Optimization of energy valorization on EGS plants

Application to Soultz-sous-Forêts demo-site

Eléonore Dalmais – 18/02/2021

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Outline

Geothermal Winter School 2021

Introduction

Soultz-sous-Forêts EGS site

Impact of colder reinjection on surface facilities

Impact of colder reinjection on the reservoir

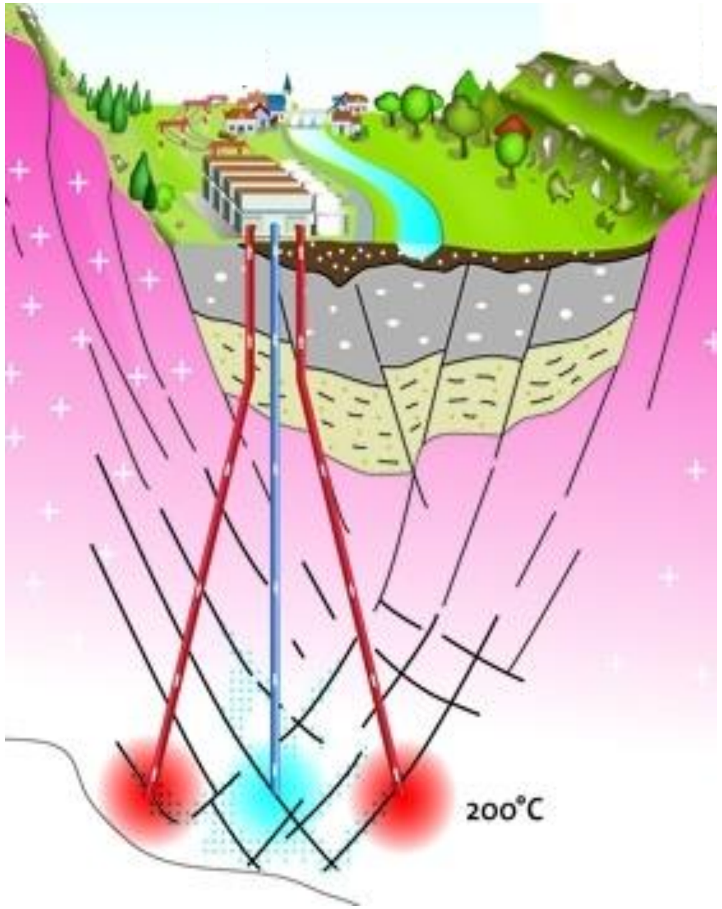
Conclusion and perspectives

Introduction

- Let's start by a question…

With a fixed well configuration (one doublet for instance), how would you enhance energy production?

- Write your ideas in the chat



Introduction

Thermal power capacity from a geothermal plant

$$P_{THERM} = \dot{m} \times [c_P]_f \times (T_{PROD} - T_{REINJ})$$

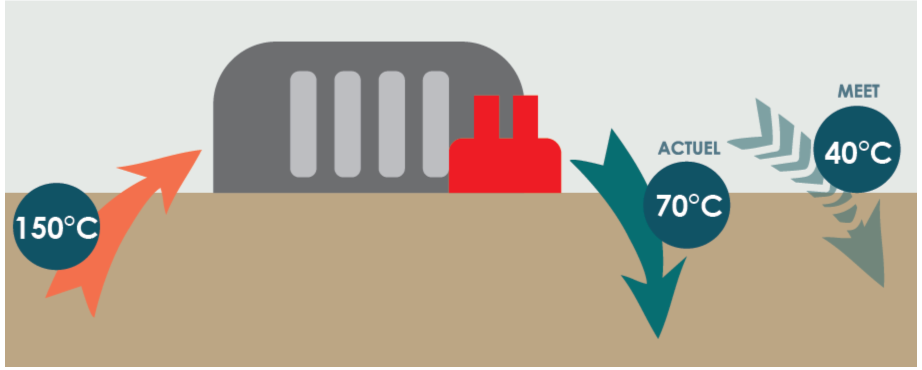
By stimulating the well

MEET demo-site
Chemical stimulation in
United Down Deep Geothermal Project
(Cornwall, UK)

c

By extracting more calories
(reinjecting at colder temperature)

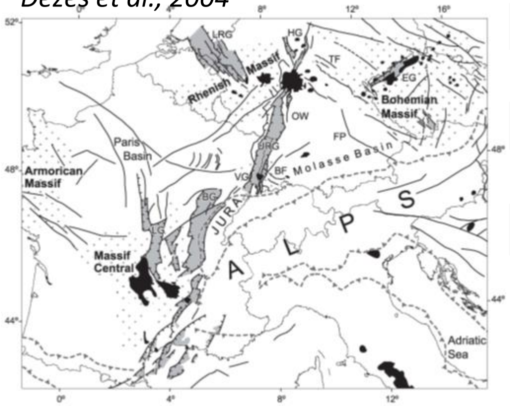
MEET demo-site
Colder reinjection
Soultz-sous-forêts (SsF) EGS power plant
(Upper Rhine Graben, France)



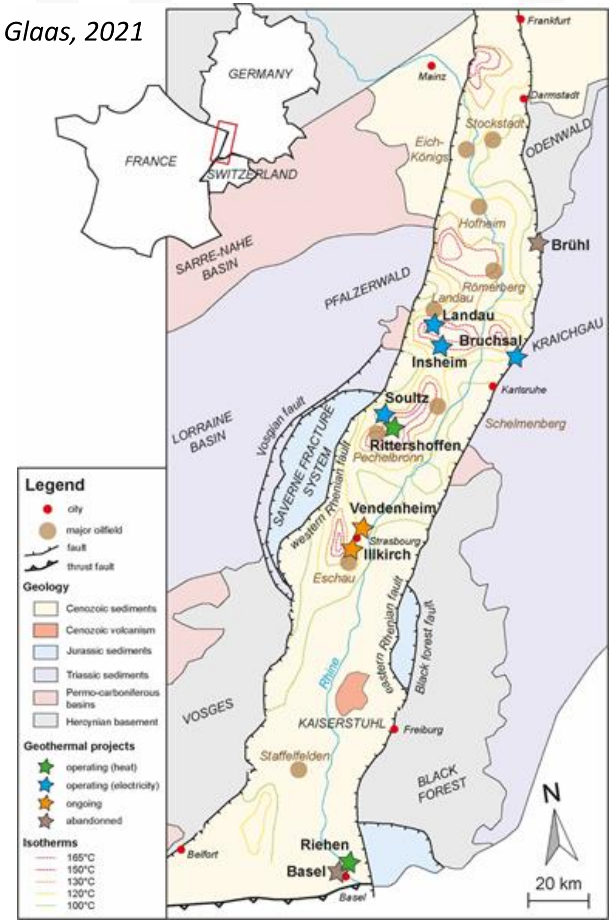
Soultz-sous-Forêts demo-site presentation

Upper Rhine Graben

Dèzes et al., 2004

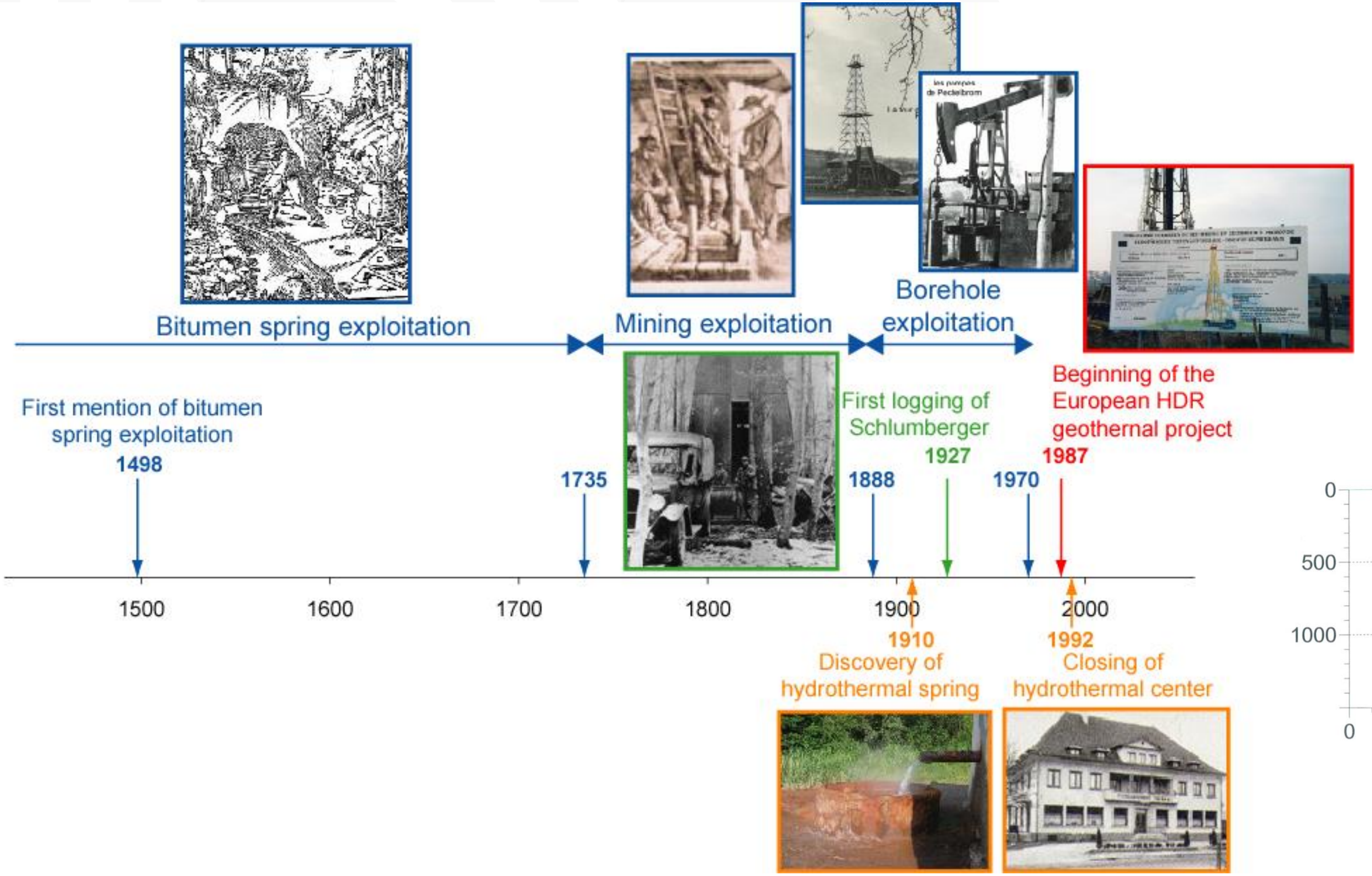


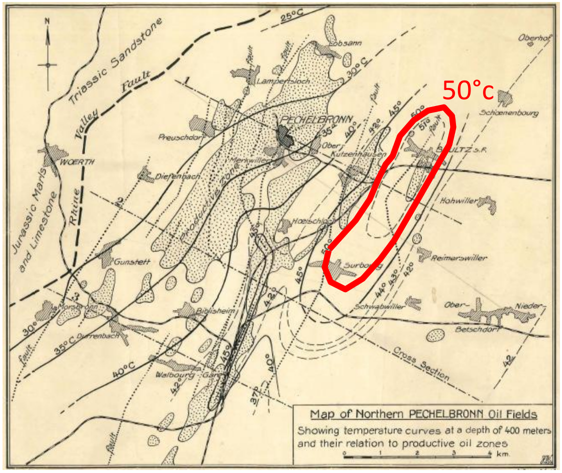
Glaas, 2021



- URG belongs to West-european rift system
- Well known thermal anomalies with thermal gradient up to 100°C/km
- Development of Enhanced Geothermal Systems technology on the Soultz-sous-Forêts project, deep in the granitic basement (5km depth)
- New plants developped base on this knowledge, targeting shallower depths (fractured sediment / basement interface)

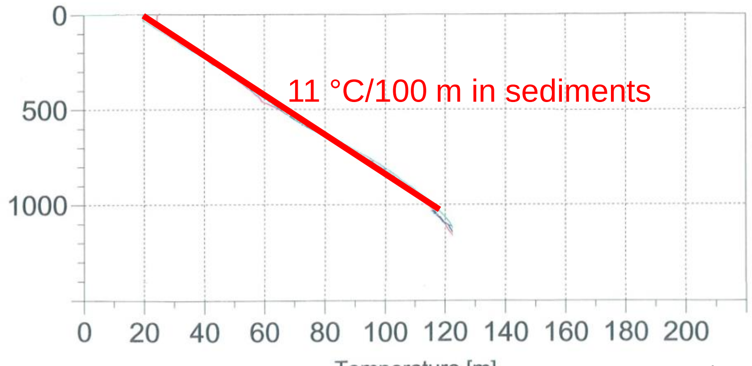
SsF historical background





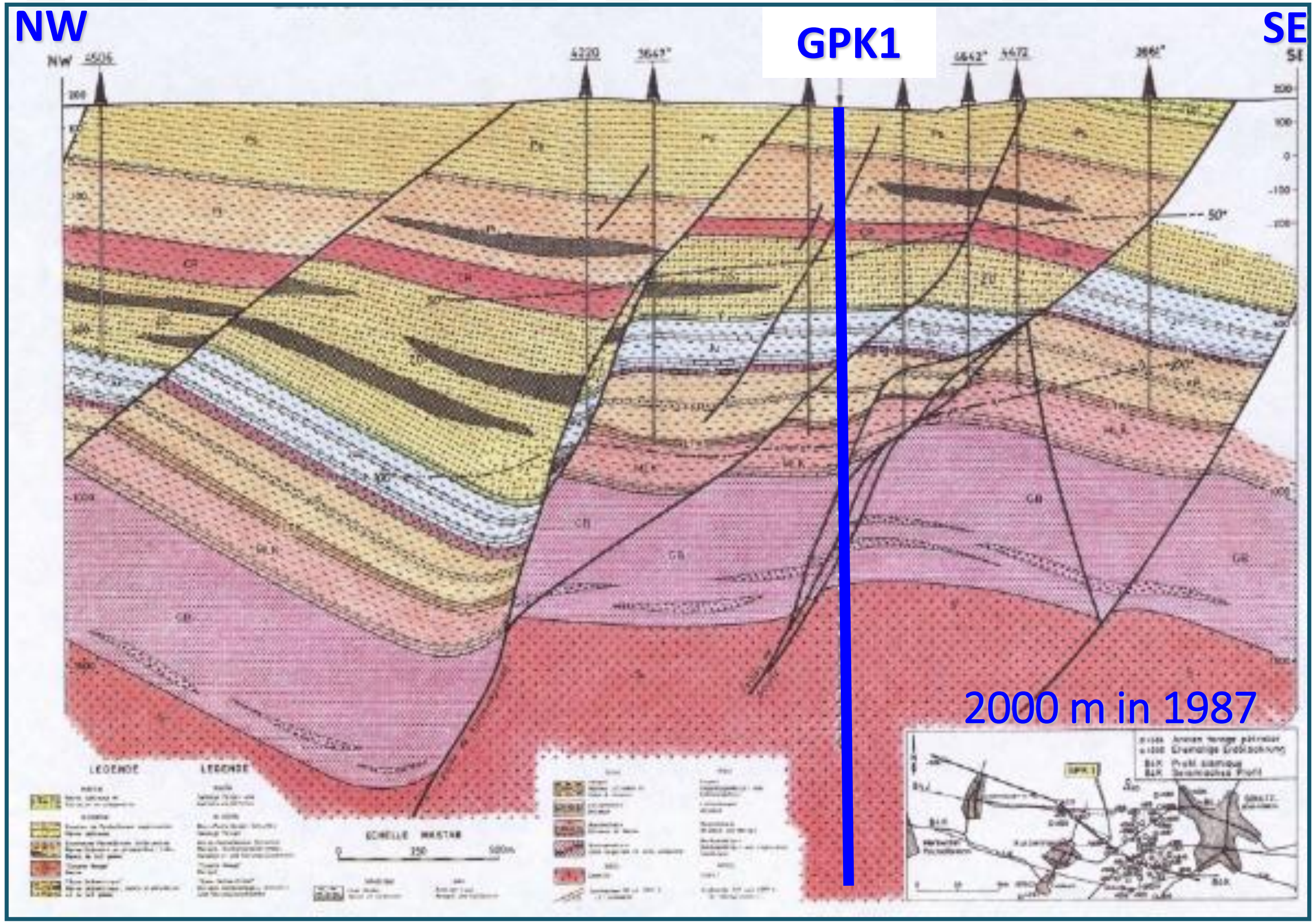
Temperature @ 400m depth

Hass et Hofmann, 1929



From Liag

GPK1



BRGM

- Initial objective to find 200°C @ 2 km depth and create a reservoir by hydrofrack (hot dry rock)

