Five Years of Permanent Fiber Optic Monitoring in Deep Geothermal Wells in Munich: Lessons, Insights, and Evaluation

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Introduction

The **Upper Jurassic carbonates** in the North Alpine Foreland Basin show very favorable conditions for **deep geothermal energy**. The reservoir is already exploited by 25 plants in Bavaria, and there are plans to extensively develop the field. To understand the **complex geologic heterogeneity** of the subsurface for future development and ensure the **production reliability/efficiency** of geothermal plants, **downhole data** must be obtained to intensively study the reservoir and specific sites.

Recording downhole data in wells is often **time-consuming and costly** or even impossible during certain operational phases. To improve our understanding of various facets of geothermal operations, such as the **long-term hydraulic, thermal, and mechanical processes** in geothermal boreholes/reservoirs, we installed a **permanent fiber optic monitoring (FOM)** system at a study site. We equipped 3 wells with **fiber optic cables (FOC)**, enabling high-resolution **Distributed Temperature Sensing (DTS), Distributed Acoustic Sensing (DAS/DDSS)** and fiber optic **point pressure gauges** in the reservoir.

Study Site

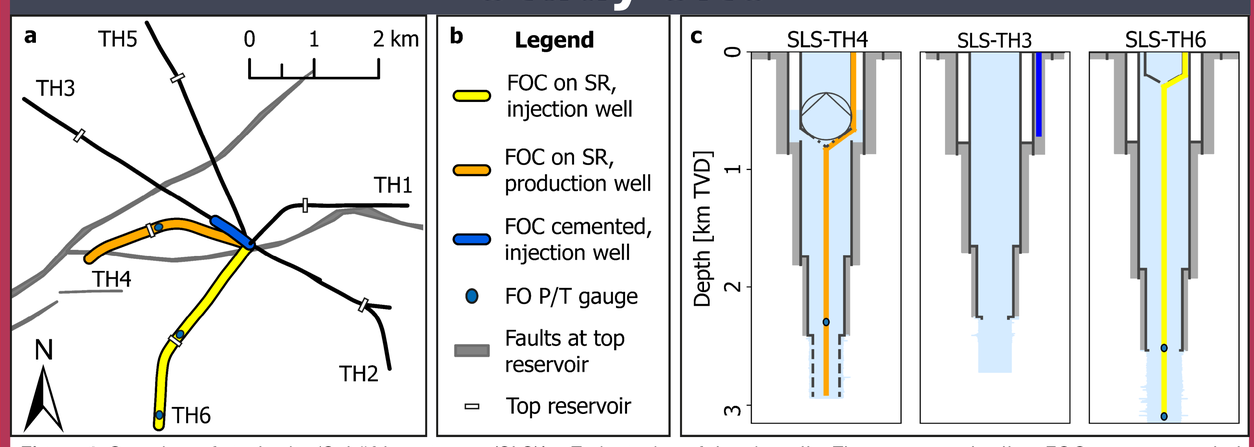


Figure 1: Overview of study site 'Schäftlarnstrasse (SLS)'. **a** Trajectories of the six wells. The orange and yellow FOCs are suspended in the boreholes down to total depth and the blue FOC is cemented behind the casing of the first section. **c** Well sketches of the producer SLS-TH4 and injectors SLS-TH3 and SLS-TH6 with FOCs projected to true vertical depth (TVD). Deviation is not shown here.

