Deep fractured EGS, concepts & reservoir assessment in the Upper Rhine Graben

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Es-Géothermie

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Motivation

EGS: Enhanced/Engineered Geothermal Systems

EGS: a geothermal concept or a technology?

Focused on Upper Rhine Graben: operating EGS plants

From concrete examples from the URG

- Concept evolution based on Soultz-sous-Forêts / Rittershoffen sites (France)
- Naturally fractured reservoirs with hydrothermal alteration

Stimulation and geothermal exploitation of fractured reservoir

Who we are?

Geothermal operator in Alsace (Central Upper Rhine Graben, France)

- Electricité de Strasbourg ES, main energy company in the Strasbourg area (Alsace, France)
- ES co-owners of two operational geothermal plants in the Central Upper Rhine Graben (URG): Soultz-sous-Forêts and Rittershoffen
- ES is developing new geothermal projects in the URG
- ES-Géothermie (ESG), subsidiary of ES, scientific and technical staff specialized in deep geothermal energy
- ESG is exploiting the two geothermal plants

és géothermie

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Two operating EGS plants

Fractured granite reservoirs with very saline brines

Brines, ~100g/L, NaCaCl
Lithium 160mg/L
1.7MWe for electricity production
Three wells @ 5000 m

Q>30L/s T>150° C

Brines, ~100g/L, NaCaCl
Lithium 180mg/L
24MWth for a heat application
Two wells @ 2 500m

Q>70L/s T>168° C

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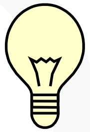
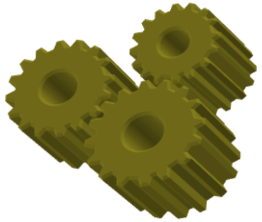
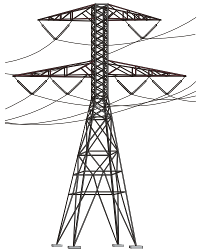
Life cycle of an industrial EGS project

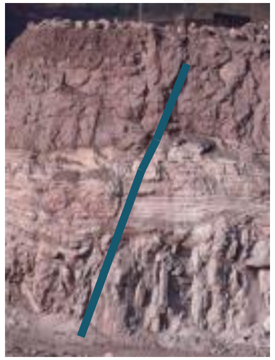
Main technical phases



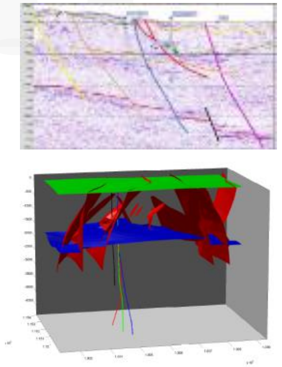


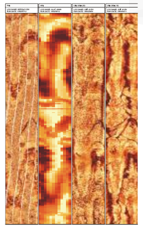

Concept → Site selection Permitting → Drilling → Stimulation Testing → Build & test power plant → Operate and circulation → Site abandonment



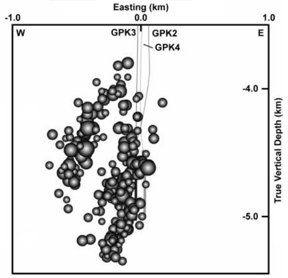
Fracture on outcrops



Concessional scale



Borehole Image



Micro-seismic cloud structure

Power plant exploitation

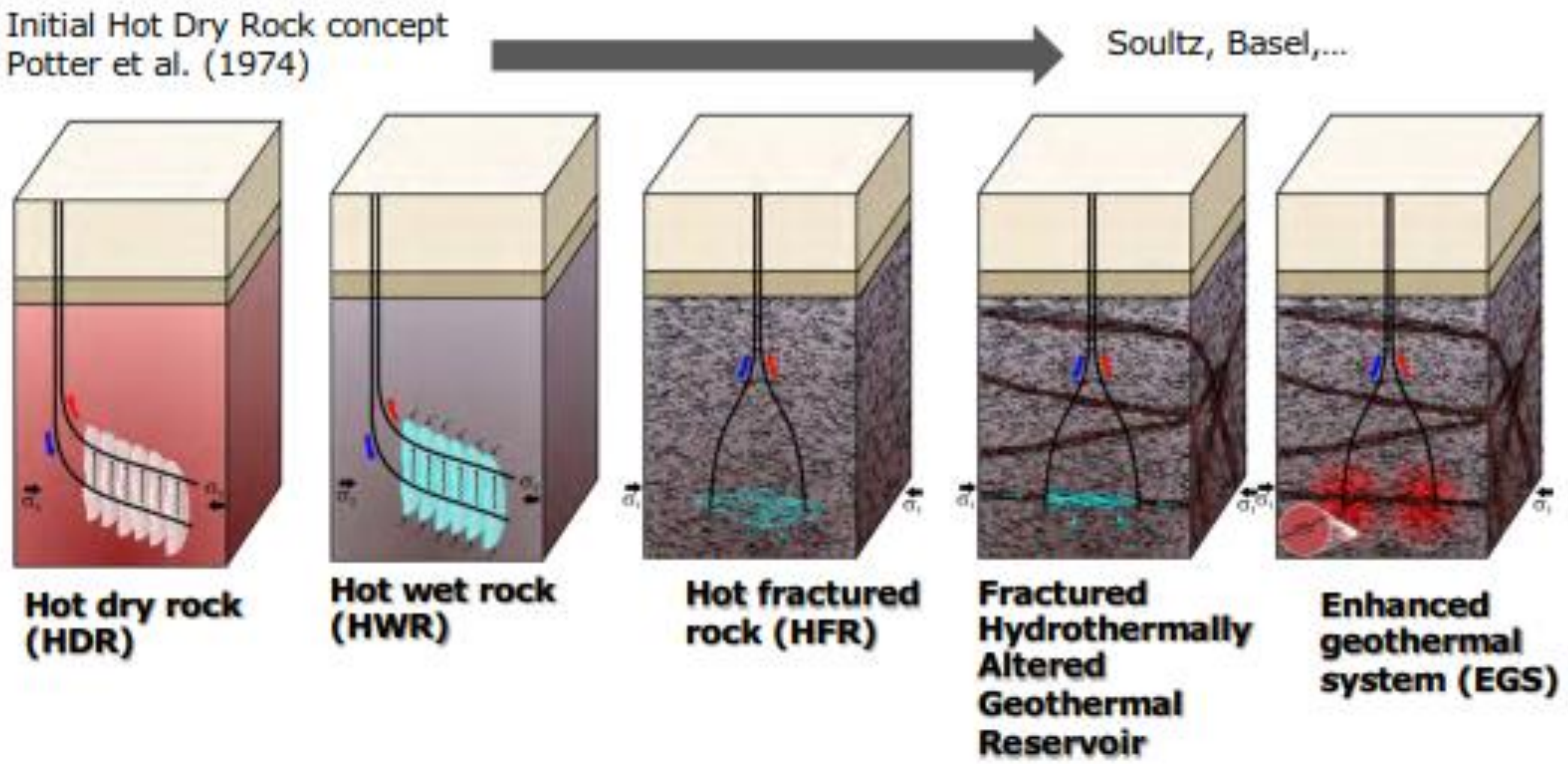
Power plant dismantlement

Duration	**1 second**	**1 year**	**½ year**	**1 week**	**>25 years**	**>1 year**
Cost			**>> €**			
Induced seismicity				**High risk**	**Low risk**	

EGS concept/technology

From HDR to EGS

From Stefan Wiemer (2018)



Soultz project presentation

Location

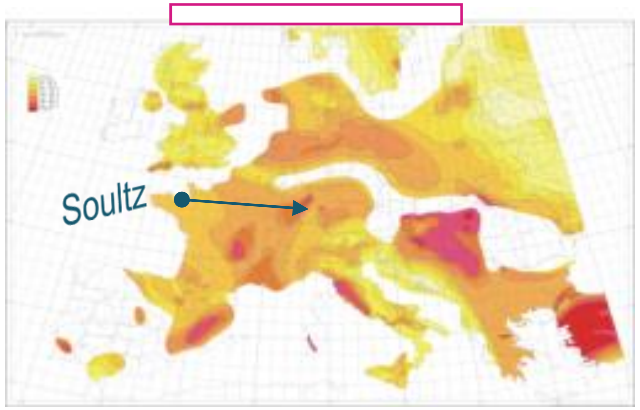
- Geothermal anomaly in the Upper Rhine Graben
- Non volcanic area
- No surface hydrothermal manifestation
- Unconventional reservoirs: deep-seated granite

Technology

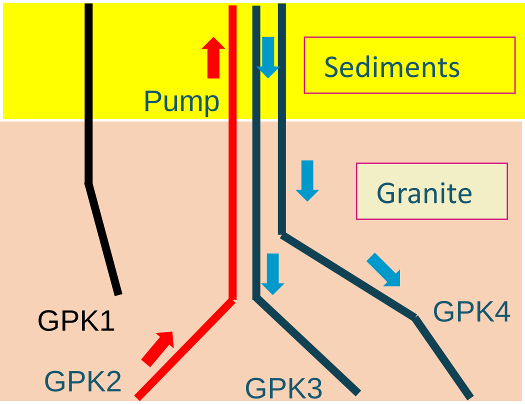
- 4 deep geothermal wells (3.6 & 5 km): 200°C @ 5 km depth
- 1st binary geothermal plant in France
- Organic Rankine Cycle (ORC) technology: 1.7 MWe
- Down-hole submersible pump: Long Shaft Pump (LSP)

Feed-in tariff in France

- Geothermal electricity 246 € per MWh
- No heat application on site



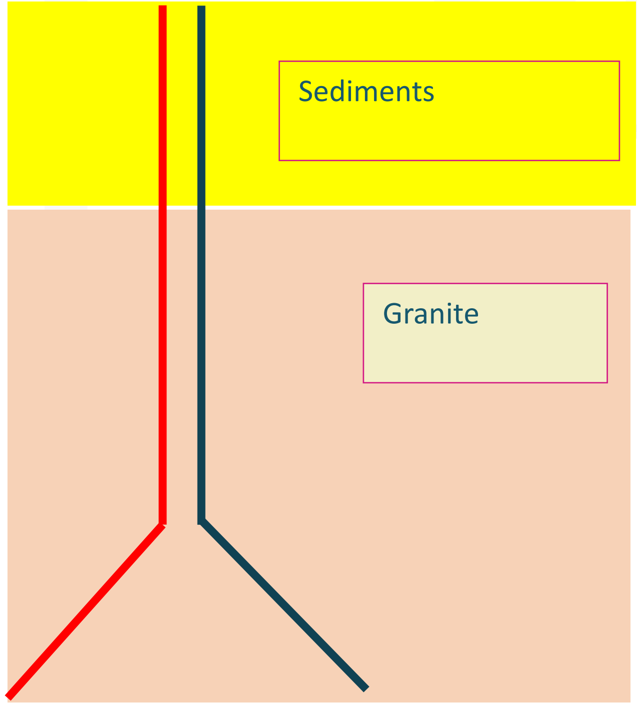
Down-hole Pump



→ *One of the highest geothermal anomalies in Western Europe*

Soultz HDR concept: no exploration

1st step: from 1987 to 2003: the Hot Dry Rock concept



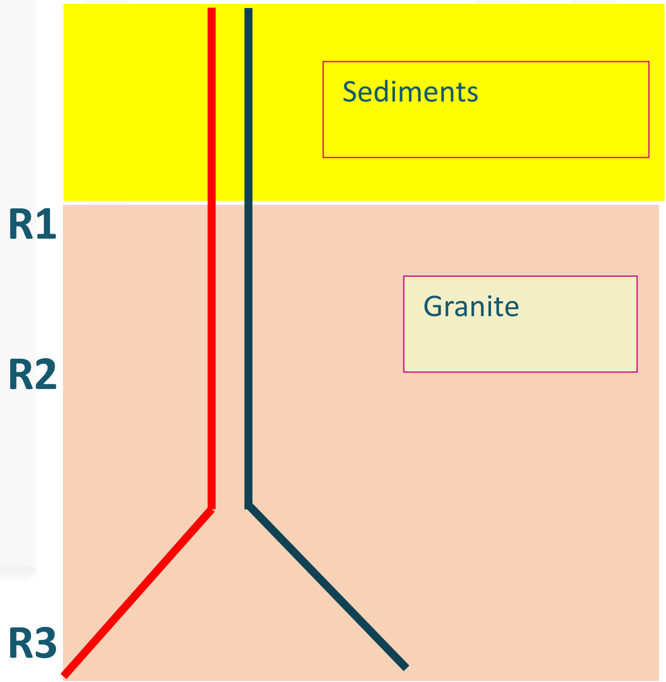
- Hydraulic fracturing
- Water injection
- Hard and tight rocks