BUT

- Only 140°C @ 2000m (convection in the deepest sediments and top basement)
- Granite naturally altered and fractured
- Circulation of a natural brine with high salinity

THEN

- The concept switch gradually to the enhancement of initial permeability by stimulating technics (hydraulically and then chemically) -> EGS

Natural brine

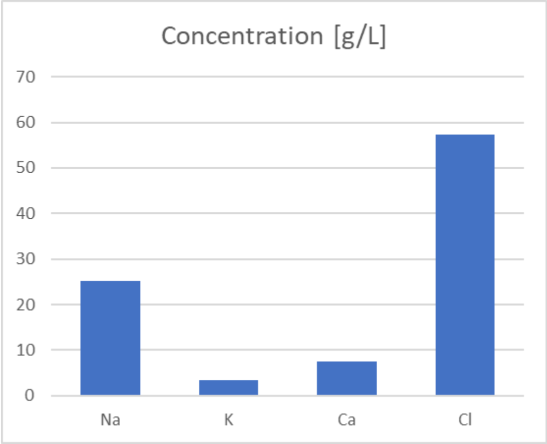
Salinity ~100g/L, pH ~ 5.0

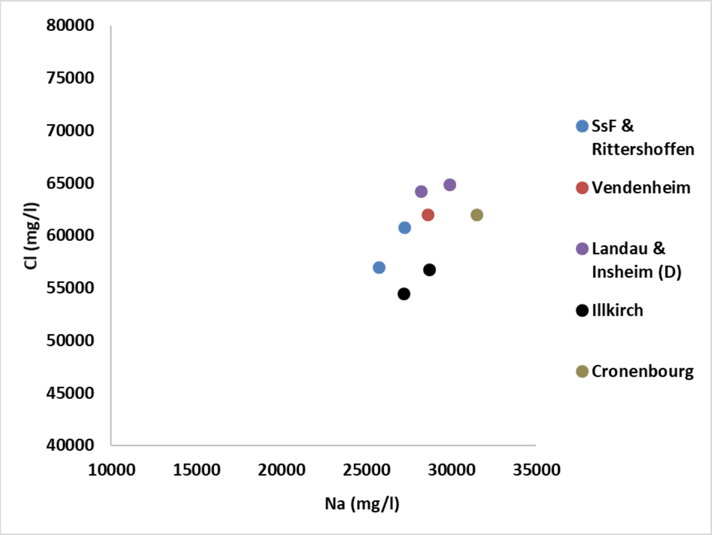
Na-Ca-Cl brines, with important concentrations of K

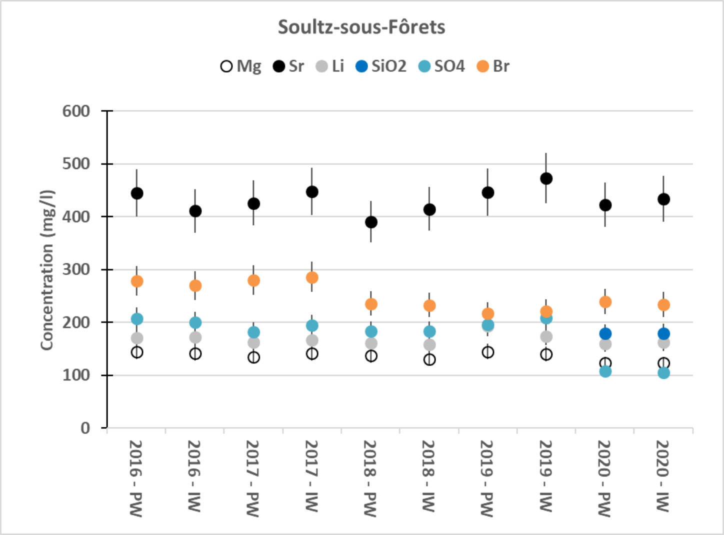
- Homogeneous in URG

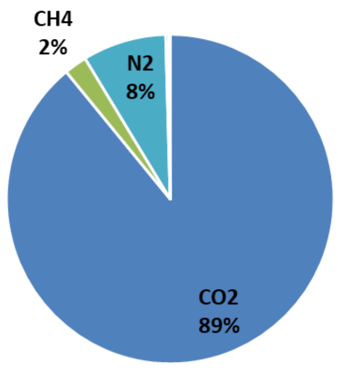
Gas-Liquid Ratio 1 Nm^3/m^3 mostly CO2

High Li concentration ~170 mg/L



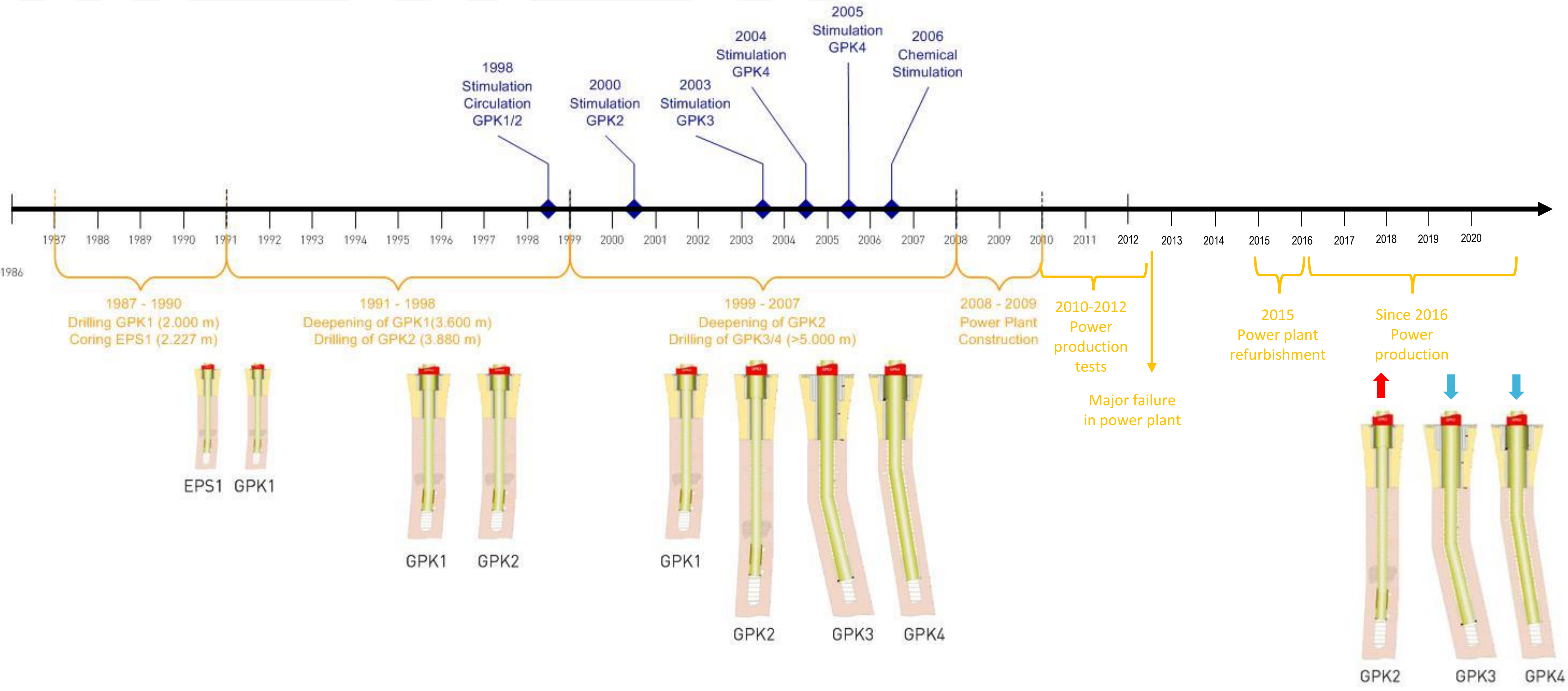




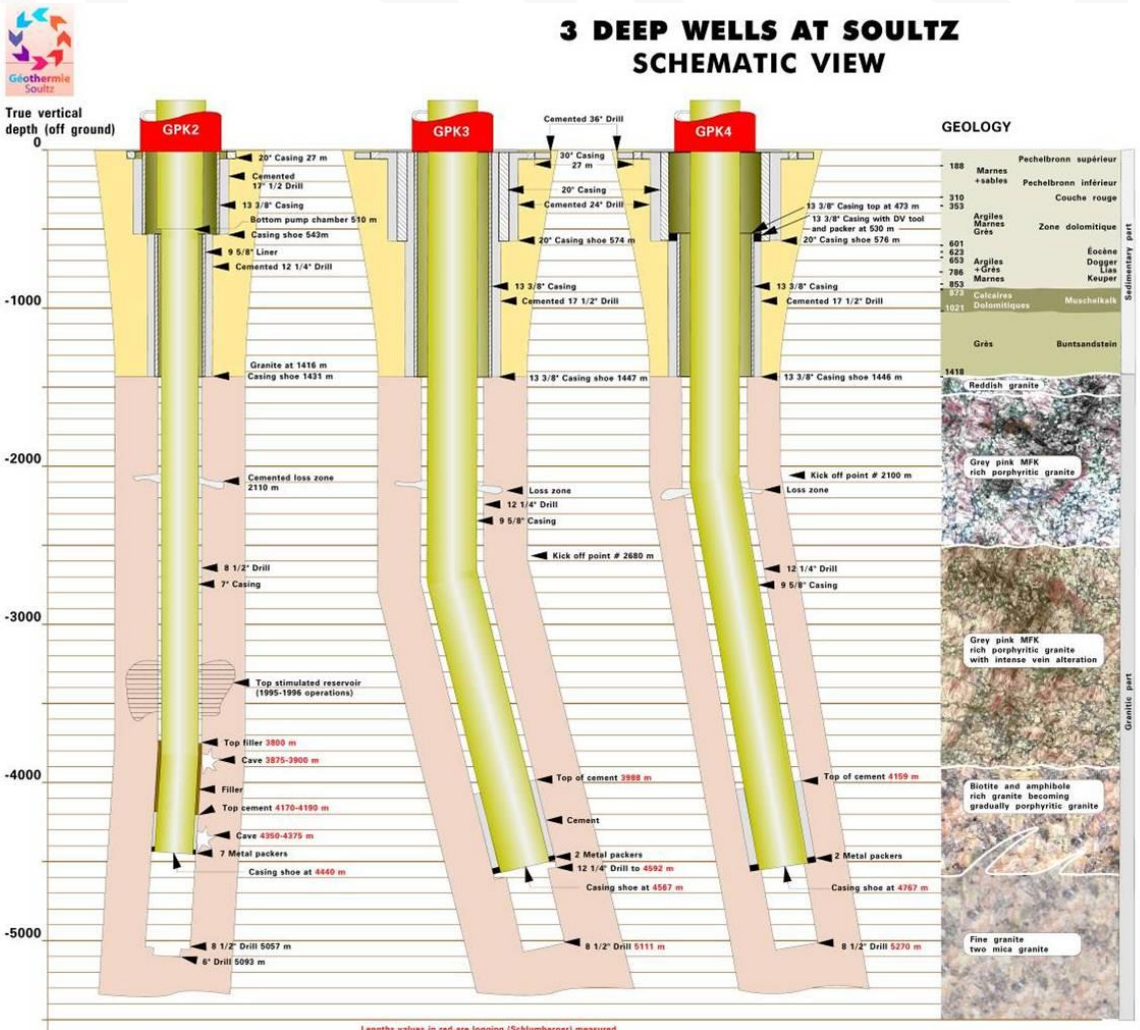


Bosia et al, 2021

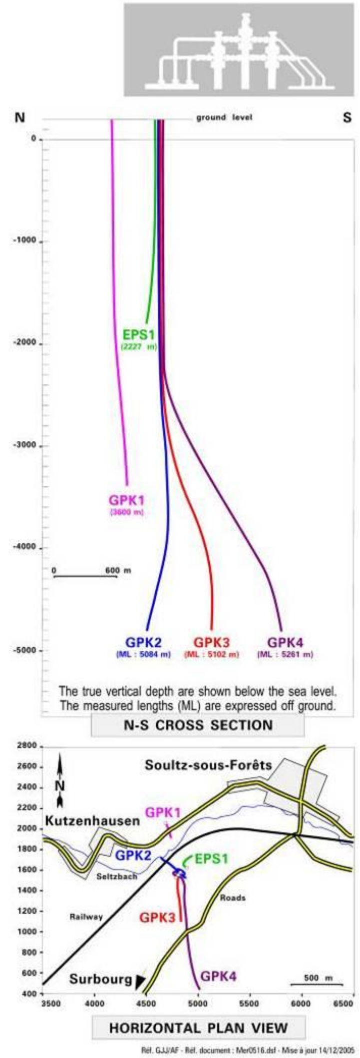
SsF development



Current situation



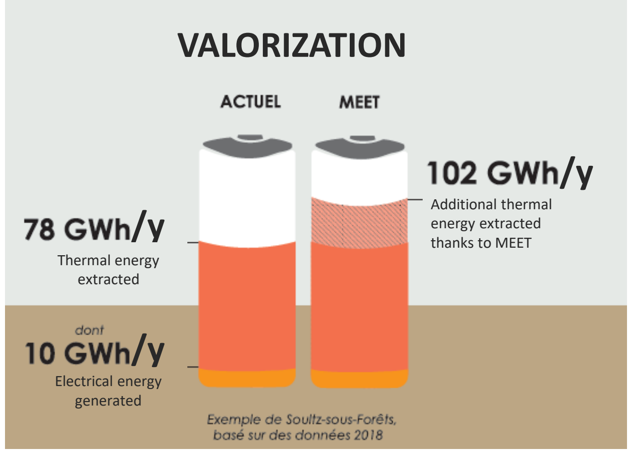
EEIG Heat Mining



3 wells @ 5 km depth (GPK2 – 3 – 4)

