Development of geothermal energy in areas with low transmissivity and/or in areas with a high density of operations. Well architectures to maximise heat extraction.

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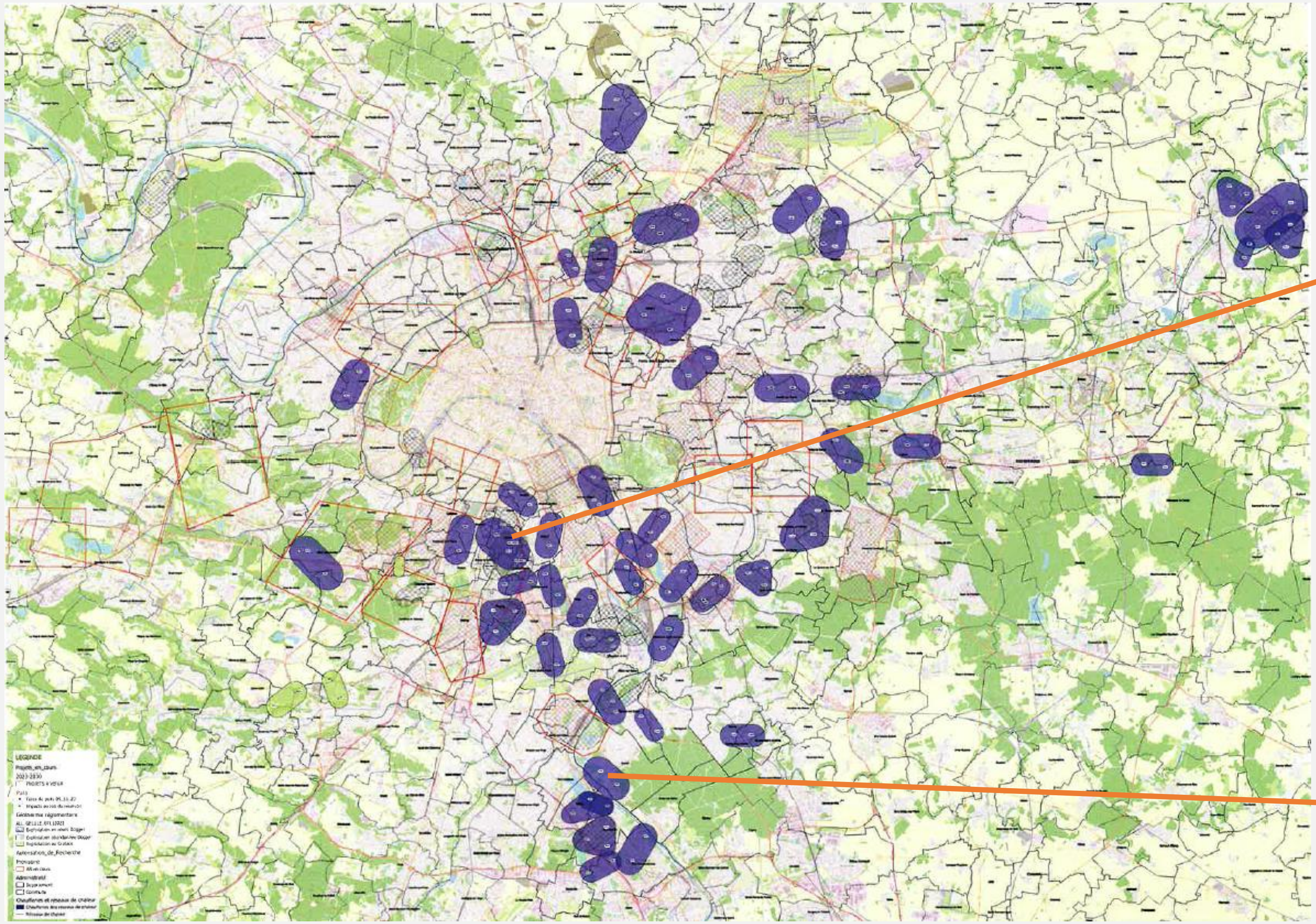
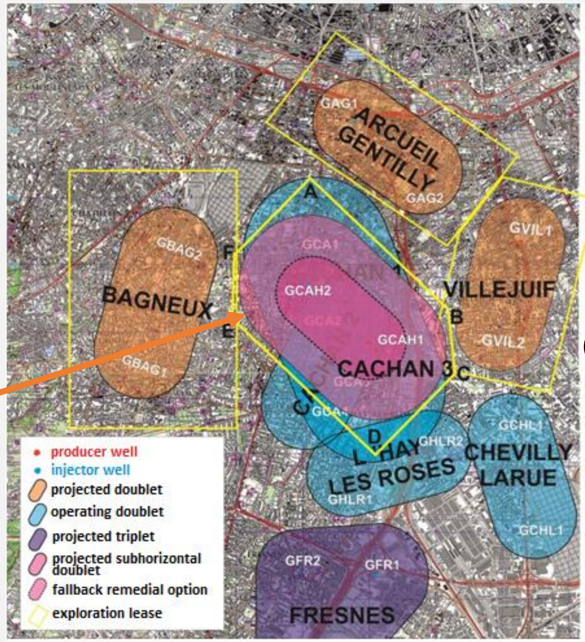
Outline

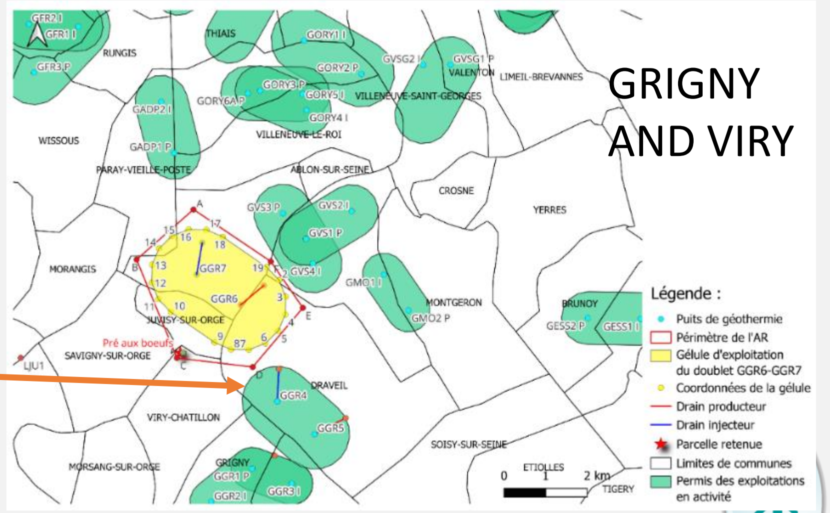
- Paris Basin Geothermal District Heating (GDH) system
- Subhorizontal well architectures
- Multiradial well architectures
- Multilateral well architectures
- Conclusions