- Induced seismic cloud
- Correlation with permeability

➢ Artificial heat exchanger

Soultz EGS concept: learning by doing

2nd step since 2004: on the route of EGS



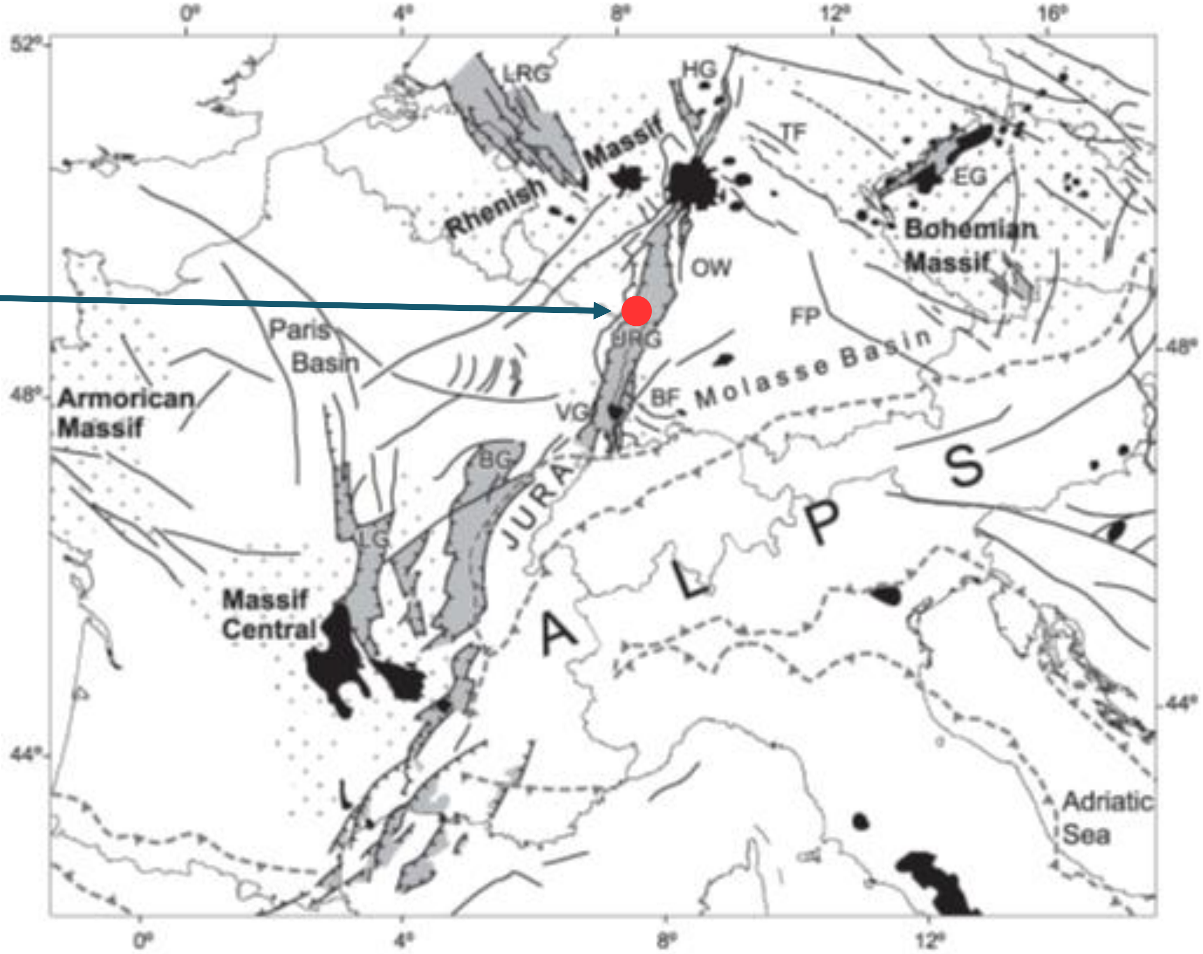
- Hydraulic & chemical stimulations
- 3 vertically distributed reservoirs? Or 1 large reservoir?
- Hydrothermally Altered & Fractured Granite Zones
- Occcurrence of natural brine
- Low natural permeability
- Connexion between the geothermal wells with the reservoir

➢ EGS concept or technology?

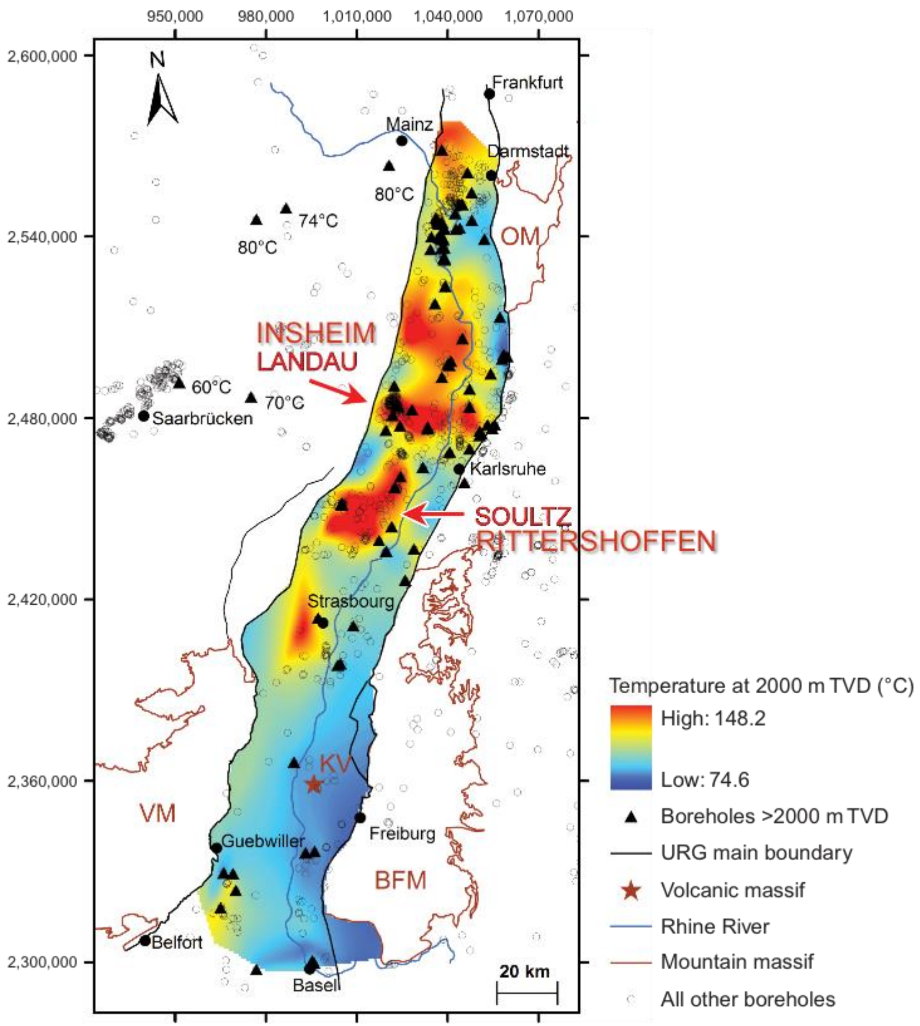
The Upper Rhine Graben

West Rift European System

Soultz



Dèzes et al., 2004



Temp @ 2000 m depth from LIAG

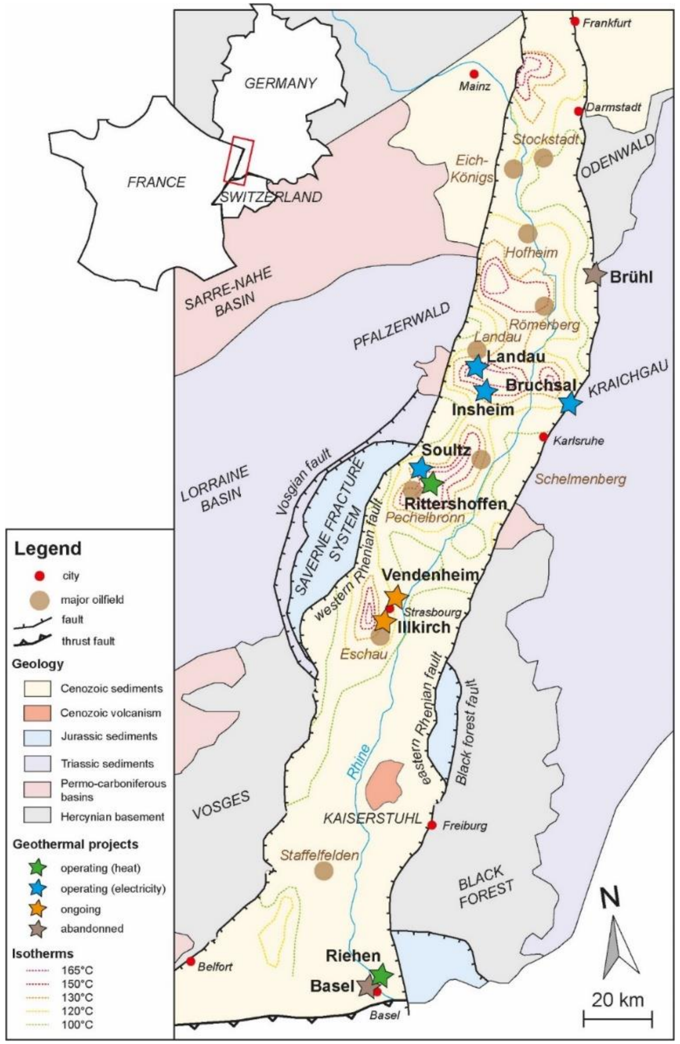
Upper Rhine Graben activity

Over the last 30 years:

- 9 geothermal projects
- 23 wells drilled
- >75 km of geothermal boreholes were drilled

Status on 2021

- 3 geothermal power plants and 2 heat plants operating
- 2 projects under development in Strasbourg area but stopped due to recent felt induced seismic events (M>3)
- 6 exploration permits for geothermal energy
- 3 licences for lithium extraction



URG reservoirs

Temperature anomalies

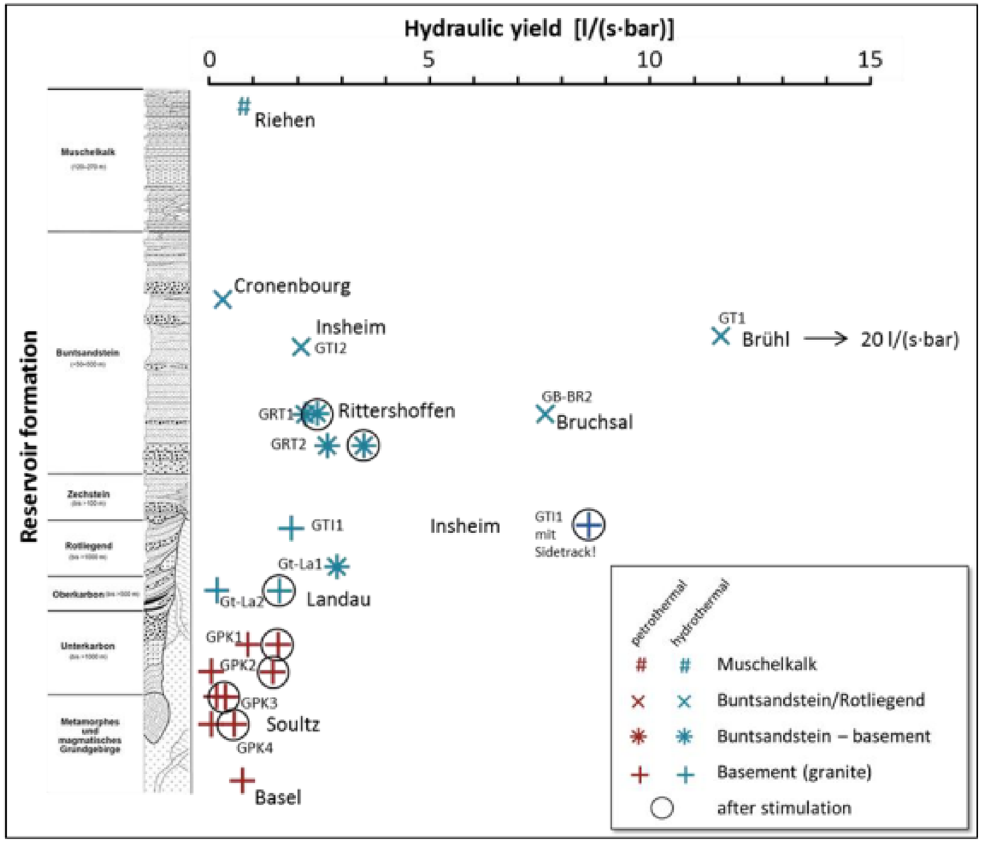
- Localized around local normal faults / strike slip faults
- Traces of the fluid circulations related to these faults

Geothermal reservoirs

- Muschelkalk limestone
- Buntsandstein and/or Permian clastic sandstone
- Palaeozoic granitic basement

Fluid circulation in natural fractures

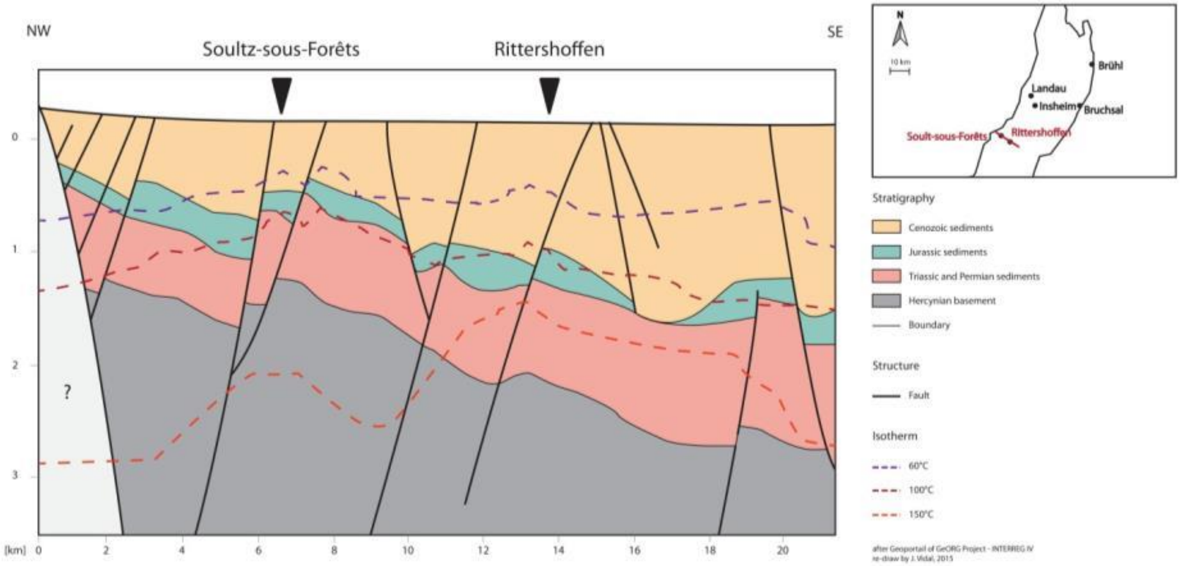
- Hydrothermal alteration & fractured zones
- In the granitic basement: 3 types of alterations
  - propylitic alteration, argillic alteration, paleoweathering alteration