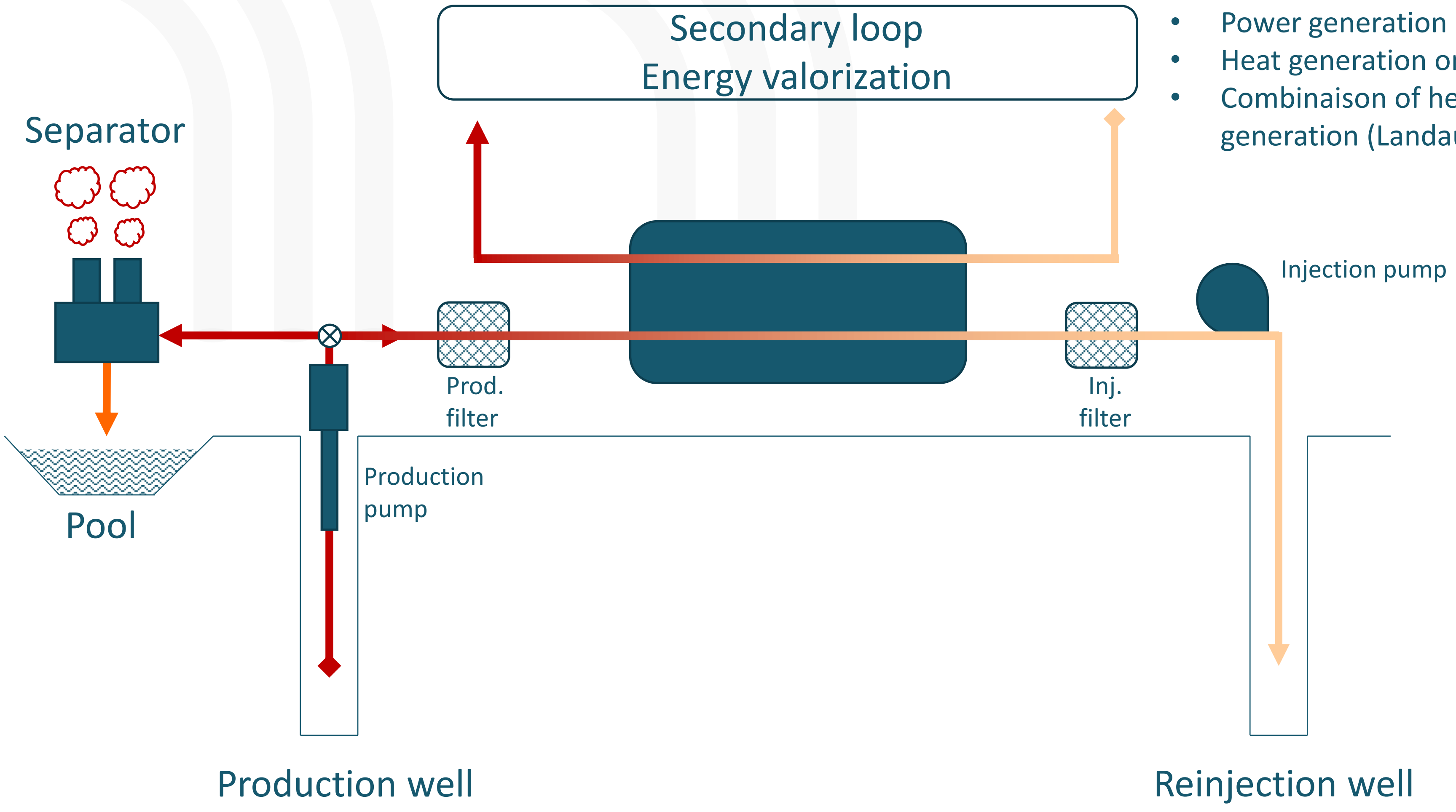
- Max temperature: 200°C @ 5 km
- WH Production Temperature: 150°C
- Reinjection temperature: 65 – 70 °C
- Flow rate: 30 kg/s

Power generation with ORC: **1.7 MWe**



Geothermal loop

- Power generation only (SsF)
- Heat generation only (Rittershoffen)
- Combinaison of heat and power generation (Landau)



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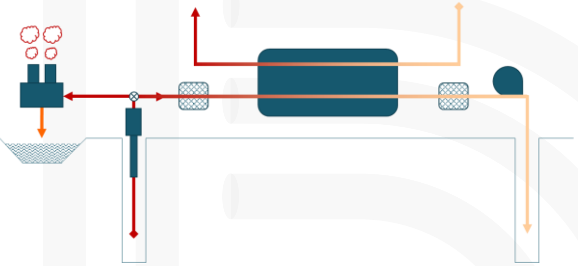
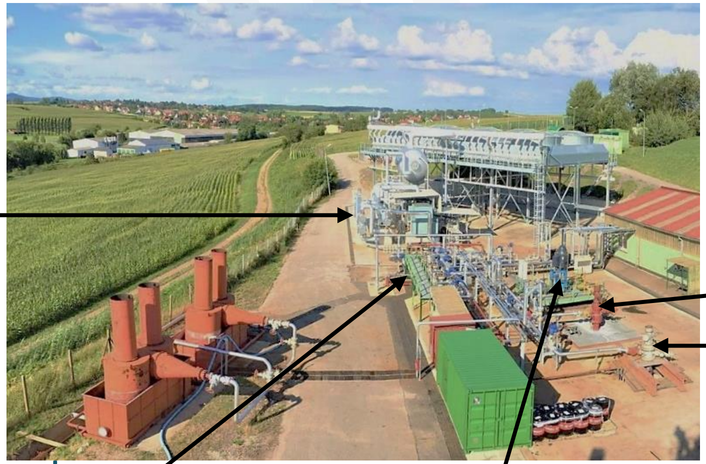
Geothermal loop



Heat exchangers
(preheaters and evaporator)



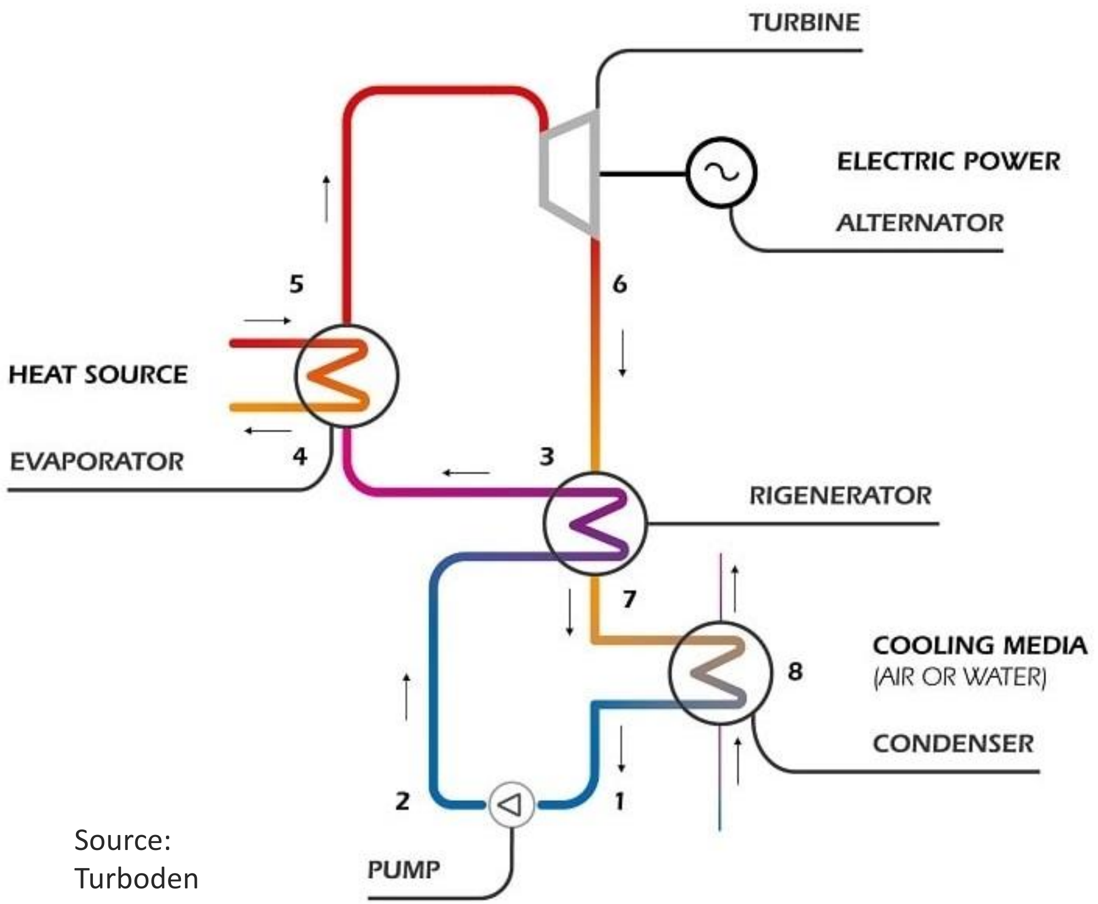
Separators

Injection wells (GPK3 and GPK4)

Production filters

Production well (GPK2) with line shaft pump

Power production



Source:
Turboden

Use of an ORC « Organic Rankine Cycle »
Binary fluid (BF) : isobutane

- 4→5: Preheat and vaporization of BF in the evaporator using geothermal heat
- 5 → 6: BF vapor rotates the turbine, which is directly coupled to the electric generator
- 6 → 7: Exhaust vapor flows through the regenerator, where it heats the organic liquid (2 → 3)
- 7 → 8 → 1: BF is condensed in the condenser and cooled by the cooling circuit
- 1 → 2: BF is then pumped into the regenerator and evaporator

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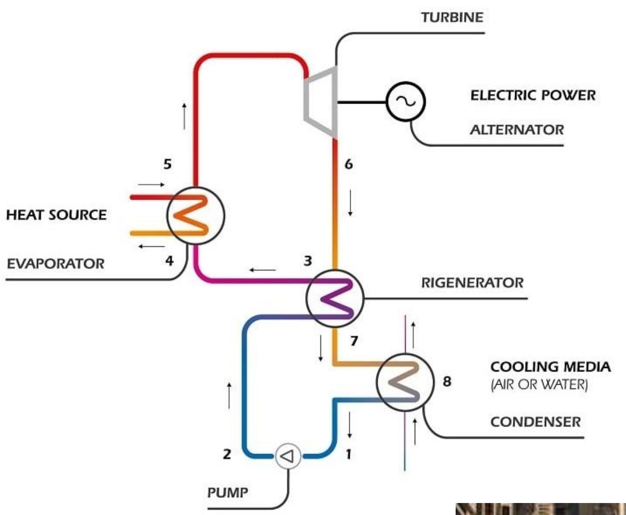
Power production



Pump

Aerocondensor

Turbine

Generator

Regenerator

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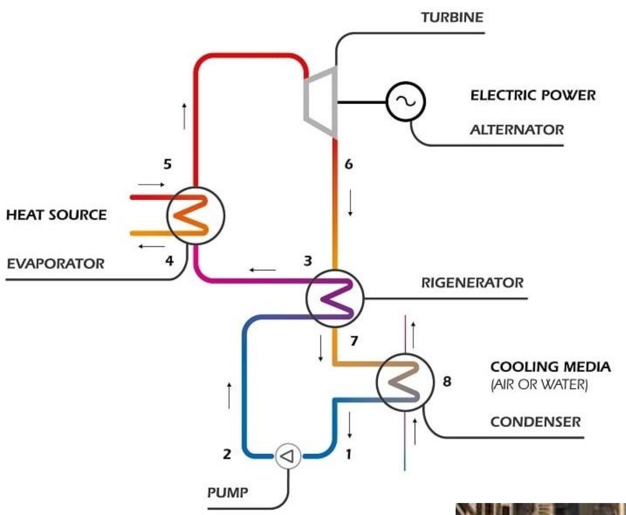
Power production



Pump

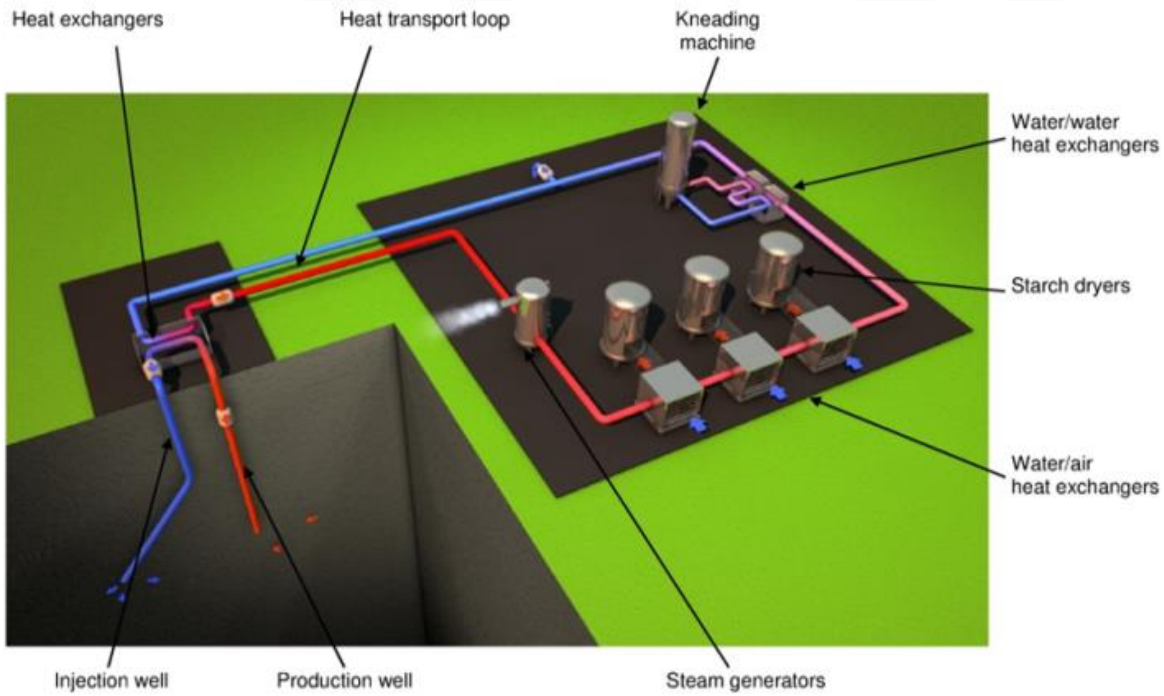
Aerocondensor

Turbine

Generator

Regenerator

Industrial heat, ECOGI



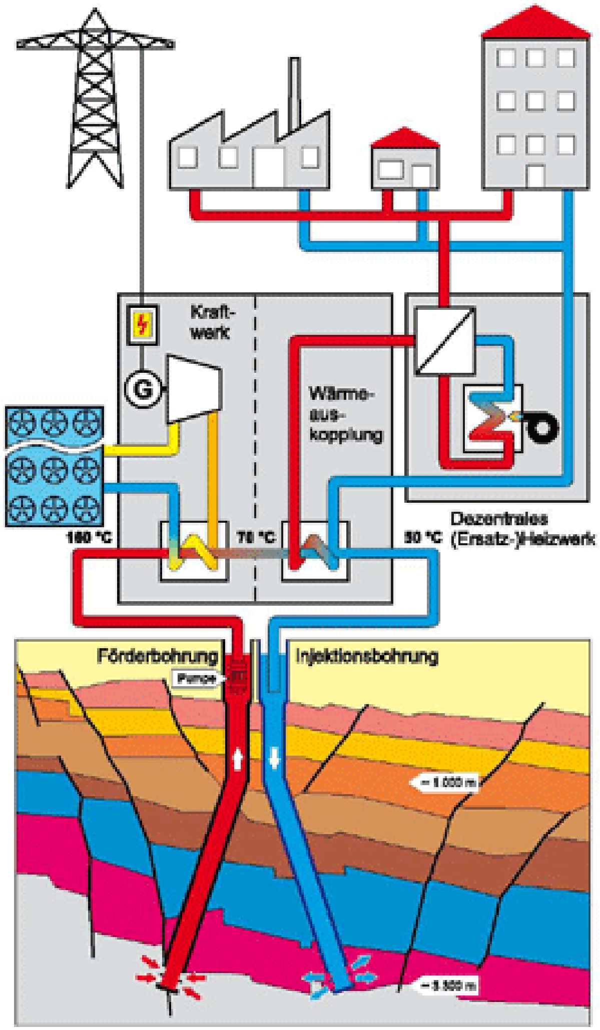
2 wells	2500-3000 m
Operating	8 000 h/year
Wellhead Temperature	170°C
Transport loop	15 km
Thermal power by the refinery	24 MW

