Deep Geothermal Projects in the Rhine Graben and Munich Area

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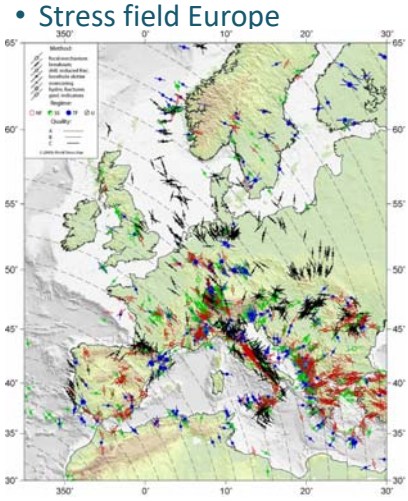
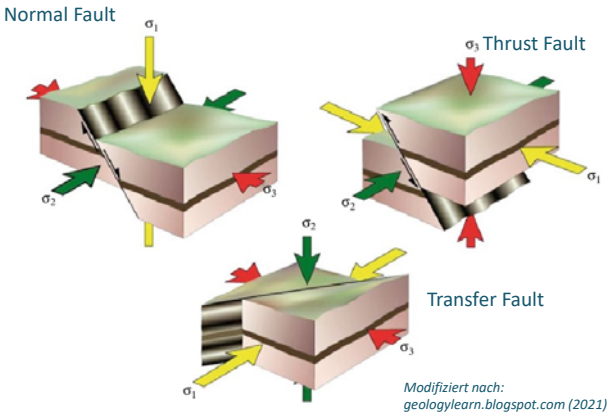
Background: Natural Stress Field in Underground

- Stress field Europe



World Stress Map (Heidbach et al., 2007)

Manifestation at Surface

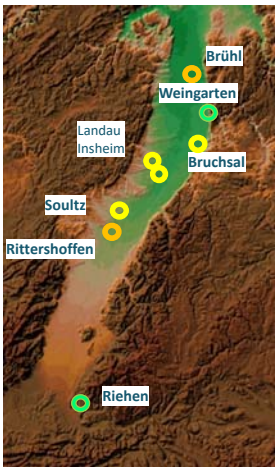


Modifiziert nach: geologylearn.blogspot.com (2021)

Overview: Upper Rhine Graben & Geothermal Projects

- Rhine Graben
  - Active tectonic
  - Bounded between Black Forest / Vosges
  - 350km N-S extension
  - 50km E-W extension

→ ***Extensional Tectonics***



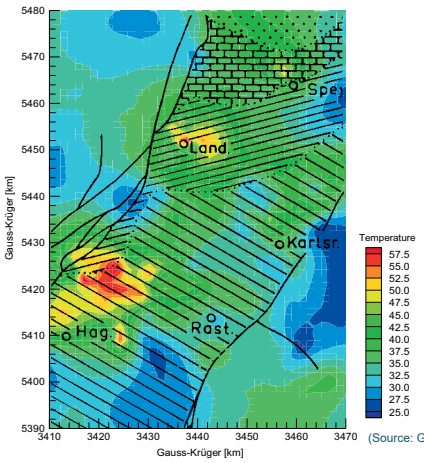
Digitale terrain model
(SRTM – Data)

Data: Illies & Greiner, 1978

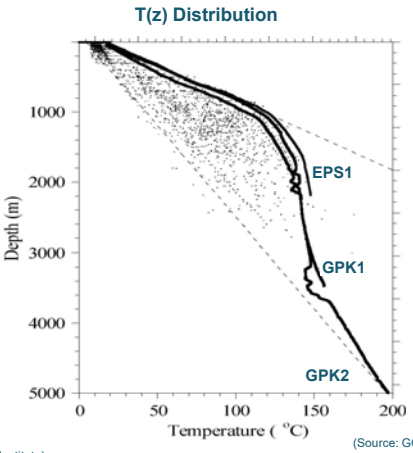
- Geothermal Systems
  - Hydrothermal
    - (e.g. Riehen, Bruchsal)
  - Petrothermal
    - EGS (e.g. Soultz)
  - Mixed

Upper Rhine Graben: Regional Temperature Anomaly

•Temperature in 500m depth



(Source: GGA Institute)



