Möglichkeiten der Geothermischen Energienutzung

T. Kohl
GEOWATT AG
Dohlenweg 28, CH-8050 Zürich

Contents

- Introduction
- Temperature Data in Rhine Graben
  - EGS site Soultz-sous-Forêts
- Electricity Generation
- Reservoir Assessment in Northern Switzerland

INTRODUCING GEOWATT AG

Geothermal Energy utilization

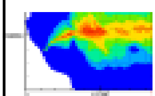
- Resource Evaluation
- Generic studies High- and Low-Enthalpy Systems
- Courses at University and Engineering Schools

Engineering

- Dimensioning Heating/Cooling (BHE-Felder)
- Reservoir Engineering
- Measurements

Hydrogeology

- Tunneling: Inflow scenario
- Flow system



Numerics

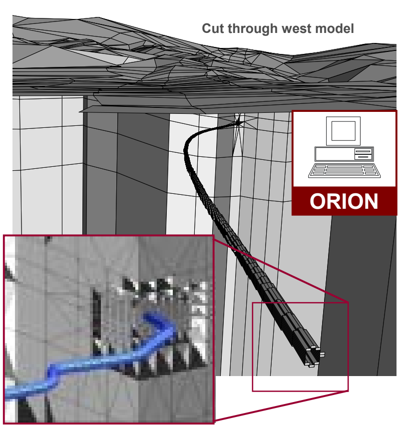
- Coupled 3D-FE calculations
- Data bank
- Specific simulation tools

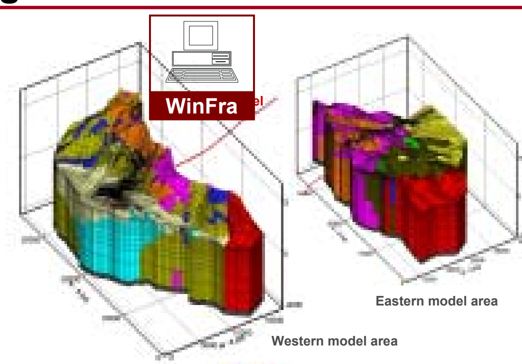
INTRODUCING GEOWATT AG
Hydraulic & Tunnelling