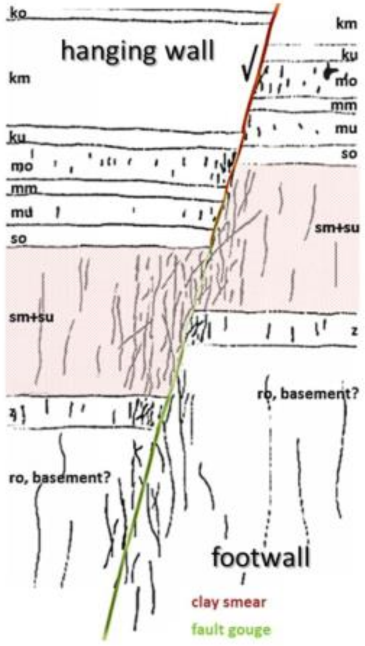
Reinecker et al., 2019

Local geology in Northern Alsace

Local map



Geological cross-section



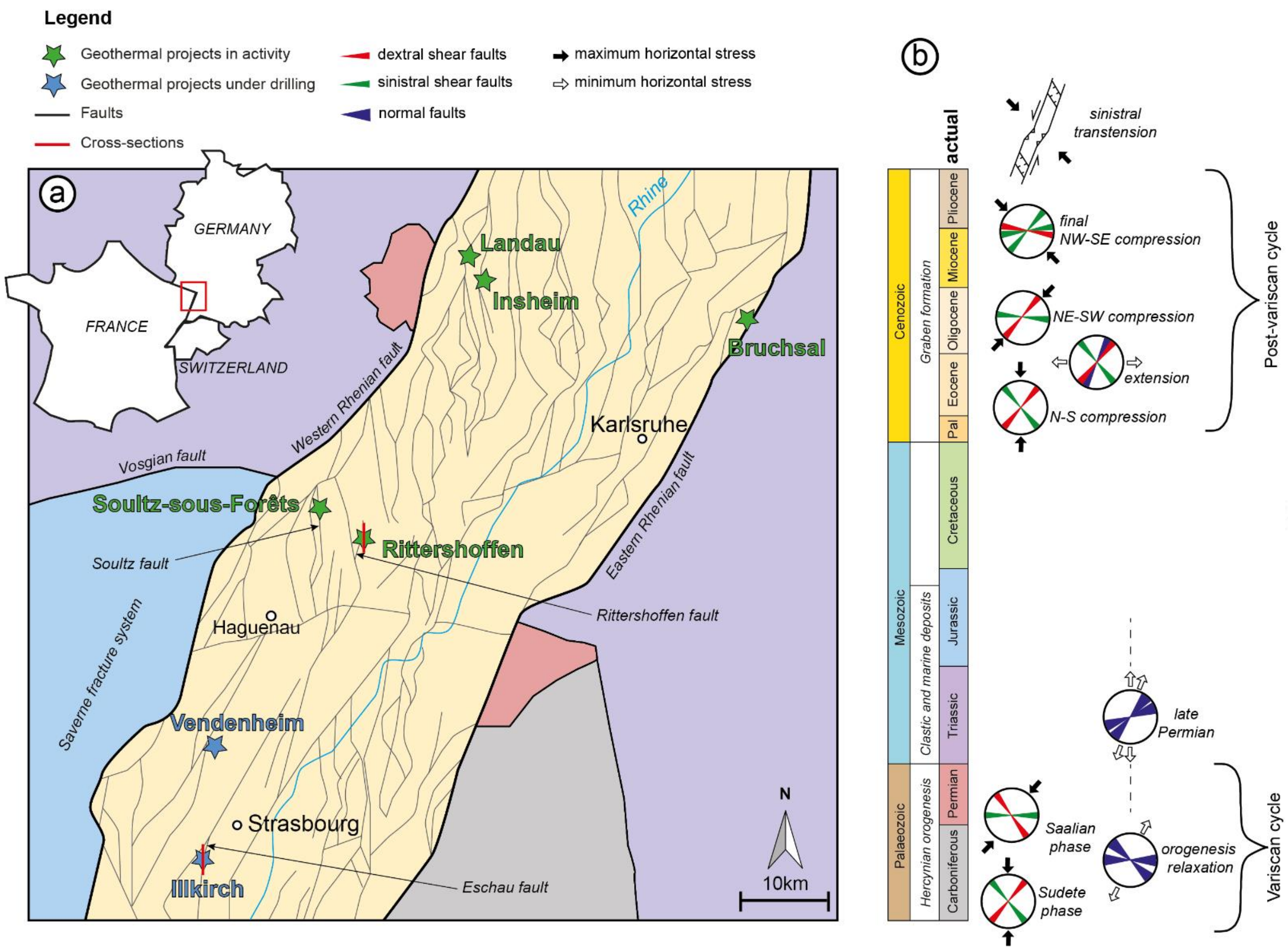
Reinecker et al., 2019

Open-hole section: fractured Triassic sandstone & fractured Carboniferous granite

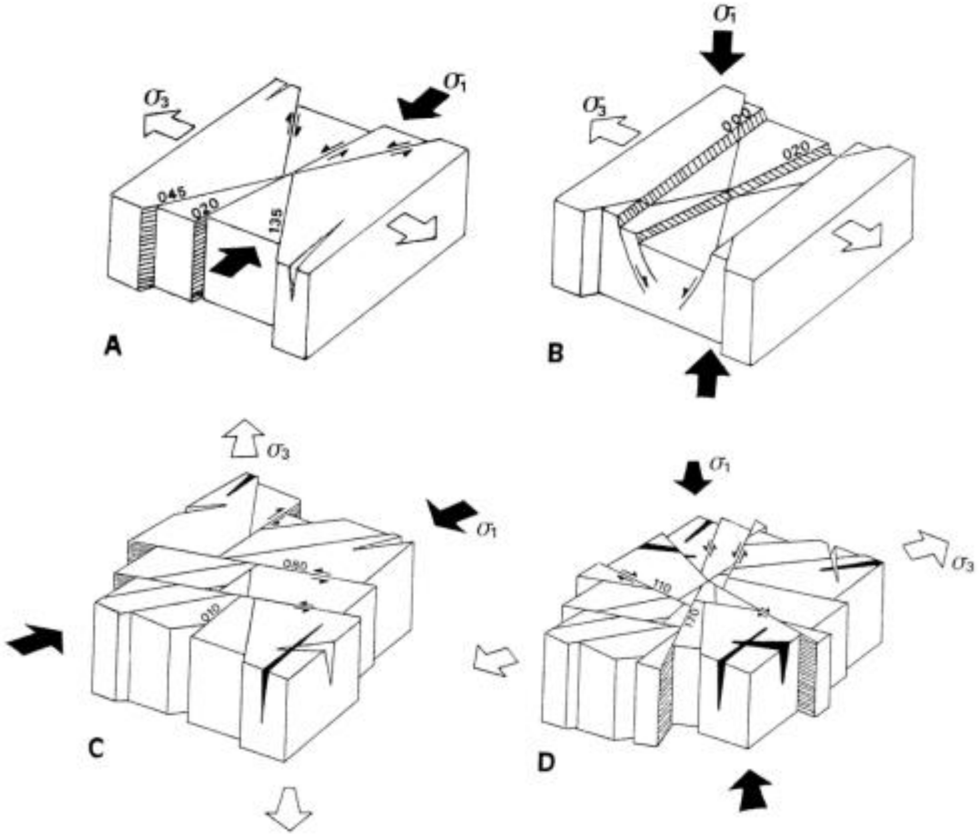
Geothermal target: a local normal fault in the basement

Stress field: transitional from normal faulting to strike-slip

Upper Rhine Graben tectonics



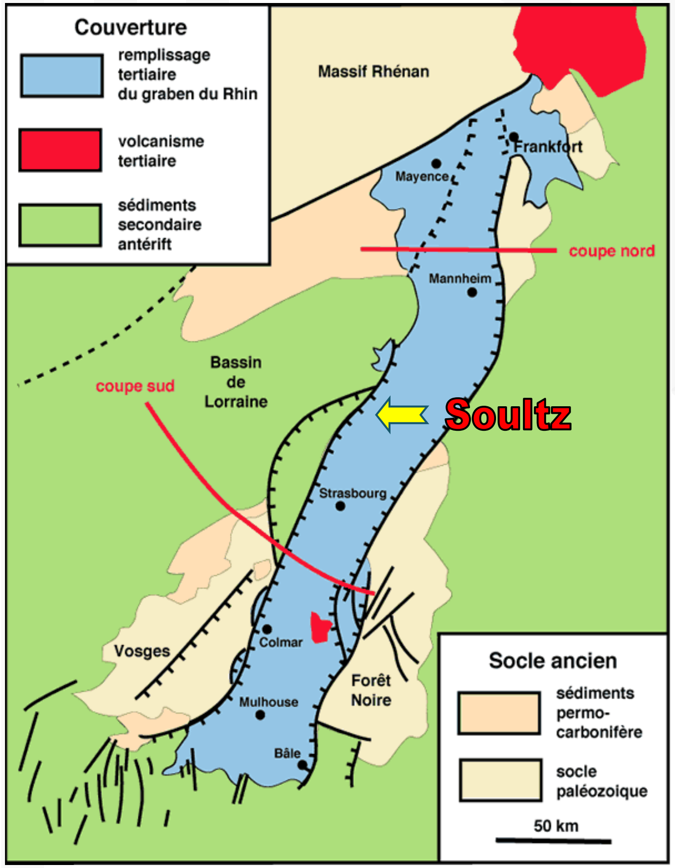
Glaas, 2021

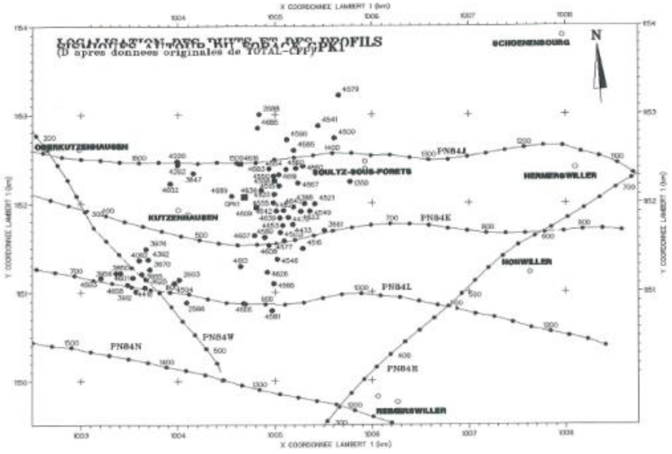


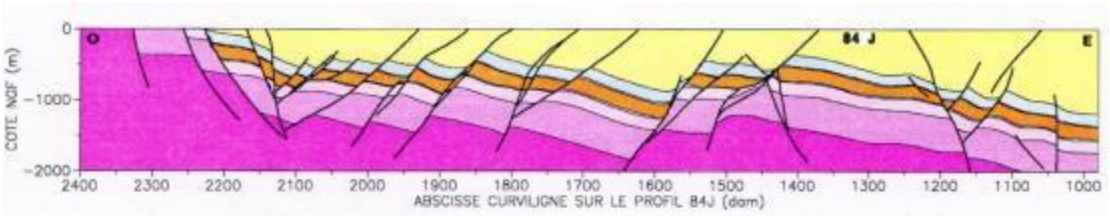
Tertiary tectonic

Villemin & Bergerat, 1987

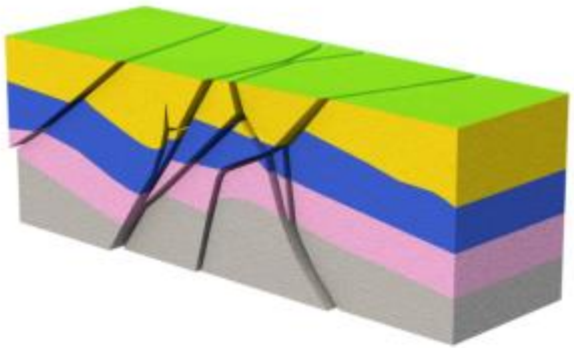
Vintage exploration from 2D seismic survey