Providing high temperature heat to the industry, example of Roquette bio-refinery

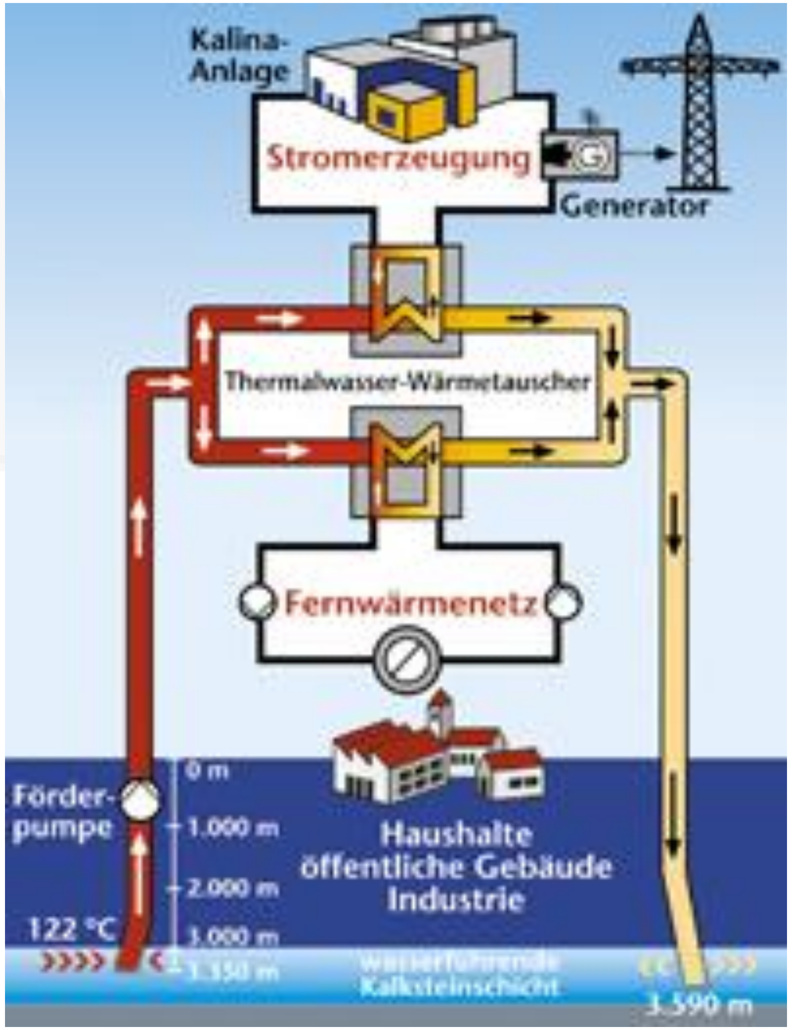
- Maximizing energy use
  - Operating nearly 24h/d 365d/y
  - No energy loss compared to electricity conversion
- Secure the industrial’s local presence
- Transform local resources (crops) locally

Industrial heat, ECOGI

Electricity and heat

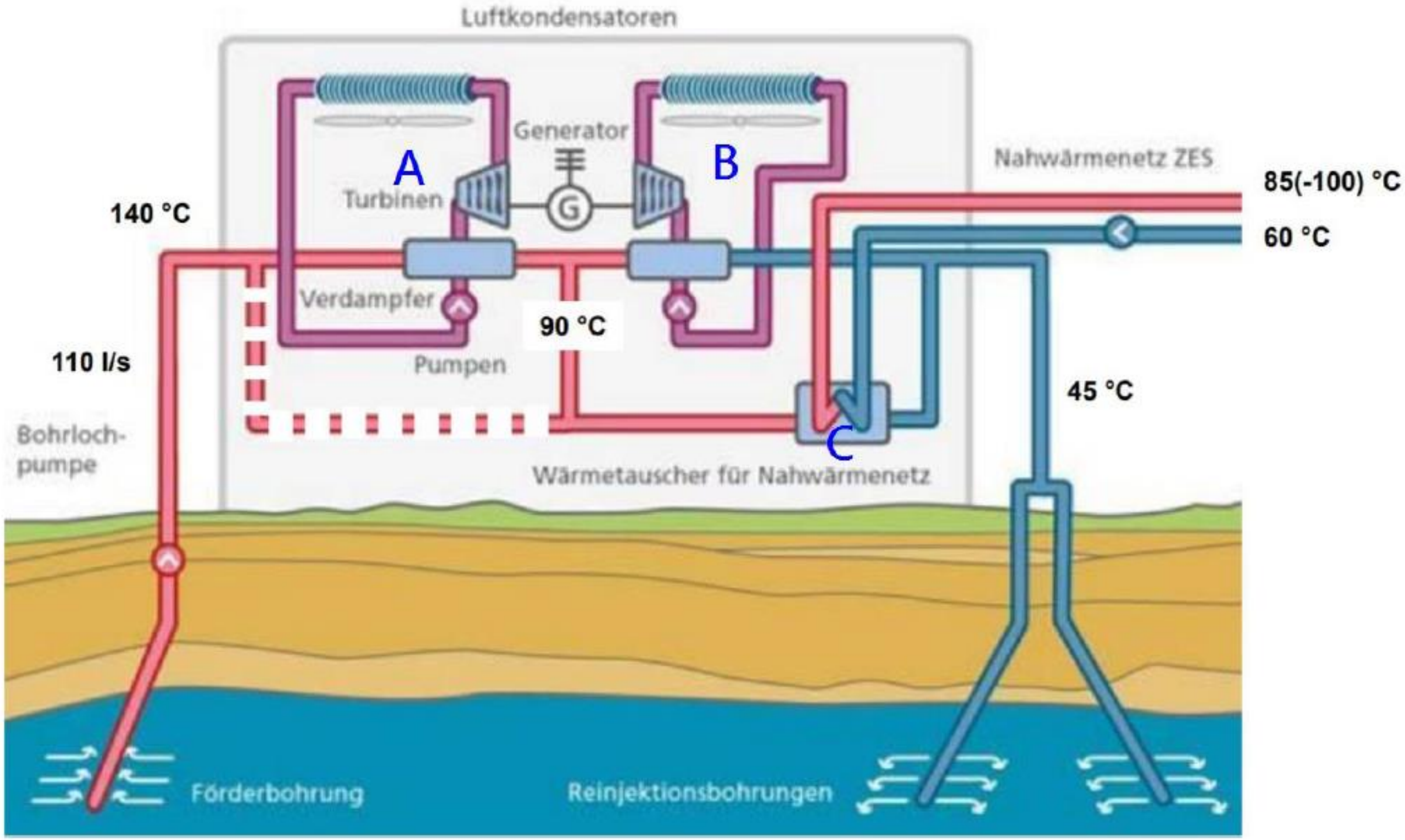


Electricity and heat in serie
Landau (URG)



Electricty and heat in parallel
Unterhaching (Bavaria)

Electricity and heat



Sauerlach (Bavaria)

Challenges in exploitation

Environment

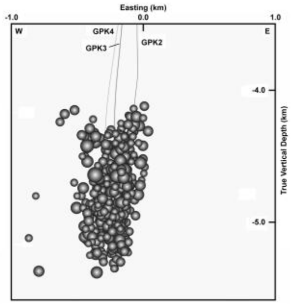
Noise
Visual impact
Natural radioactivity

Technology

Corrosion & scaling
Well integrity
Pumps

Reservoir

Microsismicity
Thermal breakthrough
Enhance well production



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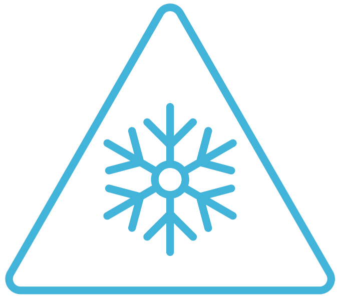
2nd quizz

What could be the negative impacts of colder reinjection for the exploitation (surface and reservoir)?



- Write your ideas in the chat

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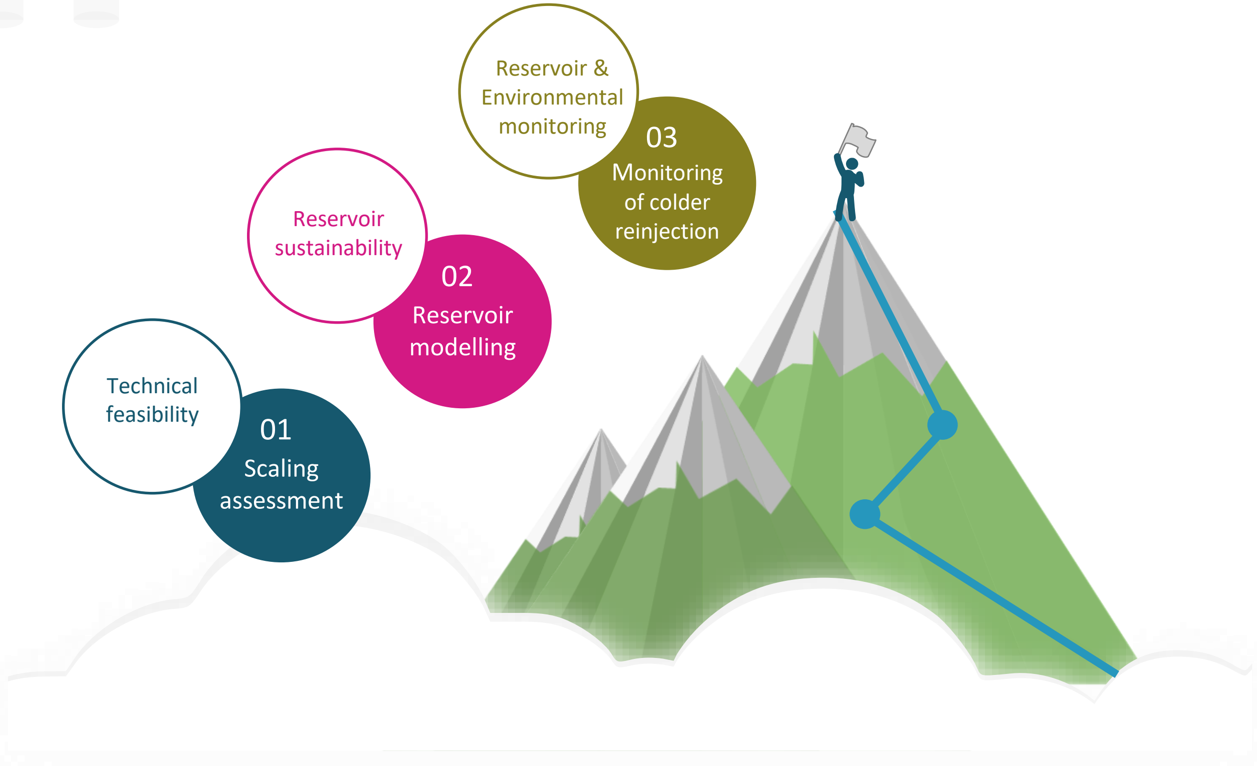
2nd quizz

What could be the negative impacts of colder reinjection for the exploitation (surface and reservoir)?

- Write your ideas in the chat

- ❑ Increase scaling issues
- ❑ Decrease production temperature
- ❑ Increase induced microseismicity
- ❑ Thermal impact on casing and cement



Impact of colder reinjection in surface facilities

Scaling issues

Scaling phenomena in SsF

Scale deposition due to change in thermodynamic conditions (pressure, temperature)

- Precipitation of sulfates (barite & celestite)
- Precipitation of sulfides (galena)

Impact on exploitation

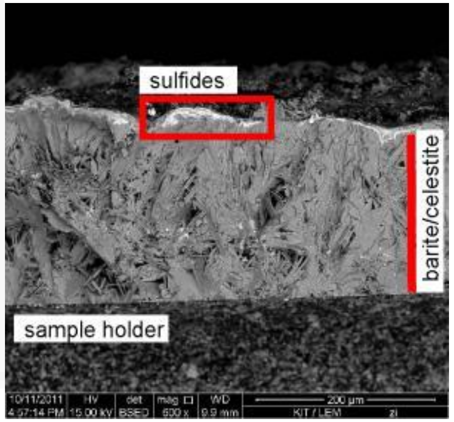
- Decrease of thermal exchange efficiency in heat exchangers
- Plugging of equipment
- Incorporation of naturally occurring radioactive material (NORM) (^{210}Pb and ^{226}Ra)

Use of scaling (and corrosion) inhibitors

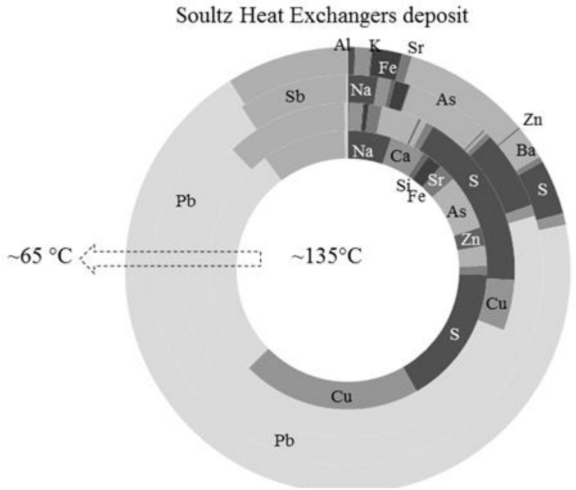
- No more sulfates
- Increase of sulfides and native metals