(Source: GGA Institute)

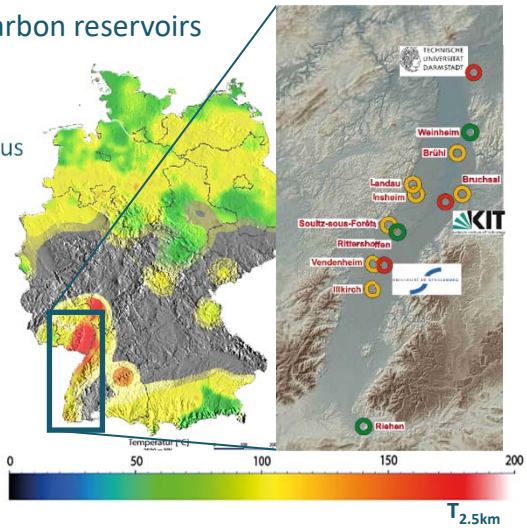
→ ***Extensional Tectonics*** → ***Permeability*** → ***Convection cells***

Motivation for Geothermal Research in Upper Rhine Graben

- Largest temperature anomaly in central Europe
- High temperature storage capacity in old hydrocarbon reservoirs
- Cross-border
  - cooperation with numerous industrial projects
  - exchange among universities with energy research focus
- State research center for geothermal research

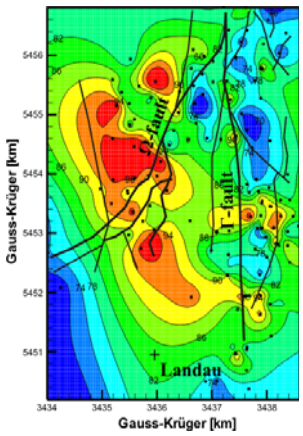
- Close Cooperation with Industry
  - EnBW, Pfalzwerke, ESG

→ ***Cooperation is essential***

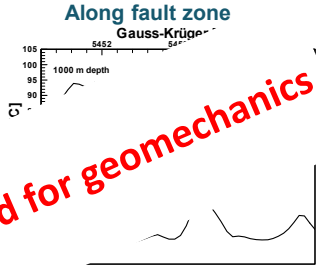


Common feature
Importance of fault zones

Landau temperature
1000 m Depth



Temperature-Distribution
Along fault zone

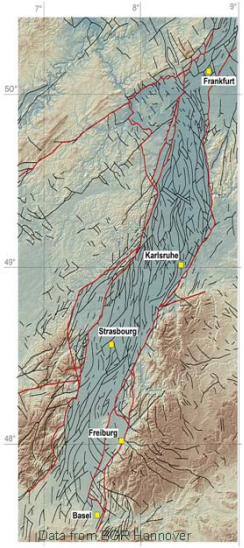


- **Need for geomechanics**

Bächler & Kohl, 2000

Digitale terrain model
(SRTM – Data)

Data: Illies & Greiner, 1978



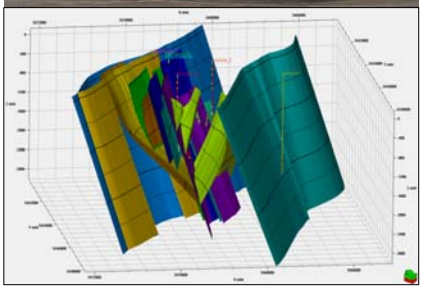
Project Overview
Geothermal Electricity Production

- Selection of Projects

Project	Reservoir	Depth	Temp.	Flow	Capacity	Status
Electricity Production						
Soultz-sous-Forêts	Granite	5000 m	200°C	30 L/s	1.5 MW	Triplet, in operation
Bruchsal	Buntsandstein	2000 m	130ºC	25 L/s	500 kW	Doublet, in operation
Landau	Buntsandstein, Granite	3000 m	150ºC	40 L/s	2.5 MW	Doublet
Insheim	Buntsandstein Granite?	3600 m	165°C	40 L/s	4.8 WW	Doublet, in operation
Rittershoffen	Buntsandstein Granite?					Doublet, in operation
Possible Development (Progressed Stage)						
Brühl				up to 100 L/s ?		1 well drilled
Stopped						
Vendenheim	Granite	5000 m	220°C	??		Earthquake
Speyer	Buntsandstein	2700 m				oil recovery
Bellheim	Muschelkalk	~2900 m				Low productivity
Basel	Granite	5000 m	200°C			Earthquake
Offenbach	Muschelkalk	2800 m				Low productivity