PARIS BASIN. RESOURCE DEVELOPMENT REFERENCE SITES





CACHAN

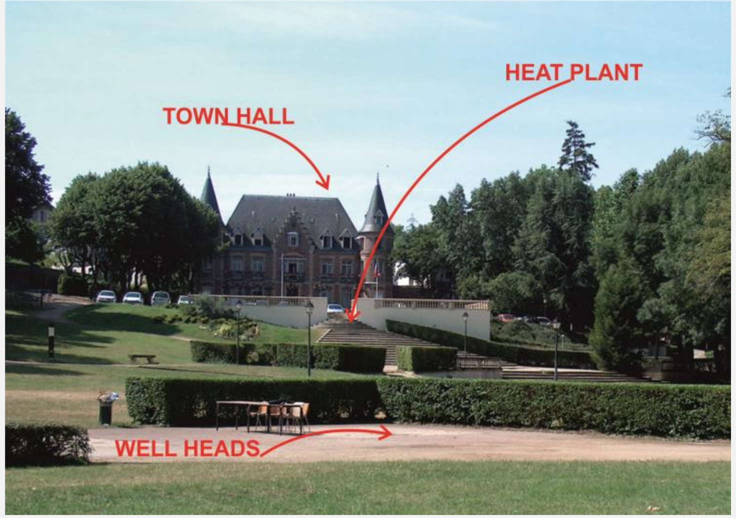


GRIGNY AND VIRY

	Today	2030
Operating GDH sites	52	80

	Today	2030
Produced heat (GWth/yr)	1600	3200

PARIS BASIN. TYPICAL GEOTHERMAL SITES



Parc *à la française*

Grigny

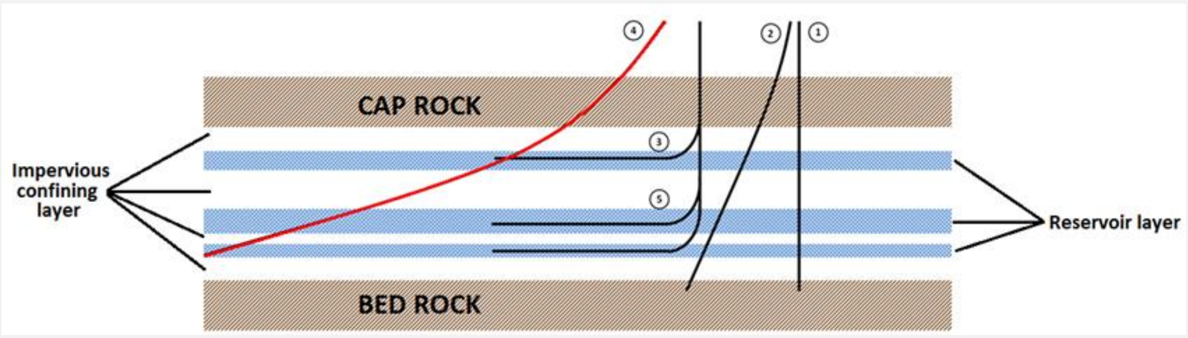
High traffic density

Paris *intra-muros*

Densely populated urban area – Cachan

SUBHORIZONTAL AND MULTILATERAL WELL CONCEPT AND EXPECTATIONS

CONCEPT



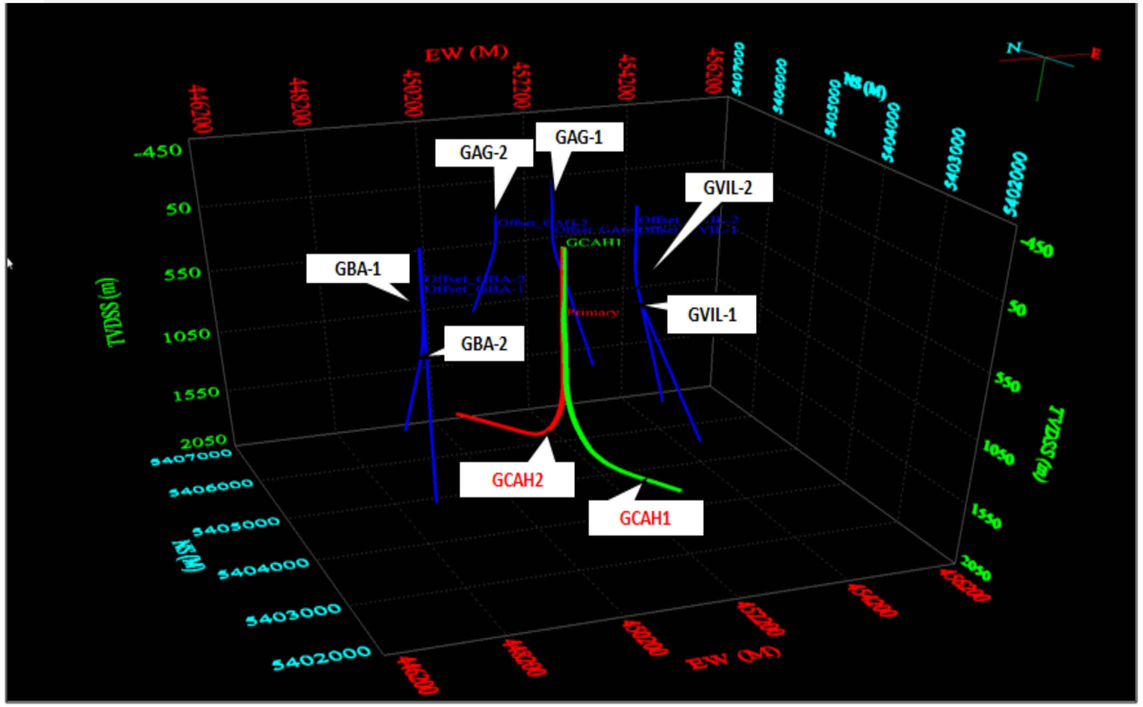
1. Vertical well
2. Deviated well (#30-35°)
3. Horizontal drain intersecting one layer
4. Subhorizontal well (SHW) (#80-85°) intersecting all producing layers
5. Multilateral well, horizontal drains intersecting all producing layers

EXPECTATIONS

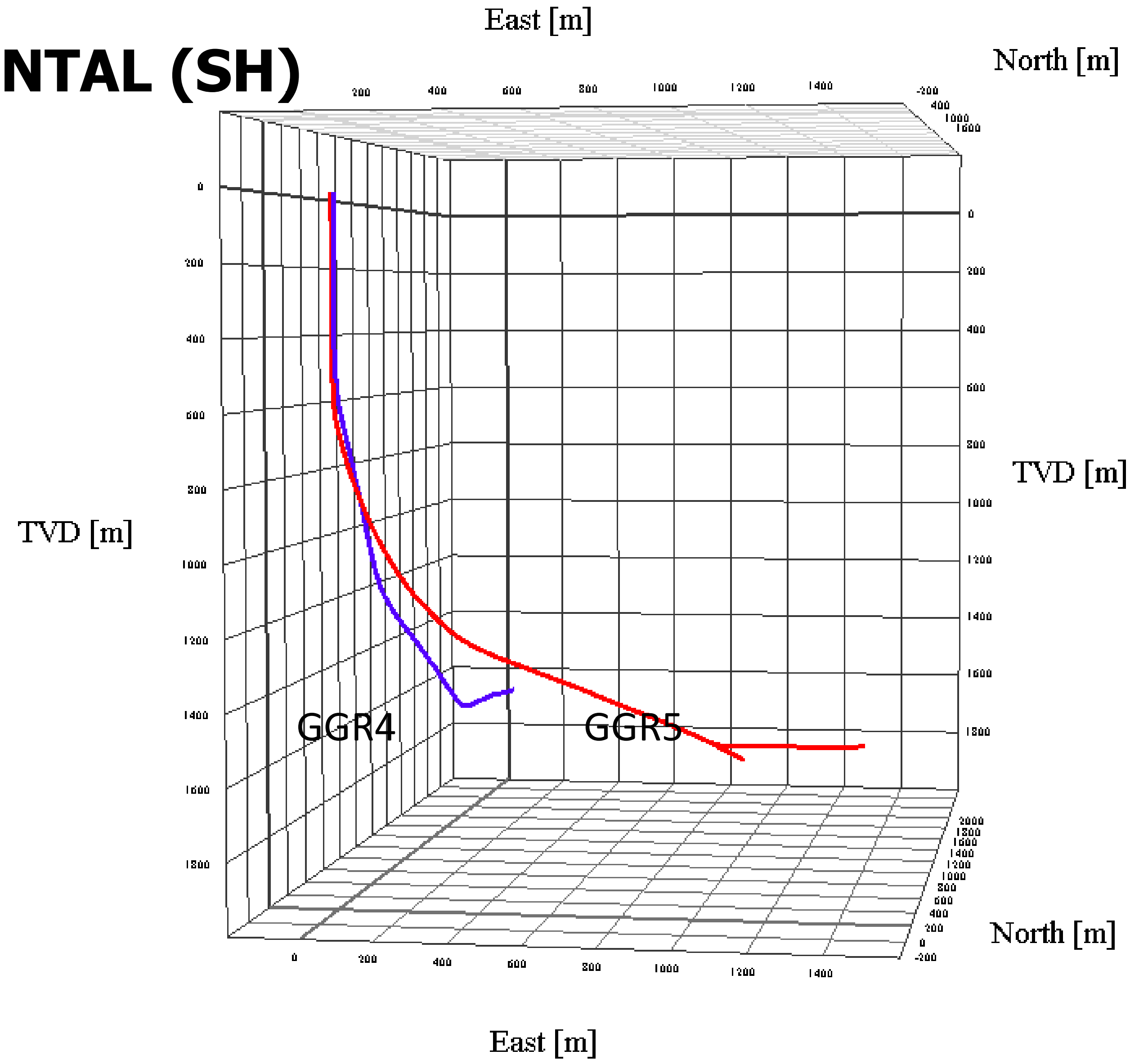
- **General**
  - Optimize land occupation in densely populated urban environments
  - Added value to presently unchallenged low permeability reservoir settings
  - Maximize geothermal exposure & minimize drilling/completion risk
  - Upgrade geothermal well architecture & reservoir evaluation standards