By decreasing reinjection temperature from 70°C to 40°C, risk of

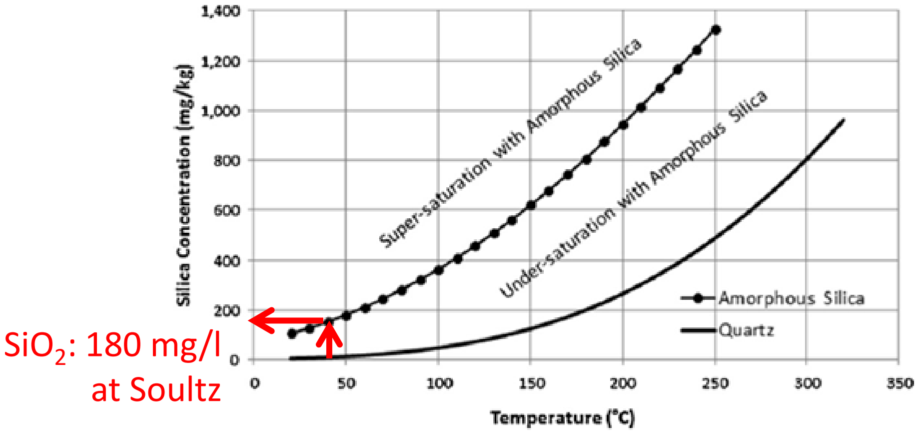
- Increase quantity of scale
- Apparition of new scale type (silica)



Scheiber et al. (2012)



Mouchot et al, 2018



Fournier and Rowe, 1977

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792037

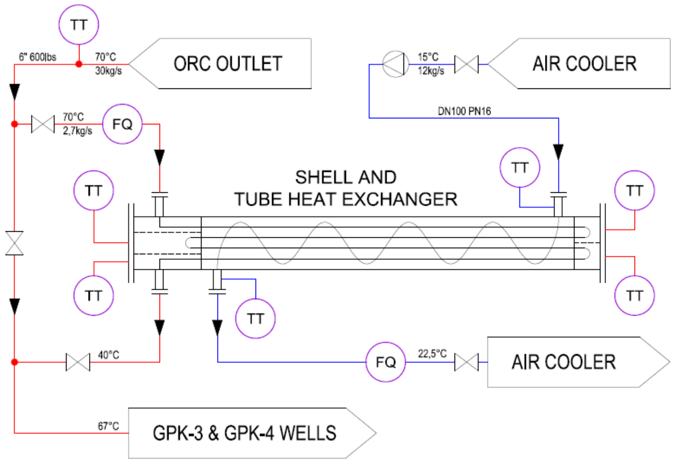
Small heat exchanger test - design

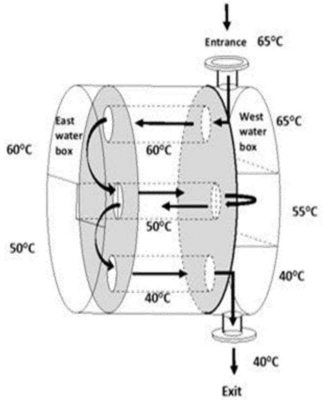
On site test of brine cooling

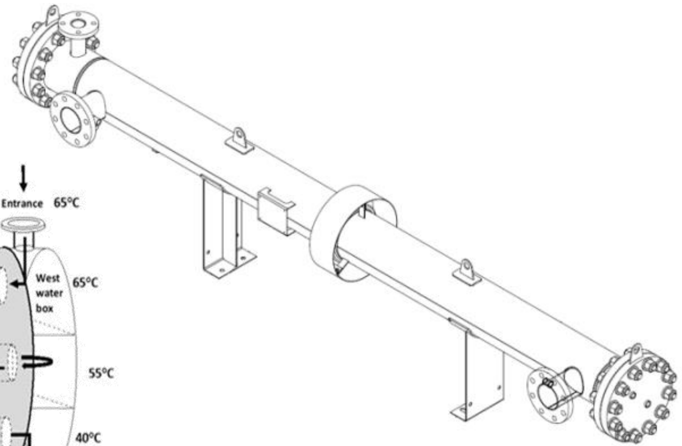
- Temperature cooling down to 40°C in 3 passes
- Flow rate Q= 4,1 kg/s for brine (10% of Soultz nominal flow rate) and 21,3 kg/s for cooling water
- Duration 3 months: February – April 2019

Design of the test heat exchanger

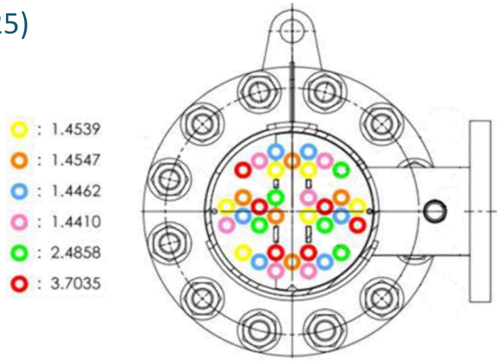
- 6 metallurgies selected for HEX tubes
  - 1.4539 : Austenitic stainless steel with molybdenum (904L)
  - 1.4547 : Highly alloyed austenitic stainless steel (254 SMO)
  - 1.4462 : duplex (austenitic-ferritic) stainless steel (2205)
  - 1.4410 : super duplex stainless steel (2507)
  - 3.7035 : pure titanium (Ti grade 2)
  - 2.4858 : High nickel alloy (Alloy 825)







Ledesert et al, 2020



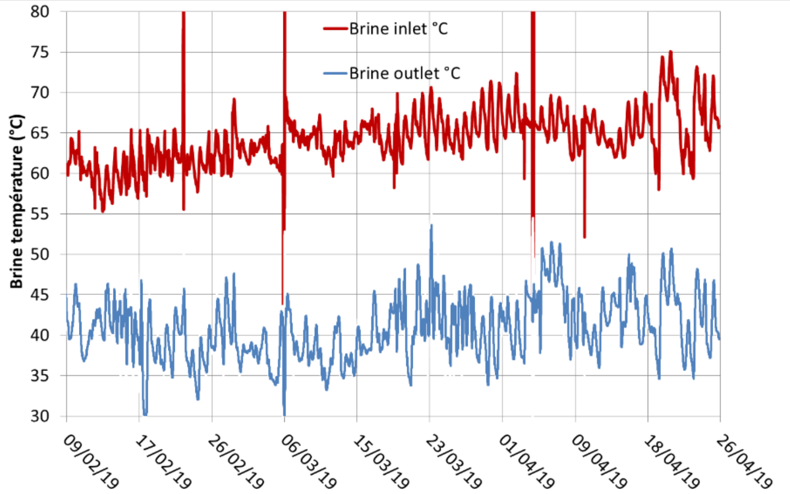
Ravier et al, 2019

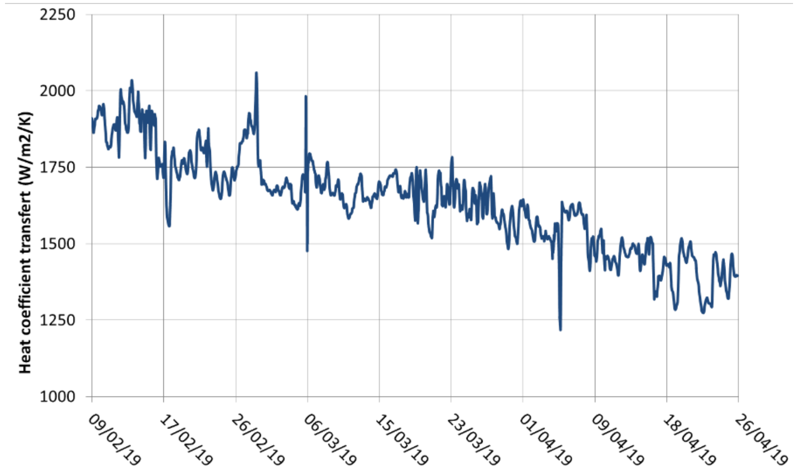
Small heat exchanger test - run

Measured temperature along the test

- Brine average inlet temperature: 64.2°C
- Brine average outlet temperature: 40.8°C
- Temperatures in line with calculation
- Heat coefficient transfer: 27% of decrease
  - Indication of scale formation

Ravier et al, 2019





Small heat exchanger test - dismantling

Observation of quantity and adhesion of scaling in the HEX pipes

		Temperature		
		64,2°C ± 3,6°C	47,5 °C ± 3,8°C	40,8 °C ± 4,2°C
Tube material	904 L	2	3	2
	254 SMO	2	1	3
	DX 2205	3	2	1
	SDX 2507	1	1	3
	Alloy 825	3	2	3
	Ti Gr.2	3	1	3

Rating of quantity of scaling (1 : low , 3 : high)

		Temperature		
		64,2°C ± 3,6°C	47,5 °C ± 3,8°C	40,8 °C ± 4,2°C
Tube material	904 L	2	1	1
	254 SMO	1	1	1
	DX 2205	3	3	3
	SDX 2507	1	1	2
	Alloy 825	2	2	1
	Ti Gr.2	3	3	3

Rating of adhesion of scaling
(1 : easy to clean , 3 : hard to clean)

Ravier et al, 2019

First qualitative results:

- Ti Gr 2 and Alloy 825 (Ni) are not recommended
- SDX 2507 (currently used) is fine until at least 47,5°C
- 254 SMO is an interesting option for new project

Scales analysis

Analytical methodology

SHEX tubes

Scales sampling

Tube cleaning
High pressure and/or blasting

In-situ characterization

Global characterization

Mineral characterization

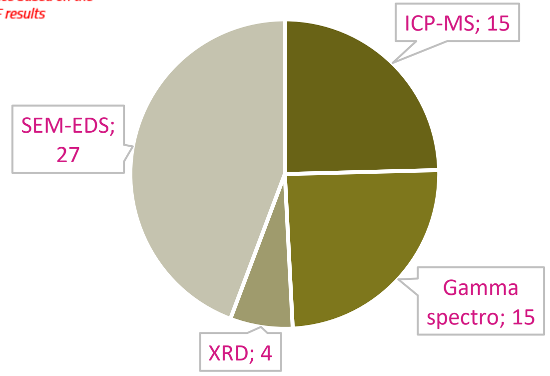
SEM
UCP

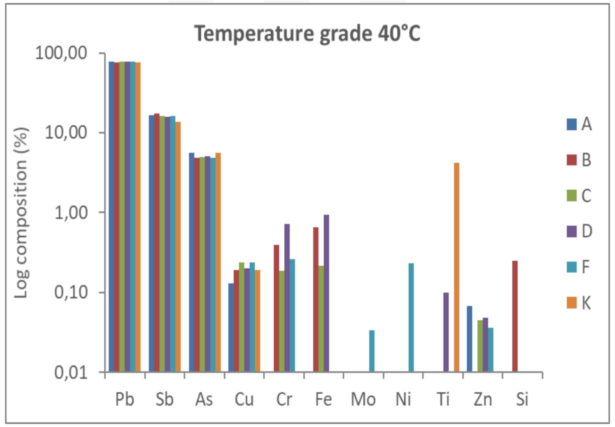
OM
UCP

XRF
External subcontractor

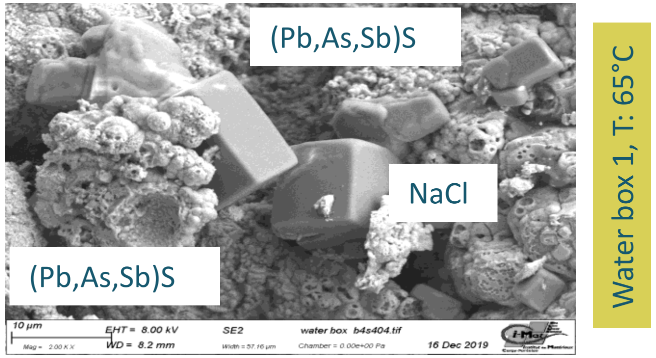
XRD
External subcontractor
Sample choice based on the scale mass(>0,5 g)

ICP-MS
&
ɣ-ray spectrometry
External subcontractors
Sample choice based on the XRF results





Chemical composition (XRF) of the scales



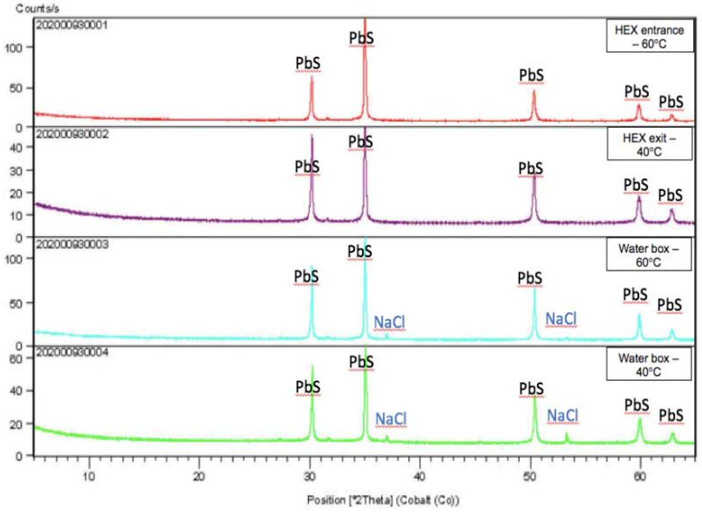
Ledesert et al, 2020

Mineralogy & chemistry

- Mostly **Galena** (PbS) enriched in As and Sb (sometimes also Cu) + Halite (NaCl)
- very little Si (no bearing mineral identified)

Radioactivity

- Only ^{210}Pb and daughter element ^{210}Po



X-ray diffraction spectra

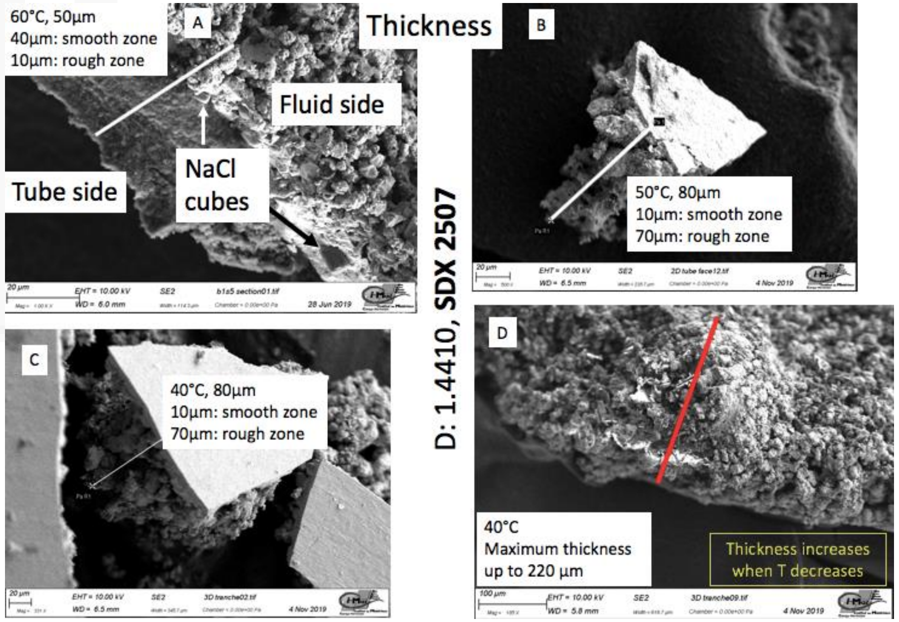
Scales analysis

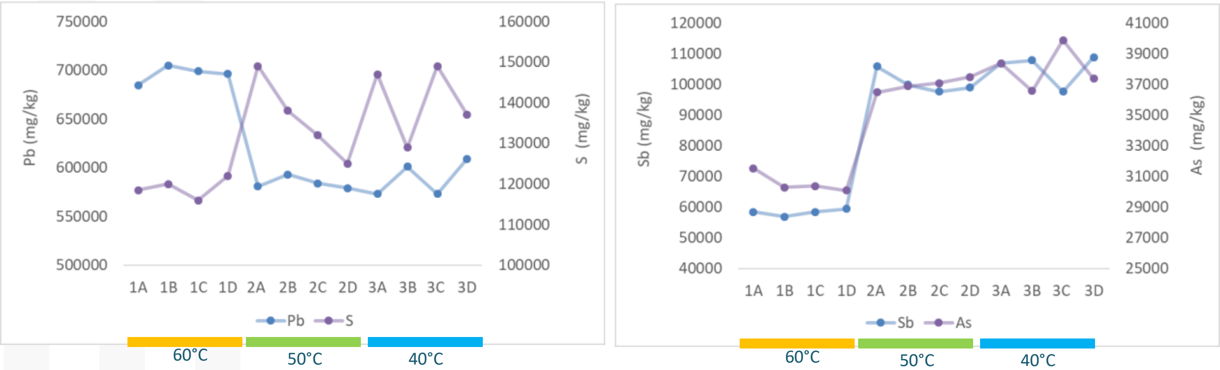
Variation between metallurgies

- No observable difference in scales
- Elemental variation like Al oxides, Ti oxides, free metal particles are likely due to pollution of scales during sawing
- Only a difference of adhesion to the pipe when sampling