Geothermal Projects: Bruchsal

- Operator: geo (EnBW / ewb Bruchsal)
- Reservoir:
  - Fault system in Buntsandstein
  - Reactivation of 2 existing wells from 1985/87
- Parameters of plant:
  - depth 2000 /2.500 m
  - temp. 120ºC
  - flowrate 22 l/s
  - capacity 550 kW (Kalina)
  - heat 5'500 MW_{th}.
- Activities:
  - 1979 Initiation of project,
  - 1987 Project standby until 2002
  - 2002 Circulation of 90'000m^3 at 115ºC
  - 2005 Repaired loop, new circulation at 135ºC, Salinity 130 g/l
  - 2008 construction of power plant
  - 2009 first operation



Source: EnBW, 2009

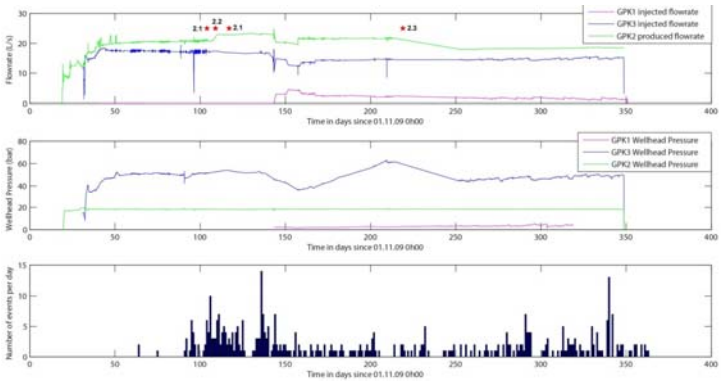
Geothermal Projects: Insheim

- Operator: Pfalzwerke geofuture
- Reservoir:
  - Permeable fault zones in Muschelkalk, Buntsandstein and Granite.
  - Multi-horizon exploration
- Parameters of plant:
  - depth 3600 m
  - temp. 165ºC
  - flowrate 50-80 l/s
  - capacity 4.8 MW (ORC)
- Activities:
  - 2008 First well / Testing
  - 2009 Second well / Testing
  - 2010 Circulation
  - 2010 Side track
  - 2012 Start Operation
  - 2013 minor Earthquake Mag 2.1
    Slow increase of pressure/flow

http://www.geothermie-insheim.de

Soultz-sous-Forêts: Controlled micro-seismicity

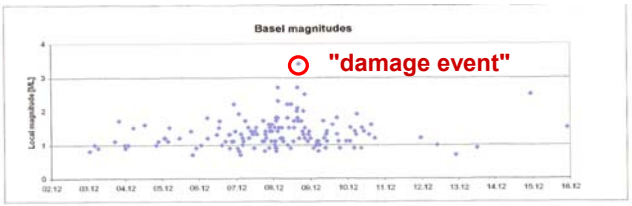
- Ex. Circulation testing 2010
  - 11 months Operation: Production GPK2, Injection GPK1 (GPK3)
  - Flowrate approx. 18 L/s; Injection Pressure < 5 bar
- Micro-seismicity
  - 412 Events
  - with
    - 25 EQ at M>1
    - 2 EQ at M>2
  - Highest Magnitude
    - At highest Flow rate
    - At Shut-In conditions

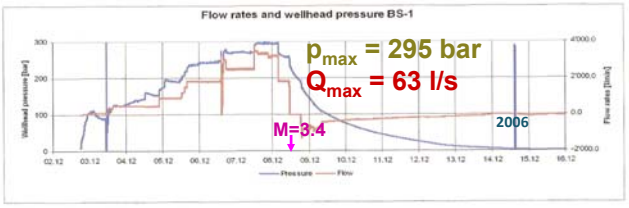


→ Stepwise Project development → Learning Curve

DHM Basel: Induced (Man-made) Seismicity (MMS)