FOC Installation

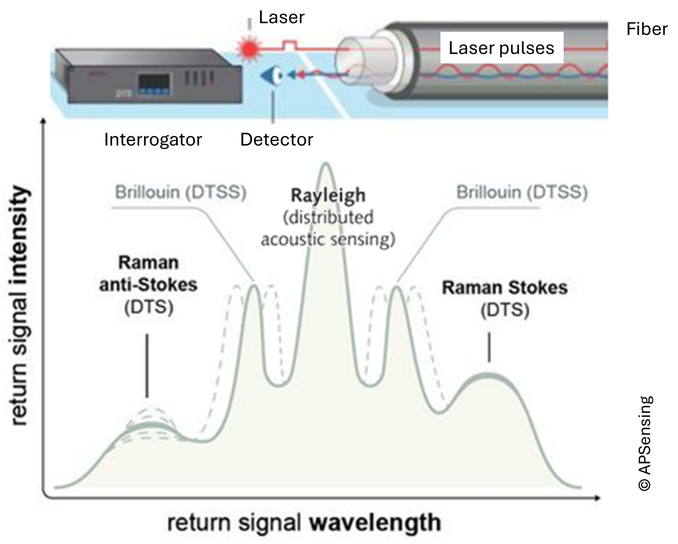
Cemented FOC behind casing

- One possible standard design for permanent FOC installations in wells
- FOC clamped on the outside of the casing of the first section before cementation
- ➢ Excellent coupling to formation
- ➢ Challenging for installations deeper than first section
- ➢ Integration of FO-PT gauges not feasible

Suspended FOCs in borehole

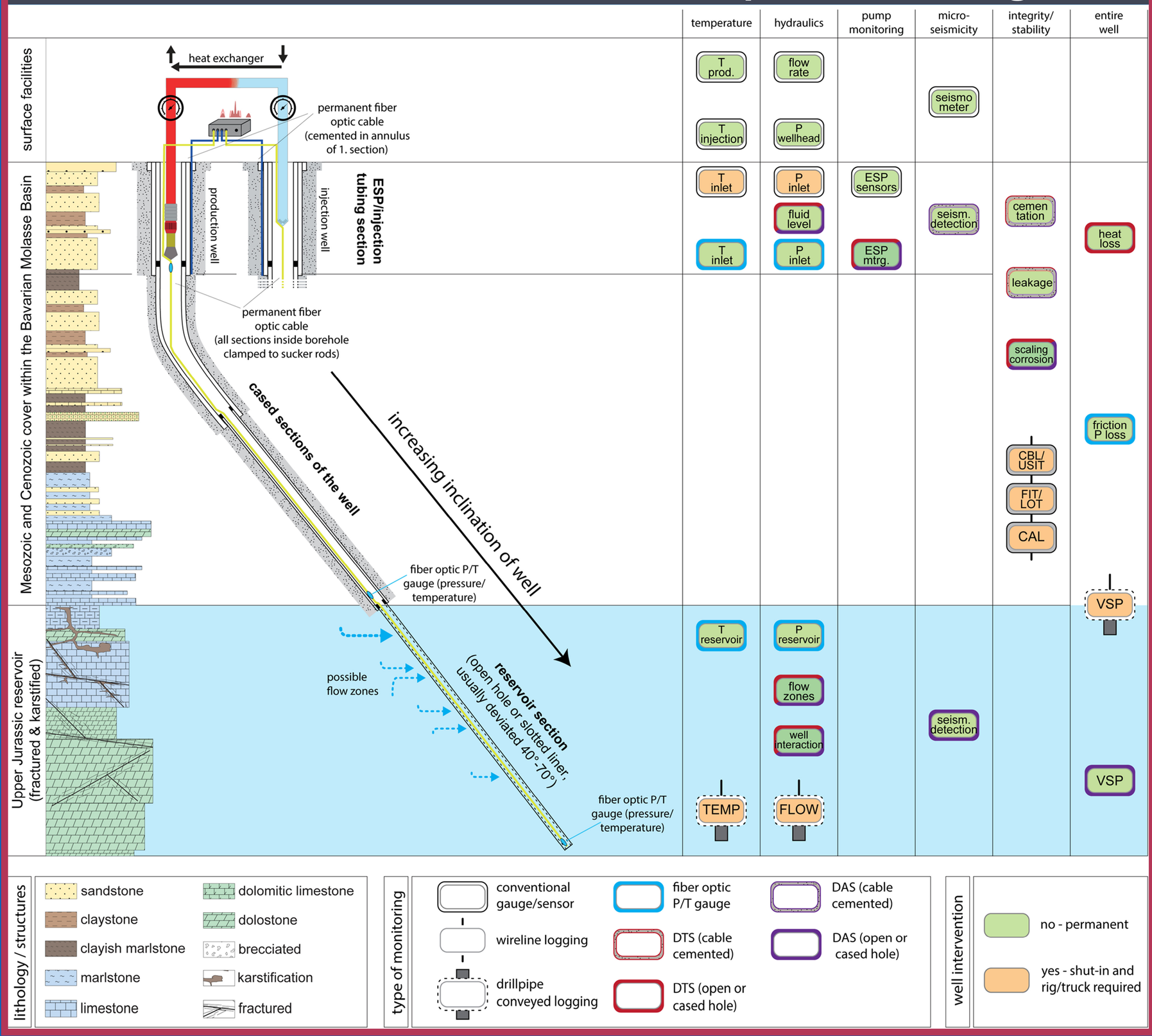
- Innovative design for permanent FOC installation design inside wellbore
- FOC clamped to prodution/injection tubing above ESP and to sucker rods below ESP
- FO-PT gauges spliced to FOC and deployed at top and bottom of reservoir
- ➢ Installation down to total depth of the well possible
- ➢ Coupling to formation worse and varying along wellbore