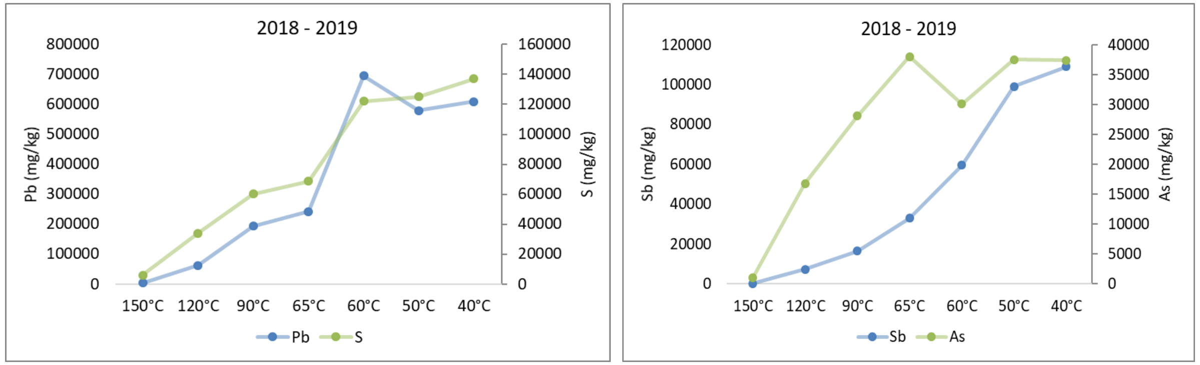
Evolution with temperature

- Pb decreases from 60°C to 50°C while Sb and As increase
- Scales tend to be thicker when T decreases





Chemical variations of Pb, S, Sb, As (ICP-MS) depending on temperature



Evolution of major elements in the scales formed from 150°C to 40°C. 2018 data is issued from exploitation scale analysis; 2019 data correspond to MEET SHEX results

Ledesert et al, 2020

Scales analysis - conclusion

No important change for scaling behaviour when decreasing reinjection temperature from 70 down to 40°C

- Same mineralogy
- Thickness slightly higher but acceptable

2 metallurgies are not recommended due to scaling adhesion

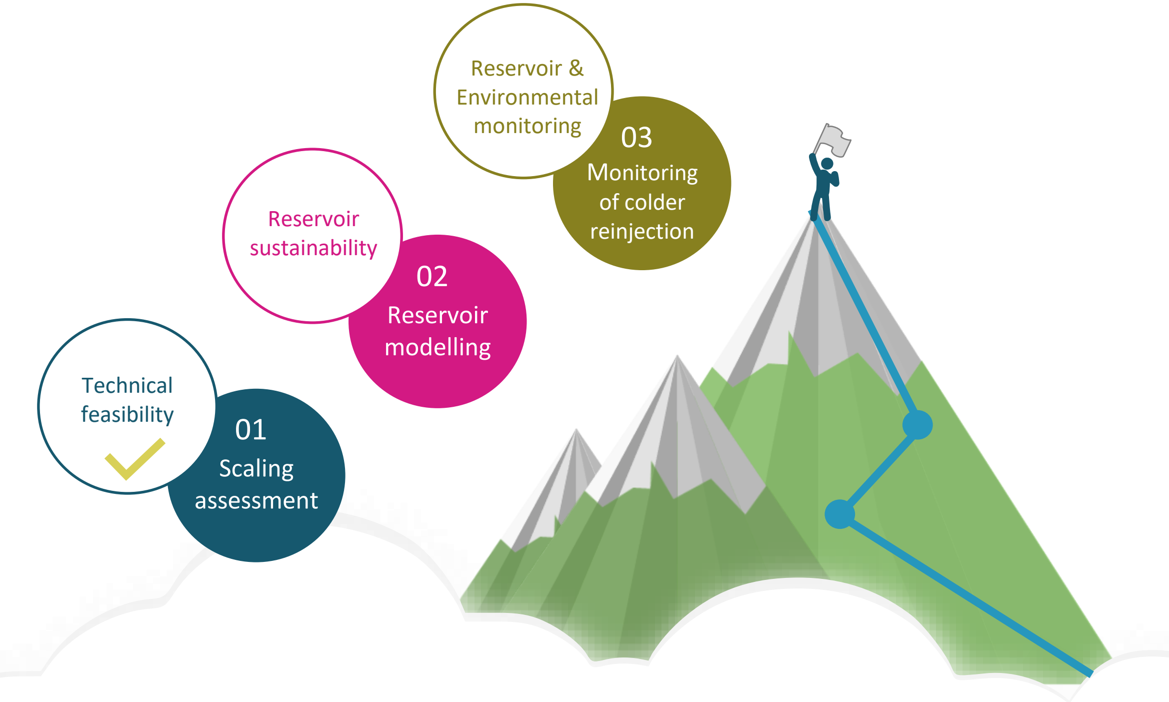
(difficulties for cleaning in plant operation)

- 3.7035 : pure titanium (Ti grade 2)
- 2.4858 : High nickel alloy (Alloy 825)

Next step : test of decreasing reinjection temperature at full flow rate with mobile ORC to valorize the extra heat into electicity

- 40kWe to be produced
- Test will start soon
- Duration: 4 months

See talk of A. C. Mintsa (19/02/2021)



Impact of colder reinjection on the reservoir

Production temperature

Challenge in modeling fractured reservoir

In reservoirs such as SsF one, flow is channeled through altered and fractured rocks.

Due to natural complexity of reservoirs and numerical limitation, models are always a simplification of reality.

Depending on the question to answer, different approaches for modeling can be undertaken:

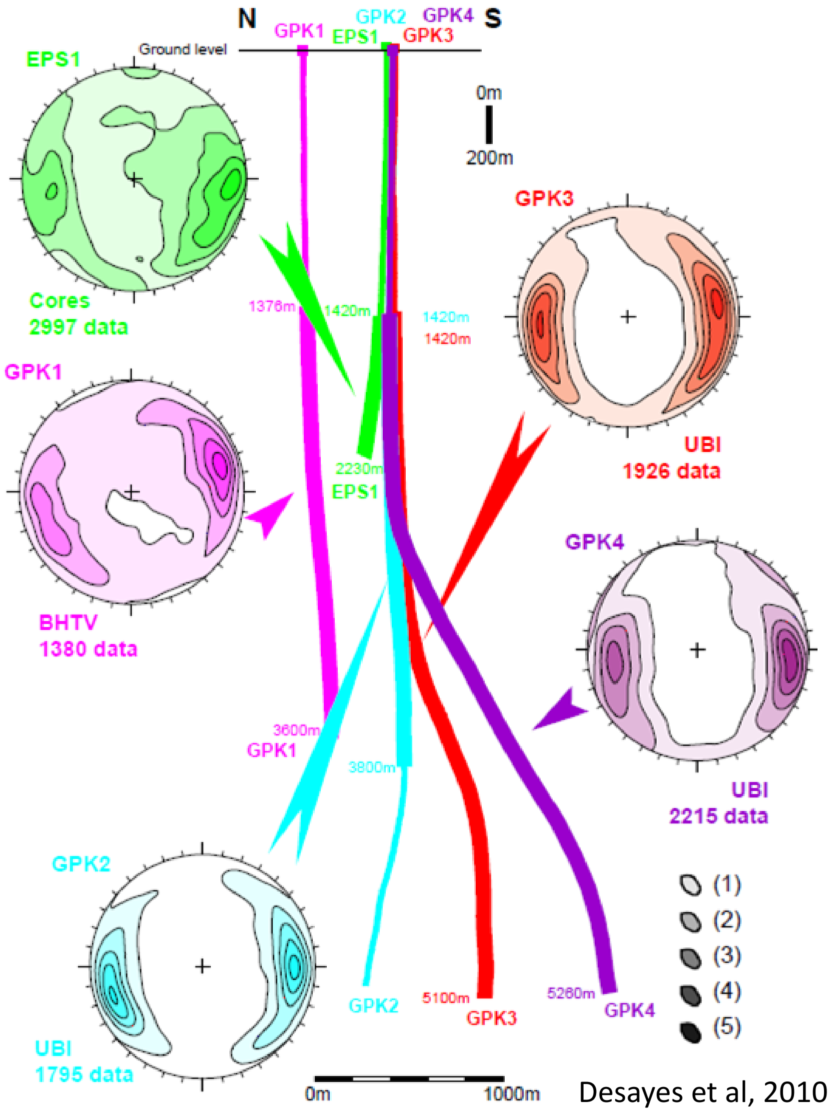
- For temperature decrease at production, modeling may focus on a small number of deterministic features connecting the wells
- For microseismicity assessment, smaller fractures needs also to be taken into account. A stockastic approach will then be more appropriate.

From data to structural model

- 3rd quizz

Thousands of fractures recorded in granite on SsF wells, but a few of them are permeable.

Which data should be acquired to determine what zones are contributing to the well flow and what discrete features should be included in a structural model ?



Desayes et al, 2010

From data to structural model

Drilling

- Mud losses -> permeable zones (qualitative)
- Gas influx -> permeable zones (qualitative)

Logging

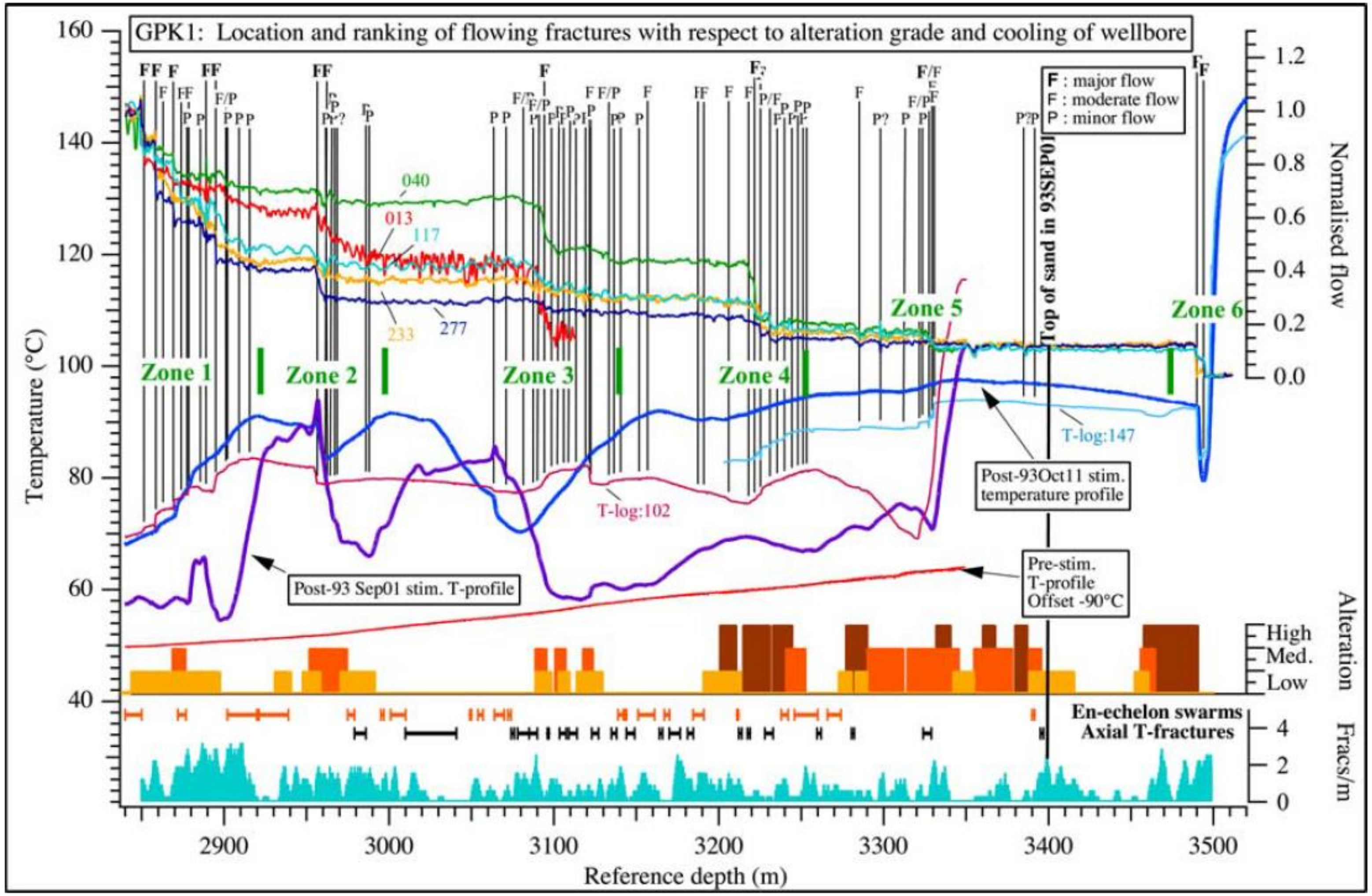
- Cores / images logs -> orientation, aperture of fractures
- Temperature logs -> permeable zones (qualitative)
- Flow logs -> permeable zones (quantitative)

Seismic information

- 2D/3D sismic surveys -> fault at sediment – basement interface
- Vertical seismic profiles -> intra-basement near well faults
- Microseismic monitoring -> fluid pathways