Low transmissivities
- High hydraulic pressure level
- High hydraulic energy
- High Seismicity





Geopower 2007

- Hypocenter in 4-5 km depth
- After 1 month, approx 23% of injected fluids were recovered

→ Forced project development → not accounting for learning curve → seismicity

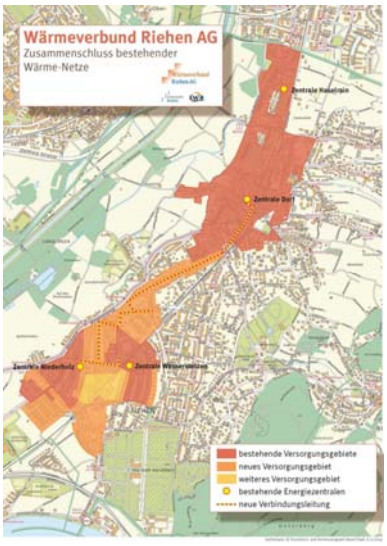
Barriers and Developments

- Developments
  - Large, well-established operators with little problems
    - ES, EnBW
  - Success with Transparency
    - Large support @ Soultz
- Barriers
  - Aspect of communication is underestimated
    - Media take information from action groups !
  - Operators may overestimate secrecy
    - Transparency missing
    - Prototype technology, typical consortium
  - Economic constraints may lead to damage
- Cooperation with scientific institutions
    - Improvement of performance
    - Common commitments industry / university
    - Possibilities for technical information

Positive example
Heat utilization Riehen / Basel

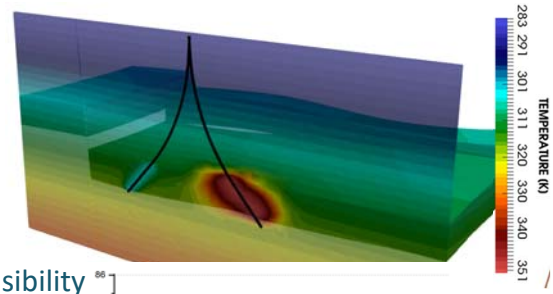
- 3 km from DHM Project:

- Population in favor of extending the existing geothermal heat utilization "Riehen Plus"
  - Vote 2 years after seism. event

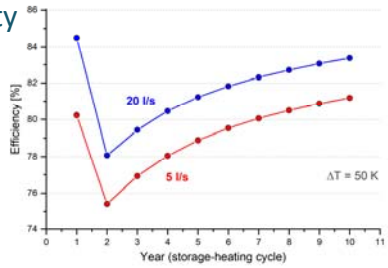


New Perspectives for geothermal research through cooperation of Science & Industry

- Seasonal storage of heat:
  - Summer:
    Injection of excess heat
  - Winter:
    Production of stored heat

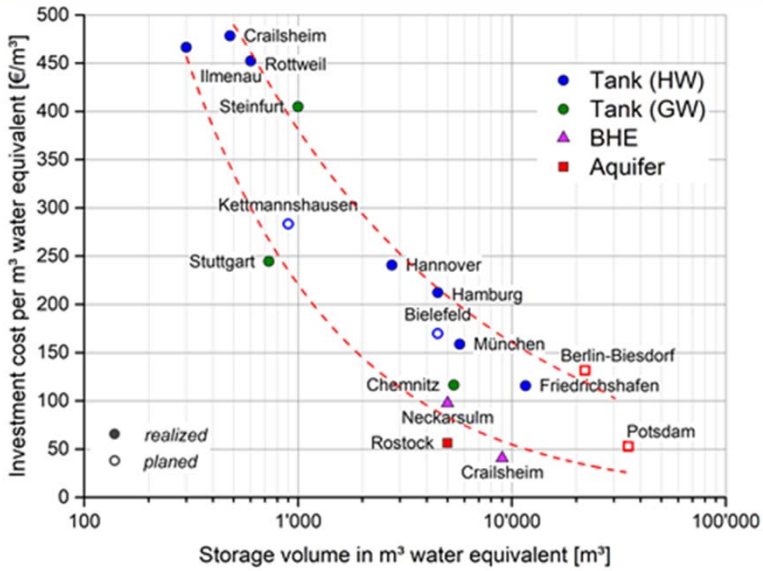


- Results on Techno-economic feasibility
  - Efficiencies η > 75% !!
  - Economic long-term stability