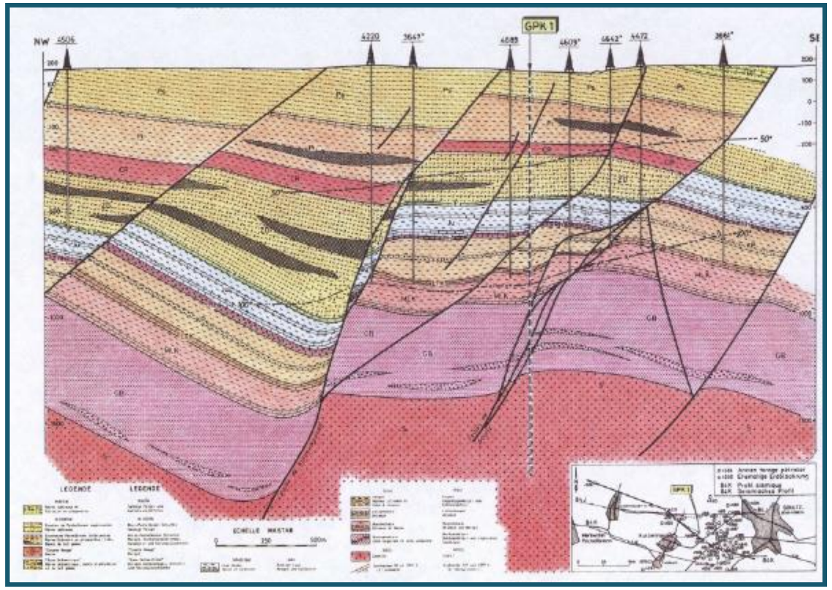




Transverse seismic line



Soultz Horst



Geothermal target is a deep crystalline rock

Soultz monzogranite

7 cm

Core K21, GPK-1 (3510 m)

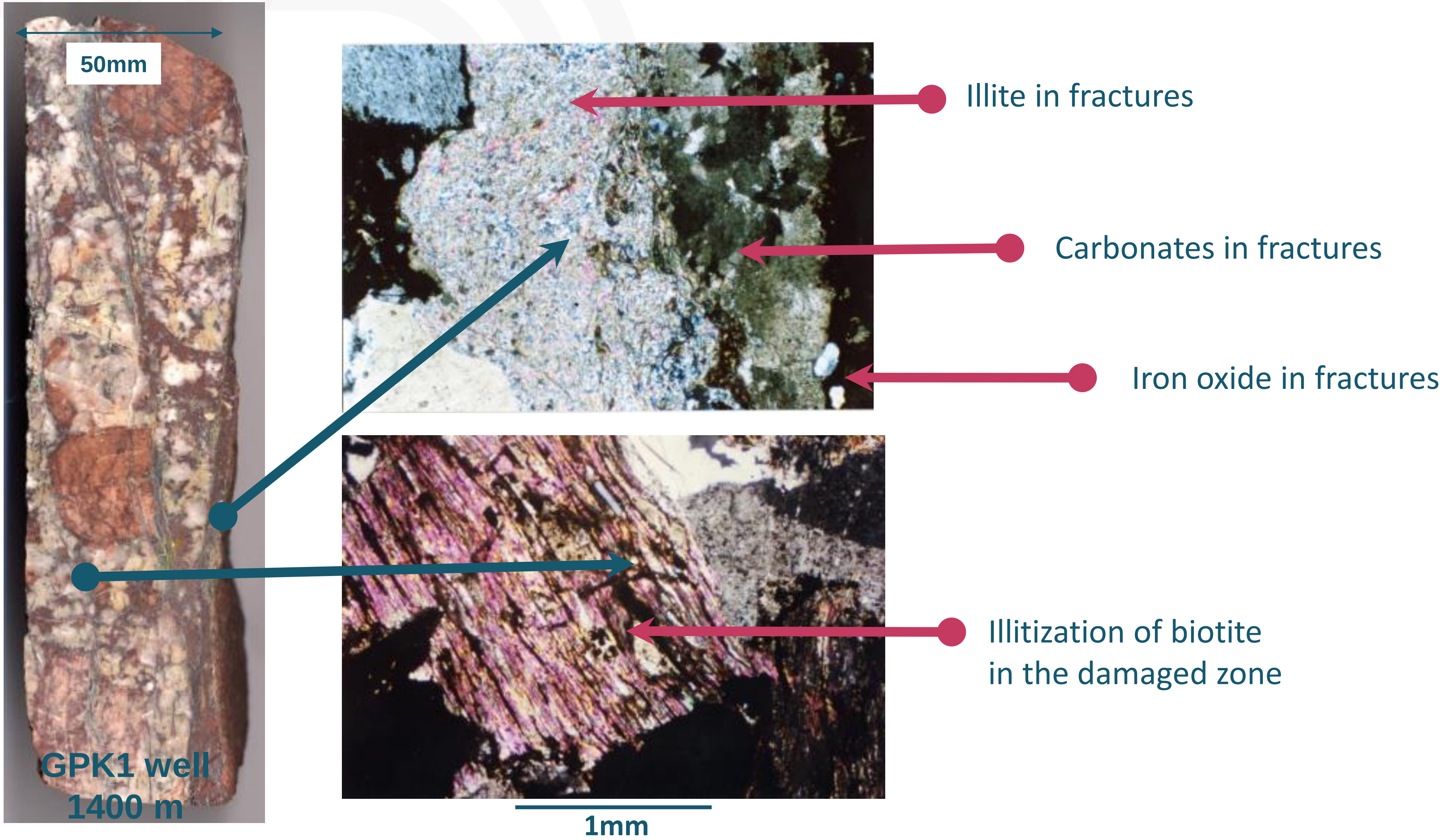
Monzogranite

Crystals of FK (1 to 4 cm)

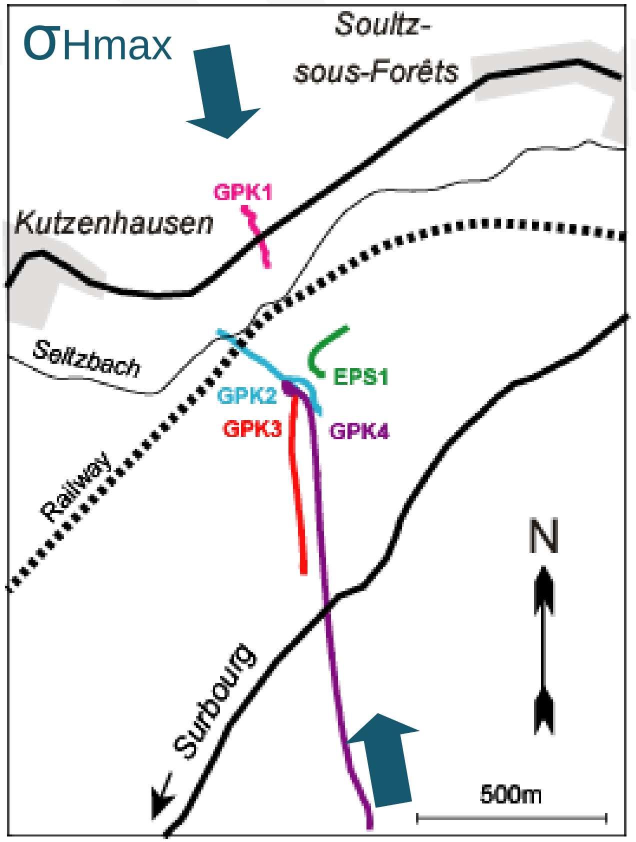
Granite matrix:
plagioclase, quartz, biotite and hornblende

Accessory minerals: magnetite, zircon, apatite, titanite, hematite, leucoxene

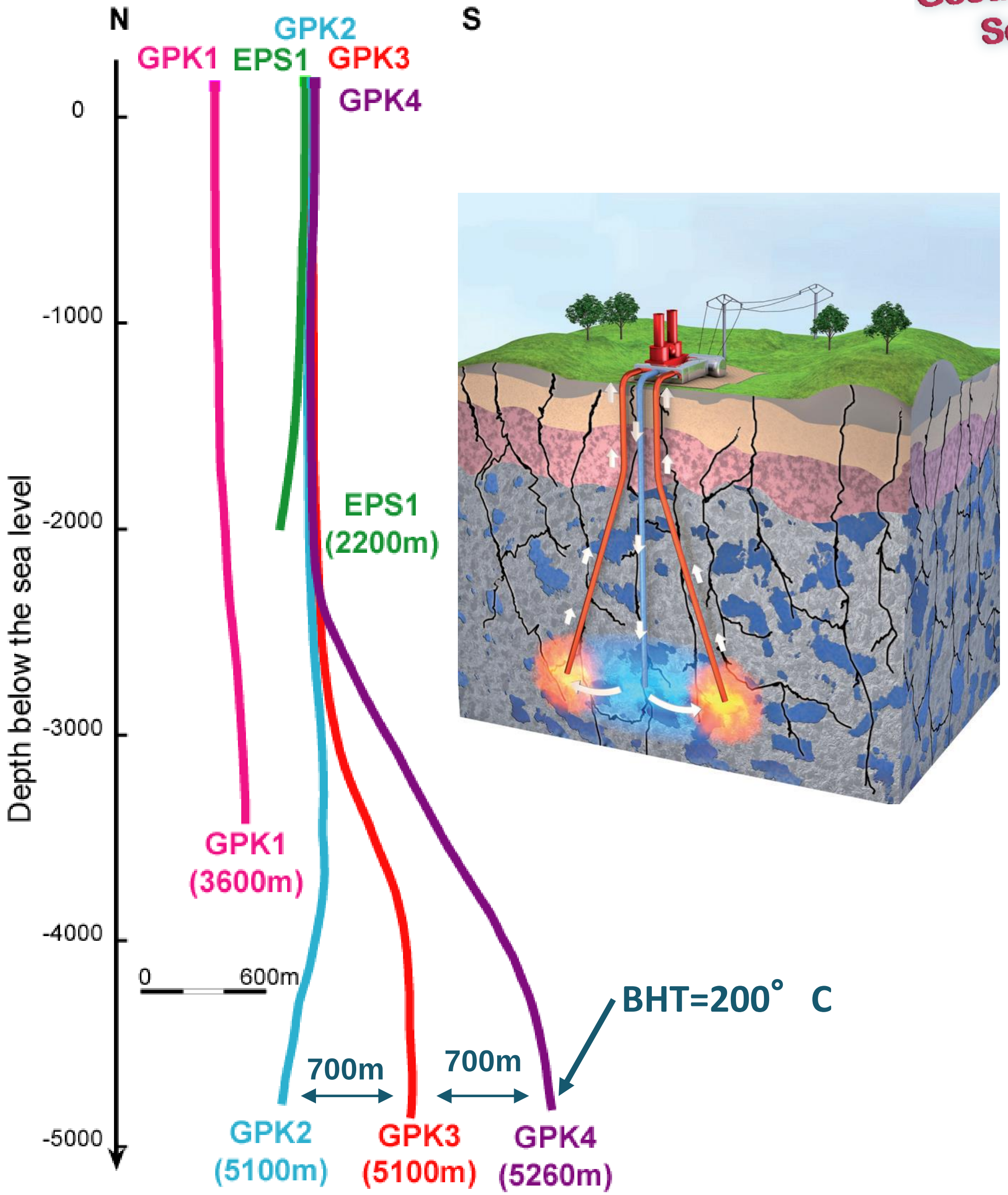
Hydrothermal deposits within fractured granite



Site map

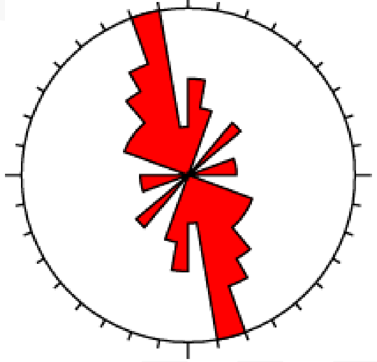


- EPS1 fully cored ➔ exploration well
- GPK1 ➔ Not used
- GPK3/GPK4 ➔ Injection wells
- GPK2 ➔ Production well