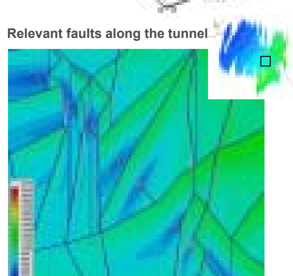
Hydrogeologic Exploration

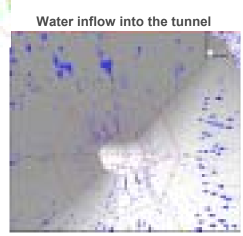
Koralm-Tunnel

- water inflow to tunnel
- change of mountain water table

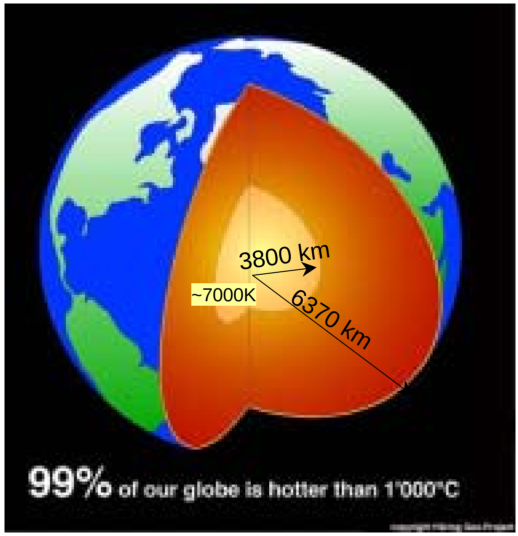




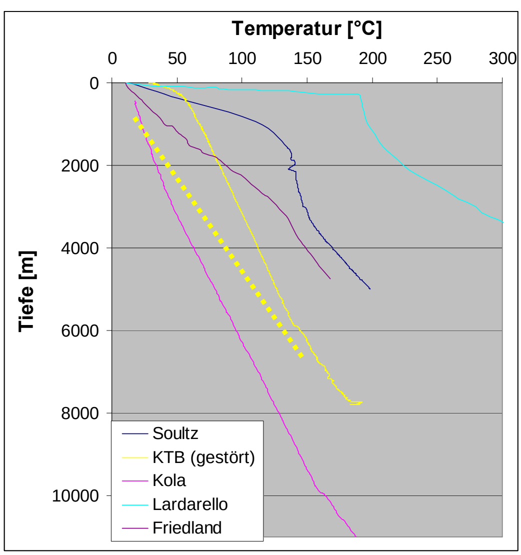




Temperature Distribution of the Earth



Temperature distribution in subsurface

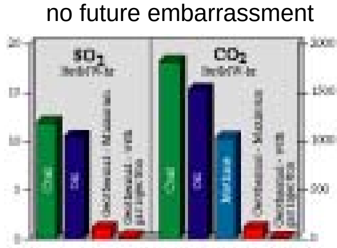


Global Heat Flow

Applied Geothermics

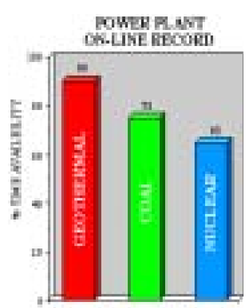
Advantage

- environment-friendly; non-polluting; environmentally sound
- local energy source
- high availability
- renewable energy source
- low space required, optically insignificant
  no future embarrassment



Disadvantage

- actual energy price for electricity production
- low level research
- lot of concepts, small experience
- high fix cost (Boreholes)



Heat flow

GEOWATT AG

Fourier Law

$$\vec{q} = -\lambda \cdot grad\ T$$

Heat flow density [W m^{-2}]

thermal conductivity [W m^{-1}K^{-1}]

Temperature gradient [K m^{-1}]
(negative!)

Reservoir utilization

GEOWATT AG

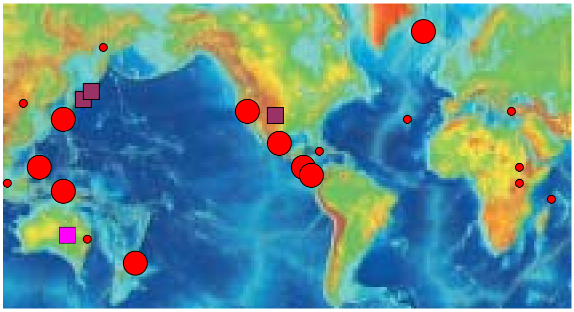
GOAL
Heat extraction using water as heat carrier

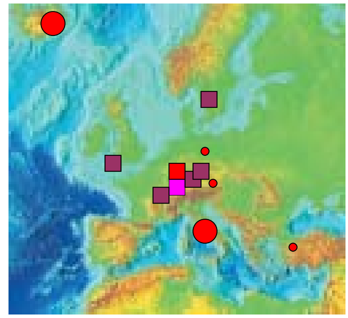
$$P_{THERM} = \dot{m} \times [c_P]_f \times (T_{PROD} - T_{REINJ})$$

$\dot{m}$ = Mass-Flowrate [kg s^{-1}]