Joint concession
KIT/EnBW at Campus Nord

Economical Perspective



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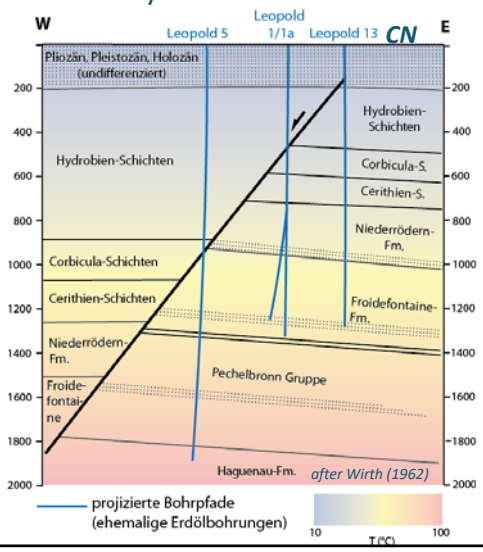
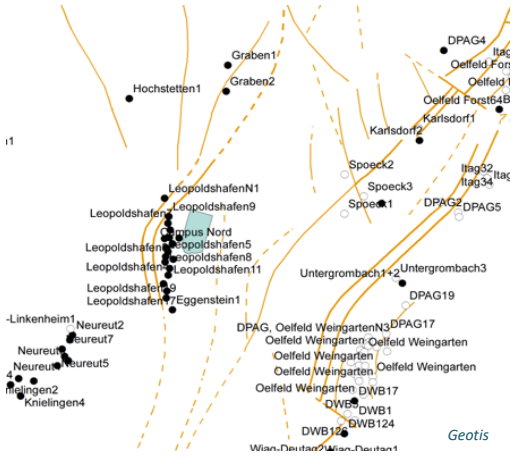
Geological Resource

- Tertiary Structures



- Boreholes @ KIT-CN
  - earlier oil production



DeepStor –
High-temperature thermal storage

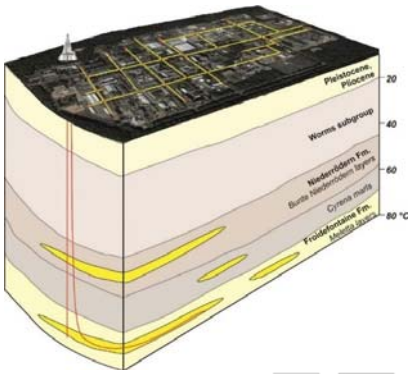
Demonstrates…

… transfer to the post-fossil age
- Storage of thermal energy in oil reservoirs
- Usage of state-of-the-art „fossil“ technologies

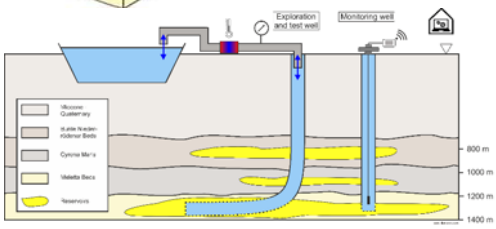
… innovative geothermal usage
- Underground storage with immense potential
- Base-load capability of renewables

… acceptance by society
- Proto type with small flow rates and pressure → no seismicity within sensitive infrastructure
- Integration of surrounding communities

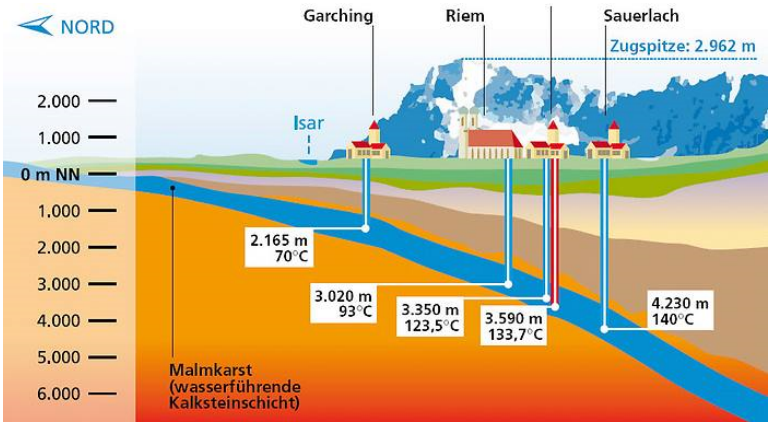
… scientific challenge
- Extraction von Li, new monitoring concepts,
- New materials → avoidance of corrosion



