Hydrothermal Spallation Drilling - a novel drilling technology for deep geothermal heat mining

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Swiss electricity supply by energy carriers

**Today 2010**
- Nuclearpower: 57%
- Hydropower: 27%
- Waste: 12%
- Solarpower: 0%
- Windpower: 0%
- Natural gas: 2%
- Biomass: 1%
- Geothermal: 0%

**Swiss energy strategy 2050**
- Nuclearpower: 0%
- Hydropower: 38%
- Waste: 13%
- Solarpower: 4%
- Windpower: 4%
- Natural gas: 22%
- Biomass: 9%
- Geothermal: 4%

Data from: BFE – Swiss Energy Strategy 2050, Scenario C&E
Common geothermal Systems

- Geothermal power:
  - Heat from the subsurface
  - Low temperature
    - Energy piles, collectors
    - Depth: 5 m – 2 km
    - Temperature: 10-70°C
    - Only heat use
  - High temperature
    - Hydrothermal, Petrothermal
    - Depth: 2 km – 7 km
    - Temperature: 120-250°C
    - Heat use and direct electricity production

- Low temperature geothermics
  - geothermal heat pump systems
  - Deep aquifer
    - 1-2 km/ 30-70°C
    - Energy piles
    - Energy collectors
    - Downhole heat exchangers
      - 5-300 m, 10-20°C

- High temperature geothermics
  - Direct use & electricity production
  - St. Gallen type
    - 4-6 km/ 120-170°C
  - Basel type
    - 4-6 km/ 150-200°C
Types of deep geothermal systems

- **Hydrothermal systems**
  - Natural Aquifers
  - Exploitation of hot water
  - Re-injected of used water

- **Petrothermal systems**
  - EGS (engineered geothermal system)
  - Extract heat from a stimulated reservoir
  - Injection of cold water from the surface
  - Water heats up in the reservoir
  - Hydraulic fracturing required
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Data from: BFE – Swiss Energy Strategy 2050, Scenario C&E
Actual deep geothermal electricity production:
in percentage of the total electricity production

- Switzerland: 0.00% [1]
- Germany: 0.02% [2]
- EU: 0.20% [3]

Boost the development of geothermal power

adapted from ESMAP Geothermal Handbook Planning and Financing Power Generation
Boost the development of geothermal power

- Engineer drilling solutions
  - Reduction of the drilling costs
  - Shift costs to low risk steps

![Graph showing project steps and risk vs. investment costs](adapted from ESMAP Geothermal Handbook Planning and Financing Power Generation)
Boost the development of geothermal power

- Engineer drilling solutions
  - Reduction of the drilling costs
  - Shift costs to low risk steps

- Enhance geological knowledge
  - Increase knowledge about the subsurface
  - Shift risk to low cost steps

→ Enhance the development of geothermal power
How can we reduce the costs for hard rock drilling operations?

- Example: Deep geothermal power plant
- Improvement of the actual technology
- Alternative drilling technologies
  - Laser assisted rotary drilling
  - Electro pulse drilling
  - Flame-jet drilling

⇒ The drilling costs account for up to 70% of the total costs
Spallation Process, the basis of flame-jet drilling

+ In application
+ No contact with the rock
+ Reduced drill bit wear and trip time
+ High penetration rates (16m/h[1])
+ Spallability ~ (Drillability)$^{-1}$

→ Reduction of drilling costs

- Difficulties to flush the cuttings in a low density environment (e.g. air)
- Bad performance in soft rocks
- Controlling of drilling direction

Simulating the downhole conditions of a deep well

- Water-based drilling fluid
  - Transport of cuttings
  - Borehole stability
  - Cooling and lubrication
- High pressure
- Aqueous environment

Challenges:
1. Ignition
2. Stable and effective combustion
3. Heat transfer to the rock
4. Optimal operating conditions
5. Rock fracturing mechanism

- Our approach → Flames in water
  - 20 years of experience!
Experiments in the laboratory at ambient conditions
# Research facilities