Geothermal electricity production and HDR experience

GEOWATT AG

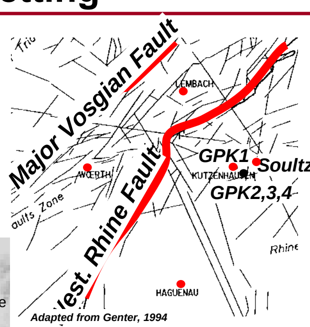


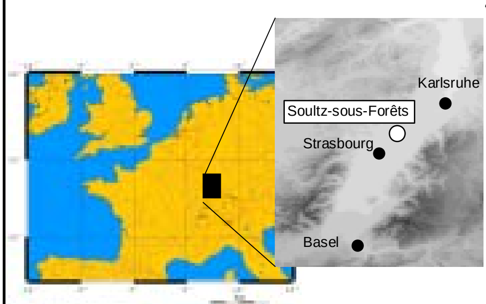


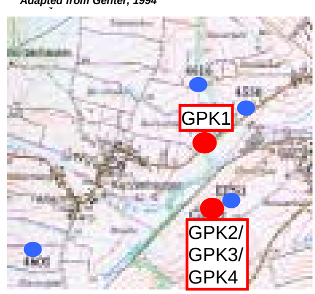
- Countries with conv. steam/hydrothermal production (large/small)
- Failed / abandoned HDR projects
- Running HDR projects
- Planned HDR projects

European HDR plant Soultz s.F. Location and tectonic setting

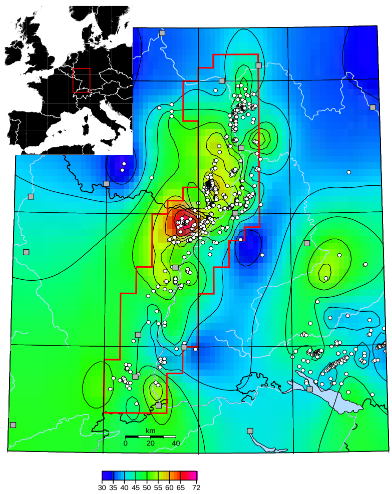
GEOWATT AG







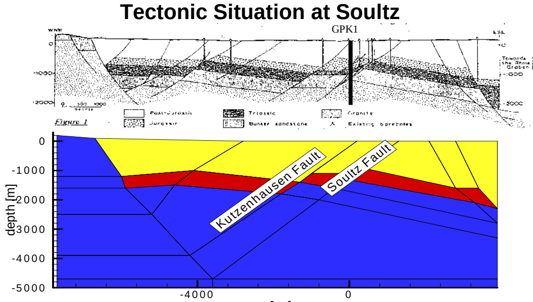
European HDR Project in Soultz

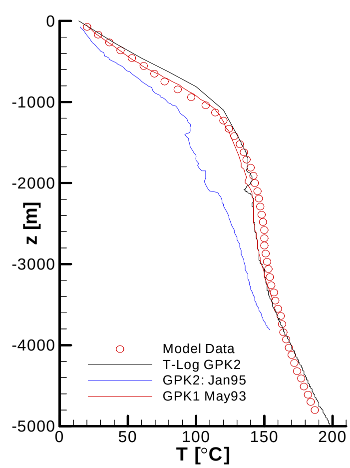


Thermo-Hydraulic Reservoir Model

Model fit of ambient temperature field by local convection

Tectonic Situation at Soultz



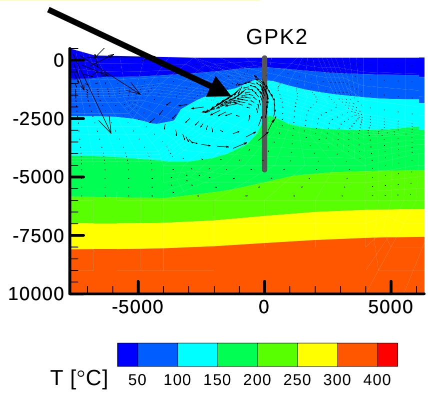


Thermo-Hydraulic Reservoir Model

GEOWATT AG

Model fit of ambient temperature field by local convection

permeabilities up to 3x10^{-14}m^{2} !