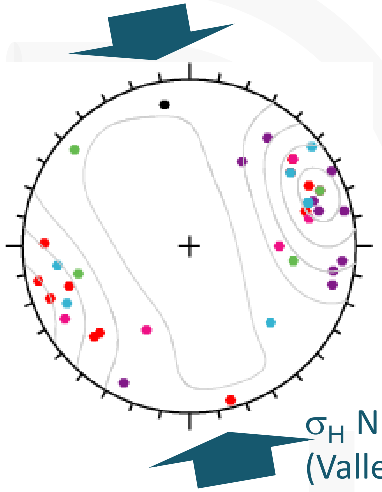


Orientation of fractures

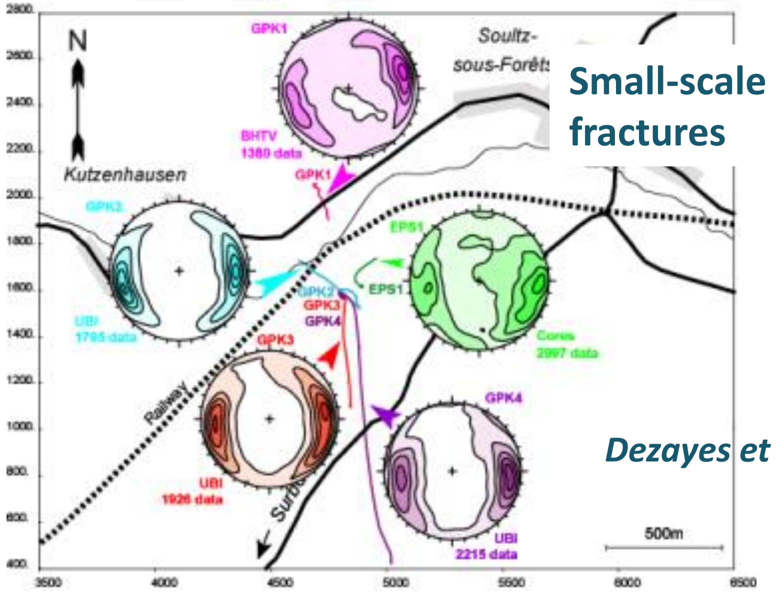
Fracture zones



N160E±10°

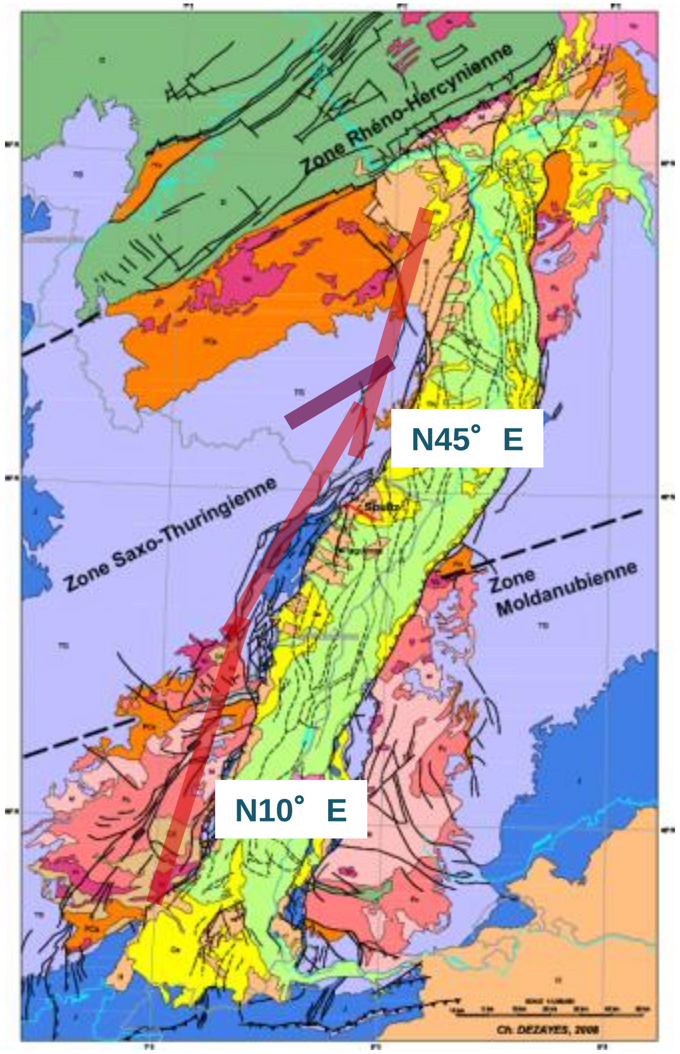


σ_H N170E (Valley, 2007)



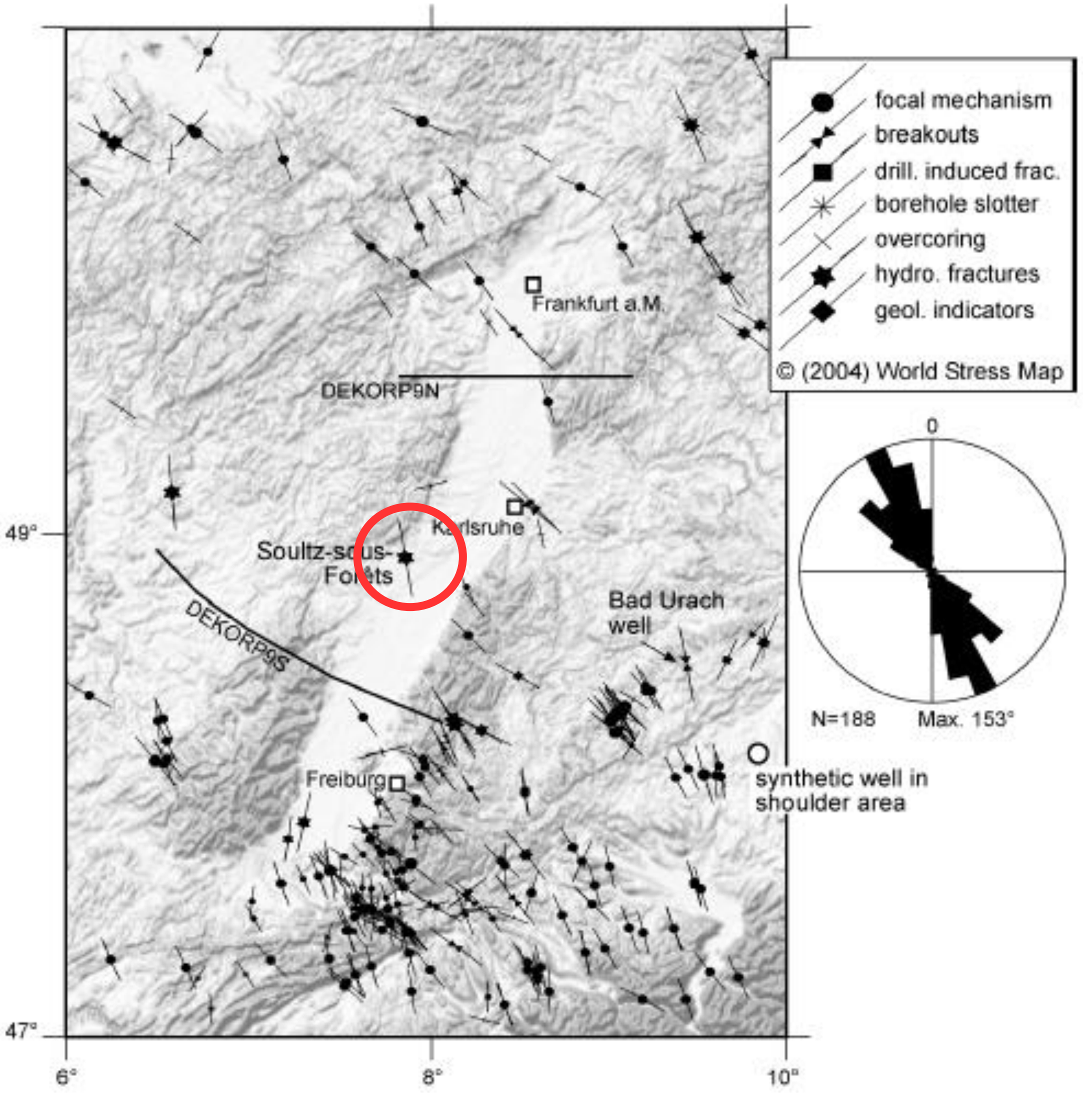
Small-scale fractures

Dezayes et al, 2010

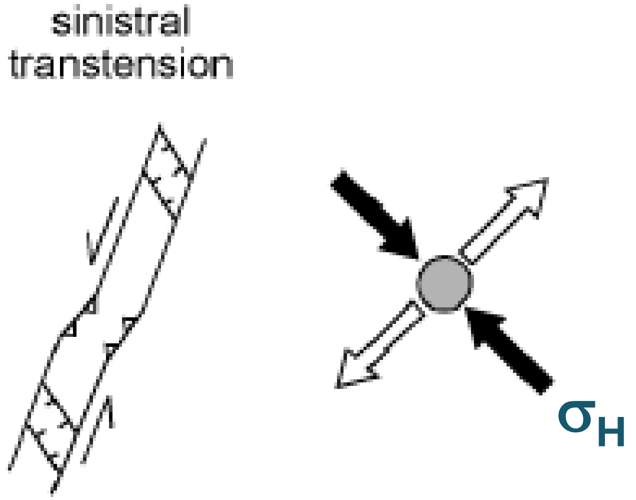


Orientations of deep fractures are not // to main Rhine graben faults

Present-day stress field



Peters, 2007

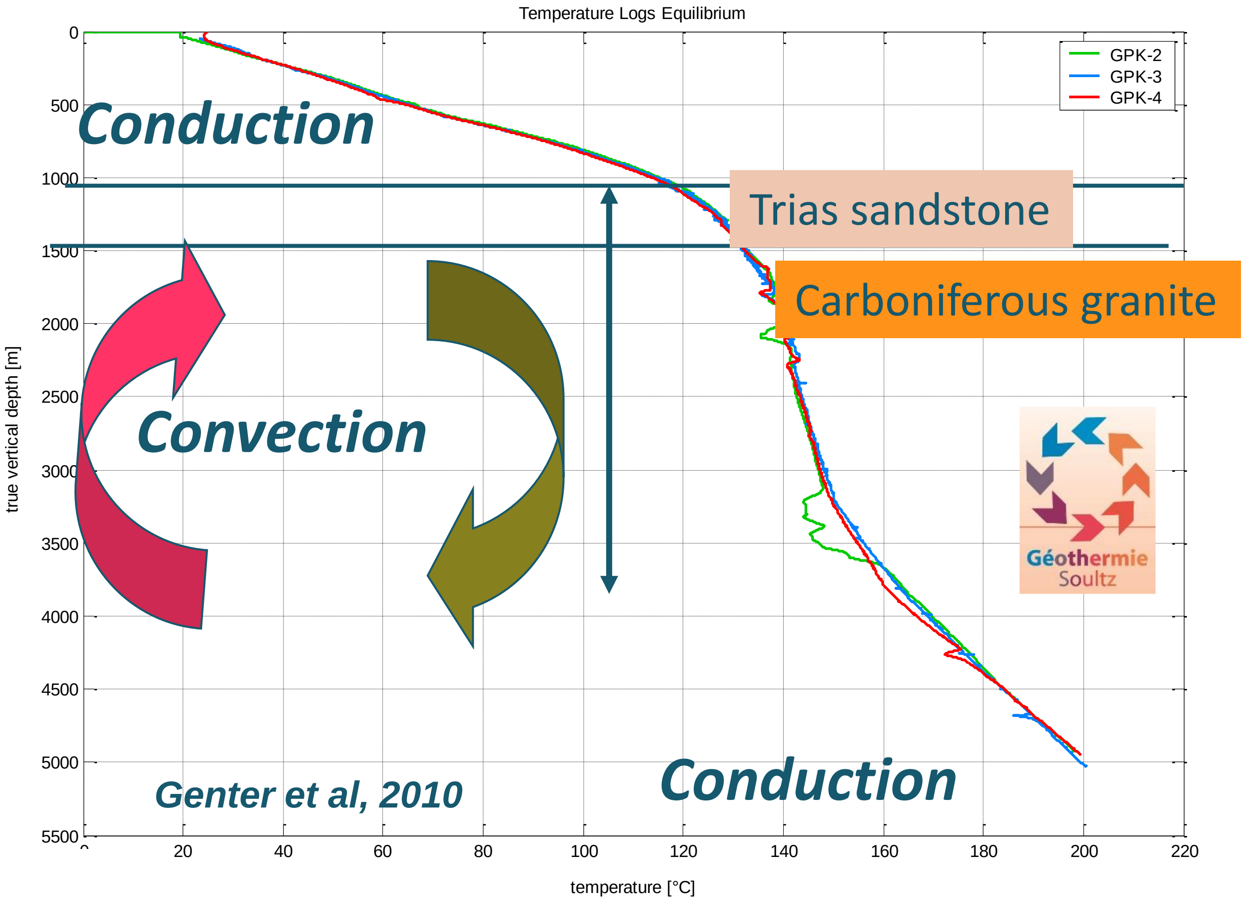


Regional scale: σH NW-SE, Compressive event
Soultz: Borehole measurements, σH NNW-SSE
NNW-SSE fractures are critically stressed

Borehole scale (Soultz): σH N170E (Valley, 2007)
Transitional stress field between normal and strike-slip
Low to moderate seismic hazard araa
Last natural earthquake in 1952 with M4.8@ 20km SE of Soultz

Thermal profiles @ Soultz

Fractured & altered granite



Fractured sandstones

Natural circulations in fractured & altered zones
Top basement is a geothermal resource target

Hydrothermal alteration

Vein Alteration related to fractures

Biotite, Hornblende	illite
Plagioclase	illite
K-Feldspath	Stable ou illite
Quartz	Stable

Pervasive Alteration: Standard monzogranite

Biotite → Chlorite
Plagioclase → Corrensite

Genter, 1989

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Native brine composition

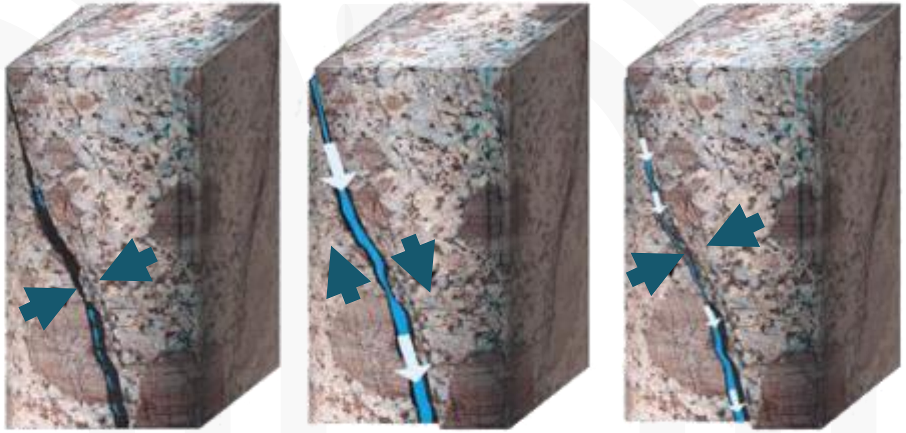
Fluid Sample 06/02/2013	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	Cl mg/l	SO_4 mg/l	NO_3 mg/l	SiO_2 mg/l	Br mg/l	Sr mg/l	Li mg/l
GPK2-PROD	25200	3360	7440	142	57300	228	<2	174	237	418	169
	F mg/l	PO_4 mg/l	B mg/l	NH_4 mg/l	Fe_{total} mg/l	Mn mg/l	Ba mg/l	As mg/l	Rb mg/l	Cs mg/l	Zn mg/l
	6	4	41	24	30	18	26	11	18	11	3
	Al µg/l	Pb µg/l	Cd µg/l	Cr µg/l	Cu µg/l	Ni µg/l	Hg µg/l	Ag µg/l	U µg/l		
	66	66	14	5	<1	1	<0.4	0.8	<0.05		

(Sanjuan, 2010)