EnBW

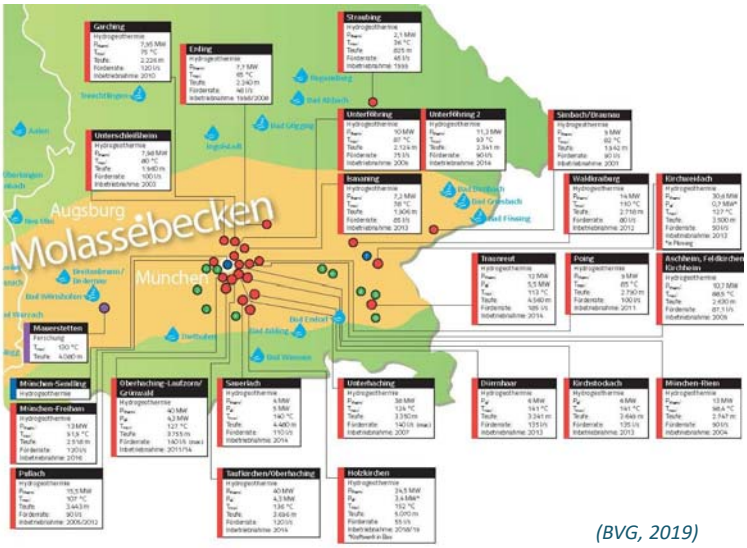


Bavarian Molasse



Projects in Bavarian Molasse
Most active geothermal development in Europe

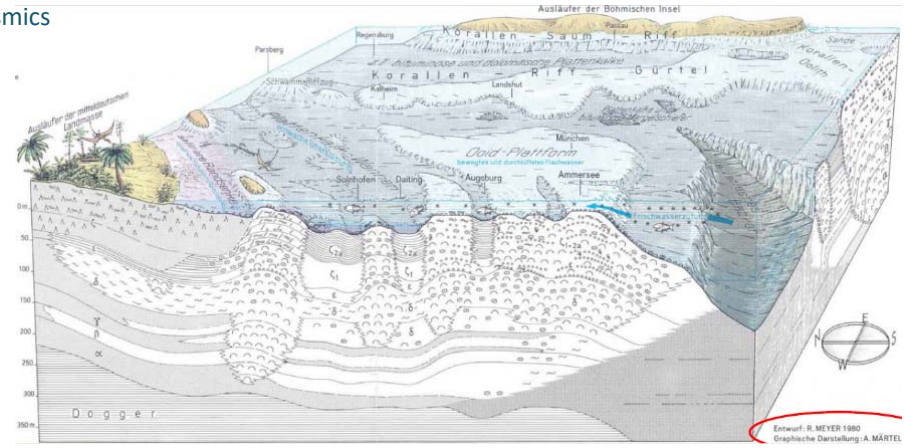
- District heating
  Focus: Geothermal !
- Total
  - 24 projects
  - 1'600 L/s
    (25'000 gpm)



(BVG, 2019)

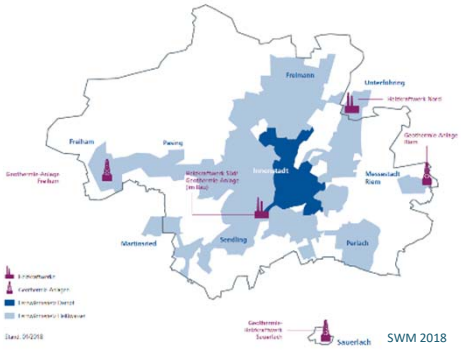
Geology
Malm Reef System

- At time of origin
  - Revealed by 3D seismics
- Malm layer
  - Today: 4km depth
  - Highly karstified
  - Low salinity
  - Potential aquifer