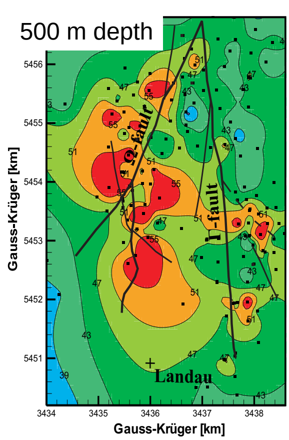


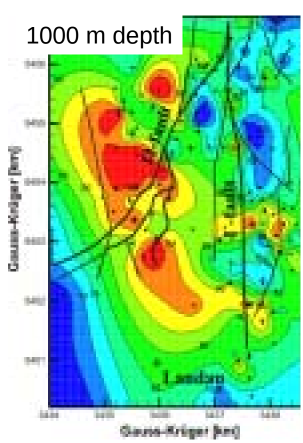
- The 1998 Soultz HDR reservoir (2000 - 3800m) is dominated by large **fault zones**.
- Less developed hydraulic connection to surface than within highly permeable zone (lower sediments and topmost granite).

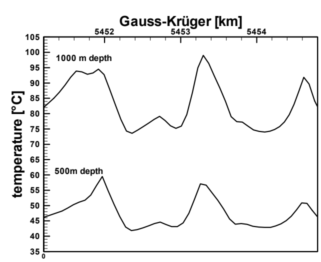
Temperature pattern at Landau

GEOWATT AG

Temperature variation along Γ fault



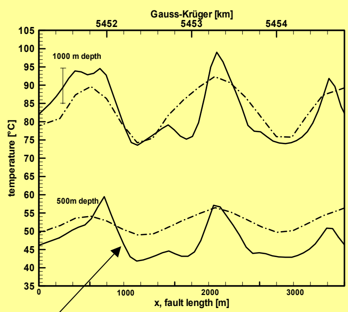




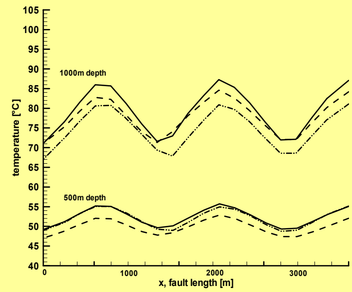
Data from BGR Hannover

Numerical model of the Γ-fault at Landau

Calculated steady-state temperatures at at 500 m and 1000 m depth



Model sensitivity for fault widths of 100-400m



Measured data

Model fit possible, however non-unique solution
broad range of possible parameter
Steady-state?

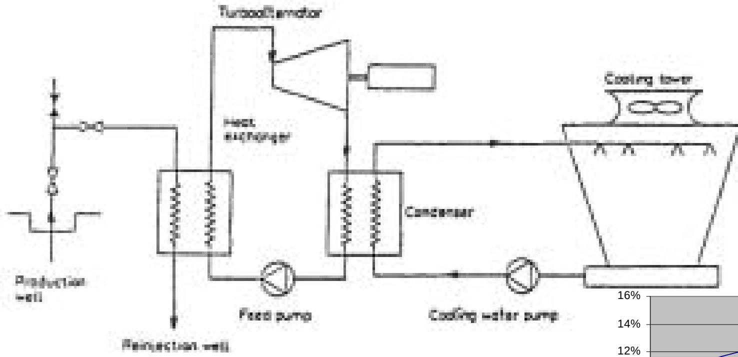
Conclusion

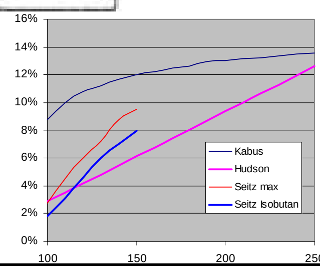
- The temperature fit of reservoir can be achieved by simple reservoir models;
  However temperature distribution in fault requires more complex 3D approaches
- Convection cells highly unstable, no steady-state for high permeabilities
- Temperature anomalies (Landau, Speyer, Soultz) are considered as the result of interaction of several graben parallel convection systems