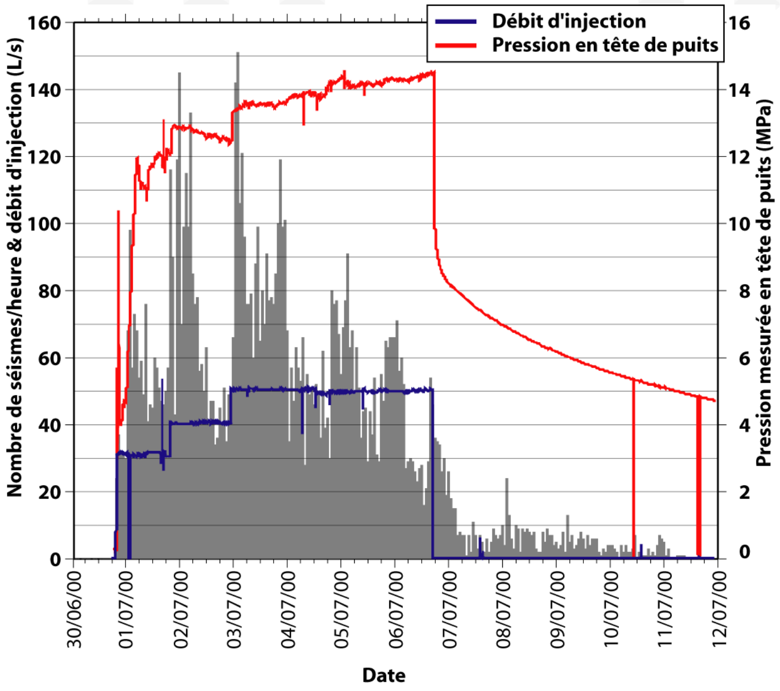
- Na-Cl-Ca dominated brine
- TDS ≈ 97 g/l, Density = 1.065 g/cm^3 (20˚C)
- pH ≈ 4.7-5.0
- Gas Liquid Ratio of 1:1 (mainly CO_2, 85%, N_2, 10%, and CH_4, 2.5%)

→ **Soultz operation conditions are highly aggressive and corrosive**

Hydraulic stimulation

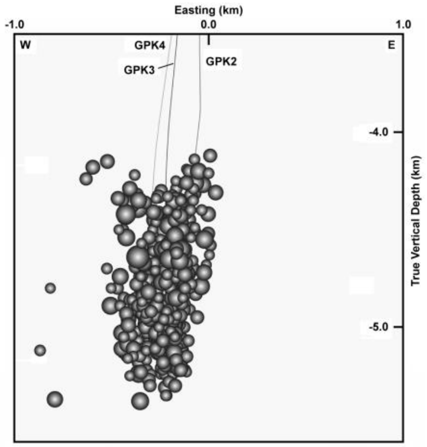


Presure

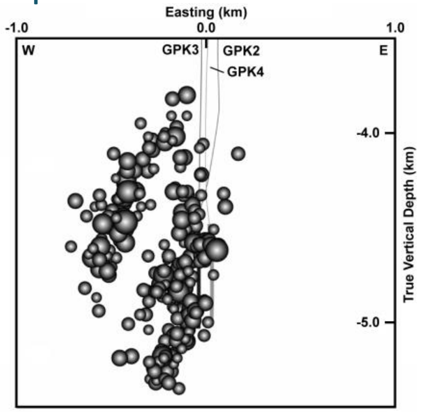


Cuenot et al., 2008

Time



GPK2, 2000
µseismic events M>1



GPK3, 2003
µseismic events M>1

Dorbath et al., 2009

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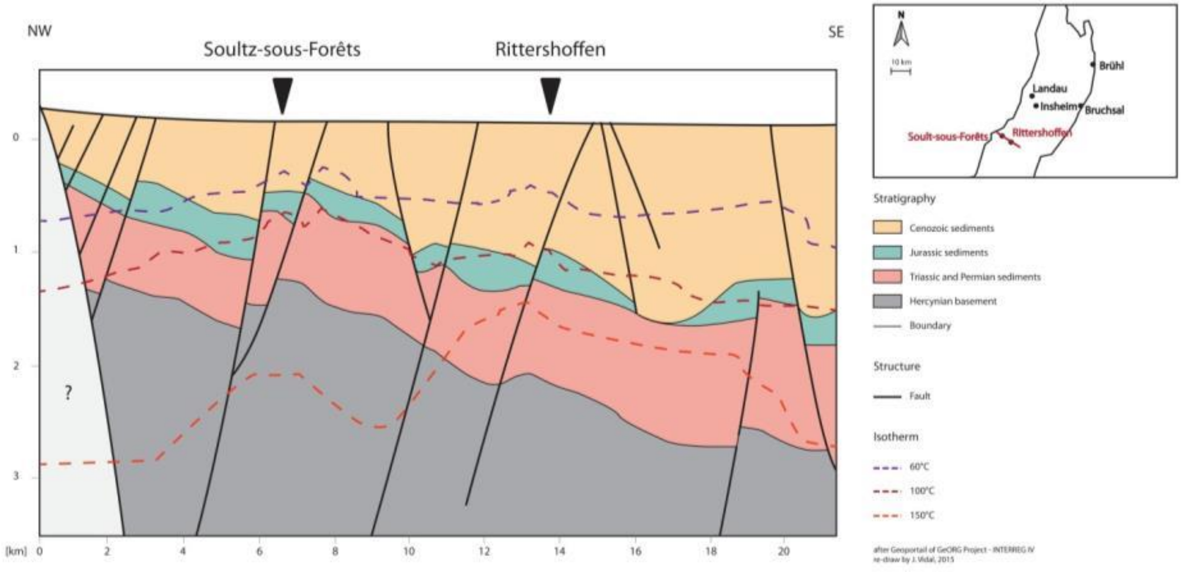
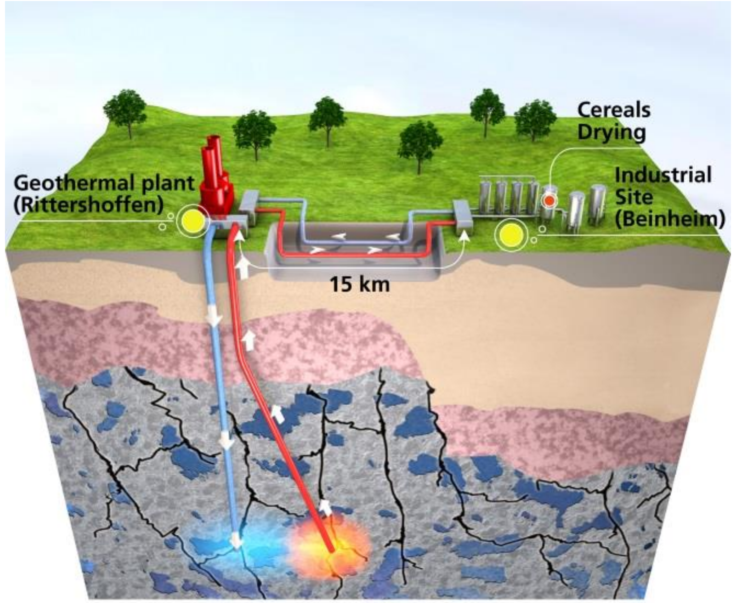
The Rittershoffen project (France)

Local geology

Local map



Geological cross-section



Open-hole section: fractured Triassic sandstone & fractured Carboniferous granite

Geothermal target: a local normal fault in the basement

Rittershoffen project: main technical phases

2011	2012	2013	2014	2015	2016

ECOGI
JV creation

Drilling
Platform construction

GRT1 Well @2560 m
Drilling and well development

Seismic
Survey

GRT2 Well @3196 m
Drilling and tracer tests

Surface construction
Thermal plant
Transport loop
Bio-refinery

ECOGI plant
Commissioning
Commercial exploitation

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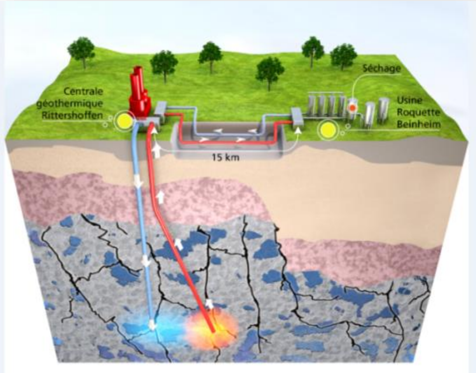

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Technical Data:

2 Wells	2500-3000 m deep
Operating hours	8.000 h/year
Temperature	170°C
Transport loop	15 km
Thermal power	24 MW

Exploration and well targeting

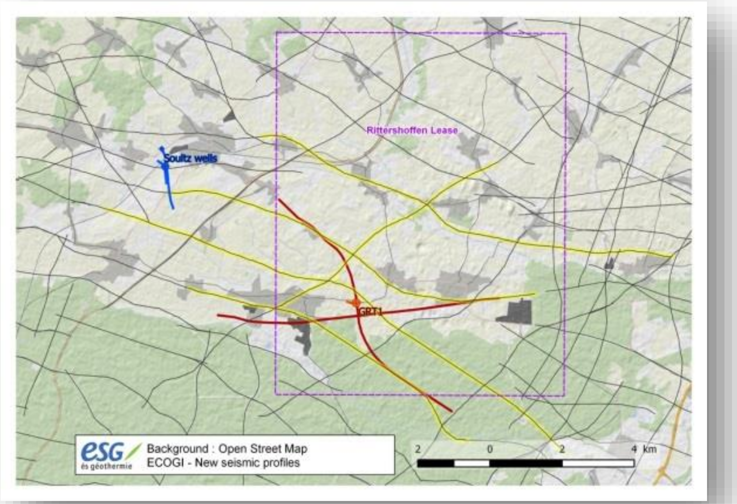
Thermal anomaly identified from old oil wells

Reprocessing and interpretation of 5 old seismic lines

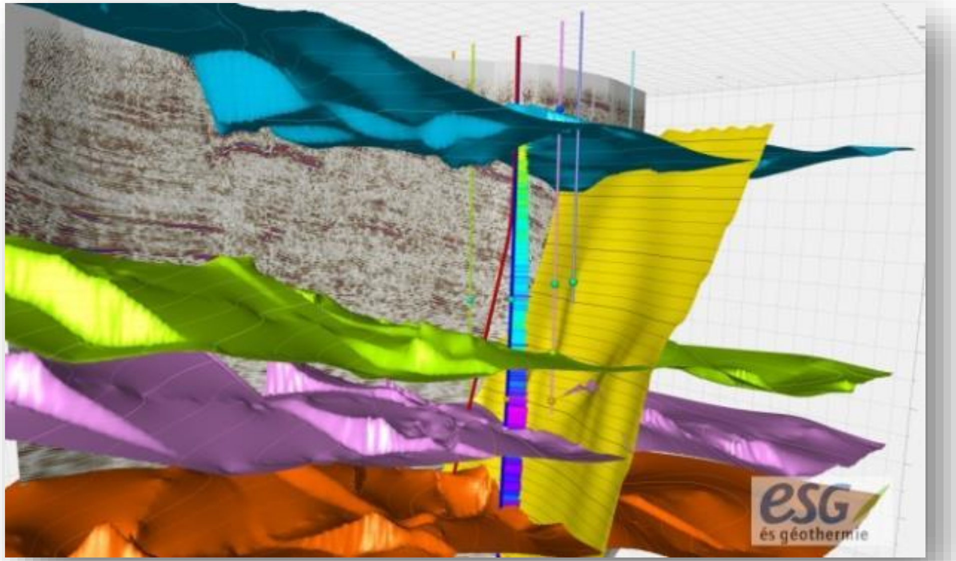
Acquisition of 2 news lines

PSDM processing of all lines

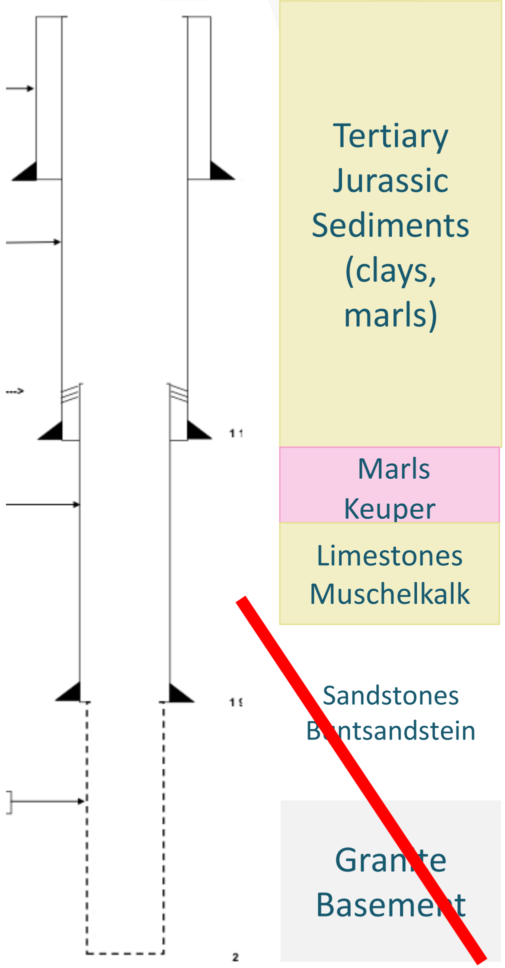
3D Structural modeling with Petrel

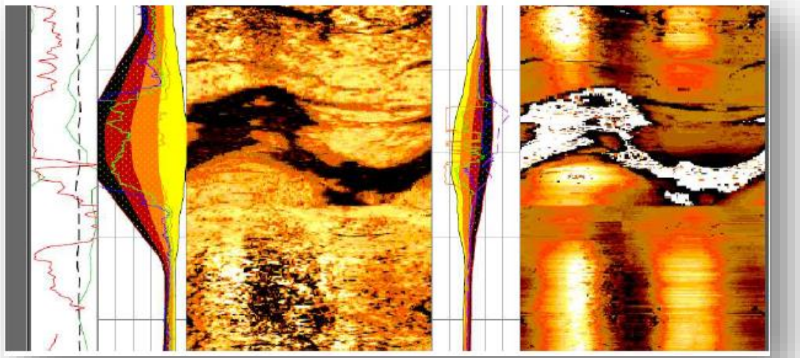


GRT-1 vertical @ 2600m MD
GRT-2 deviated well @ 3200m MD



Deep fractured reservoir: clastic versus granite





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Naturally fractured reservoir