DFOS principle



An interrogator sends a laser pulse along a fiber. Subsequently, the backscattered light is analysed for wavelength and intensity shifts. Time-of-flight is used for location of measured parameter.

Overview of Use Cases of Fiber Optic Monitoring



Published Work

- **Schölderle et al., 2021**: Monitoring cold water injections for reservoir characterization using a permanent fiber optic installation in a geothermal production well in the Southern German Molasse Basin
- **Lipus et al., 2022**: Dynamic motion monitoring of a 3.6 km long steel rod in a borehole during cold-water injection with distributed fiber-optic sensing
- **Schölderle et al., 2023**: Inverse flow zone characterization using distributed temperature sensing in a deep geothermal production well located in the Southern German Molasse Basin
- **Azzola et al., 2023**: Integration of Distributed Acoustic Sensing (DAS) for real-time seismic monitoring of a geothermal field
- **Azzola and Gaucher, 2024**: Seismic Monitoring of a Deep Geothermal Field in Munich (Germany) Using Borehole Distributed Acoustic Sensing
- **Hart et al., 2025**: A fiber optic approach for cement placement and hydration assessment of deep geothermal boreholes
- **Andy et al., 2025**, in review: Injection profiling with innovative permanent fiber optic installation and custom flowmeter in deviated deep geothermal injection well

Evaluation of Use Cases

Topic	Implementation at study site	Implementation in literature	Quality compared to conventional
Subsurface characterization/-monitoring			
PT Reservoir monitoring	★★★	★★★	★★★
Flow zones localization/monitoring	★★★	★★★	★★★
Interaction between wells	★☆☆	★☆☆	★★☆
Fluid level → injectivity/productivity index	★★☆	★★☆	★★☆
P/S wave velocity model (VSP)	★★★	★★★	★★☆
Structural imaging (VSP)	★★☆	★★★	★★☆
Seismic monitoring	★★☆	★★☆	★★☆
Borehole (technical components) monitoring			
Cementation 1. section	★★★	★★☆	★★☆
ESP monitoring	★★☆	★☆☆	-
Leakage	☆☆☆	★★★	-
Corrosion/Scaling of casing/tubing	★☆☆	★☆☆	-

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Literatur:
KEIM, M., et al. Tiefengeothermie in Bayern-Forschungsprojekt Geothermie-Allianz Bayern. 2020.
STOBER, Ingrid; BUCHER, Kurt. *Geothermie*. Springer Berlin Heidelberg, 2012.

GFK Monitor

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