➡ **Natural Hydrothermal Systems**

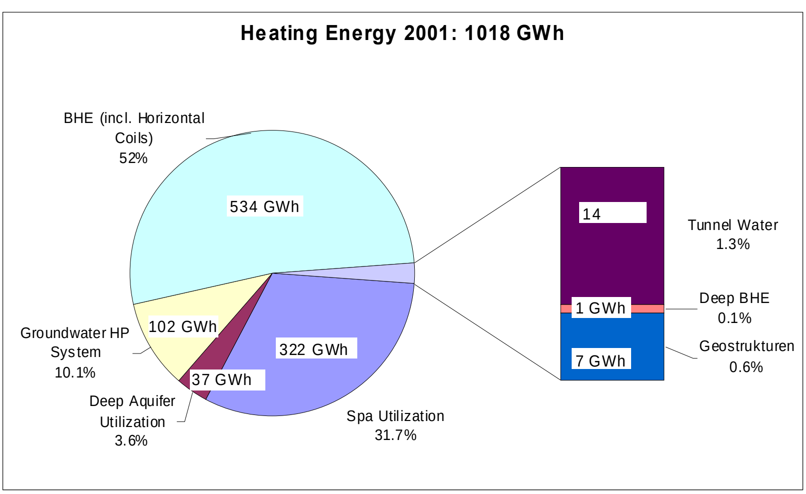
Binary Cycle-type power plant

Simplified schematics



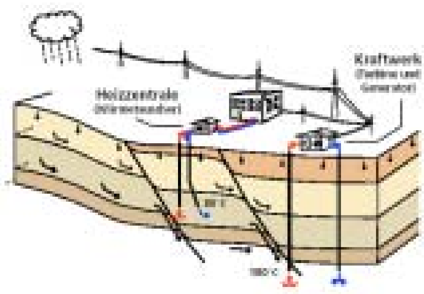


Geothermal Heat Utilization in Switzerland (2001)



Aquifer utilization

Open system with injection & production borehole
Re-injection of cooled fluids
Possible combined heat / power utilization



Aquifer utilization

Overview Aquifer utilization in Switzerland

Site	Depth (m)	T prod (°C)	Flow (l/s)	Therm. Power (kW)
Kreuzlingen	655	26.5	3.7	255
Bassersdorf	553	22.9	4.3	232
Schinznach Bad	890	44.5	8.3	1198
Riehen	1547	62	20	4351
Lavey-les-Bains	595	69	25	6172
Yverdon-les-Bains	1470	> 50	> 60	> 1000

GEOTHERMAL RESOURCES IN NORTHERN SWITZERLAND

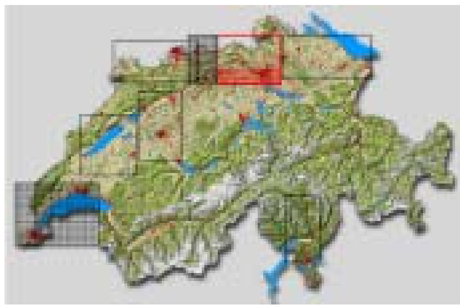
Conventional resource mapping:

- Total Energy = f(T,V)
- Utilizable Energy = total Energy x recovery factor

$$E_{tot} = \rho c_P \cdot \Delta T \cdot V$$

Objective:

- Evaluation of National Swiss Energy Resources in major populated areas
- Detection of Primary Exploration Areas



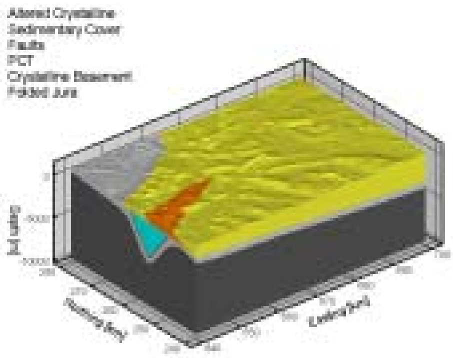
Northern Switzerland Area of Investigation

Available information:

- seismic profiles, geological interpretation
- Boreholes

→ 3D GOCAD Model

Geological structures
Example for Model I



Geological model as basis of all considerations

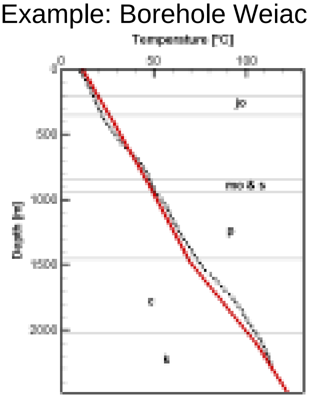
Discretized geological model for the thermal interpretation (tetrahedral element mesh).

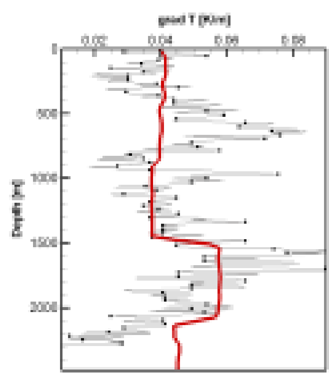
3D Thermal Model
Fitting procedure

Fitting Parameters:

- Basal heat flow (10 km depth, bandwidth: 60-110 mW/m^2)
- Thermal conductivity (±10% of measurements)
- Vertical fluid flow

Example: Borehole Weiach

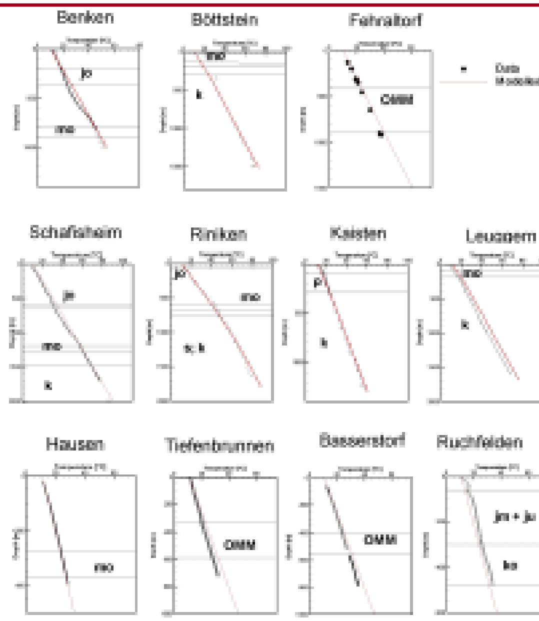




(k: crystalline, c: carboniferous, p: Permian, s: Buntsandstein, mo: Upper Muschelkalk, ju: Lias, jm: Dogger, jo: Malm, OMM: Upper Marine Molasse)

3D Thermal Model
Fitting procedure

Selected boreholes:



➔

Mostly diffusive heat transport
Advection in

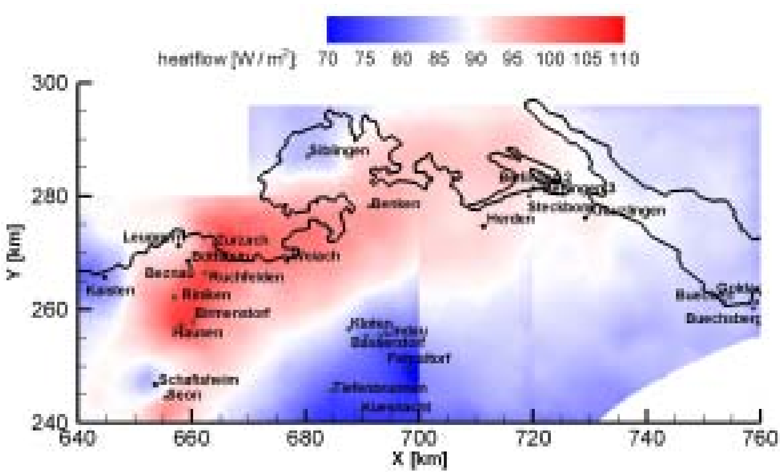
- Crystalline Basement
- Upper Muschelkalk
- Upper Marine Molasse