- **Site specific**
  - Well architecture → Innovation
  - Extend exploitation until 2045 → Sustainability
  - Increase capacity 350->450/500 m^3/hr → Well performance
  - CAPEX/OPEX reduction → Economy
  - Multilayered reservoir appraisal → Geology

CACHAN VS GRIGNY SUBHORIZONTAL (SH) COMPARED WELL TRAJECTORIES

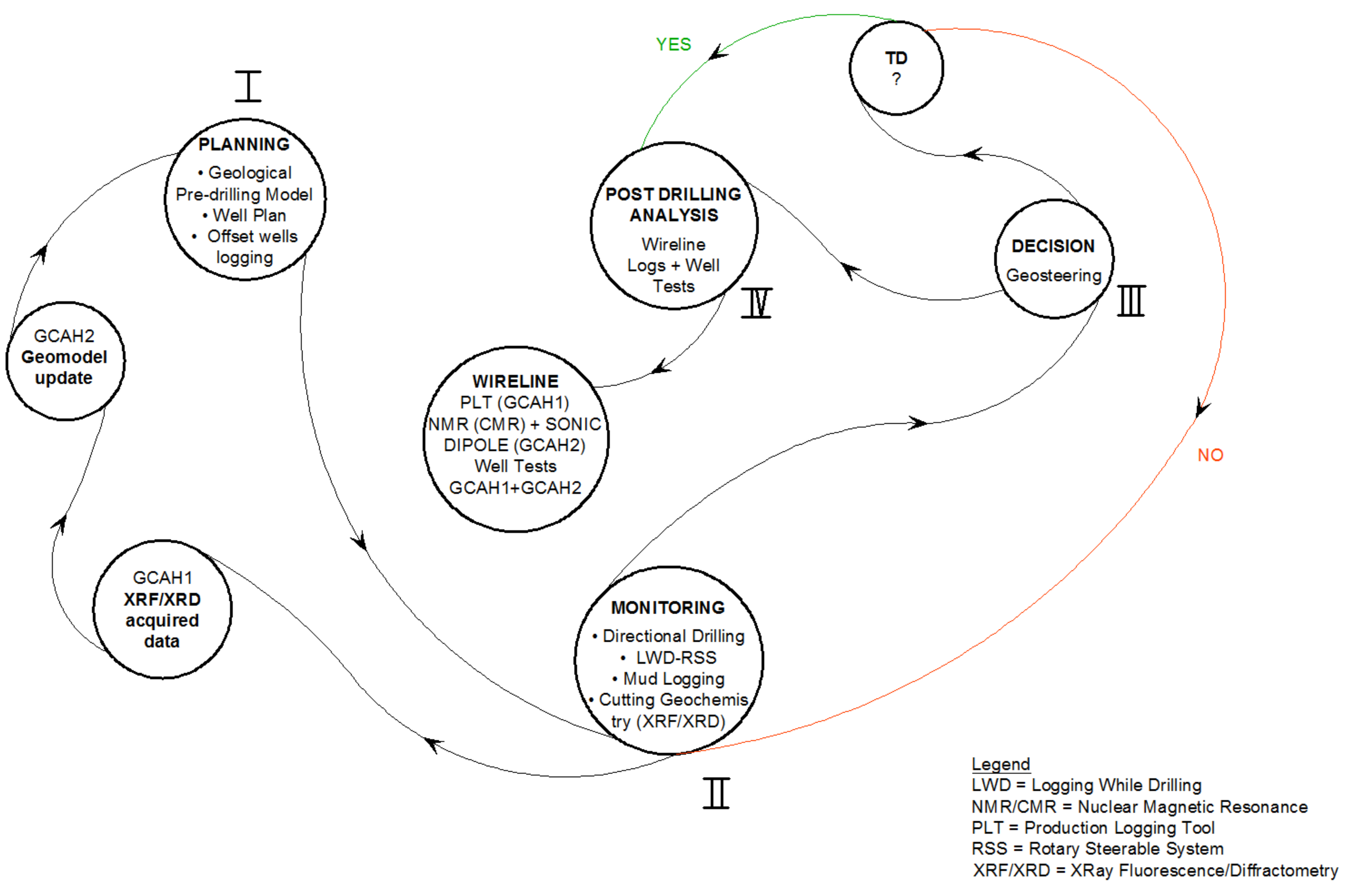


Cachan

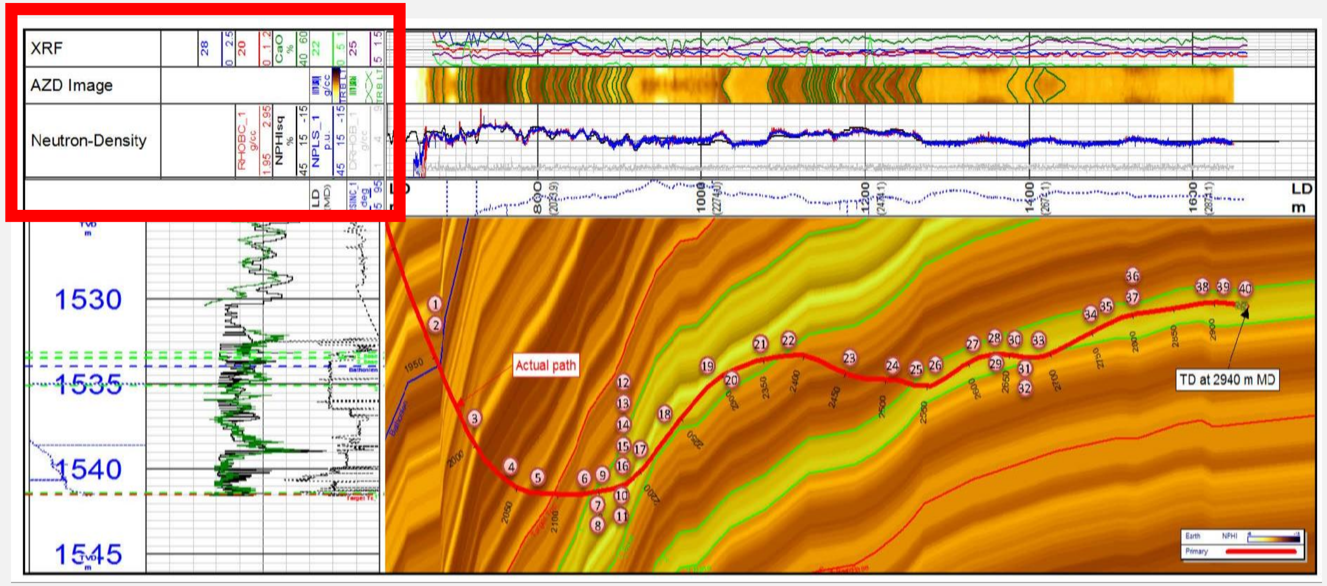


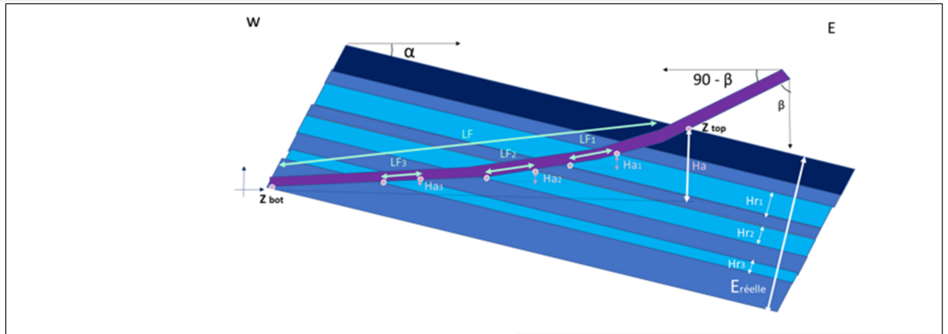
Grigny

SH GEOSTEERING WORKFLOW



GEOSTEERING WELL GCAH2. TRAJECTORY CORRECTIONS



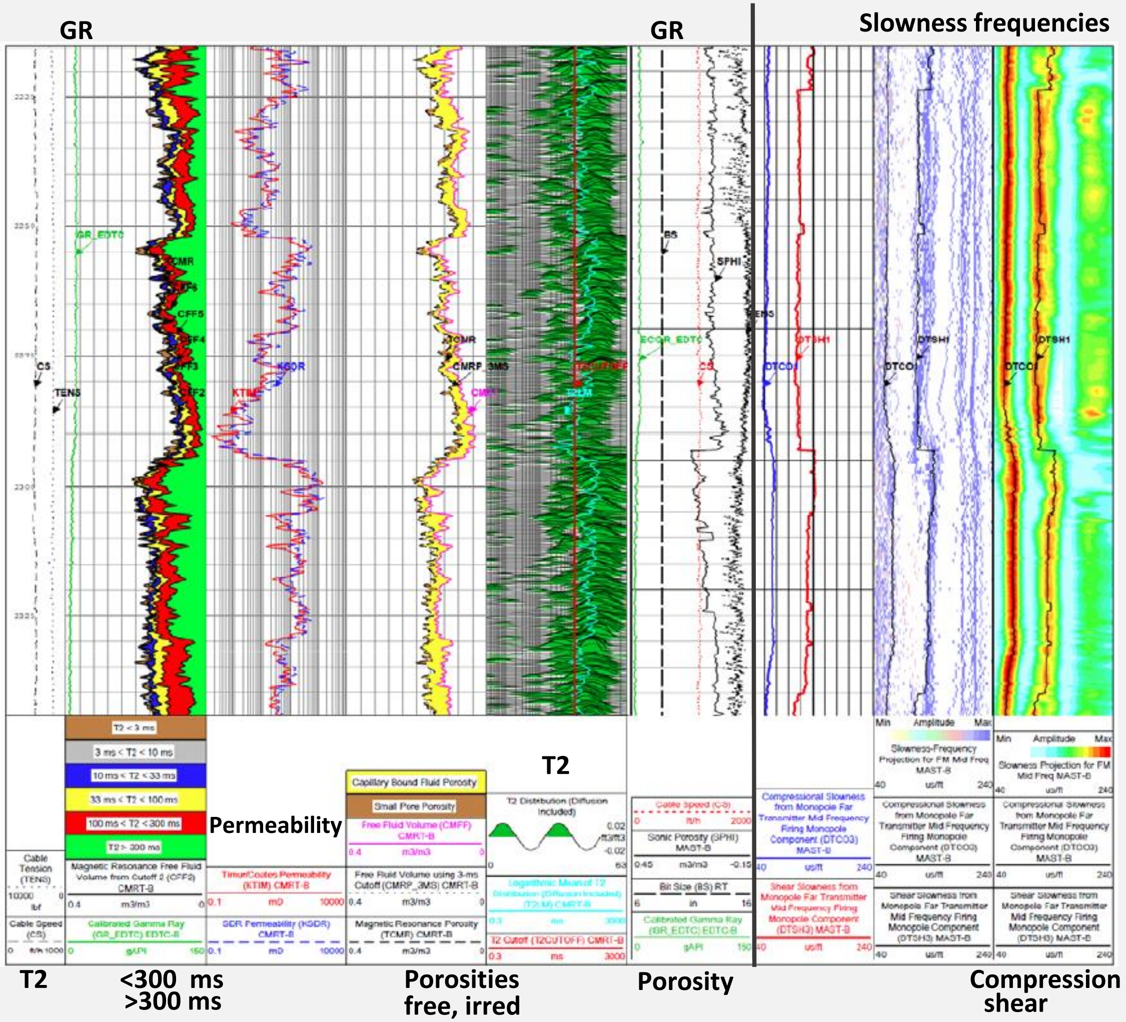