<table>
<thead>
<tr>
<th>Ambient environment</th>
<th>Experimental setups</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L-ASDP</strong></td>
<td><strong>S-ASDP-DRY</strong></td>
</tr>
<tr>
<td>1 bar, 1400 °C</td>
<td>1 bar, 2500 °C</td>
</tr>
<tr>
<td>100 kW</td>
<td>30 kW</td>
</tr>
<tr>
<td>▪ Combustion process</td>
<td>▪ Operating conditions</td>
</tr>
<tr>
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<td>▪ Penetration rate</td>
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<td>▪ Parametric studies and optimization</td>
<td></td>
</tr>
<tr>
<td><strong>S-ASDP-WET</strong></td>
<td><strong>WCHB-4</strong></td>
</tr>
<tr>
<td>1 bar, 2500 °C</td>
<td>500 bar, 2000 °C</td>
</tr>
<tr>
<td>30 kW</td>
<td>120 kW</td>
</tr>
<tr>
<td>▪ Efficient nozzle design</td>
<td>▪ Heat flux measurements</td>
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<tr>
<td>▪ Drilling under realistic conditions</td>
<td>▪ Burner design</td>
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Scientific topics on the research of spallation drilling

- Flame Operating Conditions
- Ignition and operation of flames in water
- Nozzle-Design
- Hybrid-Drilling
- Transport of the fluids
- Direction Controlling
- Safety Considerations
- Spallability Rock Properties

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- **Flame Operating Conditions**: Ignition and operation of flames in water
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- **Hybrid-Drilling**: Direction Controlling
- **Spallability Rock Properties**: Safety Considerations
Operating range of the flame-jet drilling process

- Limits the applicable operating conditions
- Ductile deformation or melting
  - Property of the rock
  - Approx. 1000°C
- Insufficient temperature level
  - No cracking
- Insufficient heat transfer
  - Global cracking
- Minimal operating conditions
  - Experimental investigation required

\[
\begin{align*}
T_{SP,\text{max}} &> \text{Ductile deformation} \\
T_{SP,\text{min}} &< \text{Minimal required boundary conditions} \\
\end{align*}
\]

\[h_{f,\text{min}} \quad \text{Heat transfer coefficient}\]

Determination of the minimal required boundary conditions

- Experiments at ambient conditions
- Rock samples
  - Gotthard Granite, Switzerland
  - Bethel Granite, USA
- Increase of the distance until no spallation occurred
- Surface temperature
  - 2 high-speed pyrometer (1000Hz)
  - Emissivity calibration required
- Heat transfer coefficient
  - Commercially available heat flux sensor
  - Or Inverse Techniques [1]

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Determination of the minimal required boundary conditions

\[ T_{SP,max} \approx 1000^\circ C \]

\[ T_{SP,min} \approx 500^\circ C \]

\[ h_{Fl,min} \approx 500 \text{ } W/(m^2 K) \]

Optimal boundary conditions

$T_{SP,max} \approx 1000^\circ C$

$T_{SP,min} \approx 500^\circ C$

$h_{F1,min} \approx 500 \, W/(m^2K)$  Heat transfer coefficient

Ductile deformation

optimal boundary conditions

Insufficient heat transfer coefficient

Insufficient temperature level
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Hybrid Drilling: Combining conventional and spallation drilling

Conventional PDC bit

Flame nozzle
Features of Hybrid Spallation Drilling

- Synergy of conventional and spallation technology
- Significant reduction of WOB and torque
- Enhances the applicability of PDC cutters for hard rock drilling
- Smoothens rock strength for drilling in alternating geological formations
- Reduction of drilling vibrations due to smoother drilling
  - Less wear rate, reduced tripping times
Possible implementation of a hybrid drill head

- Fuel and air hoses
- Drill string
- PDC Cutter
- Flame Nozzle
Implementation Challenges:

- Drill string configuration
  - Coiled tube drilling
  - Conventional drill string with integrated piping

- Safe and stable ignition
  - Re-ignition
  - Flame monitoring
  - Permanent Ignition

- Safety aspects
Roadmap – Hybrid Drilling

**Step 1**
- Preliminary Design of the Hybrid Head:
  - Required flame properties
  - Flame treatment zone
  - Ignition

**Step 2**
- 30m Drilling Tests in Grimsel:
  - Stand-alone spallation
  - Water-flushing
  - High drilling velocities

**Step 3**
- Hybrid drill head
  - Manufacturing
  - Testing
  - Drill string

**Step 4**
- Field test

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2016 | 2017
Thank you for your attention!