➔

3D thermal calibration model

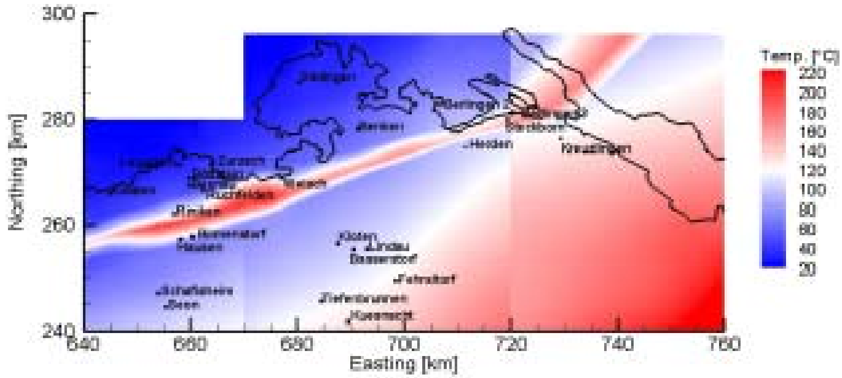
3D Thermal Calibration Model

Heat Basal Flow



3D Thermal Calibration Model

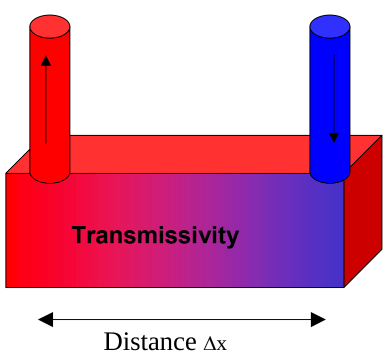
Calculated temperature distribution: top 500m crystalline



Utilization Scenario

Doublet System:

Calculation over time span
Δt=30 yr



Transient Gringarten (1978) solution:

- Necessary surface area
- Sustainable flow rate
- Reservoir geometry

$$Q_{i+1} = \frac{4\pi \cdot Tr \cdot \Delta P_b}{\ln\left(3 \cdot Q_i \cdot c \cdot \Delta t / \pi \cdot \Delta z \cdot r_w^2\right)}$$

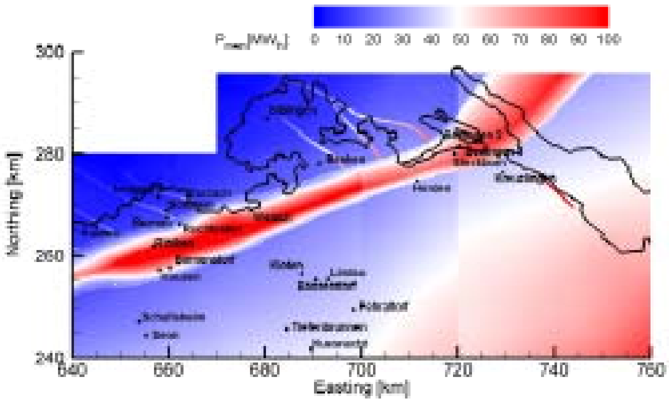
=> Utilizable heat energy

= f(t, Tr, T, V, …)