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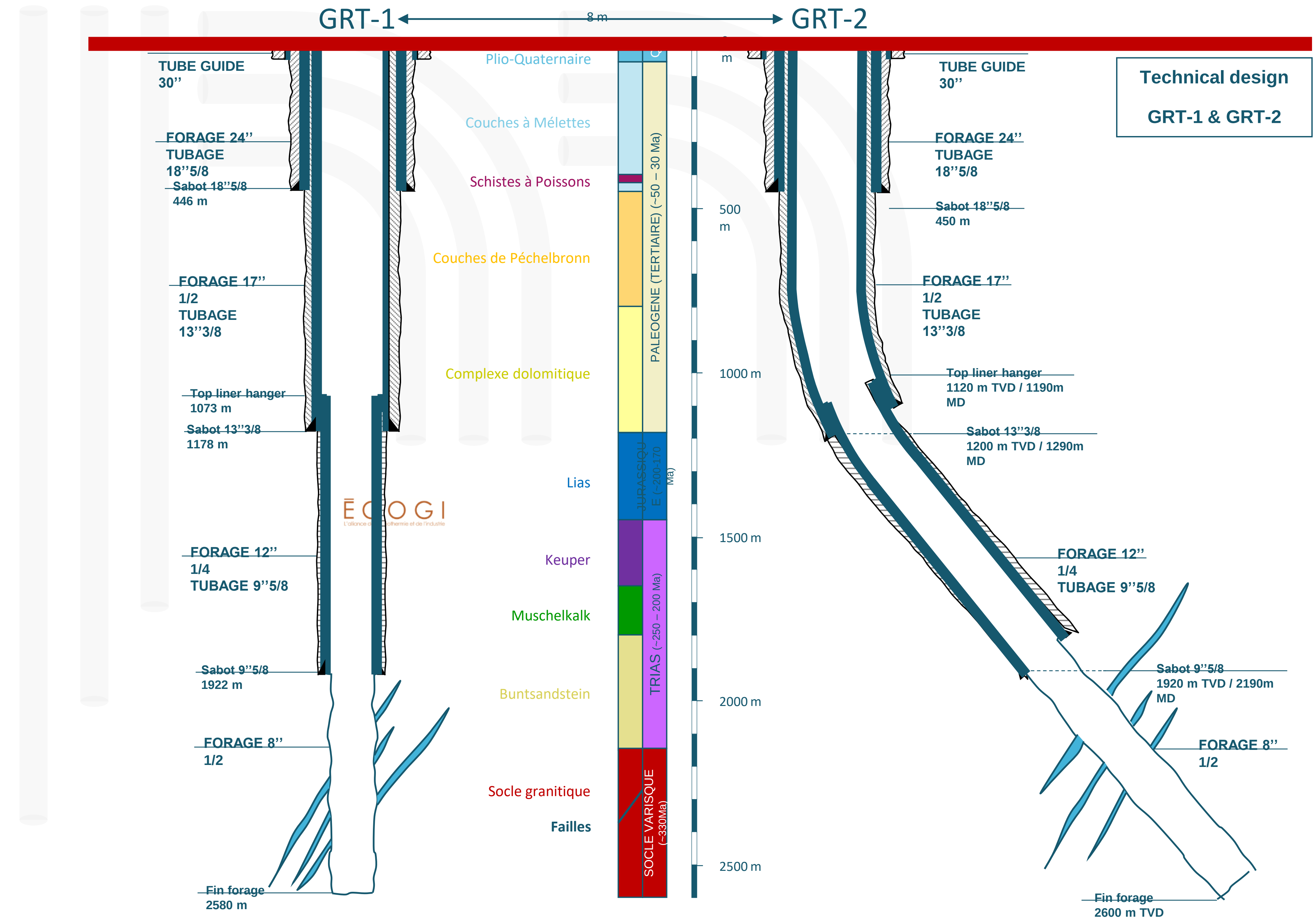
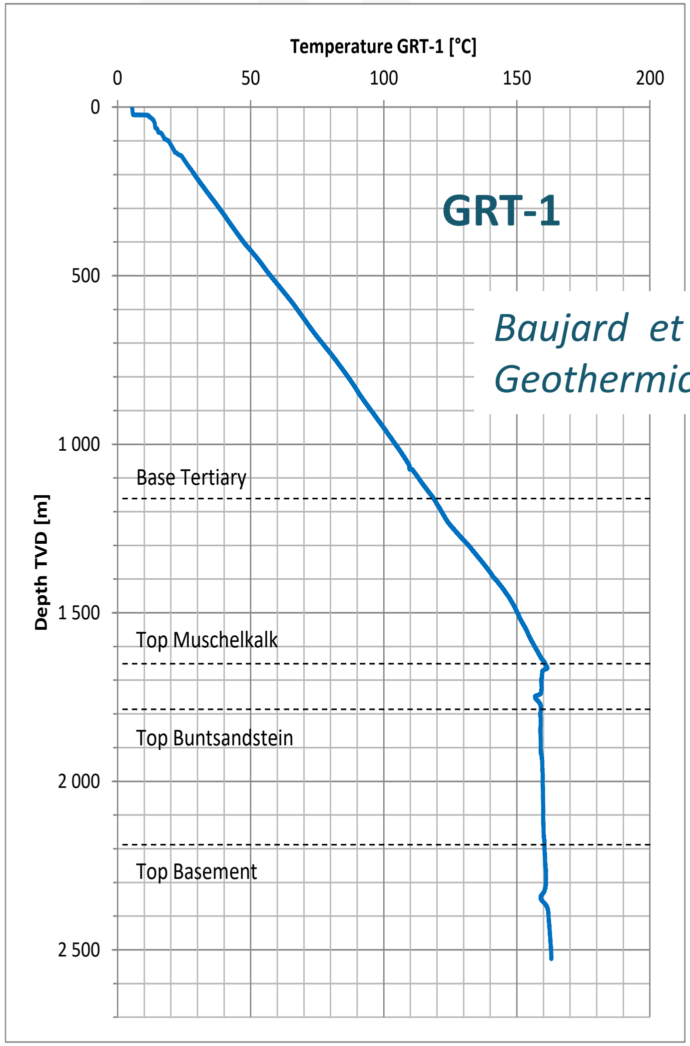
Technical design