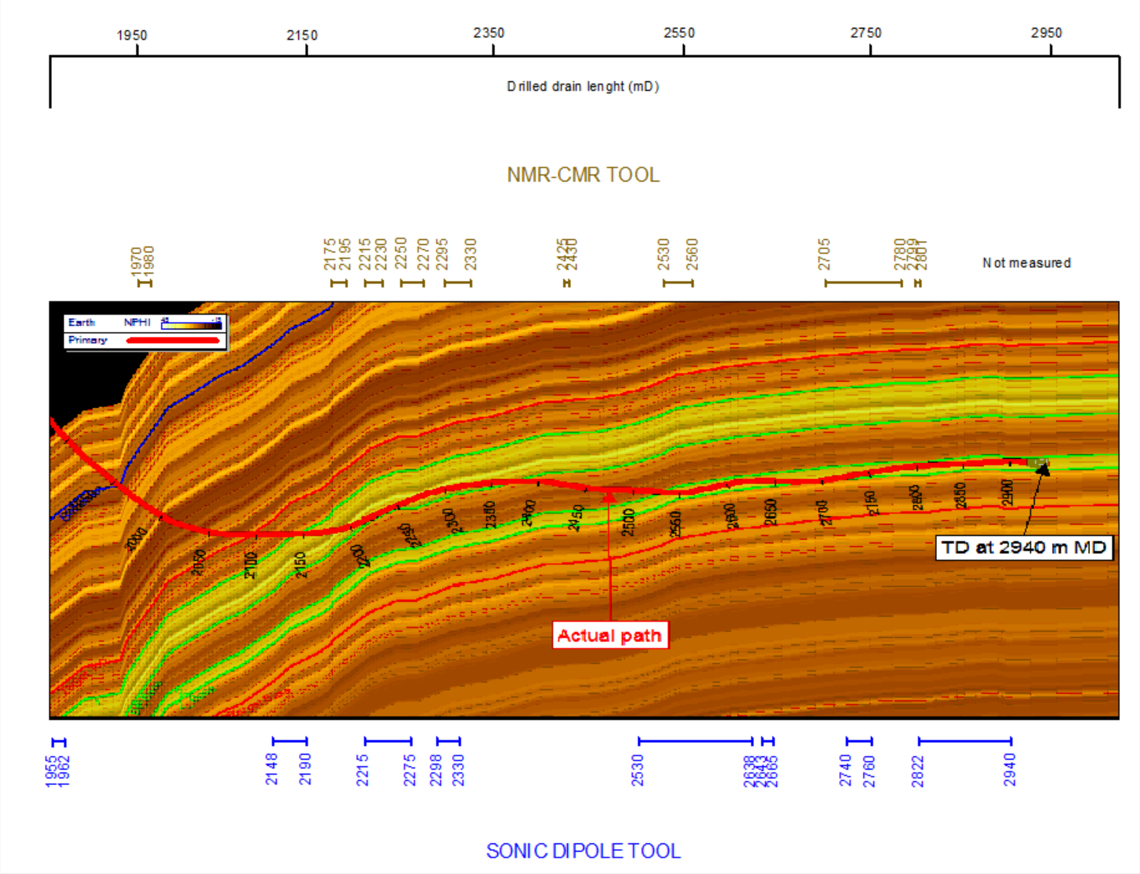
α = 1° **β = 88°** **E réelle** = 60 m **Alors :** **Ha** : 40 m ; **LF** : 1146 m	=> Well architecture similar to GCAH1 which intercepts all layers over large lenghts

α = 5° **β = 88°3** **E réelle** = 20 m **Alors :** **Ha** : 11 m ; **LF** : 104 m	=> The whole reservoir is drilled where do we go next? upwards?

- **Challenge: Real time trajectory corrections**
  - 1 to 5° varying dips, impacting drain effetive length
  - Reconcile tracking of thin (#1 m) high porosity layers with target matching delays induced by high bit to RSS recording distance (#20 m)

