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First Field Experiments with Fiber Optics for Geothermal Potential Assessment in Slovenia

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INTRODUCTION

This poster presents results of the first *in situ* fiber optic measurements in geothermal research in Slovenia, Europe. Thermal response tests were performed in three different boreholes with different lithologies and groundwater conditions.

Fibre-optic technology and distributed temperature sensing (FO-DTS) have been used globally for geothermal characterization [1]. FO-DTS was paired with thermal response tests for the first time in Slovenia in February 2025. Previously, we relied on laboratory measurements with Thermal Conductivity Scanner (TCS) and needle probes (KD2 Pro) to determine rock thermal properties and lately we integrated thermal response tests, but highly productive alluvial and karstic aquifers with strong groundwater flow often limit their applicability. With over 17,000 shallow geothermal systems across different lithologies, we are interested in detailed litho- geothermal characterization of most prospective areas for shallow geothermal.

Active distributed temperature sensing (ADTS) enables a depth-resolved temperature profile, which recognizes the influence of thermal property heterogeneities and groundwater flow on effective thermal conductivity [2]. Here, the Infinite Line Source (ILS) equation is used to generate *in situ* thermal conductivity profiles for each borehole [3].

METHODS

In spring 2025, we performed ADTS at three pilot sites in central and south-eastern Slovenia in collaboration with INRS. The results were compared to lab values.

These tests used a composite FO and copper heating cable to evaluate thermal conductivity and temperature gradient at a resolution of 0.25 m, from which heat flow is calculated. The Silixa XT-DTS M interrogator (Faculty of Civil and Geodetic Engineering) was used.

All tests consisted of a 3-days of heat injection followed by 3-days for thermal recovery. We compared stratified litho-geothermal properties of:

- GCF-1/24 (Brod v Podbočju): a marly aquitard superposed by a shallow alluvial aquifer. Both are penetrated by a 100 m deep single U-tube geoprobe with a cemented FO cable;
- CP-1/92 (Veliko Črnelo): a fissured dolomite with few caverns, penetrated by 131 m deep abandoned artesian well. CP-1/92 was accessible to 90 m.
- Pincome-1 (Ljubljana): a highly productive alluvial aquifer with average groundwater velocity of 10 m/day, penetrated by a 75 m deep monitoring well.