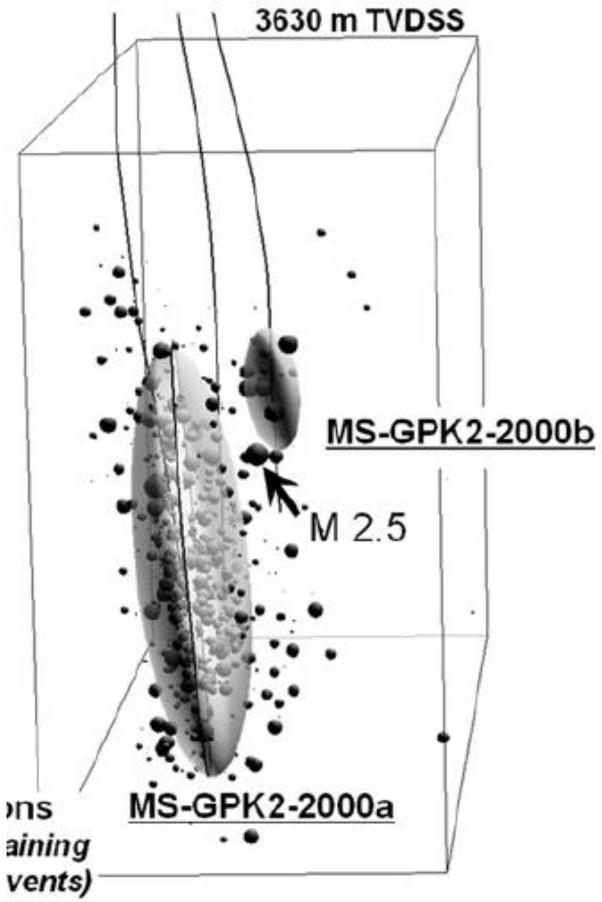
Permeable fractures from well data interpretation

Example in GPK-1

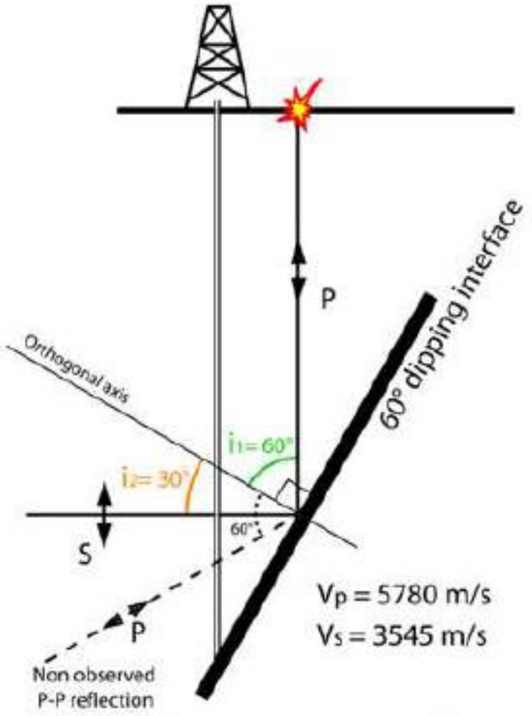


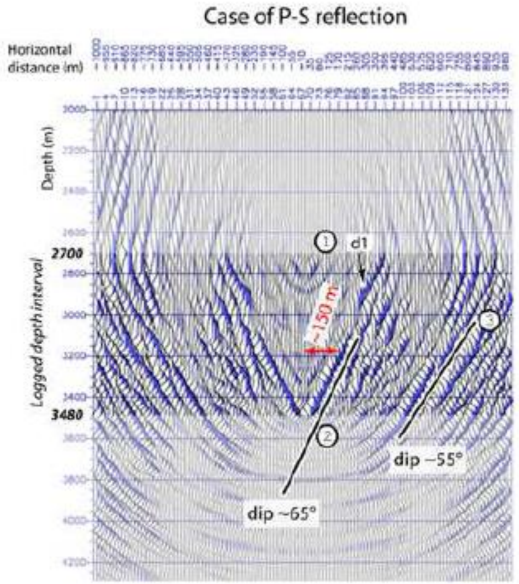
Evans et al, 2005

Intra basement faults from seismic information



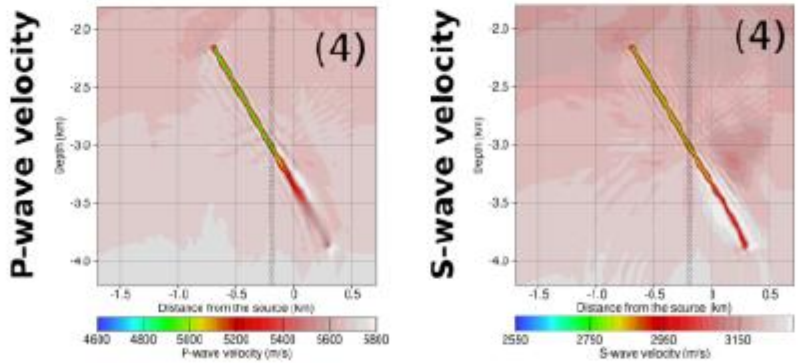
GPK2 structural interpretation from microseismic data (Sausse et al, 2010)



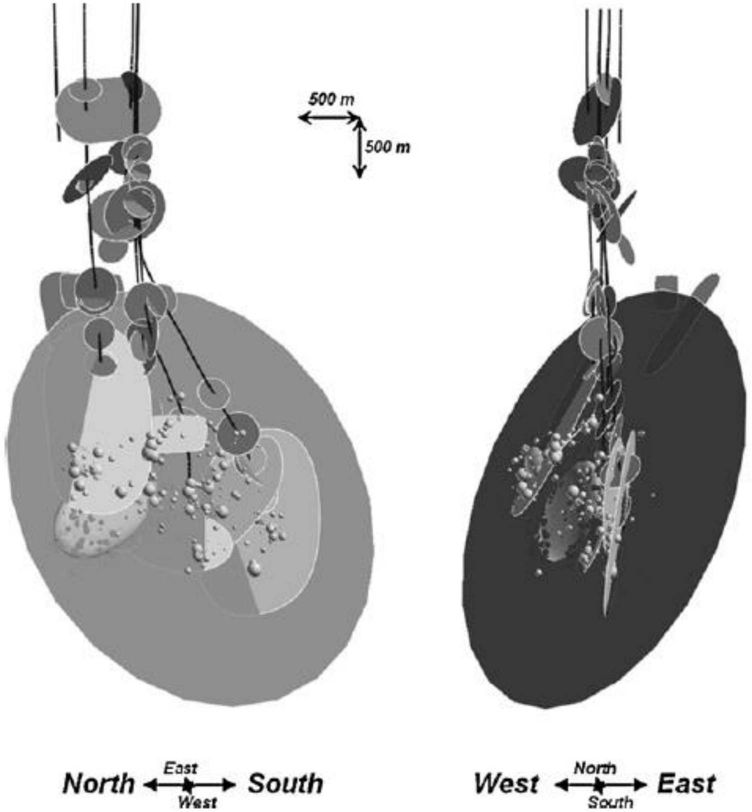


GPK1 structural interpretation from VSP data (Place, 2007)

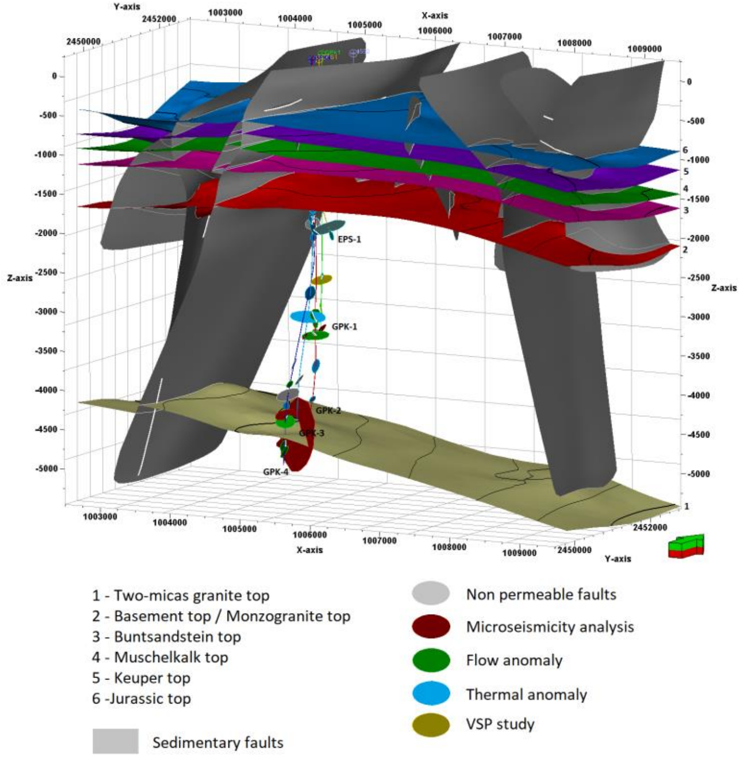
Full Wave Inversion of OVSP data
Proof of concept on synthetic data
(Abdelfettah et al, 2020)



SsF structural model



Sausse et al, 2010



Rolin, 2019

Derived from

- Well logging data
- Microseismic events analysis
- VSP analysis

Integration of information derived from 2D seismic

- Main sedimentary layers
- Faults in sediments

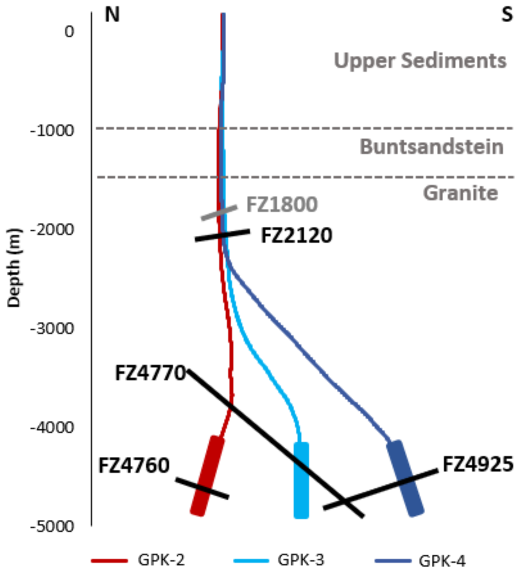
Short selection of intra-basement faults

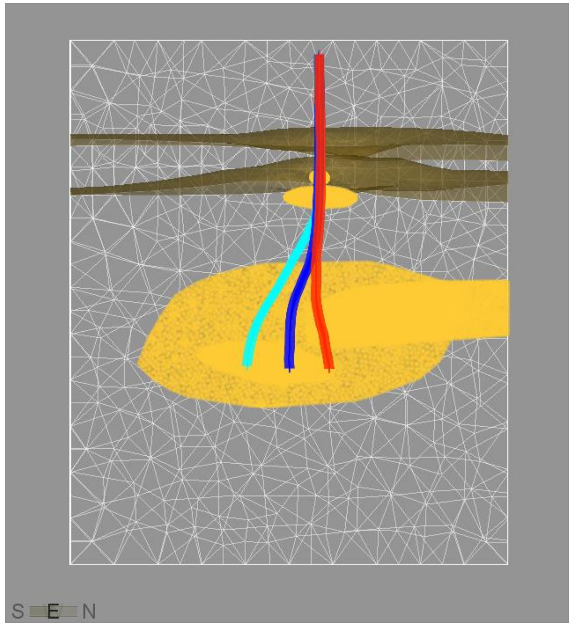
- based on permeability indicators

From structural to dynamic model

Further simplification

- 5 faults are kept
- Representative of major flowing zones and well connections
- Connection of a fault to the boundary -> far field contribution





Rolin, 2019

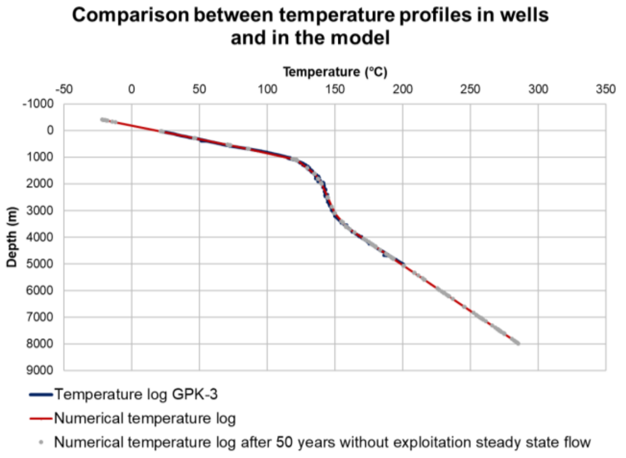
Hydrothermal modelling

Boundary and initial conditions

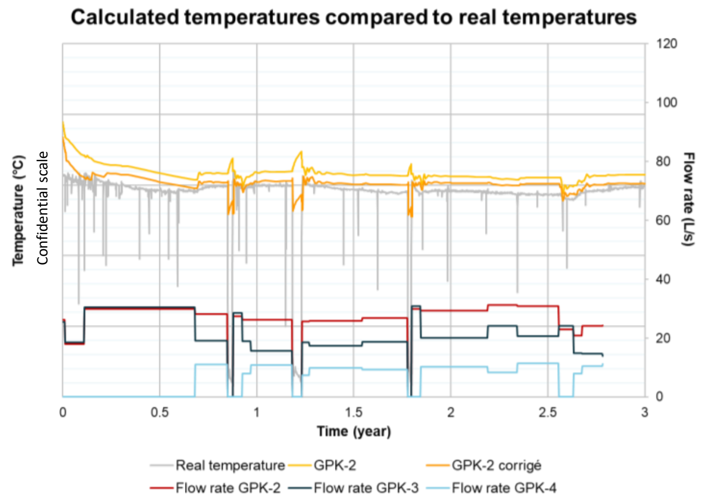
Constant Hydraulic Head condition on N,E,S,W borders

Surface temperature: 10°C
Bottom heat flux: 72 mW/m²

Initial temperature based on well temperature log (extrapolated to the bottom of the model at 8 km)
Granite radiogenic heat production: 3.10^{-6} W/m³



Rolin, 2019

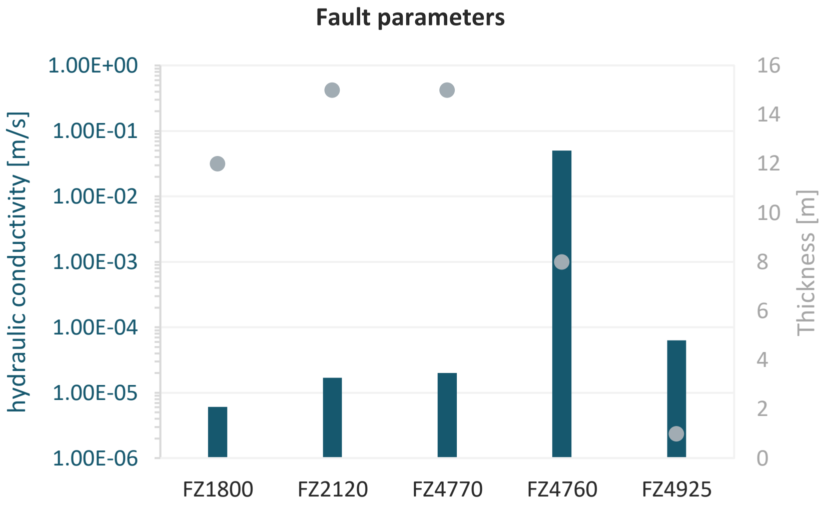


Calibration on production data

1- Hydraulic calibration (steady state): fixed flow rate, matching of well head pressure and contribution of each well section
2 – Thermal calibration (transient state): fixed flow rates and injection temperature, matching of production temperature