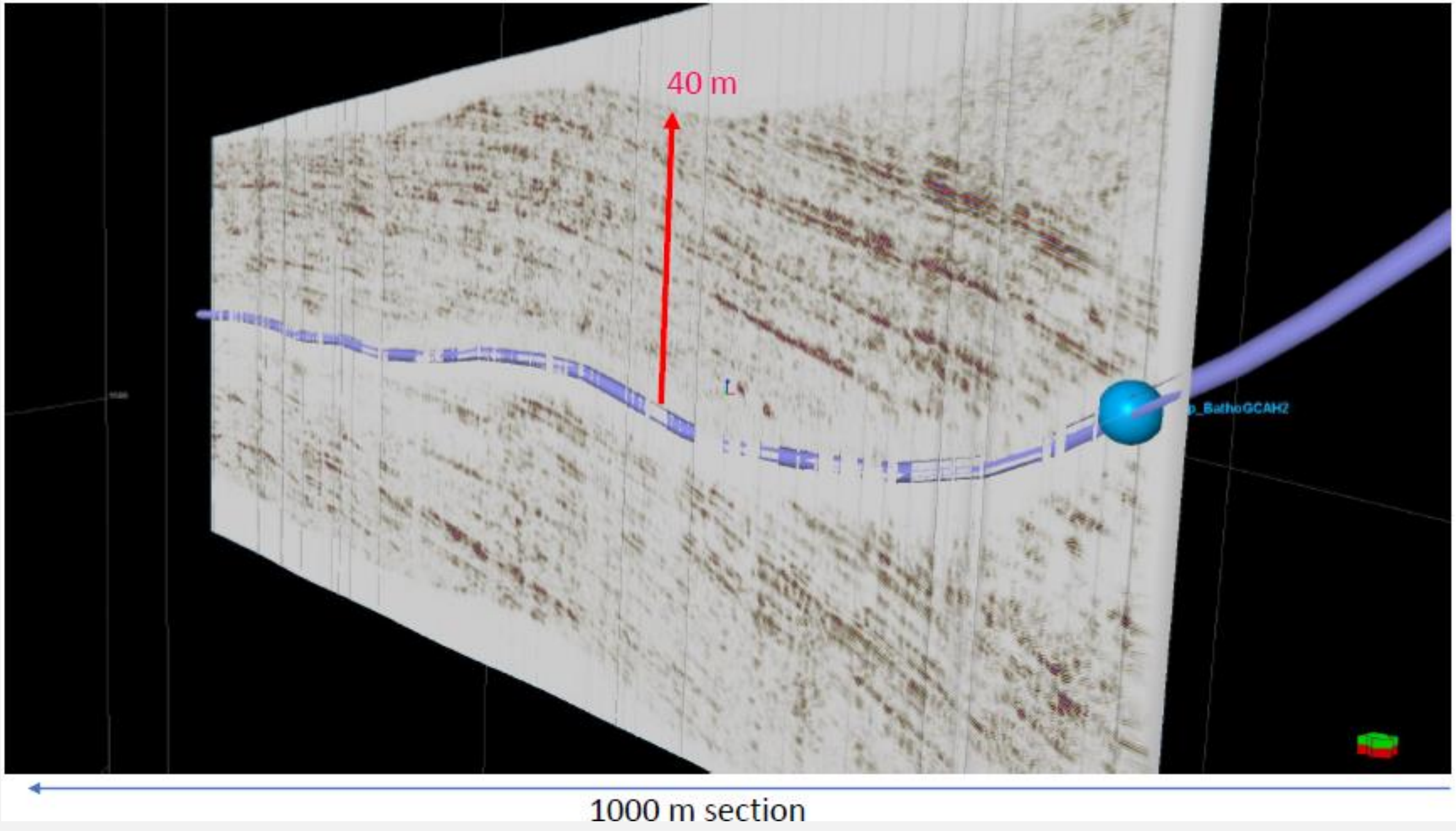
GCAH2. NMR/CMR VS SONIC DIPOLE CORRELATION





Well GCAH2. NMR/CMR vs Sonic Dipole porosity/permeability/porosity logging tool correlations

SONIC IMAGING. TO DEFINE LAYER CONTINUITY



Source: Wilemaker et al, 2020, SPWLA 61st Annual Symposium

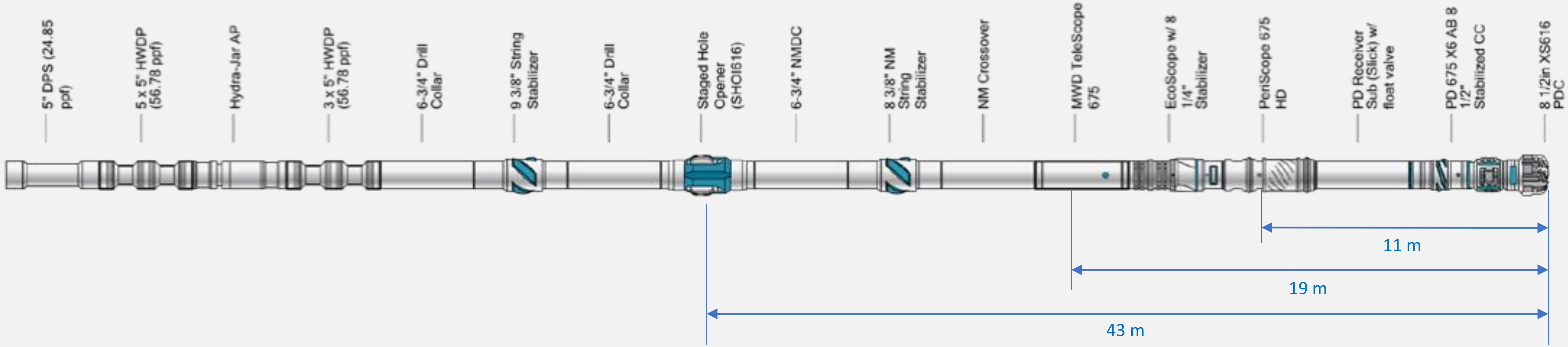
GEONAVIGATION BHA

PERISCOPE HD, ECOSCOPE SLB ™

Essentially PDC, RSS, no motor, MWD et LWD:

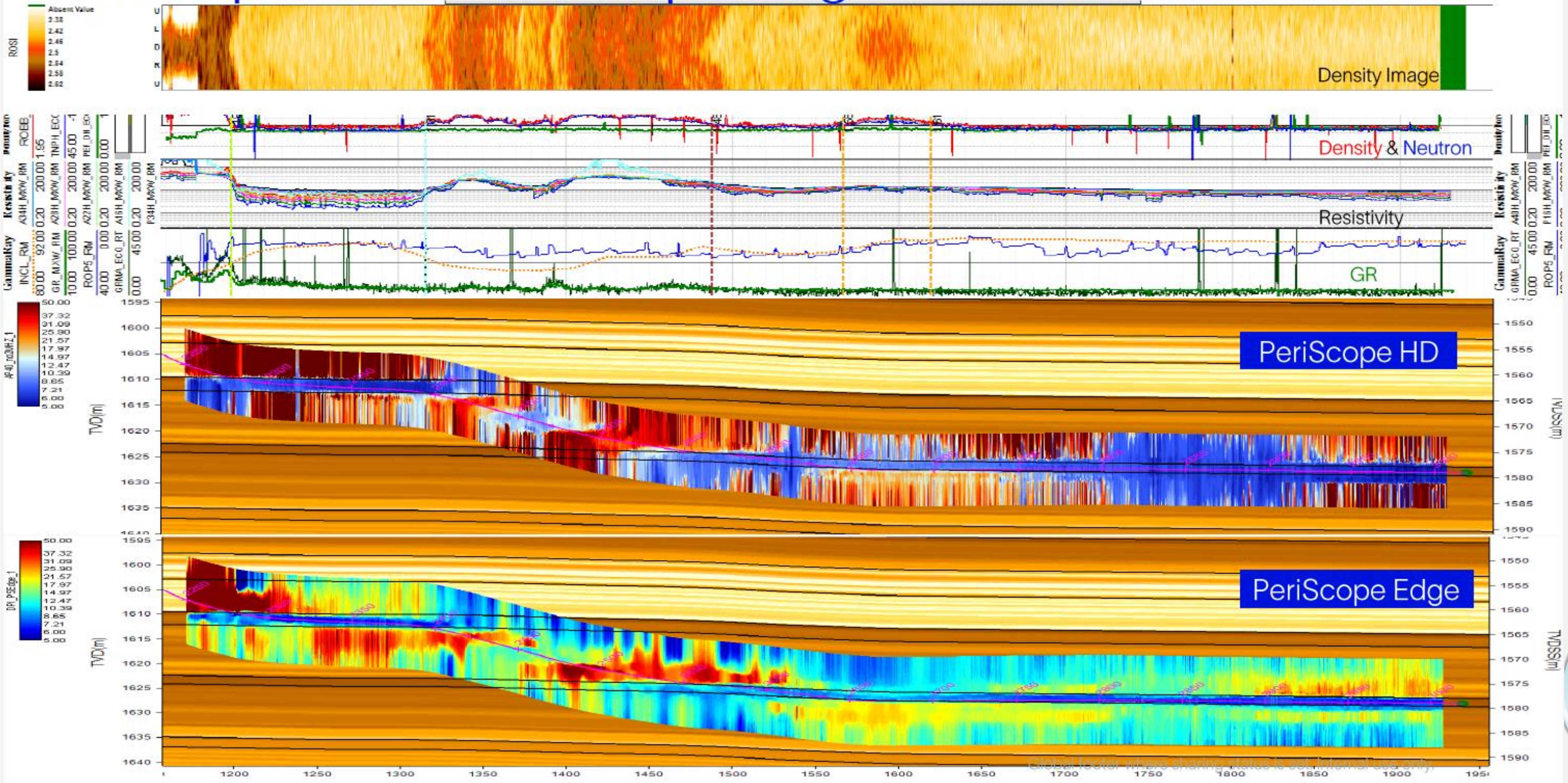
Periscope HD = azimuthal resistivity-> vision 2mTVD below and above the bit