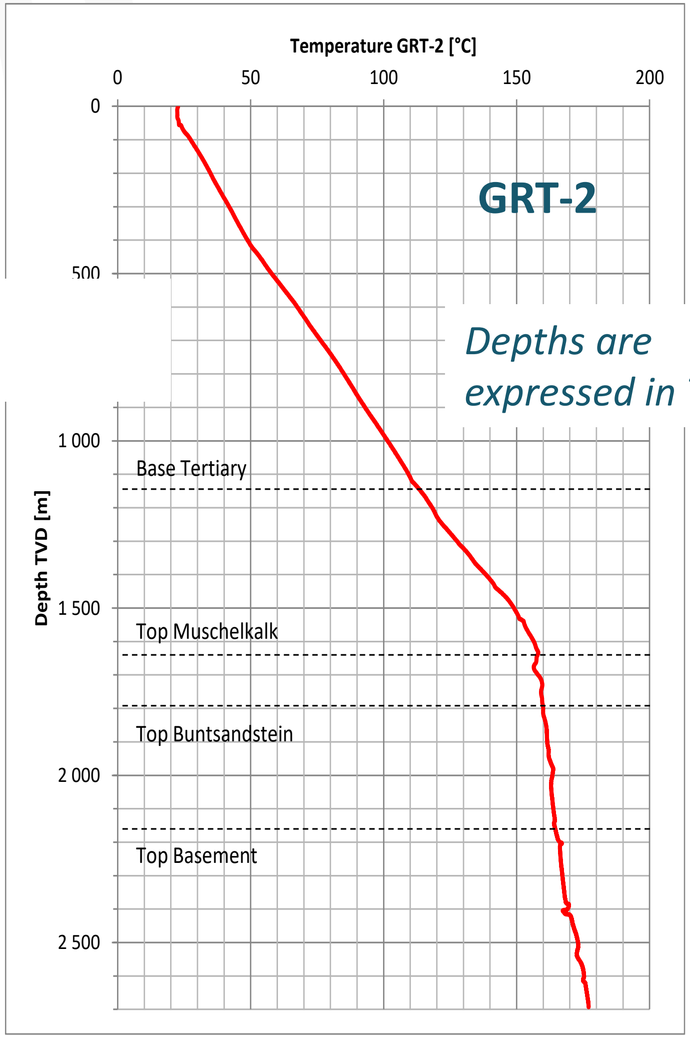
GRT-1 & GRT-2



Temperature profiles @ Rittershoffen

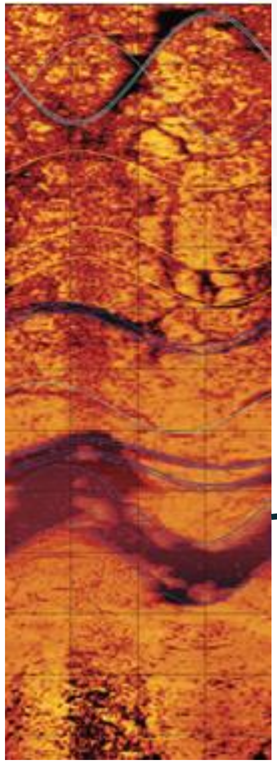


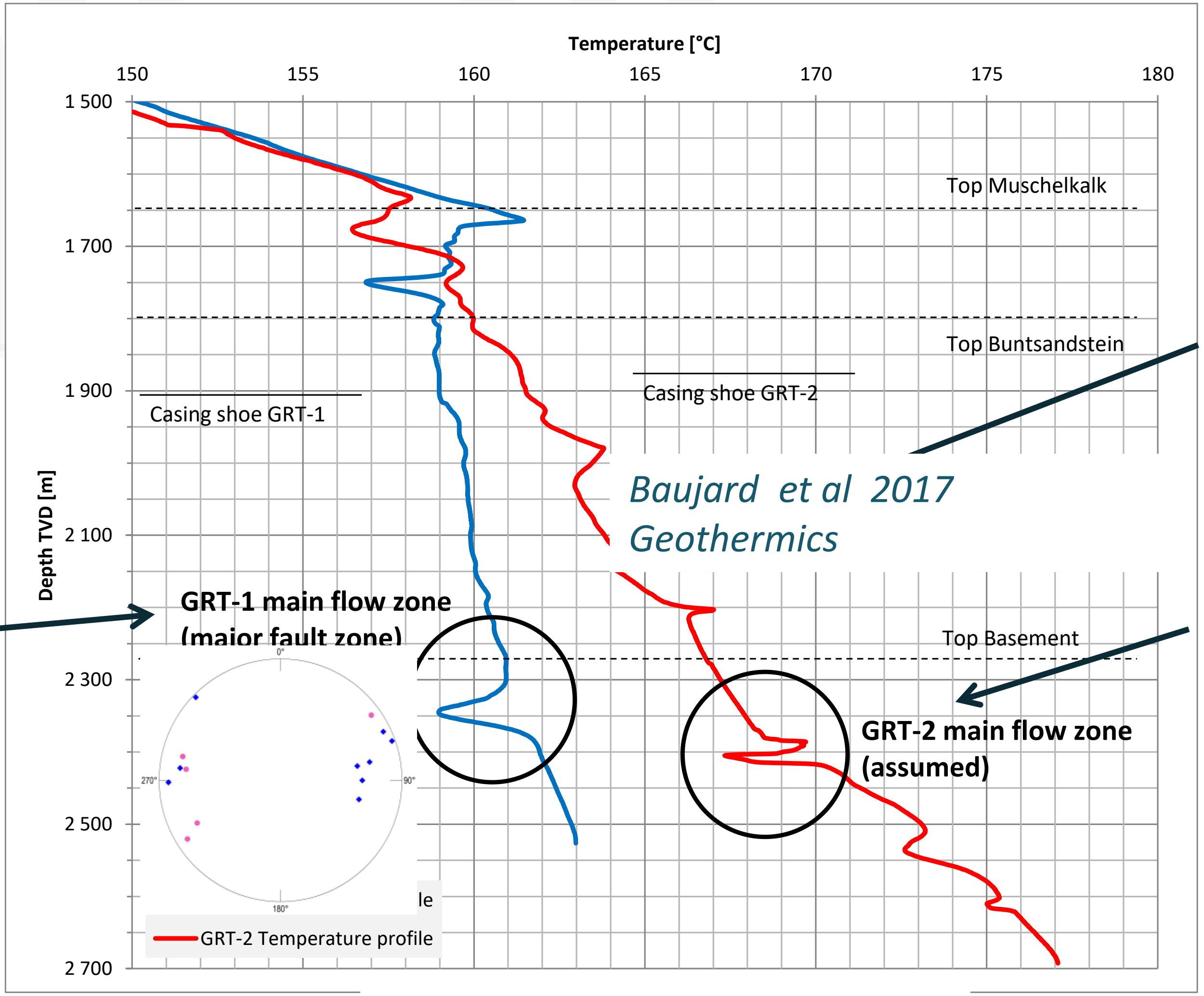
Baujard et 2017, Geothermics



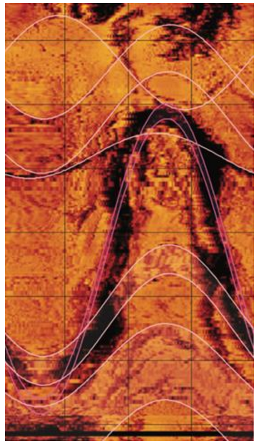
Depths are expressed in TVD

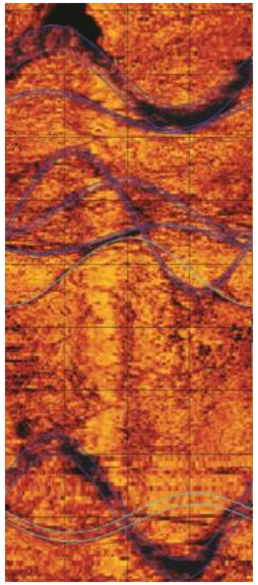
Focus on temperatures in the reservoir





Baujard et al 2017
Geothermics



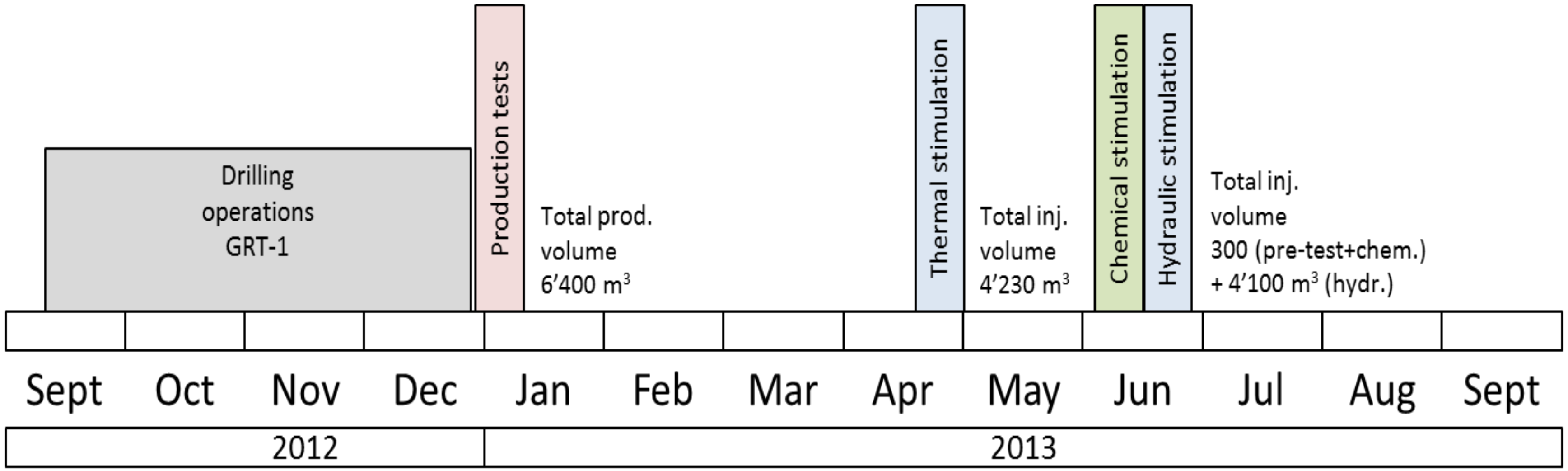


Depths are expressed in TVD

GRT-1 well testing & development strategy

Well testing GRT-1
- Low initial productivity (< 0.5L/s/bar)
- Low initial injectivity
- Economic threshold not reached

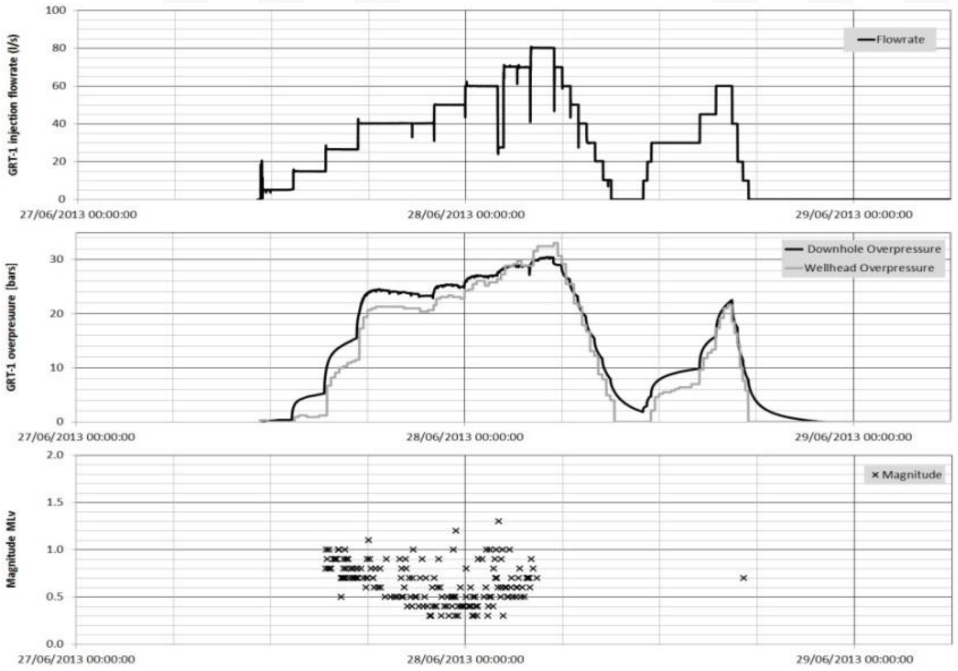
GRT-1 Well development
Thermal stimulation
Chemical stimulation
Hydraulic stimulation

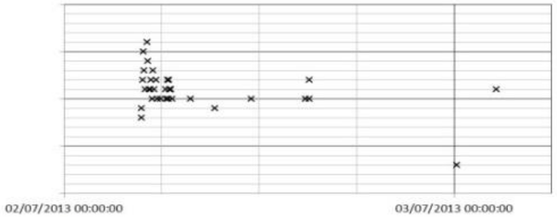


Baujard et al 2017 Geothermics

Hydraulic stimulation of GRT-1

- Objective: increase reservoir permeability using hydro-shear processes
- High rate water injection with stepwise rate (Qmax 80L/s)
- Real-time seismological monitoring



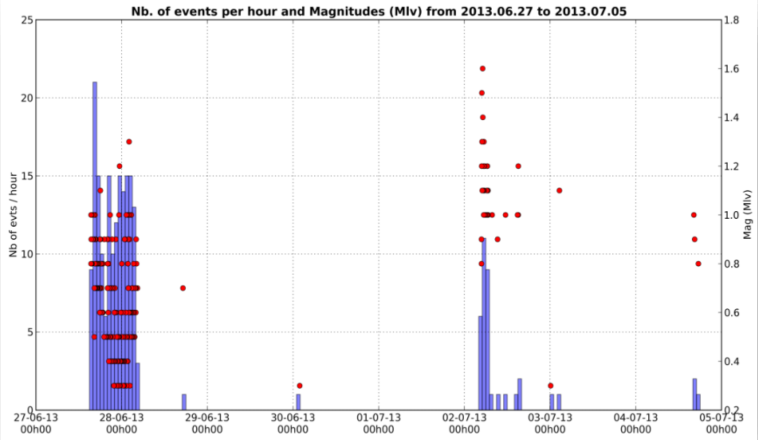


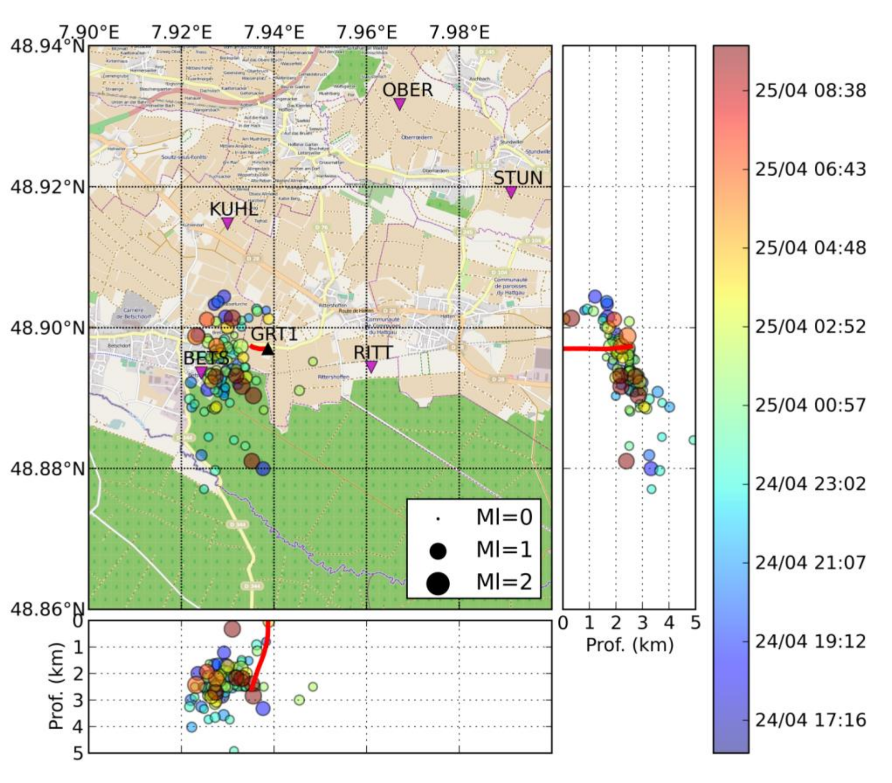
Results: Injectivity increase by a factor 2

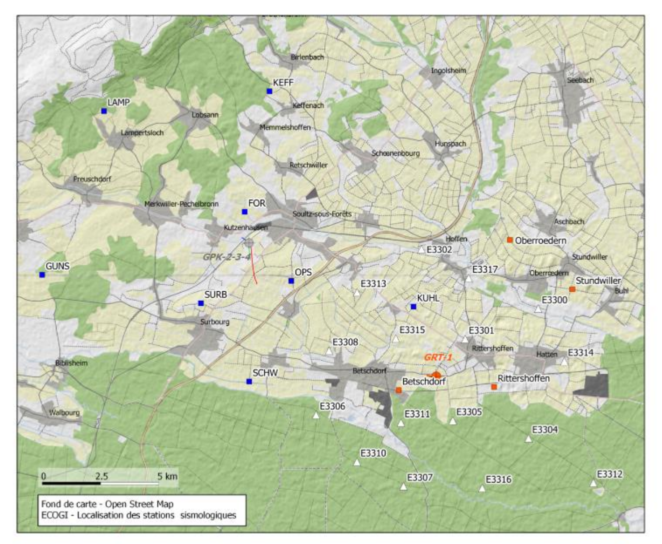
Baujard et al 2017, Geothermics

Seismological activity during GRT-1 hydraulic stimulation

- Real-time location
- > 300 events automatically picked and located
- Max magnitude 1.6 Ml
- Max Well-Head Pressure: 30 bar







Critical threshold (Ml 1.7) never reached

From Maurer et al. 2020

Conclusions

EGS technology for URG:

There is a kind of continuum between an EGS well (ex GRT1) and a hydrothermal well (ex GRT2)

Fluid flow signature in the basement

- High fracture density & low geothermal gradient in the top basement
- Argillic alteration with illite in the basement (damaged zone)
- Complexe architecture of fractured zones (fault core, quartz vein)
- Induced seismicity during stimulation but with very low magnitude
- Induced seismicity during exploitation but with very low magnitude at reinjection side

Geothermal energy from deep fractured granite reservoir is a reality

Electricity, heat, lithium, greenhouses, industrial applications are possible!

Thank you very much for your attention

Geothermal Winter School 2021

MEET
Multi-sites EGS Demonstration

és géothermie

This work was performed in the framework of the H2020 MEET EU project which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792037

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Questions

Soultz-sous-Forêts

Question 1: The Soultz geothermal project

The Soultz site is located within a high geothermal anomaly inside the Upper Rhine Graben, with a temperature of about 110°C at 1 km depth. This first km of sediments is dominated:

a) By a convective thermal regime. ☐
b) By a conductive thermal regime. ☐
c) By both convective and conductive thermal regimes. ☐

Question 2: The Soultz geothermal project

The EGS Soultz site is under exploitation by using one production well, GPK2, and two injection wells, GPK3 and GPK4. In 2019, about 800’000 m^3 of geothermal water were circulated within the geothermal installation. Where comes from this water?

a) Fresh water is injected from water supply. ☐
b) Natural brine is permanently pumped in the reservoir and re-injected. ☐
c) Natural brine is not sufficient and fresh water is regularly injected. ☐

Questions

Rittershoffen

Question 3 : Power or heat production?

The Rittershoffen geothermal project, located close to Soultz, was designed?

a) To produce power generation with a gross electricity capacity of 2.4MWe □
b) To produce heat for a bio-refinery located 15 km away from the geothermal wells □
c) To produce geothermal fluids with a surface temperature range of 160-170°C and a production flow rate of 70 L/s □

Question 4 : Top basement

At Rittershoffen, the geological interface between the sedimentary clastic cover and the top crystalline basement is exploited by deep boreholes.

a) At Soultz, the sediment-basement interface is localized at 2.2 km depth □
b) At Rittershoffen, the sediment-basement interface is deeper than at Soultz □
c) At Rittershoffen, the geothermal fluid is much more saline than at Soultz □