Name	Hydraulic Conductivity	Specific Storage	Porosity	Thermal Conductivity	Heat Capacity
	[m/s]	[1/m]		[W/m/K]	[J/m3/K]
Granite	$7\ 10^{-9}$	$1.75\ 10^{-8}$	3%	2.5	$2.9\ 10^{6}$
Faults	between 10^{-6} & 10^{-4}	$2\ 10^{-6}$	10%	2.5	$2.9\ 10^{6}$

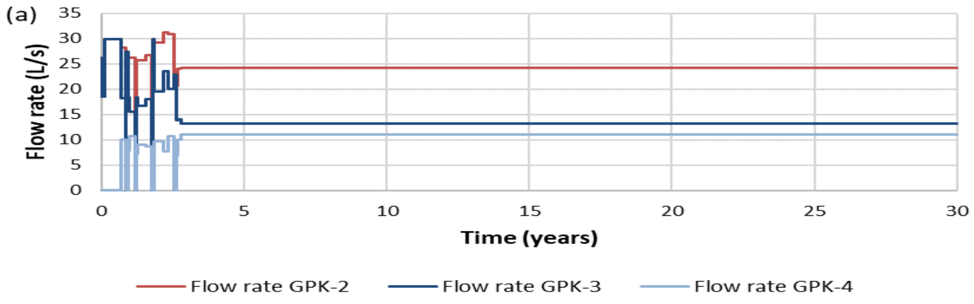
Except for FZ4760, parameters initally based on Gentier, 2010; Jung, 2013 ; Held, 2014 ; Sausse et al., 2010 and fine tuned

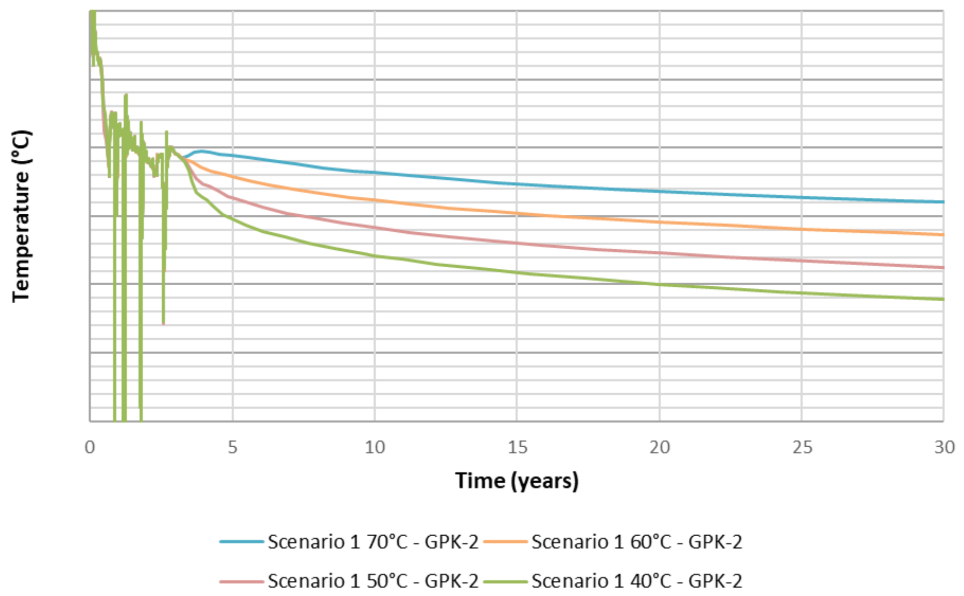


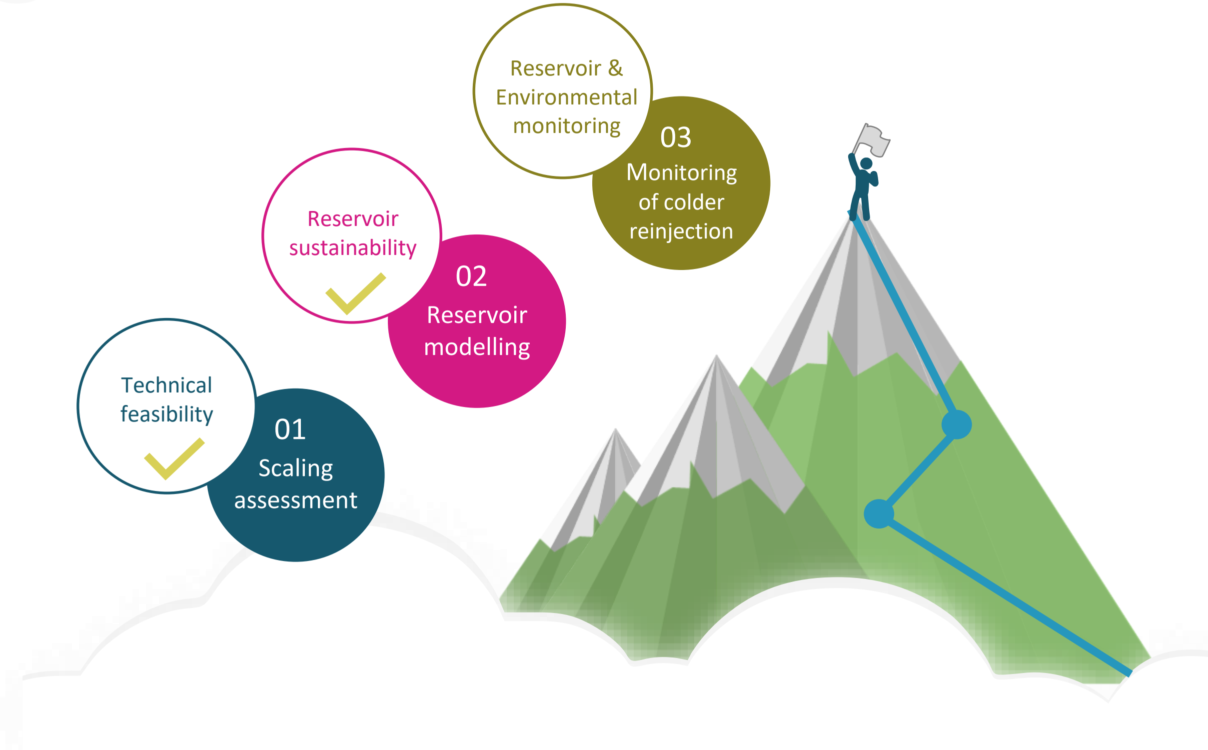
Hydrothermal modelling - conclusion

Results

- Around 5°C difference between reinjecting @ 40°C and current reinjection temperature (~65°C)
- Rapid decrease and then stable behaviour -> highlights short connection and more far field contribution





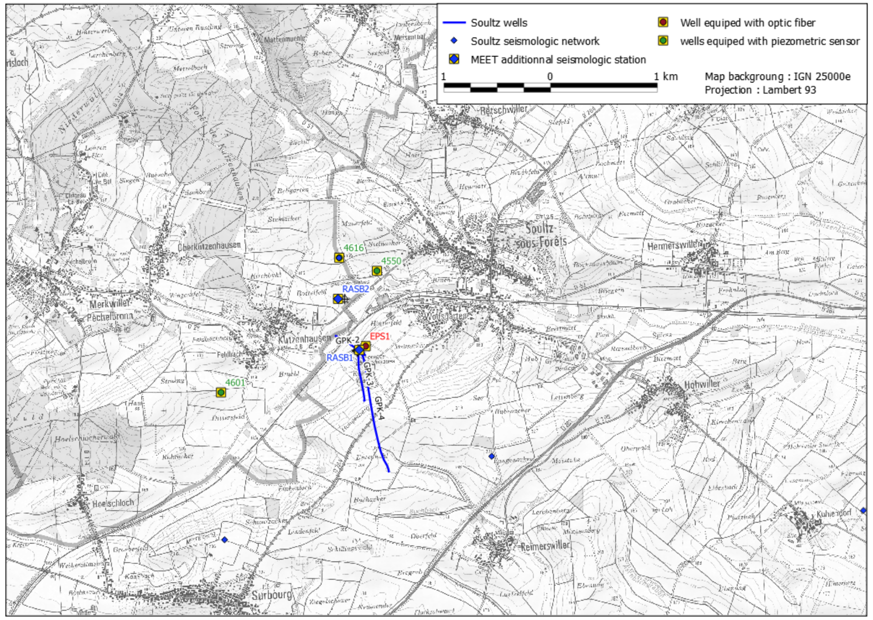


Impact on the reservoir & the environment

Microseismic activity

Increase monitoring

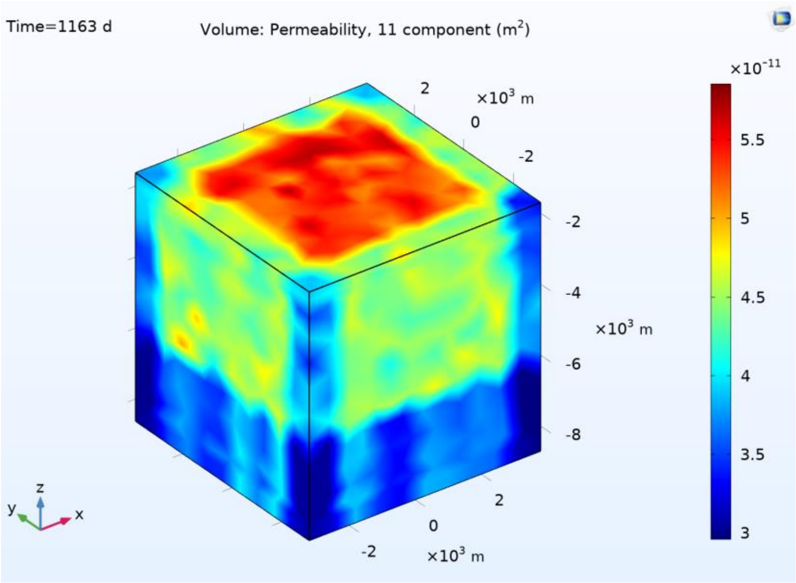
- Additionnal sensors
- Innovative monitoring with optic fibre



See talk of V. Lanticq (19/02/2021)

Thermo-hydro-mechanical modelling

- Assessment of reservoir geomechanical behaviour (increase of microseismicity due to colder reinjection?)



See talk of S. Mahmoodpour (18/02/2021)

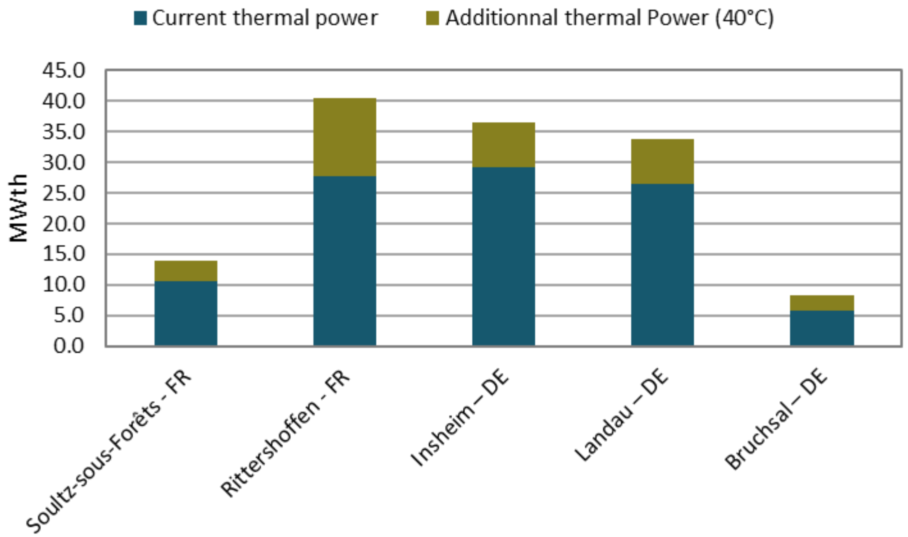
Conclusion and perspective

At this stage of MEET project, colder reinjection (down to 40°C) seems feasible

- No major impact on scaling issues
- Acceptable impact in production temperature

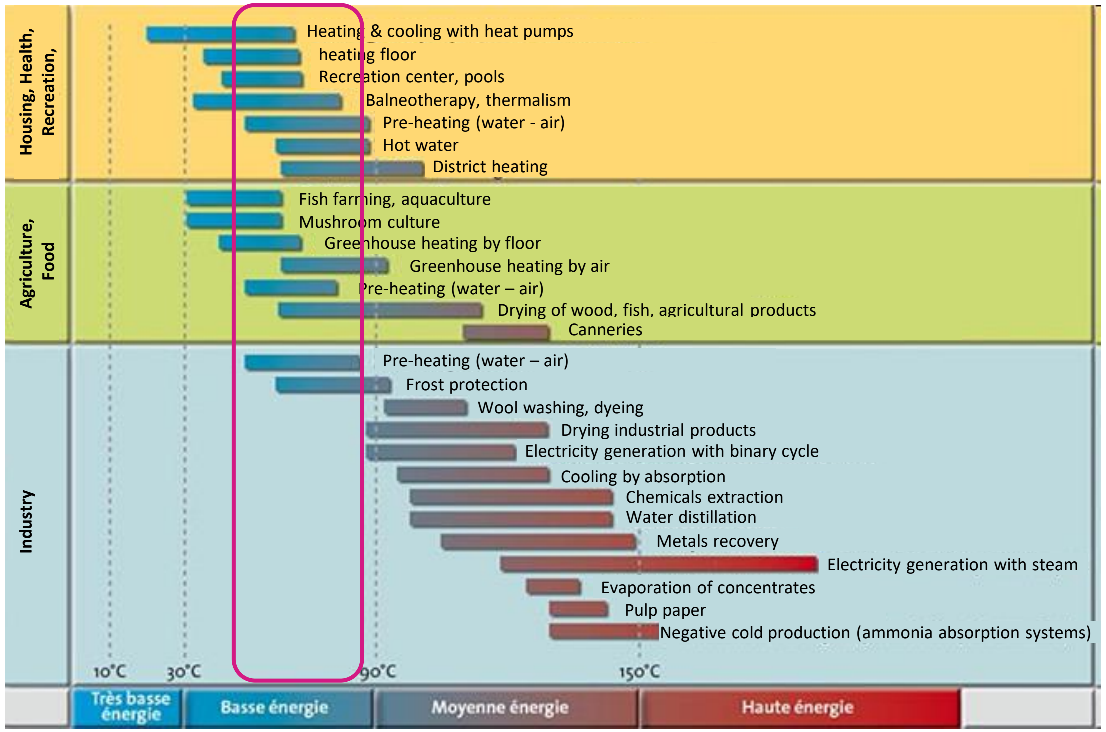
At the URG scale, this could provide additionnally

+33MWth



How to valorize this additionnal MWth ?

- Electricity generation (mobile ORC test)
- Direct heat use



Thank you very much for your attention

Geothermal Winter School 2021

MEET
Multi-sites EGS Demonstration

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