Ecoscope = GR Density, neutron porosity



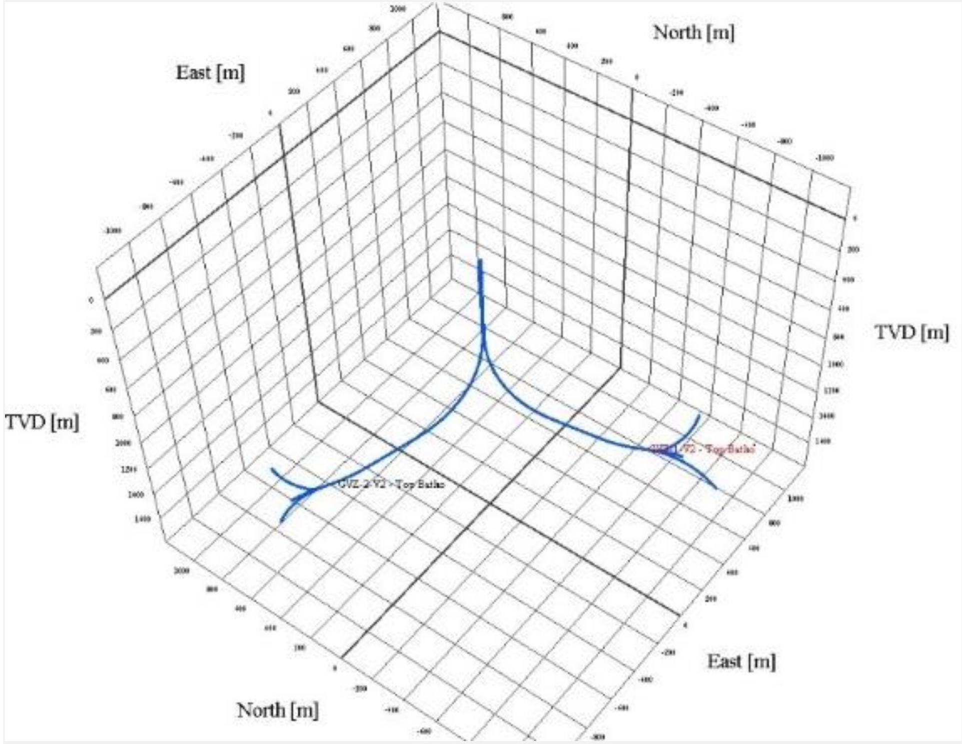
Drilling 8-1/2’’ with 9-1/2’’ fixed blade hole opener

PeriScope HD & PeriScope Edge

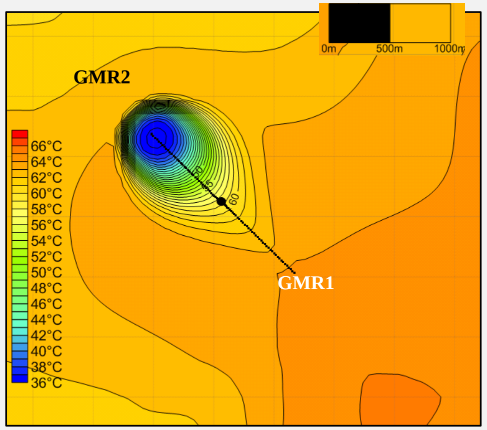


Source: SLB

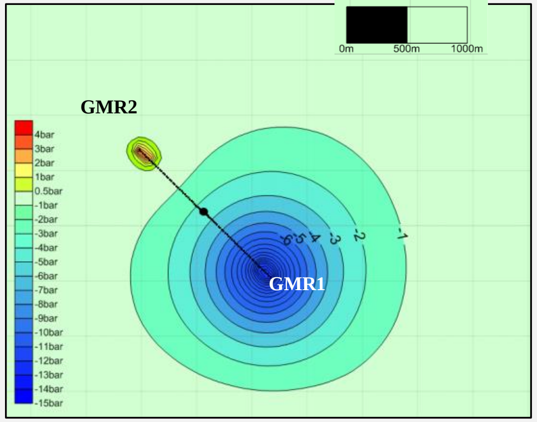
MULTIRADIAL WELL ARCHITECTURE



WELL ARCHITECTURE	CUMULATED DRAIN LENGTH (m)	MAXIMUM PRESSURE DEPLETION @400 m^3/hr (bar)	COMMENTS
Conventional Single (45° incl.) drain	15	38	
Multiradial Three (1x45° + 2x70° incl.) drains	190	37	High drain Interference Impact
Multiradial Three (1x45° + 2x80° incl.) drains	240	25	Limited drain Interference Impact



Conventional (single, inclined 45°, leg) well architecture



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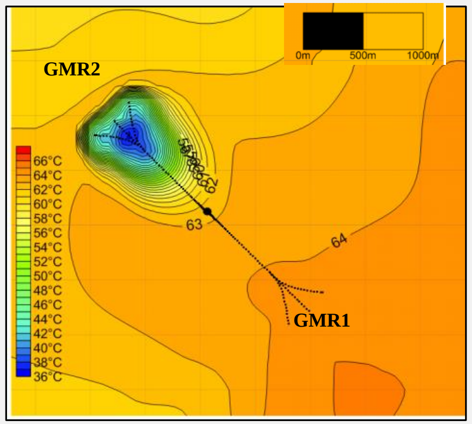
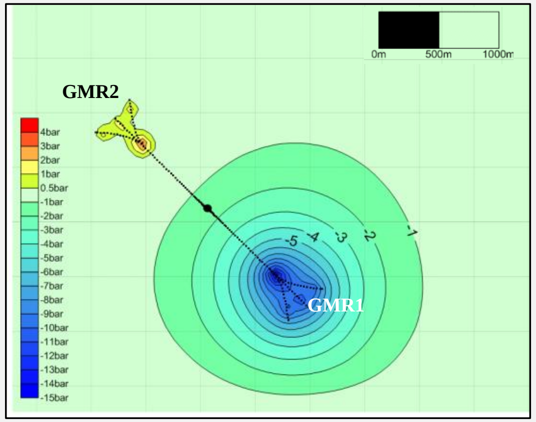
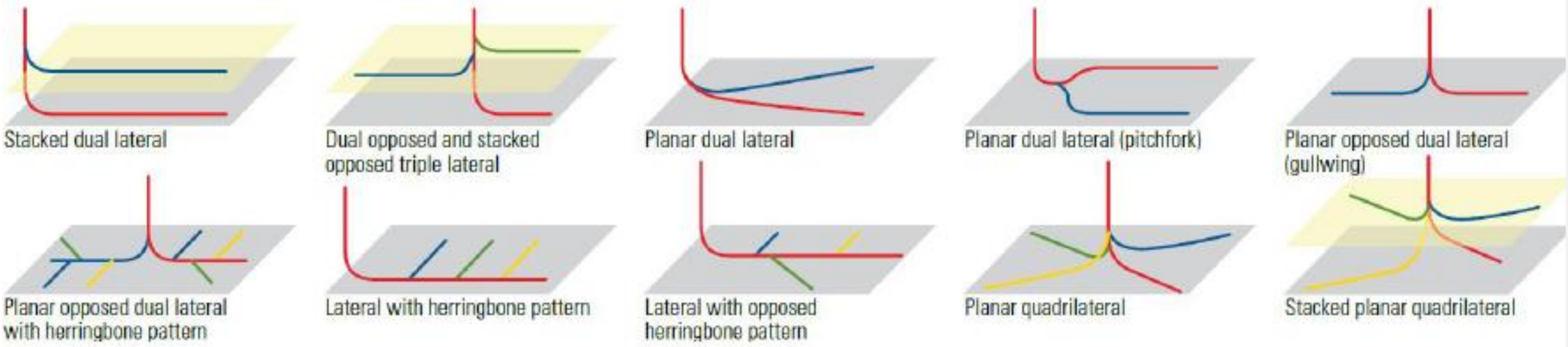


