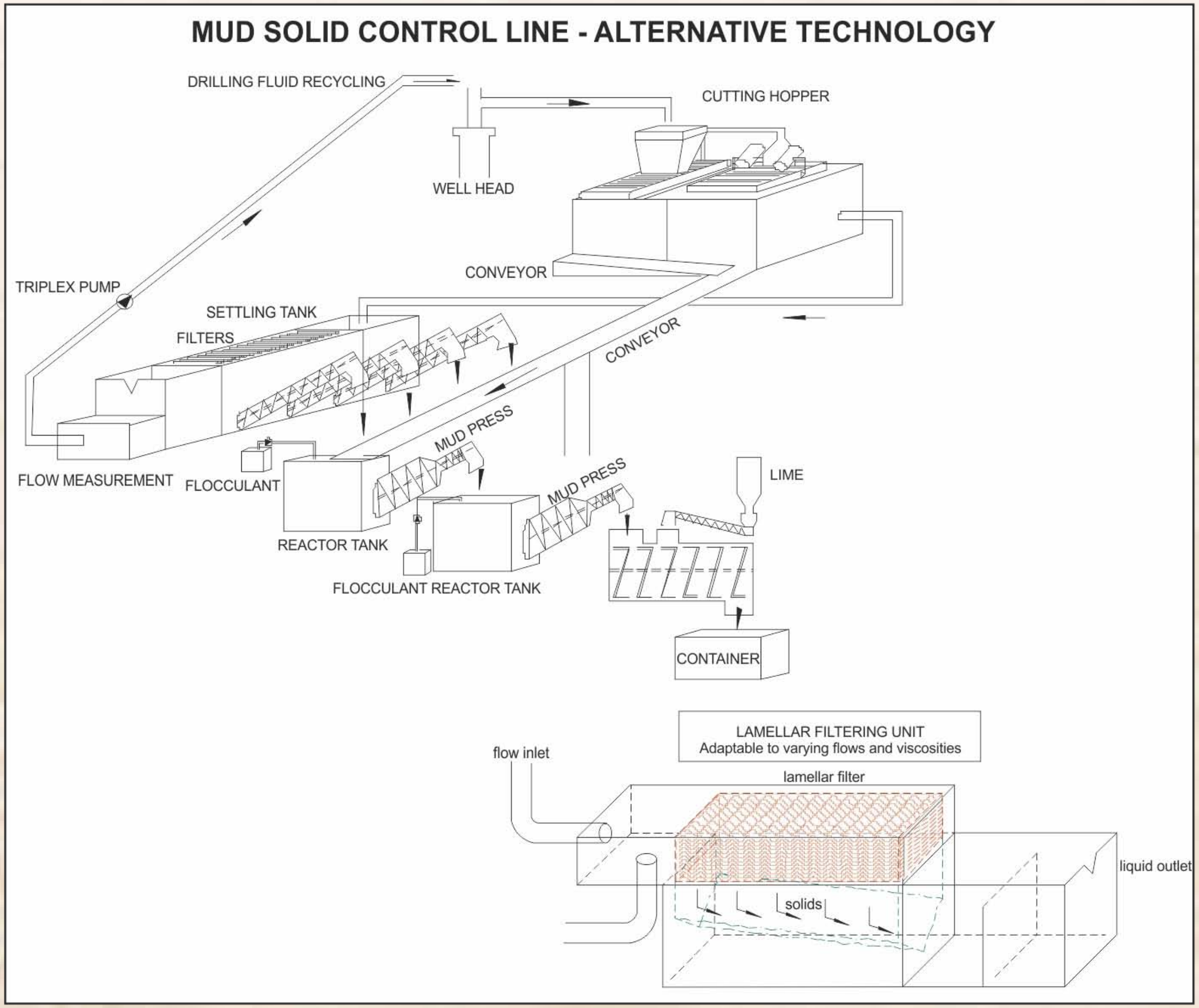
OIL & GAS
SUPER REIFORCED

Source : Johnson screens

OUTLINE

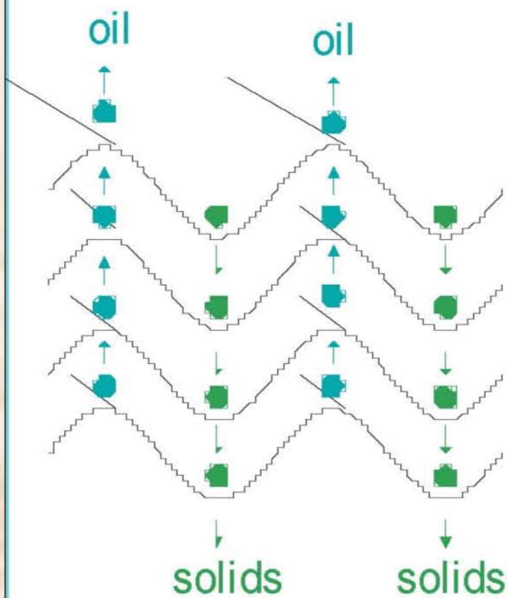
- SCOPE
- INTRODUCTION. GEOTHERMAL VS PETROLEUM
- DEEP WELL DRILLING/COMPLETION FEATURES
  - Rig selection
  - Site preparation. Rig footprint
  - Drilling
  - Bits
  - Drilling fluids
  - Directional drilling
  - Casing/lining
  - Cementing
  - Fishing
  - Waste disposal/processing
- CASE STUDY. PARIS 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
  - Screens
  - **Mud solids'control**
- DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION

MUD SOLIDS CONTROL LINE ALTERNATIVE TECHNOLOGY

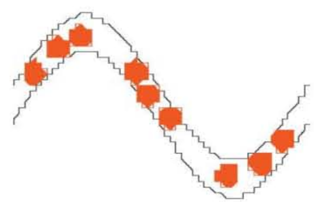


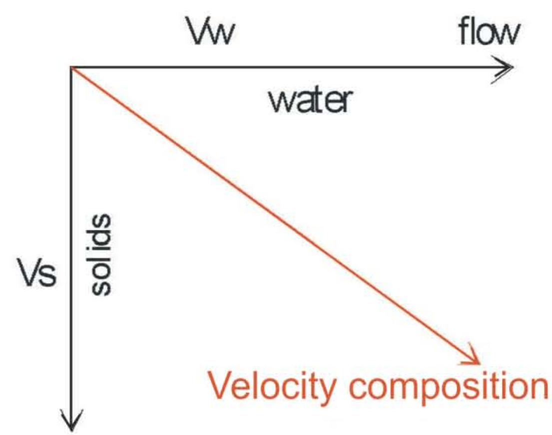
MUD SOLIDS CONTROL
LAMELLAR FILTERING PRINCIPLE

Wave shaped coalescing plates



Particulate agregation, coalescence

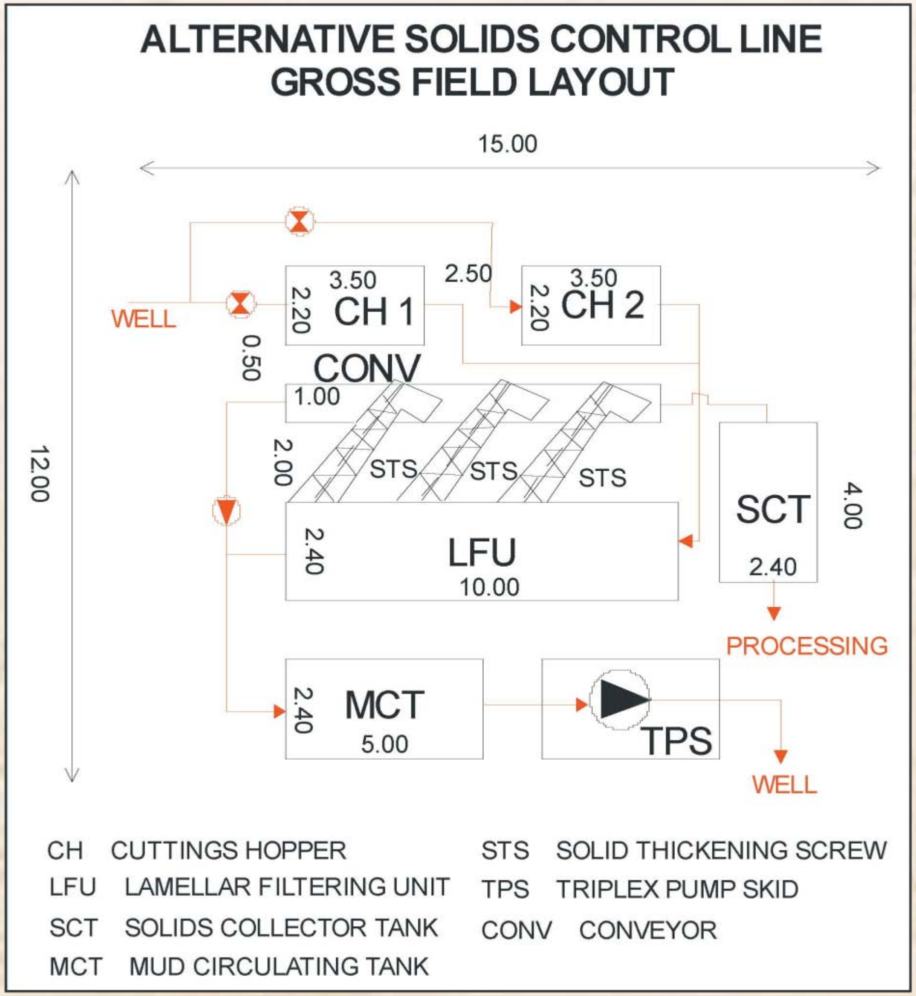




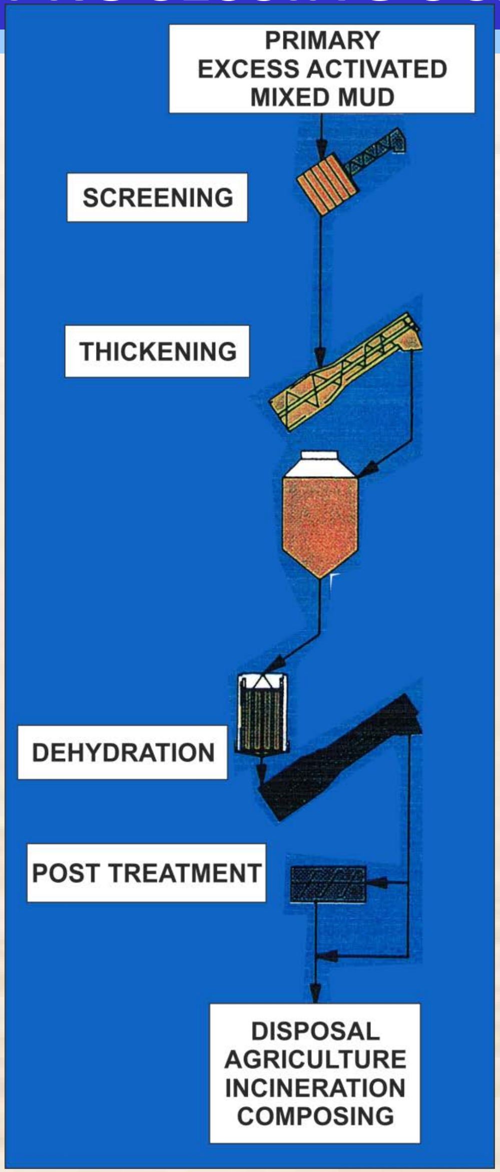
Vs calculation
d < 40 µm Stokes Law
d > 40 µm Intermediate Law
d > 1000 µm Newton Law

d (µm)	500	175	125	75	50	20	10
Vs (cm/mn)	550	170	115	65	50	4.4	1.1
tt (mn)	0.2	0.6	0.9	1.5	2.0	20	90
a recycling	85	28	19	11	8.5	0.85	0.2

MUD SOLIDS CONTROL
ALTERNATIVE SOLIDS CONTROL LINE



MUD SOLIDS CONTROL
MUD PROCESSING SCHEMATICS



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
  - Screens
  - Mud solids'control
- **DRILLING CONTRACT. RIG MANAGEMENT. WORK SUPERVISION**

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

Pierre Ungemach & Miklos Antics
GPC IP
95700 ROISSY CDG
France
pierre.ungemach@geoproduction.fr
m.antics@geoproduction.fr
www.gpc-france.com

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