in individual reservoir zone

Thermal productivity: Top Crystalline

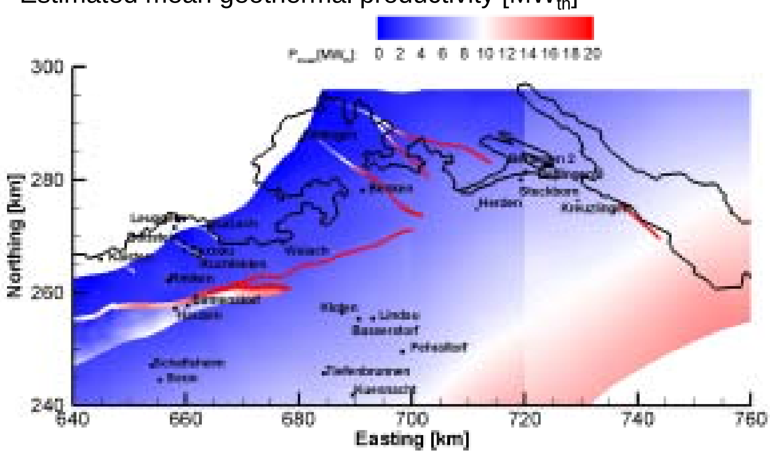
Topmost 500 m of the crystalline rock:
Calculated thermal productivity [MW_{th}]



Energy: 40'000 PJ over Δt=30 yrs
Recovery Factor: 5.2%

Thermal productivity: Upper Muschelkalk

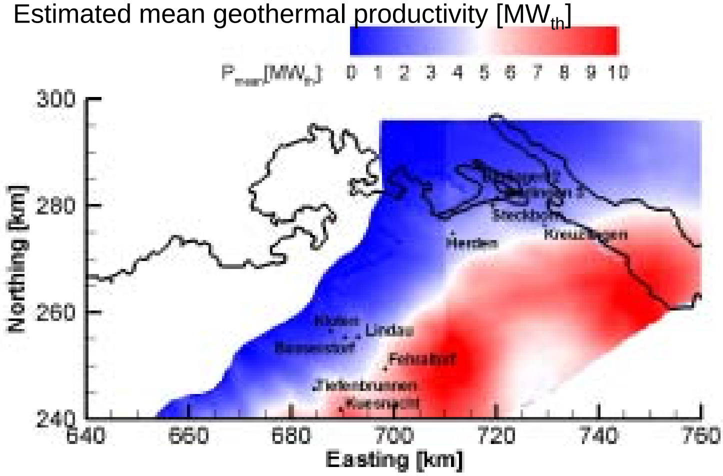
Estimated mean geothermal productivity [MW_{th}]



Energy: 3'500 PJ over Δt=30 yrs
Recovery Factor: 5.%

Geothermal productivity: Upper Marine Molasse

Estimated mean geothermal productivity [MW_{th}]

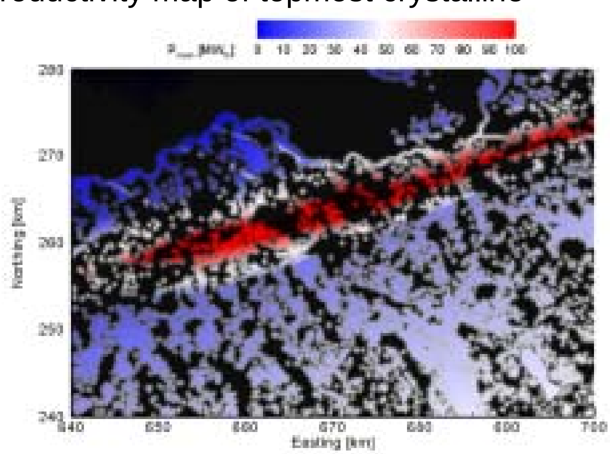


Energy: 2'600 PJ over Δt=30 yrs

Recovery Factor: 5%

Combination: Productivity / GIS data

- GIS data: industrial areas/ surface water
- Productivity map of topmost crystalline



Black: areas without GIS data or without appropriate surface utilization

Schlussfolgerung

- Jetztige CPU's erlauben 3D regionale Bewertung von Geologie und Temperaturfeldern
- Die Kombination mit GIS Tools kann mögliche Nutzungsszenarien identifizieren
- Modelle sind nur so gut wie Daten
- Zukünftig: Planungswerkzeug für lokale Behörden / Investitionsgelder