Innovative (three, inclined 80°, radial drain) well architecture



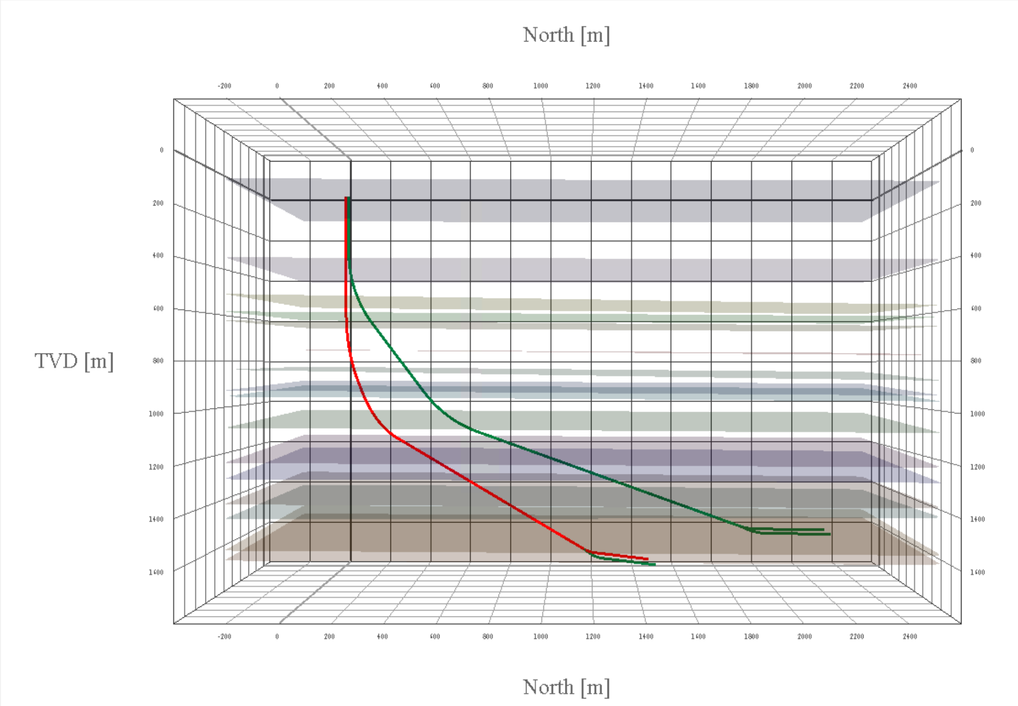
Innovative (three, inclined 80°, radial drain) well architecture

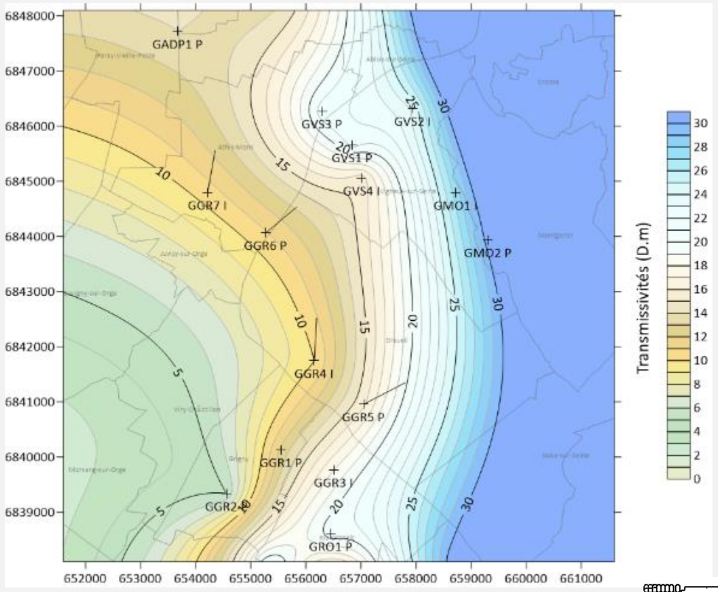
CANDIDATE MULTILATERAL WELL DESIGNS



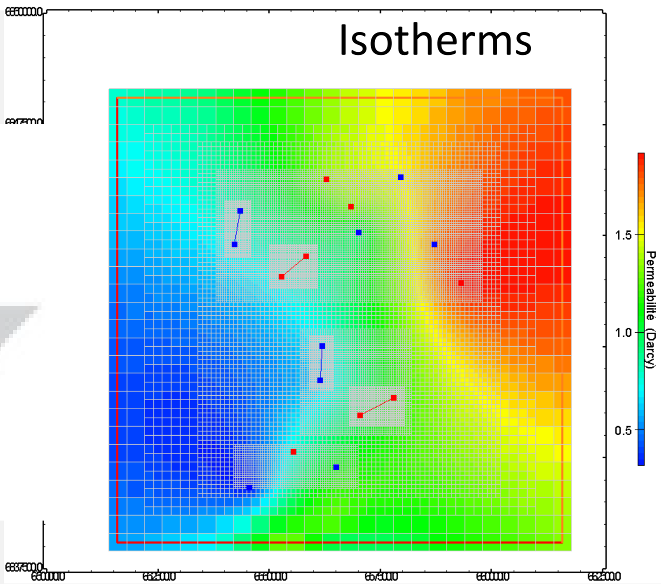
Source: SLB Oilfield Review, Defining Multilateral wells, 19/04/2021