RESULTS

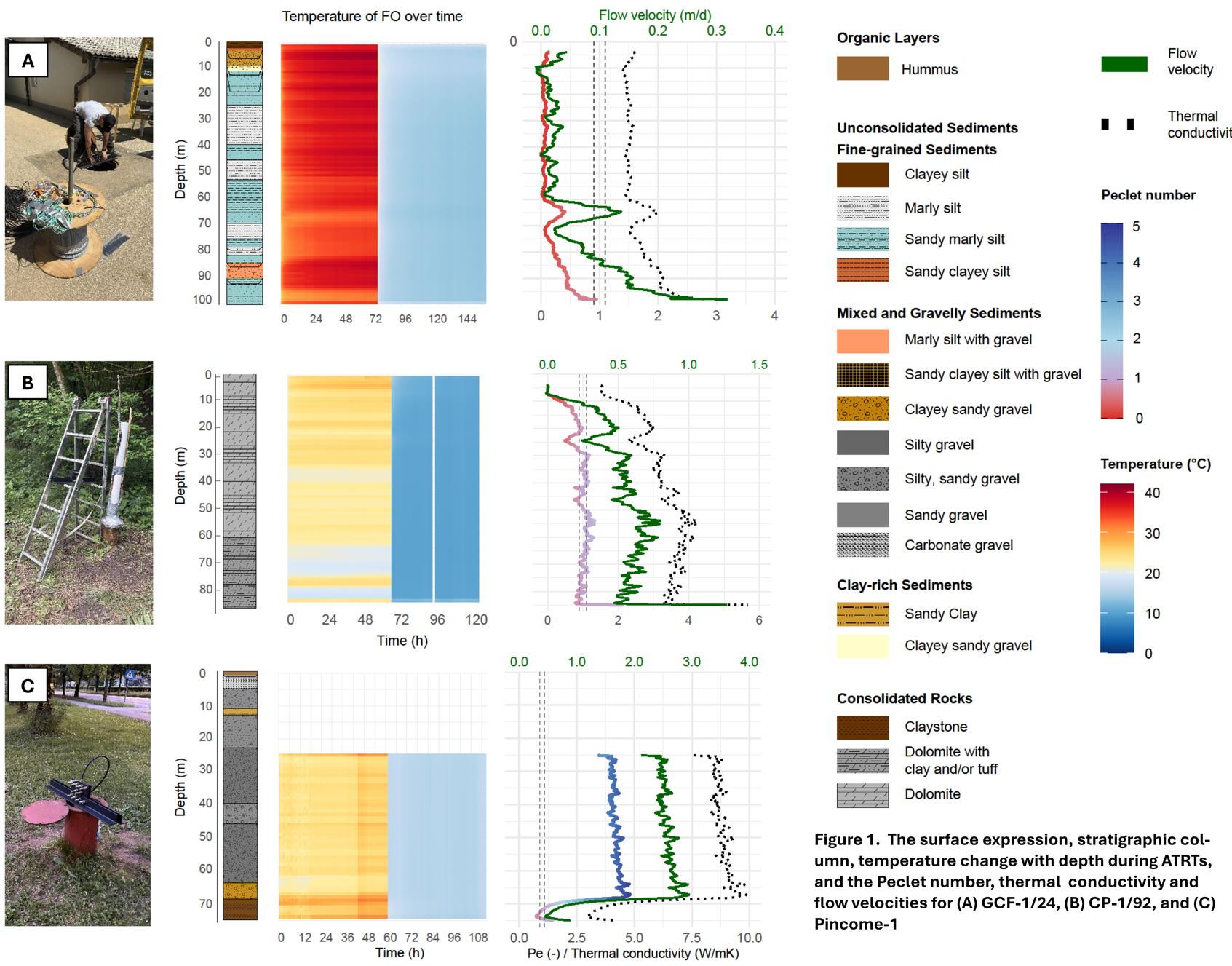


Figure 1. The surface expression, stratigraphic column, temperature change with depth during ATRTs, and the Peclet number, thermal conductivity and flow velocities for (A) GCF-1/24, (B) CP-1/92, and (C) Pincome-1

A (GCF-1/24)

- Highly uniform heating pattern with slow cooling, indicating negligible groundwater flow.
- Thermal conductivity increases in sandy–silty gravel layers but remains generally moderate; depth trends are more uniform.
- Peclet numbers stay near zero, confirming conduction-dominated conditions
- Flow velocity is near zero along nearly the entire depth.

B (CP-1/92)

- Thermal conductivity shows clear lithological contrasts, with lower values in dolomite and peaks in tuff.
- Strong heating signal with a steep thermal gradient; cooling phase shows pronounced advection effects at several depths.
- Peclet numbers remain in the lower range, consistent with mixed lithologies and reduced permeability.
- Flow velocity profile indicates several shallow and mid-depth flow intervals, but with noticeably low magnitudes.

C (Pincome-1)

- Moderately responsive heating profile with smoother transitions and weak contrasts.
- Thermal conductivity shows elevated peaks in gravel-rich intervals, reflecting advective heat transport.
- Peclet numbers indicate flow-dominated behaviour in coarse, permeable sediments.
- Flow velocities reach the highest values among the three sites, with multiple distinct flow zones.

CONCLUSION

Across all three investigated boreholes, the DTS heating tests reveal clear contrasts in subsurface thermal behaviour driven by differences in lithology and groundwater flow.

GCF-1/24 (A) shows a fully conduction-dominated system, with **uniform heating, slow cooling, near-zero flow velocity and Peclet numbers**, and only moderate λ variations—conditions ideal for deriving intrinsic thermal conductivity.

CP-1/92 (B) exhibits **distinct lithological controls on λ**, including **low values in dolomite and peaks in tuff**, while the temperature response shows **localised advection at several depths**; however, **flow velocities remain low**, keeping Peclet numbers in the lower range.

In contrast, **Pincome-1 (C)** represents the most dynamic system, with **elevated λ peaks in gravel-rich intervals**, **high Peclet numbers**, and **the greatest flow velocities**, indicating strong advective heat transport and well-defined flow zones.

Overall, these results confirm that **thermal conductivity, Peclet number patterns and DTS-derived flow velocities jointly provide a robust picture of subsurface heterogeneity**, ranging from purely conductive (A), to mixed conductive–advective (B), to strongly advective environments (C). This highlights the importance of **site-specific interpretation** and shows that DTS-based tests can reliably distinguish conductive bedrock settings from advective, gravel-dominated aquifers.

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