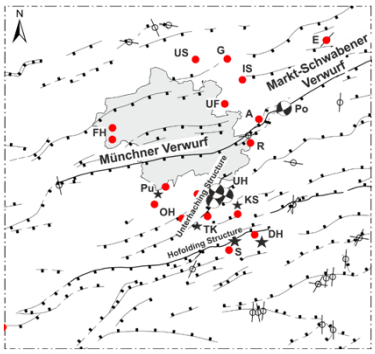


Application: Bavarian Molasse

„Fernwärme-Vision 2040“



Micro-Seismic observation



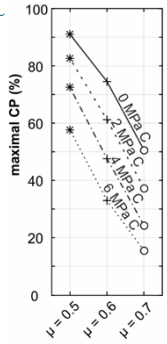
- Most active gdeothermal development in Europe
- Goal: district heating 100% from renewables.
- Special focus : geothermal

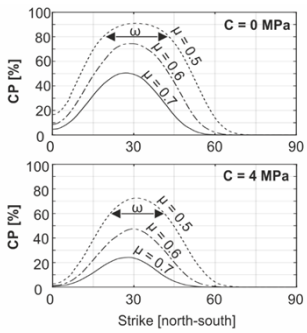
- circulation of 1'600 L/s in 16 projects.
- Total thermal energy
  - 235,6 MW_{th} / 31 MW_{el}

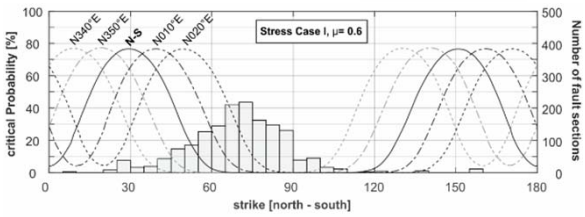
(Agemar et al. 2014)

Geomechanical impact on reservoir

- Probabilistic approach
- Evaluation of the critical probability (CP) in dependent to parameter variation.
- Correlation with micro-seismic observations.

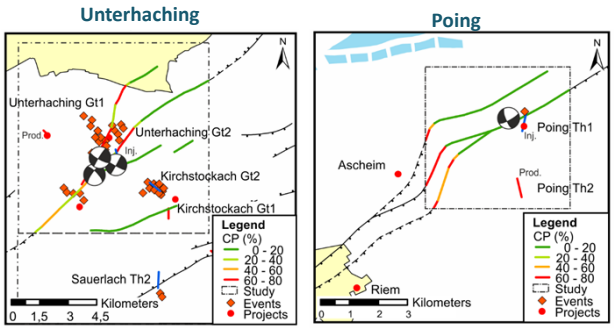






Seithel et al, 2019. Geothermics, Probability of fault reactivation in the Bavarian Molasse Basin.

Geomechanical impact on reservoir in the Bavarian Molasse



- Faults: N020°E & N055°E
- Crit. Strike (N020°E).
- Focal Mech.: Strike-Slip N055°O.
- Temporal component

(~ 5a after operation).

Local clockwise S_H – rotation 25°.

- Faults: (N030°O – N045°O)
- Focal Mech.: Strike-Slip N030°O
- high CP-values (75%).

Seithel et al, 2019. Geothermics, Probability of fault reactivation in the Bavarian Molasse Basin.

Huge Perspectives: District Heating in Munich by swm

- Schäftlarnstraße
- 23.09.2019 | News
  - **Fünfte Bohrung am HKW Süd erreicht die Endteufe**
- Requirement
  - Monitoring under urban conditions
- Future:
  - Integration of nearby projects

https://www.erdwerk.com/de/schaeftlarnstrasse

Conclusion on Perspectives of Geothermal

- New scientific approaches required
  - Monitoring and transparency
  - Importance of societal aspects
- High attention of "Induced Seismicity"
  - Processes are typically unterstood
- Problem: Forecasting Economics
  - How to forecast productivity
  - Testing of Seismicity under local conditions
- Learning curve
  - Huge experience in Munich area
  - Successful projects in Upper Rhine Graben