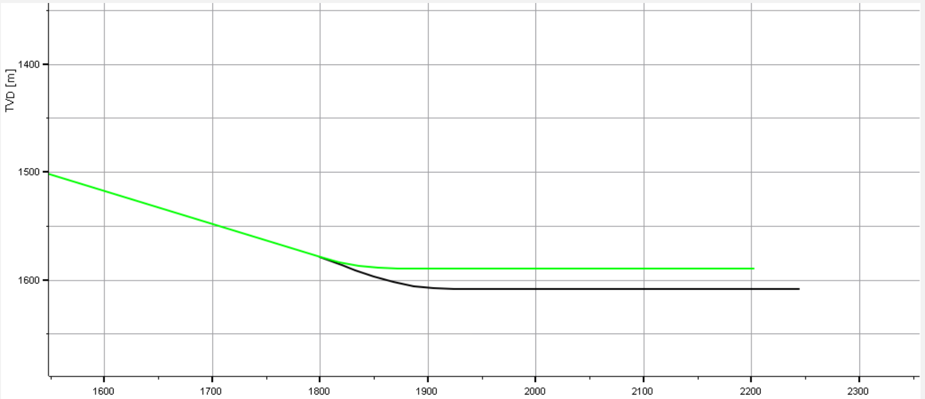
MULTILATERAL WELL ARCHITECTURE

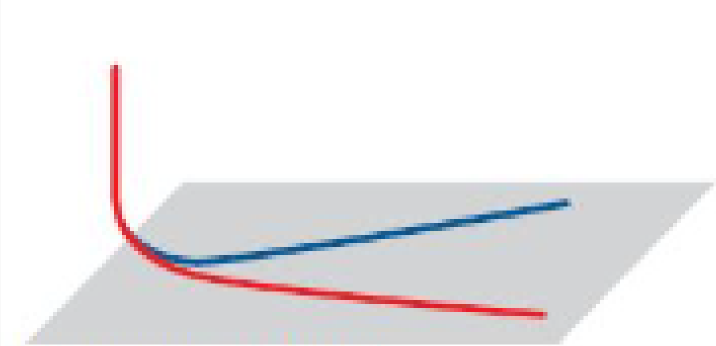




Transmissivities, Dm

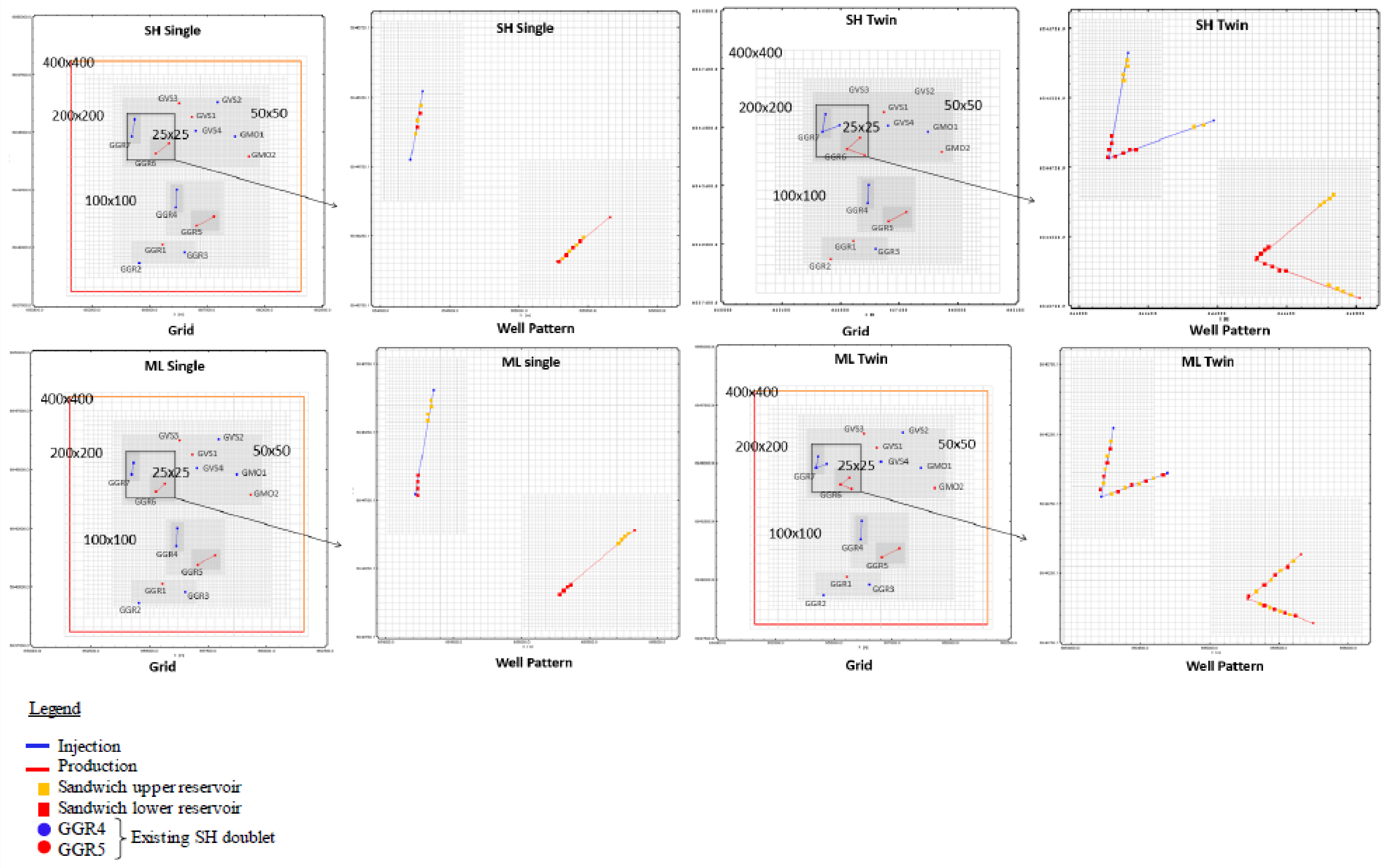




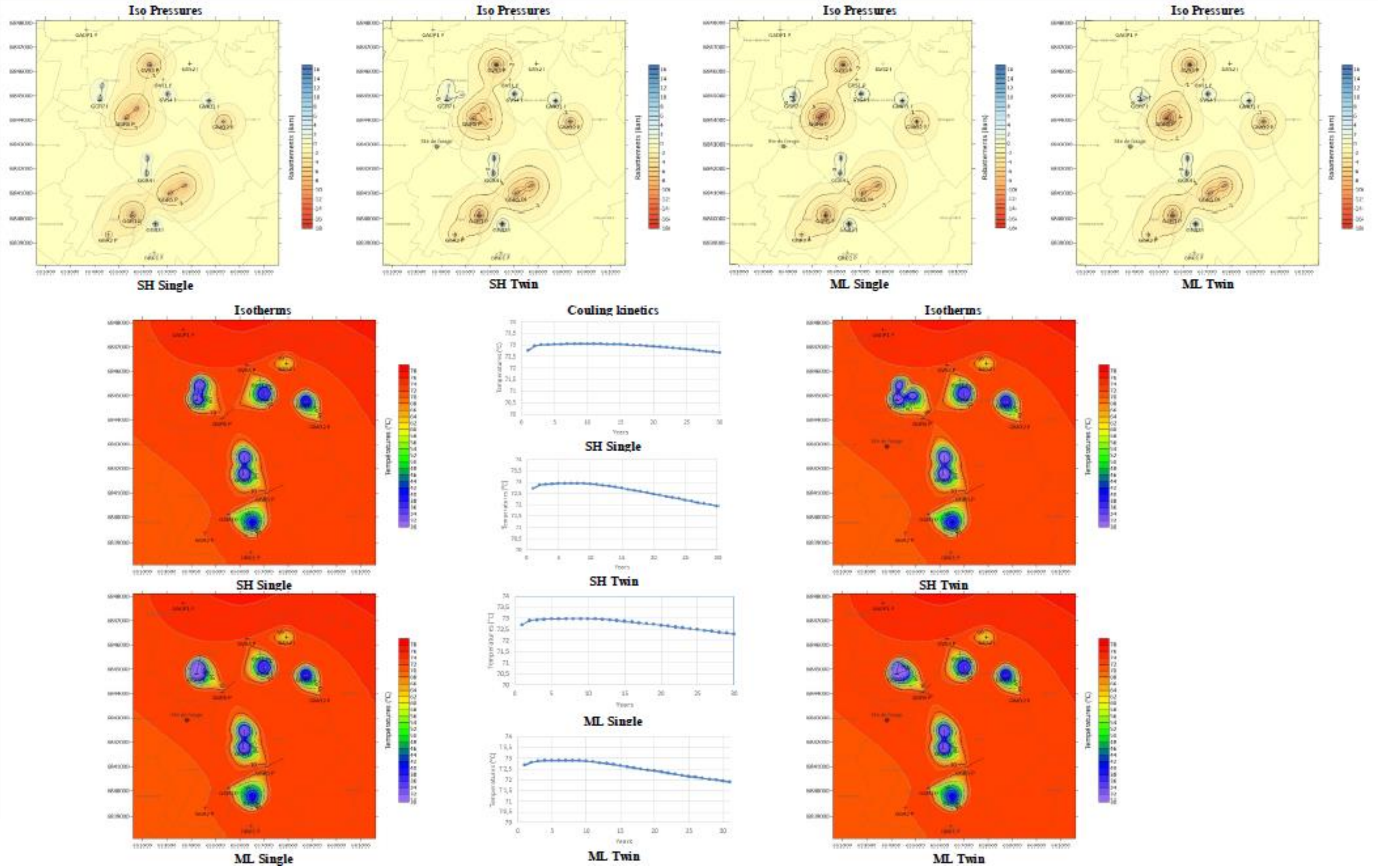


Planar dual lateral

Extended Reach (ER) subhorizontal (SH) and Multilateral (ML) single and twin azimuthal drain configurations (according to sandwich model)



Thirty year predictive hydraulic and thermal patterns respective to pressure drawdowns/uprises and cooling kinetics related to two single/twin subhorizontal and multilateral ML well architectures



Subhorizontal vs multilateral simulation results

Well architecture	Type	30 yrs average vs maximum pressure drawdowns & rises (bar)		30 yrs Temperature cooling (°C)
		Production	Injection	
Subhorizontal (SH)	Single	-11,3/-12,3	+16,7/+17,5	-0,2
	Twin	-6,5/-8,4	+11,7/+13,7	-0,55
Multilateral (ML)	Single	-9/-9,4	+15,6/+18	-0,65
	Twin	-5,5/-7	+12,4/+13,6	-1

Well architecture comparative figures

Well Architecture	Flow Performance (m3/h)	Technological Maturity	CAPEX (k€)	Pilot Hole back up	Remarks
SH	450	High	15 600	No	80° landing angle recommended VSP impedance inversion suggested
MR	350	Medium	15 300	Optional / Yes	80° landing angle recommended Delicate leg evaluation/stimulation
ML	450	High	18 000	Optional	500 m^3/h eligible (sub)vertical mother bore recommended

CONCLUSIONS

(i) All three reviewed candidates achieve nominal 350 to 450 m^3/h flow ratings taking advantage of the latest issued drilling, logging and above all geosteering/well placement technologies.

(ii) Candidate architectures exhibit capital intensive (CAPEX) mining investments balanced by the benefits expected from important OPEX savings, the latter pleading in favour of the combined subhorizontal x multilateral extended reach mining scheme, which appears to best suite the production sustainability, thermal longevity and environmental safety standards required by the geothermal community at large.

THANK YOU FOR YOUR ATTENTION !

Geothermal Energy:
renewable-sustainable-proven-achievable-realistic